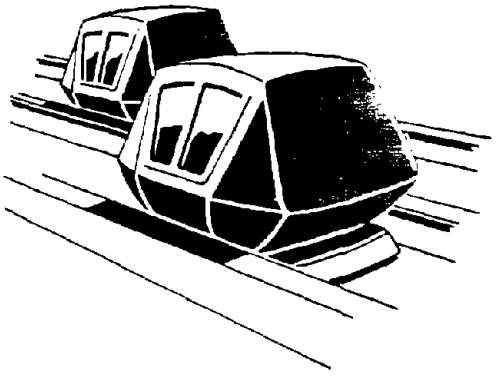
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PROCEEDINGS



Conference on Automated Guideway Transit Technology Development

Presented at the

U.S. DEPARTMENT OF TRANSPORTATION
Research and Special Programs Administration
Transportation Systems Center
Kendall Square
Cambridge, MA 02142
February 28 - March 2, 1978

1978
Conference Proceedings

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Office of Technology Development and Deployment
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16. Abstract

A three-day conference on Automated Guideway Transit Technology Development sponsored by the U.S. Department of Transportation, Urban Mass Transportation Administration, Office of Technology Development and Deployment, was held February 28 - March 2, 1978 at the Research and Special Programs Administration's Transportation Systems Center in Cambridge, Massachusetts. Twenty-eight papers were presented by experts from government and industry on system operations, passenger security, vehicle control and reliability, guideway and station structures, all-weather operation, ride comfort, deployed system assessments, automated highways, and developments in Canada, France and West Germany. The formal presentation of papers was followed by working sessions in the areas of system operations, vehicle systems and reliability, safety and security, wayside systems and all-weather operation, innovative transit, and social and economic factors. This report contains the proceedings of the conference.

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PREFACE

This report documents the Proceedings of the Automated Guideway Transit Technology Development Conference of February 28 - March 2, 1978, which was held at the Research and Special Programs Administration's Transportation Systems Center (TSC), Cambridge, Massachusetts under the sponsorship of the Urban Mass Transportation Administration (UMTA).

The Conference Chairman was George Pastor, UMTA Associate Administrator for Technology Development and Deployment. Frederick Rutyna, Chief, Automated Systems Branch, TSC, organized and hosted the conference on behalf of UMTA. Charles Broxmeyer, Director, Office of New Systems and Automation, (UMTA), and Duncan MacKinnon, Chief, Advanced Development Division, Office of New Systems and Automation, (UMTA), advised in the technical preparation of the document. The program was arranged and coordinated by Chita deVillafranca of Raytheon Service Company. Editors of the Proceedings were Richard Mahan, Richard Tucker and Linda Mauro Grasso, also of Raytheon Service Company.

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METRIC CONVERSION FACTORS

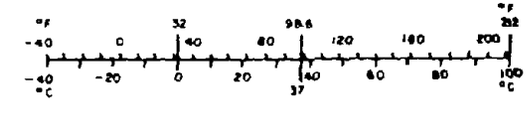
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.8	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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AUTOMATED GUIDEWAY TRANSIT
TECHNOLOGY DEVELOPMENT CONFERENCE

SUMMARY

Summary

The The Automated Guideway Transit (AGT) Technology Development Conference was held at the Research and Special Programs Administration's Transportation Systems Center in Cambridge, Massachusetts, February 28 to March 2, 1978 under the sponsorship of the Office of Technology Development and Deployment of the Urban Mass Transportation Administration.

The objective of the conference was to present the results of government-sponsored research and to provide an opportunity for researchers and other members of the transit community to exchange ideas and comments concerning the general area of AGT research and programs currently underway. The conference was attended by 241 representatives including researchers, transit planners, manufacturers, operators and local and federal government officials.

Twenty-eight papers were presented on a wide range of topics including AGT system operations, passenger safety and security, vehicle control, reliability, assessment of existing AGT systems, automative highways, advanced research projects, and developments in Canada, France and West Germany. Research programs on automated mixed traffic vehicle and accelerating moving walkway systems were also presented.

In addition to the formal proceedings, workshop sessions were held on System Operations, Safety and Security, Vehicles Systems and Reliability, Wayside Systems and All-Weather Operations, Innovative Transit, and Social and Economic Factors. The workships, attended by 140 conference participants, provided an ideal medium for generating comments on current and future research topics.

Observations

As a result of the formal proceedings and the workshop sessions, a number of general observations were made.

The AGT technology development program should preserve a balance between near-term research which is immediately applicable and research on advanced technologies suitable for deployment at a later time.

The results from operation studies of Shuttle-Loop Transit, Advanced Group Rapid Transit and the Morgantown systems demonstrate the importance of operational simulation studies for evaluating and improving system performance.

Further work is required to make simulations easier to use, to reduce running costs, and to make good simulation tools more widely available.

Innovative AGT operating strategies combining on-line and off-line station operation appear to offer potential for reducing costs and urban integration problems while preserving the advantages of short headway vehicle operation.

Assurance of high levels of perceived and real safety and security will be a significant challenge facing AGT systems deployed in urban areas.

Techniques developed to enhance security in conventional transportation systems will be applicable to AGT systems with minor modifications.

Station operations including fare collection, passenger control, and the passenger system interface are areas requiring further investigation.

Better methods need to be developed to assure the operability, reliability and maintainability of AGT components through improved specification and testing procedures.

Ride quality specification standards are very difficult to define for a system prior to development as a result of the influence of features, such as seat design and vehicle size, on perceived ride comfort.

It is important to fully account for market, regional and site dependent factors in the development of guideway and station designs.

Existing all-weather operation techniques provide a sound basis for developing high levels of all-weather operation capability. Improvements are required to reduce cost and energy requirements.

Aesthetic requirements need to be incorporated early in the design process if suitable system aesthetics are to be achieved at moderate cost.

Automated mixed traffic vehicle systems appear to offer significant cost and service advantages for short-distance low-volume applications provided safe operating speeds can be increased to levels competitive with walking through further development and operation on semi-exclusive rights of way.

Accelerating moving walkways offer service and cost advantages over competing vehicle modes for short distance, high passenger volume applications. Such systems appear particularly useful for extending the area of influence of fixed guideway system stations.

The assessment of existing AGT systems provides important insights into the operational capabilities of such technologies and a basis for estimating the cost and performance characteristics of urban AGT systems.

Citizen participation is useful in assuring the success of an AGT deployment project. It must be conditioned by targeting appropriate audiences with information tailored to their needs.

Citizen participation must be carefully handled to minimize the impact on implementation schedules by solicitation early in the project life-cycle.

WELCOMING REMARKS

James Costantino, Director
Transportation Systems Center

WELCOMING REMARKS

CONFERENCE ON
AUTOMATED GUIDEWAY TRANSIT TECHNOLOGY DEVELOPMENT

James Costantino
Director

Research and Special Programs Administration
Transportation Systems Center
Cambridge, Massachusetts 02142

I look out upon a lot of familiar faces here, and I am sure that many of you have been to the Transportation Systems Center before. I do want to welcome you to the Center, however, and to this three-day international conference on Automated Guideway Transit.

These meetings here and at the Copley Plaza Hotel in Boston, sponsored by UMTA and George Pastor, will present the results of Government-sponsored research, and the design, development and evaluation of AGT systems, and disseminate up-to-date technology on automated guideways in the United States, Canada, France and West Germany.

In addition to the U.S. attendees, we are pleased that we have so many people here from Canada and Europe, and representatives from federal and state agencies, private industry, transportation companies, consulting firms, and universities.

The Transportation Systems Center is DOT's multi-modal R&D facility for highway, air, rail, pipeline and marine transportation. TSC has an annual budget of some $65 million dollars. We have 650 federal employees and some 250 or 300 support contractors on our premises.

We perform research and development and various kinds of analyses for the Office of the Secretary, the Research and Special Programs Directorate of the Department, the Urban Mass Transportation Administration, Federal Aviation Aministration, Federal Railroad Administration, National Highway Traffic Safety Administration, Federal Highway Administration and the U.S. Coast Guard. Our staff consists of engineers, scientists, community planners, urban planners, sociologists, economists, and computer specialists. We have about 150 ongoing projects at the Transportation Systems Center at any one time in a vast variety of areas, and I invite you while you are here to take this opportunity to look around at what we are doing.

The agenda topic for today's conference presentations will be on U.S. and foreign government sponsored research. It will cover all facets of AGT technology development on passenger security, vehicle control, system operations and safety, reliability and maintenance, vehicle guideway dynamics and station technology. This TSC conference, hopefully, will contribute

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significantly to the construction of AGT's that will help to alleviate traffic congestion and augment mass transit facilities with an energy-efficient, safe and non-polluting form of transportation.

Our conference Chairman is George Pastor. He is the Associate Administrator of the Office of Technology Development and Deployment in the Urban Mass Transportation Administration. George was appointed to that office in 1974, and prior to that, as many of you know, he worked at TSC as the Chief of Ground Systems Programs overseeing research for the Office of the Secretary, and for the modal administrations.

It is my pleasure now to introduce to you, to those of you who don't already know him, the Associate Administrator for Technology Development and Deployment of the Urban Mass Transportation Administration, George Pastor.

MESSAGE FROM CONFERENCE CHAIRMAN

George Pastor, Associate Administrator
Office of Technology Development and Deployment
Urban Mass Transportation Administration

MESSAGE FROM
CONFERENCE CHAIRMAN

Mr. George Pastor
Associate Administrator for
Technology Development and Deployment
Urban Mass Transportation Administration
2100 Second Street, S.W.
Washington, DC 20590

Good morning and welcome to TSC. I want you to know that I have noticed, as some of you might have, that we have five welcoming and introductory speeches, which might seem to imply that we on the Government side try to outdo you, but that is not the case.

I am delighted to see that there is a good turnout, and I want to pay particular attention that some of the fruits of our labors to bring some international understanding and exchange and cooperation are showing up here in this conference just like in other activities. I particularly want to acknowledge and welcome our Canadian, French and German friends. Notice that I was very careful to follow the English alphabet so that I don't get into any protocol problems.

About three-four years ago, if we had had a conference like this, it would have been possible that the Government people would have outnumbered the industry people.

We had hit sort of a nadir in high technology automated transit systems around 1973 and 1974. I think we have come a long way since that time, and I think we still have a long way to go and we will keep going.

I wanted to tell you a little bit why I feel we are here today. First, let me say we are not here today to compete with the International Conference in April organized by ATRA. On the contrary, I want to solicit your participation and encourage you to go to Indianapolis in April and participate in that conference. I think that the two are complementary.

The reason that we are here today is something that left a great mark on me during the two R&D Priorities Conferences. I have heard from everybody that UMTA, and particularly my office, has failed in communicating what we are doing, what our successes and what our failures are.

You cannot learn unless you know what your successes and your failures are.

We are also here combining this day to cement a cooperative relationship that is developing between our northern neighbors in Canada and ourselves in the form of extending a Memorandum of Understanding which will cover urban transit technologies and launch some specific projects. We will sign these documents during lunchtime here today.

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Let me go on a bit with background. I mentioned in '74 we had a nadir. In '75, a few wise men in O. T. A., DOT and Congress, launched us into an AGT program which has remained fairly consistent over the past three years. We feel now we are reaching a stage in the program where it can produce some results, where we can and should give a status report, and where we can provide for you all a forum where, in two days, you can pick up what is going on in this technology.

Let us first view Figure 1, which depicts the way the AGT program in UMTA was organized three years ago. This may be very familiar to many of you. On the left is the AGT Socio-Economic Research program which is now run under Henry Nejako and Howard Evoy, who are going to give papers and participate in this conference and give you a status report.

In the middle, there is the AGT Technology Development and the AGT System Development; the latter is primarily the advanced GRT program. Both of these activities, which are technology, hardware and systems-oriented R&D, are under Charlie Broxmeyer in my shop.

Then, on the right-hand side are AGT Applications under Steve Barsony; those are the projects which get all the fanfare, all the headlines, both good and bad -- Morgantown, Downtown People Movers and the AIRTRANS programs. Now, as I say, on the right-hand side, the DPM's, the Morgantown's are in the forefront of public debate. They are in the forefront in coverage by the press.

Very few people know about the activities on the left, and yet, the activities on the left are the ones that make it possible for the activities on the right, the applications and the deployment, to happen in an orderly fashion, without overpromising and underperforming as we have done on occasions in the past.

Now, most of the discussion here will be about the two left columns, the AGT Socio-Economic Research Program and the AGT Technology program. Nevertheless, the Advanced GRT project, which I notice is not going to be discussed in detail, is a very important and integral part of the entire program. The main reason we elected not to include an awful lot about it here today is because we are in a competitive situation selecting contractors right now.

At the risk of being repetitious, I decided to show you a few slides that I had used in January at the TRB Annual Conference. But I am using them because I want to convey a message, and I hope the message will come through.

As you will notice from Figure 2, we had completed a lot of assessment projects, where we reviewed, using independent contractors, ten existing and operational AGT Systems. We tried to reconstitute their capital costs in 1976 dollars by judicious adjustment of costs, deleting some initial R&D costs, but on the other hand, adding back costs which some of the airport systems typically would not necessarily carry on the books: for buildings, stations, rights-of-way, et cetera.

A report will be published, I believe, very shortly. We have in review right now in UMTA the final version, which will give you all the background on this. So, I am not giving you a detailed review of the report, but I want to highlight some of the results.

The ten-system average cost per lane mile for these systems is $7.3 million. The total investment is $200 million, and these ten systems carry now about 44 million passengers annually.

In Figure 3 the ten systems vary all over the map. They are simple, almost primitive in some instances and range all the way up to high complexities such as in AIRTRANS and in Morgantown, where fleets of 40 and 60 vehicles are running over many miles of guideways. The utilization of some of these systems also varies all over the map. Some of them have captive ridership. Some of them induce ridership. So, it is hard to tell. The costs, logically, vary all over the map in terms of cost per vehicle mile. Very typically, AIRTRANS is showing extremely low cost per vehicle mile, but the vehicles are running around 24 hours a day covering an awful lot of mileage without, however, a very good load factor. A similar situation is occurring in Morgantown with the Phase I System. Looking at Figure 4, which shows cost per passenger mile, you see an entirely different distribution.

I think it is educational to this audience to look at the capital cost distribution which is shown on Figure 5. You will see that guideways, which in conventional fixed guideway systems typically are 70-80 and even 90 percent of the total costs, have been reduced. Guideways and stations here are only about one-third of the cost, which shows the increased cost of control, communications, vehicles, and a very significant cost, engineering and project management. That is how it should be for high technology and new systems, but it also points out that we can make an awful lot of dollar savings still in the guideway and station area.

Figure 6 addresses the distribution of O&M costs. We always hear talk that some people feel that automation threatens labor utilization. Automation, I think history has proven, does not create unemployment. It creates more labor utilization with higher productivity. I think this is borne out here, where it shows that over half of the operating and maintenance costs are for labor. It is for a different kind of labor than in conventional transit.

This data on Figure 7, our next chart, may be controversial; nevertheless, it is the best data I could lay my hands on.

If you average out the ten People Movers' operating and maintenance costs either on a vehicle mile or passenger mile basis, you wind up with numbers which are slightly less than average bus costs and significantly less than average light rail and heavy rail costs. Now, these numbers are not too significant because, when you talk about averages, they are rather meaningless, especially when you are talking about averages of ten AGT systems which are a rather special kind. But, nevertheless, when you talk about bus systems, you also talk about a tremendous range, a spectrum of various systems. All it shows -- in a ballpark fashion -- is that one can

indeed hope that operating and maintenance costs of automated systems should be lower than those of conventional systems. They are already lower in the ten pioneering systems, many of which include the initial introduction and the initial difficulties that most of these systems have experienced.

Carrying this analogy and comparison one step further, we put together this chart, Figure 8, which can be extremely confusing, but those of you who know UMTA's capital grant program will understand. We finance 80 percent of capital grants for urban transit investments. This attempts to show, if these ten systems were UMTA funded, capital funded systems, what would be the equivalent annualized cost of these systems both capital and operating. The top row shows the operating cost and the next one the annualized cost of the local share, which then shows how much it would cost a local community on an annualized basis to both write off the capital cost and operate the systems. The number comes out in the middle, right-hand column. A fare of 27 cents could pay off both the local share of the capital and the total operating costs.

Now, this may be unbelievable, but it is this way only because it includes some extremely simple AGT Systems which, indeed, have low capital costs and also low operating costs.

I don't mean to draw the inference that all automated systems will have this kind of performance, but nevertheless, I think one can draw the conclusion that I have kept harping on for years, before Congress and in meetings like this: that we are in the AGT business because these systems do hold out the promise of being able to pay for their operating and maintenance costs out of the fare box. Because of that promise, I believe, it is worthwhile for the Government and industry to pursue this kind of alternative, not as a cure-all, not as a substitute, but as a complement to existing transportation systems.

Well, finishing on this subject, it was these kinds of considerations and presentations that led us in the Department to our reassessment, which we do periodically, of what to do about the Advanced GRT program.

We underwent a couple of months of highly intensive task force audits of the past history of the program and what should we do with it in view of DPM and all the developments of the past two years. As you know, the Advanced GRT program has completed Phase I and now Phase II-A viewed in Figure 9, which represents over three years of activities by three contractors.

The Department, with very heavy participation of the Deputy Secretary and his chief scientific advisor, Jack Fearnsides, the Administrator, Dick Page, and ourselves concluded that in view of OMB Circular A-109 -- I am becoming a pretty good bureaucrat -- we ought to pursue at least two competing technologies, as indicated in Figure 10.

We are restructuring the Advanced GRT program. We will select two contractors, and we have determined that we will develop both competing systems to the breadboard engineering prototype test stage at the facilities of the manufacturers; after that we will deploy the test systems at Pueblo and complete a full evaluation.

Now, this is the first time, certainly in my experience, that a secretarial office proceeded and doubled my budget on a given project without my asking for it. That is what happened just recently, and I think it shows the credibility that some of the AGT projects and systems have achieved.

Well, I am running out of slides, and I'm surely also running out of time, but before completing I wanted to ask you just in a couple of words: What do we see really on the horizon? What should you be addressing in this meeting?

There are no large spectaculars on the horizon. Budgets for urban transportation are going to be still strained and limited. There are tremendous demands for conventional systems which must be met. We don't expect to cover the map of the United States with ten, 200-mile AGT Systems in the next five years. Growth is going to be very evolutionary, very gradual, very cautious, and we will take one step at a time. I think that the DPM Program is running in that vein. It will be kept in that vein.

Nevertheless, by doing the market testing and the test marketing of AGT Systems in the urban core, in the urban fabric, I think we will open up a second change for these systems which will, I believe-if they are successful economically and from a social acceptability point of view-put these systems in the repertoire of transit alternatives for the rest of the century.

I emphasized here the cost advantages. We have developed these systems in the early '70's at which time energy was not as significant a consideration as it is today. I think we have to stress energy utilization far more than we have in the past. We all know that there is no energy crisis. There is a petroleum fuel crisis. But the excuse that these all work on electric energy is not sufficient to permit us to ignore the energy consumption of these systems. Witness West Virginia, where right now the Morgantown system is shut down because of energy emergency considerations in that state. We don't have to look around too carefully to see what winter weather can do to transportation. I know here in Boston we had some trouble, and, as I was driven around here in the canyons of snow on the streets, I gained another appreciation of what winter can do to fixed guideway transportation and, for that matter, all transportation. We cannot afford to ignore winterization in automated transit systems. I think Morgantown shows that the people mover there has worked with a 97 percent availability throughout the winter. In the worst snow and ice it was working. It can be done, but it costs money and energy.

So, we have to concentrate more on that.

Then, we all know that perhaps the age of the electric vehicles is coming. We don't know yet how we will approach it, but all the indications are that the electric age is coming, and I think that has a relevance to automated systems. Self-propelled potentially electric vehicles are in the future.

I think we have to think how to meet the needs, how to use the available technologies, and, in the meantime, proceed ahead with the deployment of those technologies which are proven safe and which are available today.

I will be looking with great interest on the findings and on the recommendations of this conference. I hope it will not be one where we tell you, or the contractors tell you, what they are doing and you go home and say, "Now, I know what they are doing."

We are looking here for your critique, for your advice, for your comment. What are we doing right? What are we doing wrong?

This is your program. It is paid for by the taxpayers, and we want it to be the best that we know how to do. So, have a good three days here in Boston, and I will be looking forward to meeting you again. Thank you.

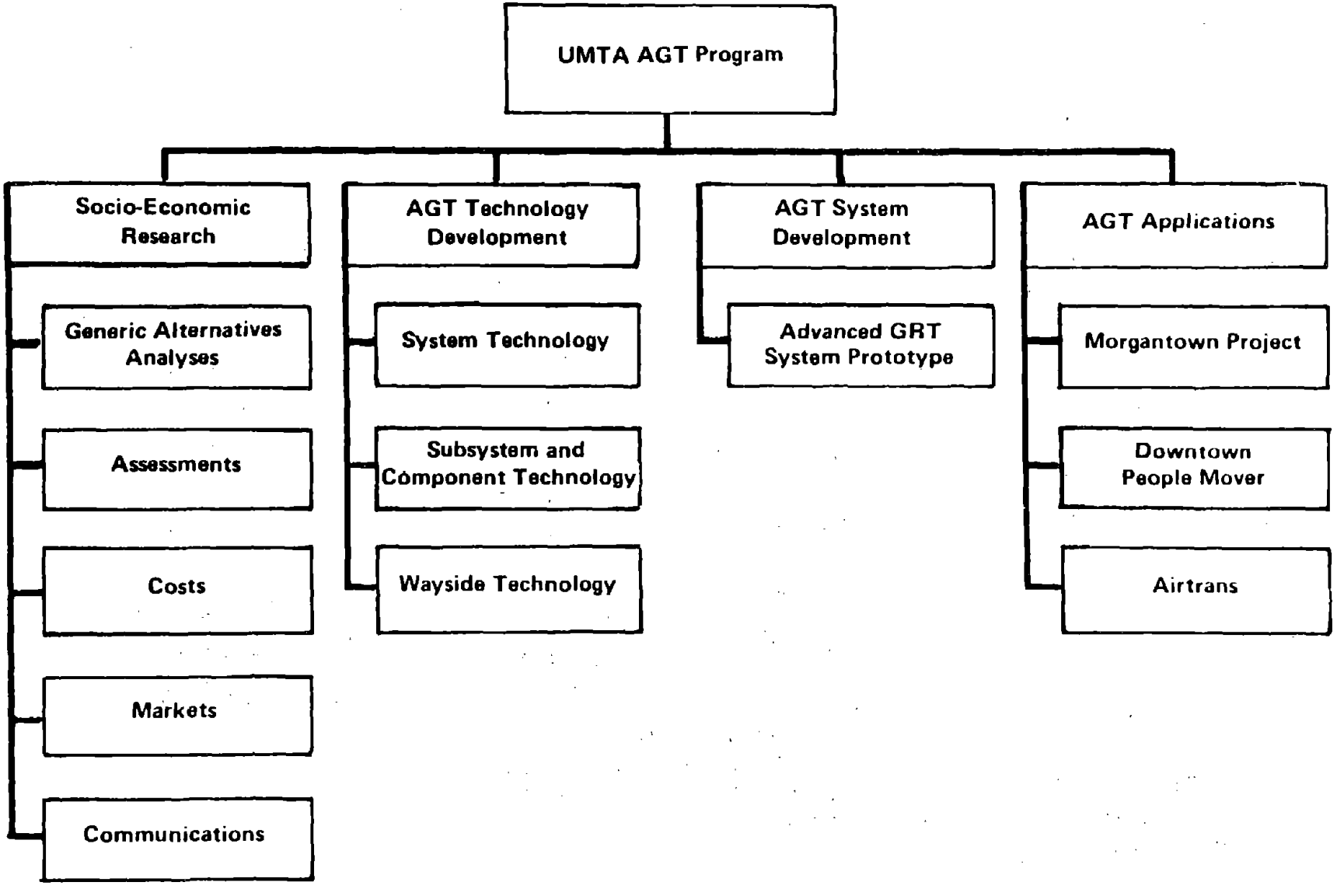


FIGURE 1. AUTOMATED GUIDEWAY TRANSIT (AGT) PROGRAM

	Amount	Per Lane Mile	Per Passenger Space Provided
	(Thousands)		
Morgantown I	57,883	11,004	61
Airtrans	60,793	4,749	30
Jet Rail	4,424	2,949	44
Cabin Lift	900	2,500	75
Tampa	14,266	10,567	18
Sea Tac	34,635	20,254	28
Houston	6,857	5,963	38
Fairlane	6,107	10,178	127
Wedway	12,248	14,078	20
Kings Dominion	5,490	2,665	10
Total	203,607	7,361 (Avg.)	31 (Avg.)

FIGURE 2. ESTIMATED COST TO DUPLICATE TEN SYSTEMS IN 1976

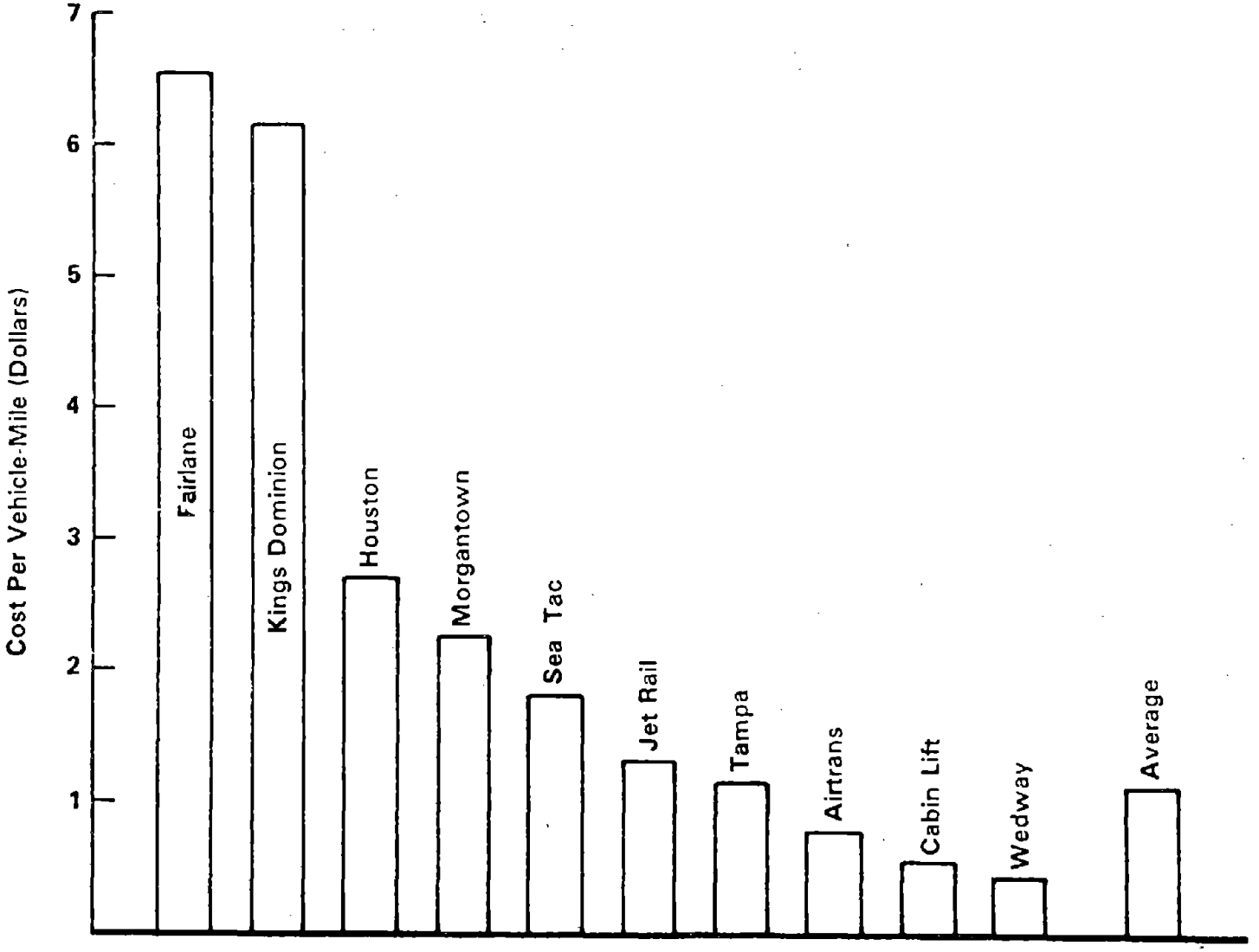


FIGURE 3. 1976 O&M COSTS PER VEHICLE-MILE

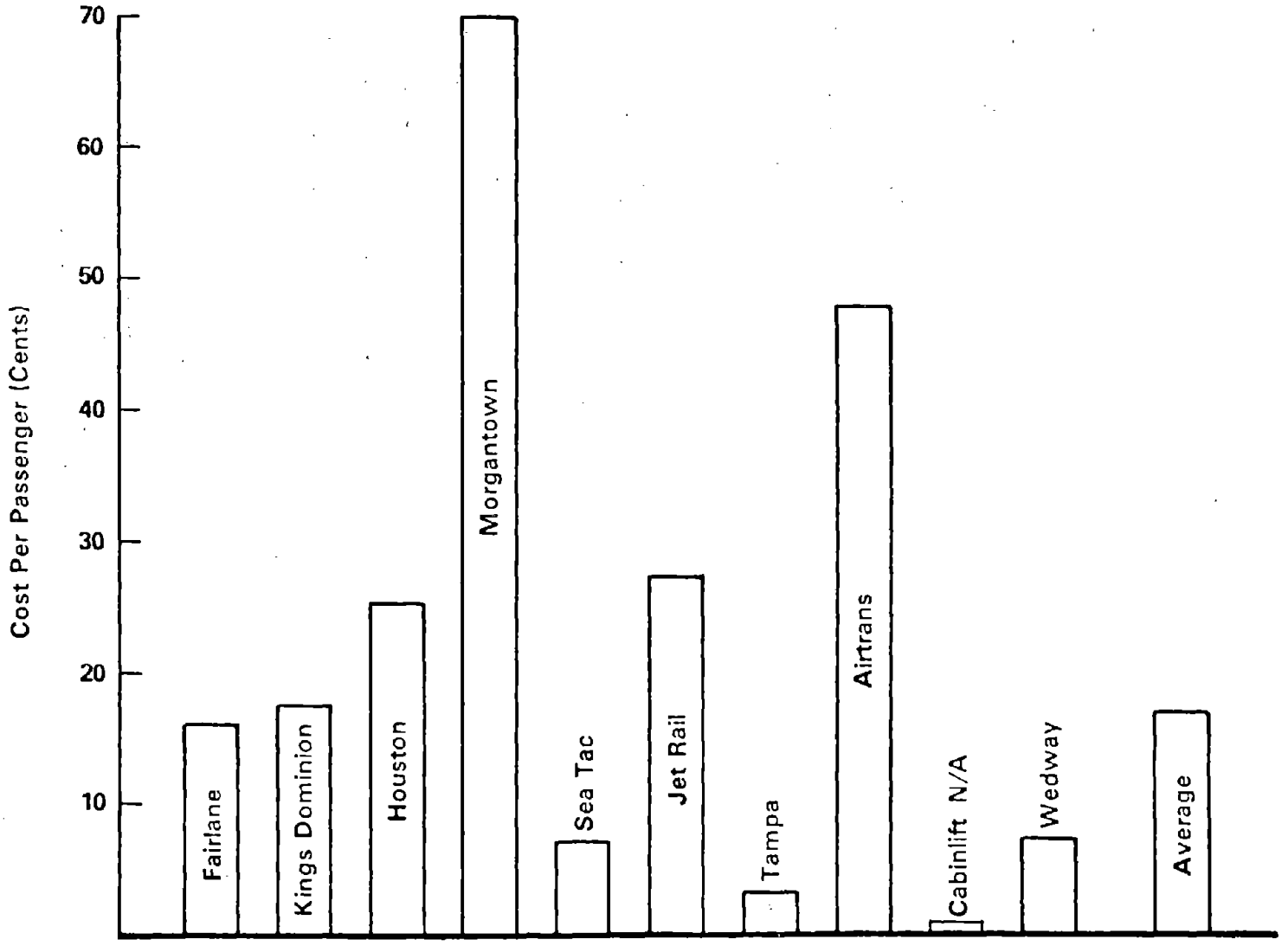
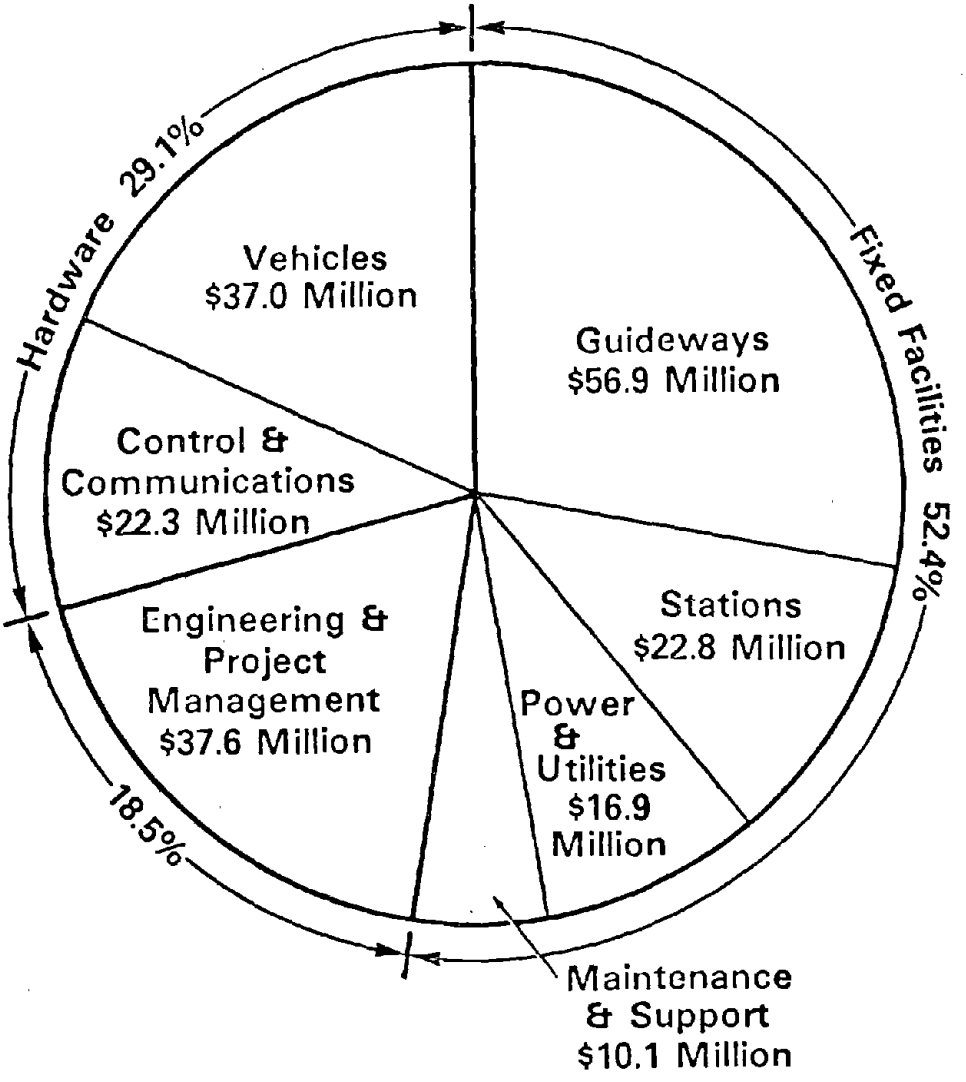
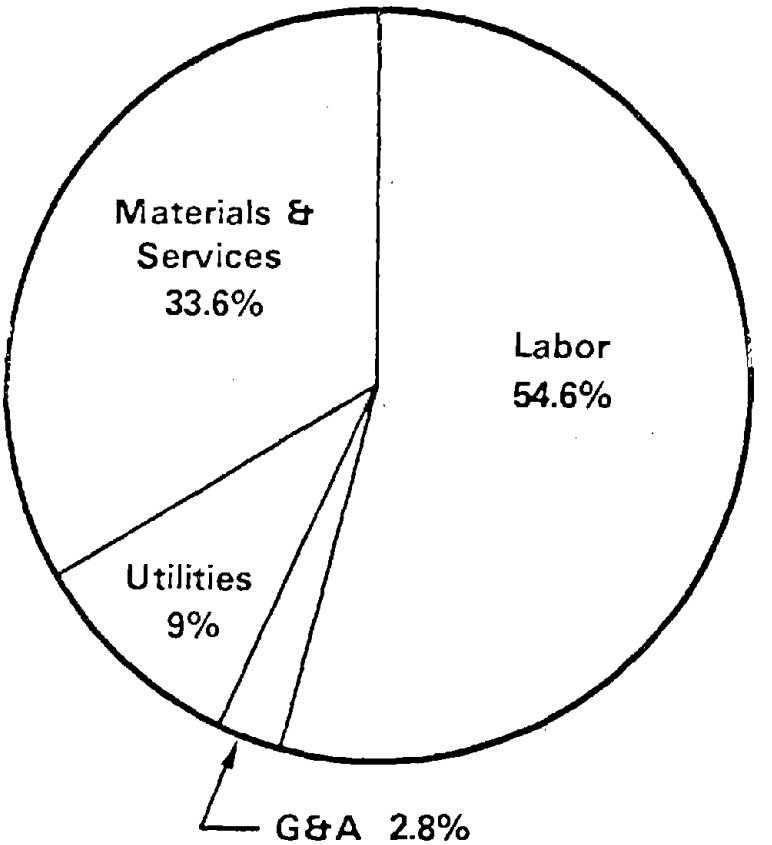


FIGURE 4. 1976 O&M COSTS PER PASSENGER CARRIED



Estimated 1976 Dollars

FIGURE 5. CAPITAL COST SUMMARY (TEN AGT SYSTEMS)



1976 Costs

Average Cost/Veh Mile	$1.12
Average Cost/Place Mile	.027
Average Cost/Passenger	.165
Average Passengers/Vehicle Mile	6.8

FIGURE 6. TEN AGT SYSTEMS O&M COST DISTRIBUTION

	PER VEHICLE MILE	PER PASSENGER MILE
AVERAGE OF 10 PEOPLE MOVERS	1.12	.16
TRANSIT BUS*	1.41**	.50**
LIGHT RAIL*	2.25	.50
RAPID RAIL*	2.46	.83

(*Source: Mitre Corp Study)

(**Includes No Roadway Maintenance)

FIGURE 7. COMPARATIVE O&M COSTS

	AMOUNTS (IN THOUSANDS)	PER VEHICLE MILE	PER PASSENGER
ANNUAL OPERATIONS & MAINTENANCE COST	$ 7,161*	1.12	.16
EQUIVALENT ANNUAL COST OF LOCALLY FINANCED (20%) CAPITAL INVESTMENT	5,175	0.18	.12
TOTAL LOCALLY PERCEIVED ANNUAL COST	12,336	1.93**	.27
ANNUAL EQUIVALENT COST OF FEDERAL CAPITAL GRANTS	20,701	3.25	.48
TOTAL EQUIVALENT ANNUAL COST	$33,038	5.19	.76

* Based on 10% time value of money, 15 years service life for vehicles and hardware and 35 years for facilities.

** O&M costs alone for light rail and rapid rail exceed this amount, i.e., $2.25 and $2.46 per vehicle mile respectively.

FIGURE 8. COMPOSITE COST DATA FOR TEN AGT SYSTEMS

- **PHASE I**

  Design and definition

  3 contractors

  Boeing - supported wheeled vehicle
  Otis - supported air - cushion vehicle
  Rohr - suspended monorail

- **PHASE II A**

  Engineering analysis

  Subsystem design and test

FIGURE 9. ADVANCED GRT PROGRAM–FIRST TWO PHASES

PHASE II B

- **ORIGINAL PROGRAM**

  Select 1 contractor

  Deploy system in a test track configurations at Pueblo

- **REVISED PROGRAM**

  Select 2 contractors

  Develop engineering prototypes at the contractor's own facilities

  Deploy both systems in test track configuration at Pueblo

  Utilize common facilities where possible

FIGURE 10. ADVANCED GRT PROGRAM-ORIGINAL & REVISED PROGRAM

PROGRAM INTRODUCTION

Charles Broxmeyer, Director
Office of New Systems and Automation
Urban Mass Transportation Administration

PROGRAM INTRODUCTION

Charles Broxmeyer
Department of Transportation
Urban Mass Transportation Administration
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Good Morning Ladies and Gentlemen.

Let me add my welcome to those of Dr. Costantino and Mr. Pastor.

In a few minutes, Dr. Duncan MacKinnon will give you an overview of the AGTT program. Most of the papers you will hear over the next few days are derived from that program. Dr. MacKinnon's remarks will begin to deal specifically with the material of this conference.

In my remarks, I'd like to deal with the New Systems program in general, including some background and some information on a major New Systems program element that will not be covered during the course of this meeting.

When one is immersed in the specifics of a research and development program, it is sometimes difficult to see the outlines of major trends of which the program may be a part. It's interesting, however, to try to see the trends and to recapitulate some of the individual events which were later seen to be part of the trend.

In the 1960's there was a decrease in the general level of government research and development in the military and space fields. This was a change from a period of steady growth that started around the time of the Korean war. At the same time there was a desire, quite widespread, to apply the results of the military and space engineering achievements to the pursuits of everyday life. Transportation research, especially in its automation aspects, certainly appeared to be a fruitful area in which to apply these results--and to try to mount a technical effort which might lead to means of moving people with service sufficiently good to attract at least some passengers away from the private automobile.

The creation of the Department of Transportation provided a powerful stimulus, and there was strong support from a number of DOT leaders, notably Secretary Volpe, for the pursuit of a number of ambitious and imaginative programs.

In addition to a growing federal support for new R&D urban transportation projects, there were a number of other phenomena which could be observed.

- There was a blizzard of hundreds of proposals for automated systems concepts of various types and requests for federal support for these concepts.

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- A large number of small organizations were formed to develop systems. Over the years these organizations have largely been absorbed by, and supplanted by, the older aerospace engineering organizations with significant internal resources and staying power.

- A number of modest scale, but technically ambitious automated transit systems were developed and put into service, principally at airports.

After the first surge of activity - which those of us who were involved expected to continue at a growing rate - there was a hesitation and a falling-back. Tracked air cushion vehicle programs were cancelled, a follow-on to the TRANSPO demonstration was long delayed in coming, and a program to develop a dual-mode transit system was shelved.

While some momentum was lost, and the results were certainly painful for the organizations involved, the automated systems program continued. A new program was initiated for the consolidation and development of the fundamentals of automated guideway transit technology. This week's conference is devoted to such a program of fundamentals - where the emphasis is on the generalized areas which new transportation systems have in common rather than on individual system concepts.

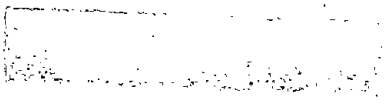
Since the future in this field has been so hard to predict, I would hesitate to suggest that we have now reached a period of steady growth. Nevertheless, there are signs that new systems development is a vigorous area and getting stronger.

Expectations are more realistic, and this has taken some of the pressure off. The Advanced GRT program, a major element of the New Systems program, now seems assured of completion, and the possibilities of non-petroleum based transportation seem at last to be having an impact.

The program of fundamentals, the AGTT program, constitutes half of the government's R&D effort in new systems development. The other half is a major program which started some years back.

I want to address a few words to this program which, as I noted, is not covered in any of the scheduled papers - this is the Advanced Group Rapid Transit or AGRT program. The origin of this program can be traced back to the spring of 1971 when the TRANSPO demonstration was started. Maybe the details of the story will be of interest.

A system concept known as Carveyer was proposed as a transportation element of the International Transportation Exposition (TRANSPO 72) scheduled for Dulles Airport. A crash program to install Carveyer as the main transportation system at Dulles Airport seemed a risky business. A counterproposal for installation of a new transit system to be selected on a competitive basis also seemed risky, because of the short amount of time involved (one year) and



the need to carry large numbers of the public. However, in the end, a decision was made to select four systems competitively and install them in limited configurations.

Four small systems were demonstrated - and one of these systems achieved a headway of 10 seconds. The next natural goals after TRANSPO seemed clear. These were to:

1) do the engineering to turn some, or at least one, of these systems into a transit system capable of providing reliable service measured over a period of decades;

2) increase the capacity (and that meant reducing the headway) to the point just before we had to worry about the possibility of collision--in other words, work up to brick wall stopping criterion.

A program to achieve these goals was started and was initially called the High Performance Personal Rapid Transit Program. Relabled the AGRT program, it has now gone through two design phases, encompassing a period of contractor activity of about two years.

We are now initiating the final phase of the program leading to development of what will certainly be the most advanced American urban transportation system and we look forward to city installations of this system to the post 1985 era.

Before turning the program over to Dr. MacKinnon, I want to make an aside and mention one aspect of the AGTT program which is of considerable theoretical interest. This is discrete event simulation, which will be referred to in the General Motors paper and which is also in use by the AGRT contractors.

Analysis of the behavior or urban scale transportation systems interacting with passengers using the systems involves the simulation of very large sets of differential equations. The classical differential equation solving methods of the textbooks all needed to have every state variable updated periodically. However, we were faced with problems where we had thousands of state variables. Computer runs using the conventional differential equation techniques were simply too long by more than an order of magnitude.

The solution, as they say, was in the wind and is now becoming another formalized tool. Instead of updating every variable each time step--update a variable only when you need to - only when it changes enough--and while some fidelity is lost, simulation of a complex AGT system interacting with individual passengers then becomes economically feasible. We are preparing programs for general use of this technique for those who have need for it, there will be more about this in the first paper.

This concludes my remarks. The next speaker is Dr. Duncan MacKinnon who will provide you with an overview of the program of the next few days.

PROGRAM OVERVIEW

Duncan MacKinnon, Chief, Advanced Development Division
Office of New Systems and Automation
Urban Mass Transportation Administration

PROGRAM OVERVIEW

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ABSTRACT. Automation of transit systems is one of the most promising approaches to increase service levels while reducing operating deficits through increased system productivity. The successful development of automated transit hinges on the identification and solution of many technical problems. The assessment and solution of these technical problems is being addressed by research sponsored by the Department of Transportation. This conference reports on the progress of this research.

INTRODUCTION

The concept of Automated Guideway Transit emerged in the early 60's, spurred by the successful application of the concepts of automatic control in the areas of defense and industrial process control. One of the first major developments of an automated urban transit system was the Westinghouse "Transit Expressway" which was developed under Urban Mass Transportation Administration sponsorship in the 1960's. Capable of automatic operation at 60-second headways, the service characteristics of the "Transit Expressway" were similar in many respects to conventional rail rapid transit systems. Towards the end of the 60's, it was recognized that improvements in service and ability to adapt to the diverse trip patterns in modern urban areas could be achieved by operating smaller vehicles at shorter headways with off-line stations. This led to serious studies of short headway operation, the development of system concepts, and the deployment of the "Airtrans" and "Morgantown" AGT systems which began revenue service in 1973 and 1975, respectively.

While AGT technological development continued, the severe operational problems encountered by the deployed systems in the early stages of revenue service eroded confidence in the ability of AGT to solve urban transportation problems. It was recognized that Government sponsorship of research on solutions to the critical problems of AGT systems and a complete assessment of existing AGT designs were required to achieve a sound basis for urban deployment. The Automated Guideway Transit Technology and the AGT Socio-Economic Research programs were initiated by UMTA in 1975 to address this need.

In addition to these activities, the Department of Transportation has been sponsoring related research under a variety of programs. The Transportation Advanced Research Program and the Offices of University Research in the Office of the Secretary of Transportation and UMTA have sponsored a number of related

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research projects. This conference summarizes the progress of the current research on AGT in these programs.

AUTOMATED GUIDEWAY TRANSIT TECHNOLOGY

The major part of the program presents results from the Automated Guideway Transit Technology (AGTT) program. The AGTT program was established in 1975 to address research required for the successful development and deployment of automated transit systems.

The objectives of the AGTT development effort are (1) to establish the service and cost characteristics of all classes of automated guideway transit systems and (2) to develop the critical technologies that are required for the successful deployment of such systems, with particular emphasis on control, safety, reliability, and maintainability.

The lack of adequate data on the operating characteristics of various AGT systems in different applications has often thwarted adequate planning for system deployment. Since few systems are in service, and none serve major urban areas, such data must be developed by computer analysis and simulation. The requirement for computer models, analysis results, and AGT vehicle and passenger control algorithms is being met in the System Operations Studies program. This program is performing operational analyses and computer simulations to determine the characteristics of automated guideway transit systems in various network configurations, including simple shuttles or loops, line-haul arterials, and complex areawide networks. As part of the project, a number of computer models for analyzing various aspects of AGT system operation are being developed and delivered to the Government. The computer programs will be made generally available, and it is anticipated that they will be extensively used by planners and developers of AGT systems. Operational studies of the Downtown People Mover systems will provide one of the first applications of these models.

AGT systems must make very effective use of operating personnel to achieve low per-passenger costs. In addition to eliminating vehicle operators, it is essential to minimize personnel required to staff stations. This reduction in personnel results in potential safety and security problems which must be overcome. The System Safety and Passenger Security project is developing and evaluating methods for enhancing the safety and security of AGT systems. The project will identify techniques and evaluate the effectiveness of these methods. Studies are also underway to establish the effects of emergency deceleration and jerk levels on system safety.

Small vehicle AGT systems must operate at short headways in order to achieve guideway capacities sufficient to justify the investment in guideway and station structures. Replacing a very large vehicle with smaller vehicles places more stringent reliability requirements on the vehicles. The Vehicle Longitudinal Control and Reliability project was established to improve short headway control technology and to increase vehicle reliability (since the major contributors to reliability problems such as power collectors, power conditioners, motors, drive trains, brakes, suspension components, etc., are associated with the longitudinal control system).

Concepts considered include fixed- and moving-block vehicle protection, vehicle- and point-follower control, and electronic (platooned) and mechanical (trained) vehicle coupling. Reliability enhancement techniques will include component design improvements as well as redundant implementation concepts. Extensive experimental testing will include operation at headways less than five seconds, separations less than the emergency stopping distance, as well as platooned and trained operation.

To complement the longitudinal control research, the Vehicle Lateral Control and Switching project is developing improved steering and switching techniques. Comparative studies and experiments will be made on purely mechanical and power-assisted mechanical systems utilizing side wall-following guidance sensors as well as power-assisted mechanical systems utilizing a buried radiating wire as a lateral position reference. Improved lateral steering systems permit a reduction in guideway sidewall construction tolerances and/or improvement in lateral ride comfort. Both onboard and wayside switch concepts are being considered.

The major capital investment in an AGT system is the guideway and station infrastructure. The Guideway and Station Technology project is aimed at reducing the cost and installation time of guideways and stations. Improved structural designs and techniques such as prefabrication are being studied. Case studies using techniques such as models and photomontage will be used to reduce the visual impact of AGT structures and to explore the problems associated with installation in urban areas. The project will also define techniques for enhancing AGT all-weather operation capability.

The specification of service reliability as perceived by the passenger, operator, and developer is an important issue in the development of procurement documents and in-service evaluation. The Hardware Reliability and Service Availability project was established to survey and define measures of service availability which have been used by operators, manufacturers, and researchers to characterize the operating reliability of AGT systems.

The Station Security Features project examines the security features required to adapt stations to the security characteristics of different urban sites.

A significant contribution to AGT research was made in the early 70's by the Aerospace Corporation through an extensive in-house funded study of the feasibility of AGT systems using very small vehicles at fractional-second headways. The Study on Personal Rapid Transit provided funds to update this research and to place the results in the public domain.

Dynamic interaction between the vehicle and the dynamics of elevated guideways can significantly affect ride comfort. The Massachusetts Institute of Technology has been performing research in this area with support from the UMTA Office of University Research since 1974. Sponsorship of this research is continuing under the AGTT program in the area of Vehicle-Guideway Dynamics and operational analysis of training and platooning.

Independent non-profit organizations such as the Applied Physics Laboratory of Johns Hopkins University and the MITRE Corporation have played a valuable role

in the UMTA AGT program through independent analyses and assistance in monitoring system design, integration and test activities. The Applied Physics Laboratory has been conducting theoretical studies on AGT system control since 1969. The current Independent Studies on Vehicle Control are extending the results of previous research with particular emphasis on the problems of longitudinal control at short headways. The MITRE Corporation is performing a variety of research tasks as part of the AGTT Independent Studies activities. The Life Cycle Costs and Application Analysis for New Systems is directed towards establishing performance characteristics (speed, cost, capacity) which will result in viable deployments.

The innovative concept of an automated transit vehicle which is capable of safely mixing with pedestrian traffic on existing rights-of-way offers the promise of providing inexpensive transit in applications such as shuttles and loops in auto-free zones where passenger volumes would not justify the capital investment implied by conventional AGT or moving walkway systems. The Jet Propulsion Laboratory (JPL) has been developing an automated Mixed Traffic Vehicle transit technology which utilizes a small vehicle equipped with sophisticated sensors which permit the vehicle to operate at low (2-5 kph) speeds in pedestrian areas or at higher speeds on semi-protected rights-of-way. The project is funded jointly by the National Aeronautics and Space Administration and the Urban Mass Transportation Administration. A breadboard test vehicle has already successfully operated on a 600-meter loop at JPL. Current studies are focusing on the development of a transitworthy vehicle design and improved control techniques.

The Hydrostatic Drive Development at Mobility Systems and Equipment is directed towards the test of a hydrostatic drive for AGT vehicles. The major objective of this project is to reduce hydrostatic drive noise to an acceptable level. Hydrostatic drives permit the elimination of the complex electronics power modulator and the use of a common squirrel cage motor, resulting in significant cost savings and electromagnetic interference reduction.

A Vehicle Data Acquisition system is being developed by the Port of Seattle which will collect and record data from a large number of test points in a specially instrumented SeaTac Satellite Transit System vehicle. The recorded data will help maintenance personnel to rapidly diagnose vehicle failures, thus reducing vehicle downtime and maintenance costs.

ACCELERATING WALKWAY

Moving walkway systems are capable of moving large volumes of pedestrians over short distances. The Accelerating Walkway project provides a unique opportunity for UMTA to demonstrate a new urban transportation technology. By permitting speeds up to five times that of conventional fixed-speed walkways, the accelerating systems overcome the major disadvantage of the fixed-speed system--low speed. The higher speed accelerating walkway is, thus, much more attractive to the user and should, as a result, draw a significantly higher percentage of potential riders than a conventional moving walkway. The higher speed will also permit the deployment of much longer walkways (up to 1000 m) with potential for application to collection-distribution in urban areas.

The Accelerating Walkway project is being performed by the Port Authority of New York and New Jersey through a grant to the Tri-State Regional Planning

Commission. The Port Authority is providing a local share of the total project cost.

An Accelerating Walkway Feasibility Study was completed in FY 1977 by the Port Authority of New York and New Jersey. The study provided a comprehensive overview of accelerating walkway technology, including systems which have been developed to the full-scale prototype stage. The study also identified four classes of potential applications and associated cost benefits. An independent safety analysis was conducted. The results of the study indicated that the safety characteristics of accelerating walks would be similar to those of conventional walks and escalators. The study also provided a preliminary demonstration planning analysis, as well as system requirements for elderly and handicapped individuals.

During FY 1978, two or more system manufacturers will be awarded contracts to perform detailed accelerating walkway design and demonstration implementation studies. FY 1979 activities will involve detailed hardware design, component testing and demonstration site selection. Subsequent activities include pre-demonstration system testing and public demonstration of an accelerating walkway at least 100 meters in length, for a period of at least one year.

AGT ASSESSMENTS

The AGT Socio-Economic Research (SER) program was established 1975. The AGT SER studies are directed toward system alternatives analysis for various applications, assessments of existing technology, analysis of capital, operating and life-cycle costs, and the projection of markets for AGT systems. The papers presented at this conference describe the results of the assessment activities. Domestic Assessments are being performed by a number of contractors. Systems in the domestic assessment activity include the Morgantown, Airtrans, Tampa, SEATAC, Jetrail, and Duke University AGT systems. The Foreign Assessments are being performed through cooperative agreements with foreign government agencies. Assessments to date have included the French MATRA "VAL" system and the West German Messerschmitt-Bolkow-Blohm "Cabinlift" and "Cabintaxi" systems.

FOREIGN RESEARCH

Ambitious AGT technology development and deployment programs are in progress in Canada, France, West Germany, and Japan. The Canadian projects include the Intermediate Capacity Transit Systems being developed by the Urban Transportation Development Corporation and Transport-Canada. The French developments include the MATRA "VAL" and "Aramis" systems, while West German developments include the Messerschmitt-Bolkow-Blohm "Cabinlift" and "Cabintaxi" systems and the Siemens "H-Bahn" system. Japanese developments include the Kawasaki "KCV", the Kobe Steel "KRT", the Niigata Engineering "NTS", and the Mitsubishi "MAT" systems. This session reports on developments in Canada, France, and West Germany.

AUTOMATED HIGHWAYS

Automation of vehicle operation on highways and expressways offers advantages in terms of increased capacity and travel speed and improved safety. Since 1960, the Federal Highway Administration has supported efforts leading toward

the development of system specifications for an Automated Highway System. The Federal Highway Administration currently is sponsoring research on automated highway vehicle control at Ohio State University which is reported at this conference. Ohio State University is developing lateral and longitudinal automatic control concepts for automobiles. The lateral control concepts utilize a buried cable as a lateral position reference. Electromagnetic radiation from the cable is measured by an array of coils on the vehicle and processed by an onboard computer to translate the lateral position error into appropriate steering signals. The longitudinal control research has focused on methods to provide the vehicle with position and velocity along the path data as well as methods to generate vehicle accelerator and brake commands and to coordinate the operation of vehicles.

TRANSPORTATION ADVANCED RESEARCH PROJECTS/UNIVERSITY RESEARCH

The Office of the Secretary of Transportation's (OST) Transportation Advanced Research Projects (TARP) is an applied research program whose principal objective is to provide a knowledge base in critical, multimodal technologies. It is defined as an advanced research program to indicate that it provides knowledge and tools for subsequent application to specific modal programs by members of the research and development community. The major project areas of the TARP program are (1) traffic flow management and control, (2) ride quality measurement, evaluation and impact on guideway costs, and (3) noncontact suspension and propulsion technology.

The OST University Research program was established to provide funds to assure that the resources of the university community are effectively brought to bear on transportation problems and, in particular, on those problems related to national transportation policy. Research priorities which are emphasized in FY 1978 include economics and regulation, science and technology, operations and system concepts, social and behavioral studies, and safety and environment problems.

This section of the program will report the results of work on ride comfort, guideway roughness evaluation, and innovative guideway designs.

SUMMARY

On Tuesday and Wednesday, papers will be presented that will describe the AGTT program projects and other related AGT programs in detail. On Thursday morning, there will be parallel workshop sessions on System Operations, Vehicle Systems and Reliability, Safety and Security, Wayside Systems and All-Weather Operation, Innovative Transit, and Social and Economic Factors. The conference will be concluded Thursday afternoon with the panel chairmen's summaries of the workshop sessions and a summary message from the conference chairman.

PAPER 1

Systems Operations Studies

James Thompson
General Motors Corporation

AGT SYSTEMS OPERATION STUDIES PROGRESS REPORT

James F. Thompson
SOS Program Manager
GM Transportation Systems Division

ABSTRACT. This paper summarizes the purpose, scope, technical approach, and results to date of the AGT-SOS project being performed under contract DOT-TSC-1220 with the Transportation Systems Center.

The AGT-SOS project is an across-the-board study of the applicability and capability of automated guideway transit systems. In the course of the study, representative system types, networks, and demands have been delineated and a set of representative combinations selected for investigation. A software set which provides a generalized capability for modeling the performance, cost, and availability characteristics of such deployments has been developed.

The selected deployments are subject to a two-stage analysis process. First, a set of design trade-off and parametric sensitivity studies is performed to establish a reference mechanization for each application; second, a comparative study establishing the relative advantages and disadvantages of different system types in similar applications is performed.

These analyses of the selected deployments lead to generalized performance summaries and guidelines for the system designer and application planner.

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A. INTRODUCTION

In July of 1976 the Transportation Systems Center (TSC) under the Urban Mass Transportation Administration (UMTA) awarded the Automated Guideway Transit Systems Operation Studies (AGT-SOS) contract (DOT-TSC-1220) to GM Transportation Systems Division with IBM Federal Systems Division as a major subcontractor for software development. This project, scheduled for a 36-month period, has just passed the halfway point. The analysis planning and software development work is largely completed, and the project is now in a phase where the execution of the various analyses dominates. This paper is intended as a progress report, and as such, it is useful to discuss the context within which the results to date were achieved and future work has been planned. To do this, subsequent sections cover the stated purpose of AGT-SOS within the larger Automated Guideway Transit Technology (AGTT) program and outline the technical approach employed by GM Transportation Systems Division. Finally, the results to date and the remaining work are summarized.

B. PURPOSE OF AGT-SOS

The AGT-SOS project is an across-the-board study of the applicability and capability of automated guideway transit systems. The statement of work identifies the project objectives as two-fold: "(1) to conduct comparative automated guideway system analyses evaluating the system cost, performance, and operating characteristics of a number of generic systems in representative urban network configurations, and (2) to develop and document a set of proven computer models that will allow the contractor to perform the analyses...and allow planners to perform similar analyses of automated guideway systems...." Dealing with "generic" and "representative" systems and network configurations requires the development of well-defined groupings of systems, networks, and demands so that useful results with broad application can be obtained, while limiting investigations to a reasonable number of examples of system deployments.

Coupled with the need for generality is a need to provide a relatively detailed representation of system characteristics so that attributes specific to automation can be identified and evaluated. Another influence in favor of a detailed system representation is the requirement that the software tools be useful for supporting system planning and design operations for specific real deplolyments. These parallel goals of developing generalized parametric data and providing the ability to model a variety of specific applications were the basic constraints observed in specifying the modeling software to be developed.

C. SOS APPROACH

The approach to the AGT-SOS problem is quite straight-forward and consists of eight basic steps:

1. Bound the problem by establishing the state-of-the-art.
2. Partition the data and establish representative characteristics for each partition.

3. Determine the information which the analyses are intended to provide and how it will be measured.
4. Select a set of representative applications which is of practical size and will allow the analyses to develop the desired data.
5. Develop computer software to support the analysis effort.
6. Establish nominal models of the characteristics of the partitions mentioned in Step 2.
7. Design a representative mechanization for each application and exercise it over a range of parameter values appropriate to the partitions involved.
8. Review results and establish the desired comparisons and generalized parameter/measure relationships.

So far, the eight steps have been defined in general problem-solving terms. The rest of this section is devoted to redefining these general steps in terms of their specific AGT-SOS implementation.

1. Establish The State Of The Art

From the start, GM TSD viewed an AGT application as having three major components: a demand, a network, and a set of system equipment. This is a convenient approach from a data acquisition point of view and also seems to have analysis and modeling advantages. The first step was to collect data in these three areas through direct contacts with manufacturers, operators, and planners, and through a search of reference sources such as the N. D. Lea Compendium, Standard Metropolitan Statistical Area (SMSA) data, systems specifications, requests for proposal, and proposals. The data acquired have been assembled in an SOS reference library. The systems covered are in various stages of development. Production equipment, prototype equipment, experimental breadboards, and conceptual designs are all represented to some extent. Demand data are in several forms. There are area-wide trip matrices derived from direct interviews, demand projections from transit planning projects, and station-to-station demand estimates from DPM developmental studies and proposals, as well as directly measured experience from operating systems such as Airtrans and Morgantown. The network information is derived from both existing AGT deployment drawings and from a number of proposals and requests for proposal.

2. Partition The Problem

Given the variety of data, the next step was to determine if it could be organized so that the major descriptive parameters or characteristics fell into consistent ranges or groupings. In addressing this part of the problem, the three basic components (system, network, and demand) were retained and a further grouping developed within each. The types or classes of systems, networks, and demands which ultimately were defined are of course arbitrary and other criteria for selecion could be chosen. Alternative approaches have been suggested and evaluated; however, none of the alternatives tested appeared to be significantly more useful than the set selected.

3. Plan The Analyses

Having begun definition of the set of characteristics and parameter values to be used, the next step was to plan the analysis process: defining the issues to be addressed, the relationships to be established, and measurement of the results. In this planning process, it is necessary to recognize that the plan is likely to change as the analysis proceeds. Parameters which appear to be fundamental to system performance may well prove to have little or no effect on the measures chosen. Unanticipated dependencies of measure values on parameter variations may indicate the need to redirect the analysis work or perhaps to revise the set of representative applications in some way.

4. Select Application Set

Starting from the sets of system, network, and demand types, it is possible to select a number of representative applications (an application is a combination of a system, a network, and a demand) which will be of practical size and contain several applications of each system type as well as alternative system types utilized for the same application. At this point in the process, cost and schedule considerations have a major impact. From the standpoint of completeness and rigor, a large set of applications is desirable. Unfortunately, the practical constraints of time and money forced the choice of a smaller set; this was based on a priori judgement, and the goal was to choose a cross section of the most representative or most interesting applications.

5. Develop Software

To perform the desired analyses on systems of the complexity and range typical of AGT, some form of computer modeling is necessary. For inter-application comparisons, it is convenient to have high-level measures which represent system performance in total. In general, these are averages over a fairly large time period, such as the peak 2 hours, or the total area of the deployment. However, the processes being investigated are dynamic and subject to local effects which averaging can mask. Therefore, the approach taken in developing the software tools is to generate data at a relatively detailed level and provide generalized aggregation processes which operate on that data at the analyst's option. The development of the software set is controlled by three types of documents: AGT-SOS Software Standards, Functional Specifications, and Technical Specifications. The software standards control the format and contents of the specifications as well as establish general rules for programming and documentation. The functional specifications define the system and subsystem characteristics which the software must model to allow execution of the analysis plan. The technical specifications are program design documents which control the coding process. The use and maintenance of the final software will be supported by user and programmer manuals.

6. Establish Nominal Models

These nominal models can be viewed as sets of model processor default input sets which are characteristic of a generic type or class of system,

network, or demand. For instance, a nominal system model consists of a set of parameters defining equipment unit costs, reliability, and performance. A nominal network model consists of a list of link and node interconnections and identities. In this model, station locations are identified but no station configuration information is given. A nominal demand model can be either a geograhic zone-to-zone transit demand or a station-to-station transit demand. In the SOS approach, no traditional modal split analysis is performed. All geographic demand is selected to be transit oriented. Geographic demand is mapped through a coarse model of three station access submodes (walking, private auto, and bus feeder) onto station locations. This process uses a set of simple diversion curves to divert those trips which cannot reasonably be expected to use the guideway.

7. Design And Evaluate Representative Applications

Once the nominal models of the system network and demand types exist, and configurations of them which are the representative applications have been selected, the analysis process can start. Since the parameters which make up each nominal model can take on a range of values, it is first necessary to perform a series of design trade-offs to establish the best combination of specific values for each representative application. Usually this set is different from application to application so that each system type must be re-evaluated in each of its deployments. To perform these trade-offs, goals for the resulting designs must be selected. Initially, constraints in terms of maximum values were established for four measures of performance:

1. Total Trip Time
2. Vehicle-Based Availability
3. Energy Consumption
4. Noise

As the analysis work has proceeded, Total Trip Time has been replaced by Average Trip Speed to make comparisons between dissimilar applications more intelligible.

The AGT System Analysis Requirements and Plan (Volume I, Requirements; Volume II, Plan) define the analysis tasks to be performed and the alternatives to be investigated for each representative application.

8. Establish Comparisons

As the final step in the AGT-SOS approach, the results of the previous trade-off and sensitivity analyses are reviewed to establish comparisons between the various system types in terms of their applicability to the selected representative application.

At present it seems unlikely that a formalized and rigorous comparative process can be established. There are two reasons for this. First, there is no generally accepted set of measures and weights on which to base an analytic comparison; second, the cost of any such formalized process tends to be very sensitive to the number of parameters and measures involved. The lack of agreement on measures and their relative importance probably reflects the fact that real deployments are motivated by many diverse

requirements which tend to have political or social rather than technological bases. Thus the present view, subject to further refinement, is that the comparisons are likely to be of the form, "if an installation has goals of this kind, then this type of deployment strategy should be considered," rather than formal ranking of system types within application types.

A second output which is planned at this stage of the project is to establish a set of quick-look models which summarize any parameter to measure relationships which can be observed from the trade-off and sensitivity analyses. To complete the project, all basic data, computer software, and significant analysis results are being organized into a data base both to document the current work and to provide a basis for future users to build on.

D. SUMMARY OF RESULTS TO DATE

At this point in the AGT-SOS project, the basic data acquisition, analysis planning, and software development is essentially complete. The results to date are covered in a series of delivered documents listed in Appendix A.

As could be expected, the implementation of the approach for the specific AGT-SOS problem has been far from straightforward. It has been necessary to make many judgments as to what is of first-order importance using incomplete data. There have been occasions where, after the fact, one could see where an alternative partitioning or selection of modeling technique might have been more useful. However, GM TSD feels that in general the approach has been successful. This section discusses plans and results generated to date and summarizes the rationale for the various selections and classifications made.

1. Data Acquisition

To establish the state-of-the-art for AGT type systems, both a literature search[1] and a series of direct contracts with representatives of planning agencies, system operations, and equipment developers/manufacturers were performed. The following list identifies the agencies or organizations visited:

1. Southeastern Michigan Transportation Authority (SEMTA)
2. Ford Motor Company, Fairlane Tower Center
3. Otis Elevator Company/Transportation Technology Division (OTIS/TTD)
4. Universal Mobility, Inc. (UMI)
5. Rohr Industries, Inc.
6. Southern California Council of Governments (SCAG)
7. Bay Area Rapid Transit (BART) District
8. Seattle-Tacoma Internationl Airport (SEATAC)
9. Boeing Aircraft Corp.
10. Denver Regional Transportation District (RTD)
11. Metropolitan Transit Commission (MTC, Minneapolis/St. Paul)

[1] See attached bibliography

12. Westinghouse Electric Corporation
13. West Virginia University, Morgantown, West Virginia
14. General Railway Signal Company (GRS)
15. Kings Island Amusement Park

These agencies/organizations provided information in the following general categories:

1. Physical configuration of existing or proposed systems
2. Operating characteristics, such as headway, vehicle velocity, and acceleration
3. Design parameters relating to stations, vehicles, and guideway.
4. Management strategies governing normal vehicle operation both in stations and on guideway
5. Management strategies governing system recovery from failures
6. Component reliability and maintenance schedules
7. Some cost items with respect to system elements
8. Measures of effectiveness used to evaluate system design alternatives and system operation

A compilation of the data collection contacts is contained in "Date Collection Trip Reports," Report No. EP-77059.

2. System Classes

A system classification structure has been developed based on consideration of the overall characteristics of existing and proposed AGT systems. The final structure, depicted in Table 1, includes five major classes and eight subclasses defined on the basis of service type, minimum traveling unit capacity, and maximum operating speed. Each system class also implies a characteristic range of minimum headway.

TABLE 1. CLASSIFICATION STRUCTURE

Category	Class	Subclass	Service Type	Minimum Traveling Unit Capacity (Passengers)	Maximum Operating Speed (km/hr)	Characteristic Minimum Headway (s)
PRT	PRT	low speed	personal	3-6	13-54	3 or less
		high speed	personal	3-6	55+	3 or less
GRT	SGRT	low speed	group	7-24	13-54	3-15
		high speed	group	7-24	55+	3-15
	IGRT	low speed	group	25-69	13-54	15-60
		high speed	group	25-69	55+	15-90
	LGRT		group	70-109	13-54	50-110
ART	ART		group	110+	55+	60+

Legend:

PRT - Personal Rapid Transit
GRT - Group Rapid Transit
SGRT - Small Vehicle GRT
IGRT - Intermediate Vehicle GRT
LGRT - Large Vehicle GRT
ART - Automated Rail Transit

These classes are intended to segregate basic hardware capabilities independent of the limitations introduced by deployment characteristics such as on-line or off-line stations. This led to the conclusion, discussed later, that Shuttle-Loop Transit is a deployment or network type, not a basic system type.

The system parameters selected to define the classes were chosen from among five alternative system characteristics - service type, vehicle capacity, minimum train consist, vehicle velocity, and minimum headway. Service type distinguishes between point-to-point, non-stop service which is characteristic of PRT systems and intermediate-stop or multiple-stop service. In multiple-stop service, passengers with destinations along a given route are grouped on one vehicle which makes intermediate stops along the route. It has been pointed out that non-stop service can be provided by GRT-type vehicles and that a better distinction would be single-party or multiple-party service. This is a valid observation, but the end set of system classes remains unchanged.

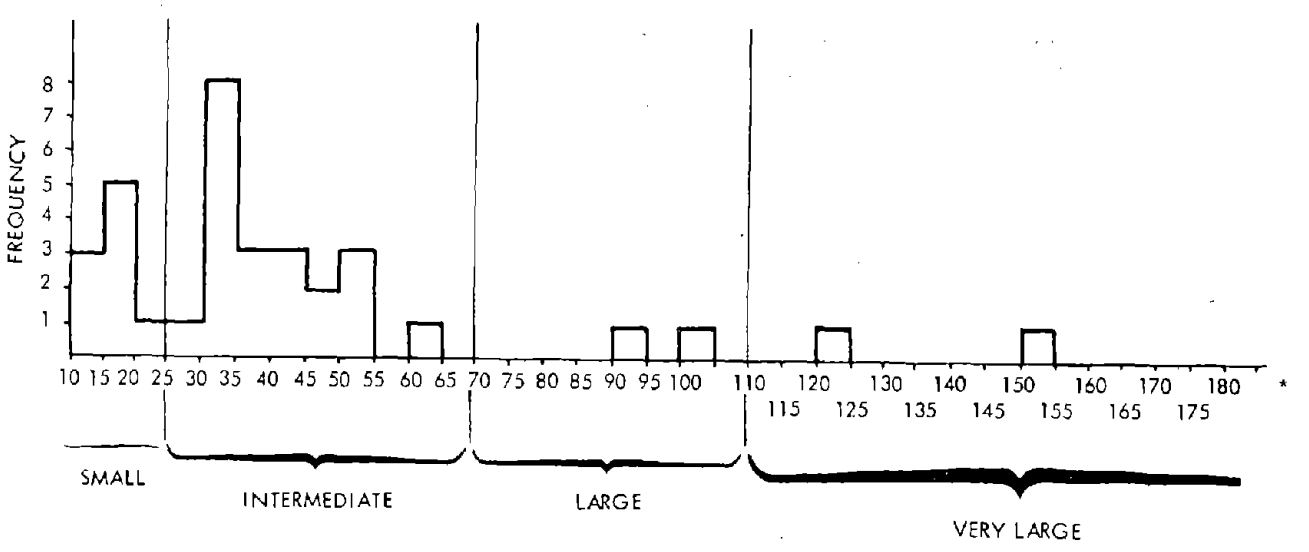
Vehicle capacity provides an indication of the systems capability of handling various demand situations and is also a measure of the degree of privacy afforded to individual passengers by a system. It also has some impact on the relative number of intermediate stops that passengers may expect before they reach their final designation. Since in most systems vehicle space is provided for both seated passengers and standees, the total passenger-carrying capacity of vehicles is of interest as a classification parameter.

Many systems permit vehicles to be operated in trains. In some cases, vehicles must be operated in trains of some minimum length. In those systems the minimum number of cars per train (minimum train consist) affects the typical service capabilities and system capacity in much the same way that vehicle capacity does. To accurately reflect the servce capabilities of systems, vehicle capacity and minimum train consist have been combined to form one classification parameter - minimum traveling unit capacity.

The characteristics of 44 existing and proposed AGT systems were surveyed to define the range and distribution of minimum traveling unit capacities. The minimum traveling unit capacity of the eight systems surveyed which are designed to provide non-stop, single-party service ranges from three to six passengers.

For systems which typically provide multiple-stop service, the capacities range from ten to 416 passengers. The distribution of minimum traveling unit capacities is illustrated in Figure 1. Based primarily on the histogram, four additional ranges of minimum traveling unit capacity were identified. Thus, five ranges of minimum traveling unit capacity have been identified for use in the system classification process as follows:

Very small	3 to 6 passengers
Small	10 to 24 passengers
Intermediate	25 to 69 passengers
Large	70 to 109 passengers
Very large	110+



*Three systems beyond the range of this table, at 248, 340, and 416

FIGURE 1. HISTOGRAM OF CAPACITIES

Vehicle velocity influences service level through its direct effect on travel time, especially for longer trips. Maximum speed capability also implies a range of applications for which a system may be suited. Maximum operating speed rather than cruise speed is used as a classification parameter because the former describes a system capability while the latter may refer to a network constraint or deployment option. The range of maximum operating speeds represented by the 44 AGT systems which were surveyed is from 13 km/h to 129 km/h. The distribution of these velocities is illustrated by the histograms presented in Figure 2. The histogram in the upper part of the figure shows the distribution of speeds for the personal transit systems. The histogram in the lower part of the figure summarizes the speed characteristics of 36 multiple-stop (group transit) systems. The distributions for the two categories of systems are not markedly different. As a rsult, two speed ranges (low and high) have been identified with the breakpoint at 55 km/h.

The final potential classification parameter which was considered, minimum headway, is directly related to theoretical system capacity and is an in-

dication of the level of control system complexity which a system requires. Minimum headway has been defined in two ways - theoretical minimum headway and practical minimum headway. Whenever both values were given in the literature, the latter was recorded. To evaluate the usefulness of minimum practical headway as a separate classification parameter, the correlation between minimum headway and minimum traveling unit capacity was investigated.

Figure 3, minimum traveling unit capacity versus minimum (practical) headway, shows that each range of unit capacity has a characteristic, though not exclusive, range of headway. The correlation between these parameters is sufficient to suggest that they should not be used together to define classes.

In summary, three parameters have been selected for use in defining a classification structure for AGT: service type, minimum traveling unit capacity, and maximum operating velocity.

The final classification structure is illustrated in Figure 4. Automated Guideway Transit is divided into two main categories - personal transit and group transit - on the basis of the type of service provided. Three major categories are identified on the basis of traveling unit capacity; Personal Rapid Transit (PRT), Group Rapid Transit (GRT), and Automted Rail Transit (ART). GRT is further partitioned into three distinct ranges of traveling unit capacity - Small Vehicle GRT (SGRT), Intermediate Vehicle GRT (IGRT), and Large Vehicle GRT (LGRT). The resulting five classes are further divided as appropriate into eight subclasses on the basis of maximum operating velocity.

To help clarify the relationship between the classification structure presented in this report and the terminology commonly used to denote AGT systems, commonly used acronyms are associated with the appropriate subclasses in Figure 5. Many of the terms in general use today are so broad that the systems they denote can be considered to be members of several subclasses. The figure shows that systems commonly referred to as Shuttle-Loop Transit (SLT) are classified as low-speed GRT systems while Dual Mode Transit (DMT) systems are members of the high-speed Small Vehicle GRT (SGRT) subclass. The classification work is reported in "Classification and Definition of AGT Systems," Report No. EP-77002.

In the process of developing this structure, alternative approaches were proposed based on the use of theoretical link capacity as one of the classification parameters. The motivation, of course, is to have the system classes provide some insight into the demand levels for which a system class can be considered. Clearly such classes should be examined and were. However, link capacity is a relevant measure only when the system is deployed on a network which allows the minimum headway to be approached. Shuttle networks do not allow the minimum system headway to be utilized. Similarly, networks having on-line stations may restrict the headway which can be specified even though the system technology could perhaps support a shorter headway. Finally, if the maximum link capacity can be achieved at all, it is a very localized phenomenon in both space and time. Link capa-

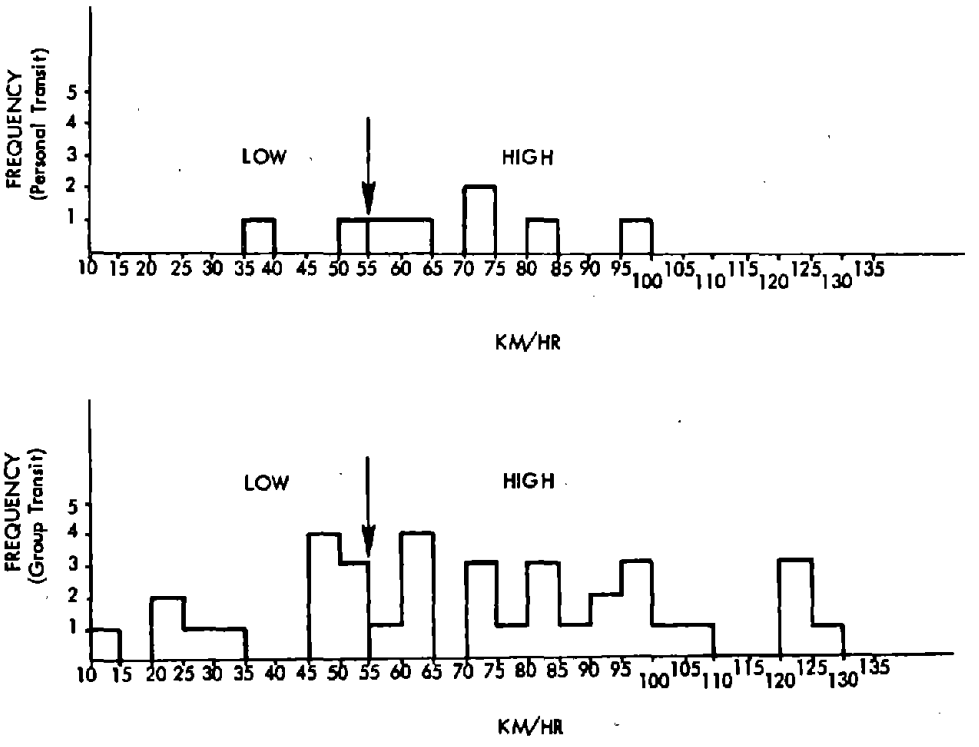


FIGURE 2. HISTOGRAM OF VELOCITIES

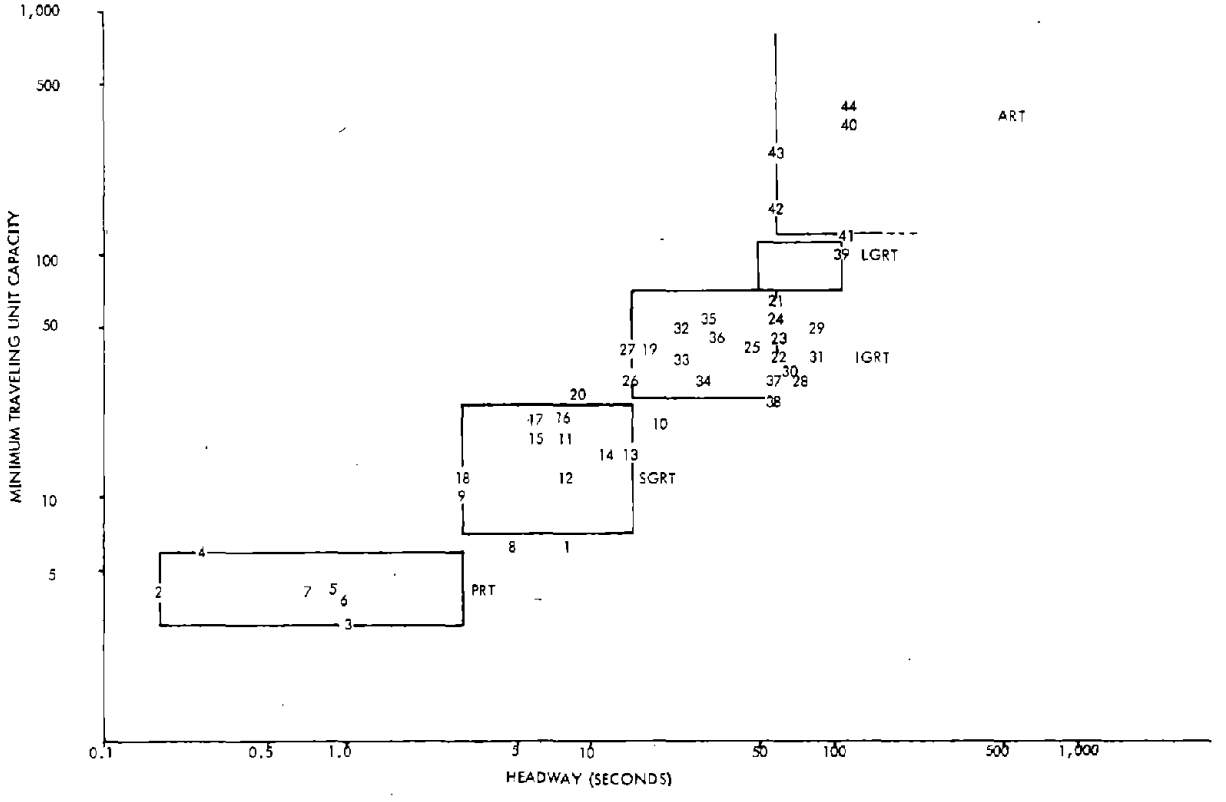


FIGURE 3. UNIT CAPACITY VS. HEADWAY

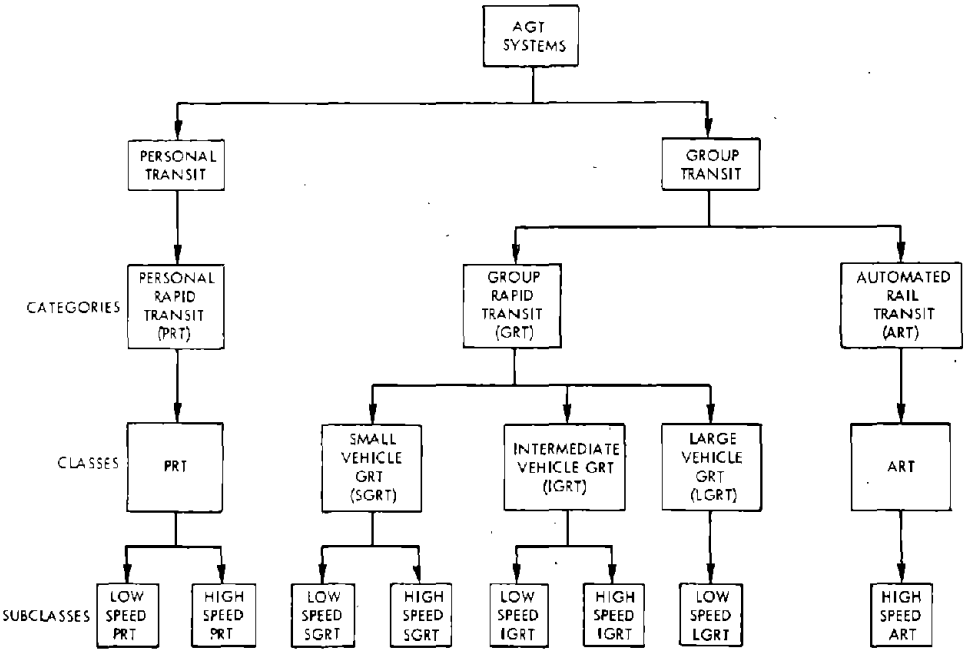


FIGURE 4. FINAL CLASSIFICATION STRUCTURE

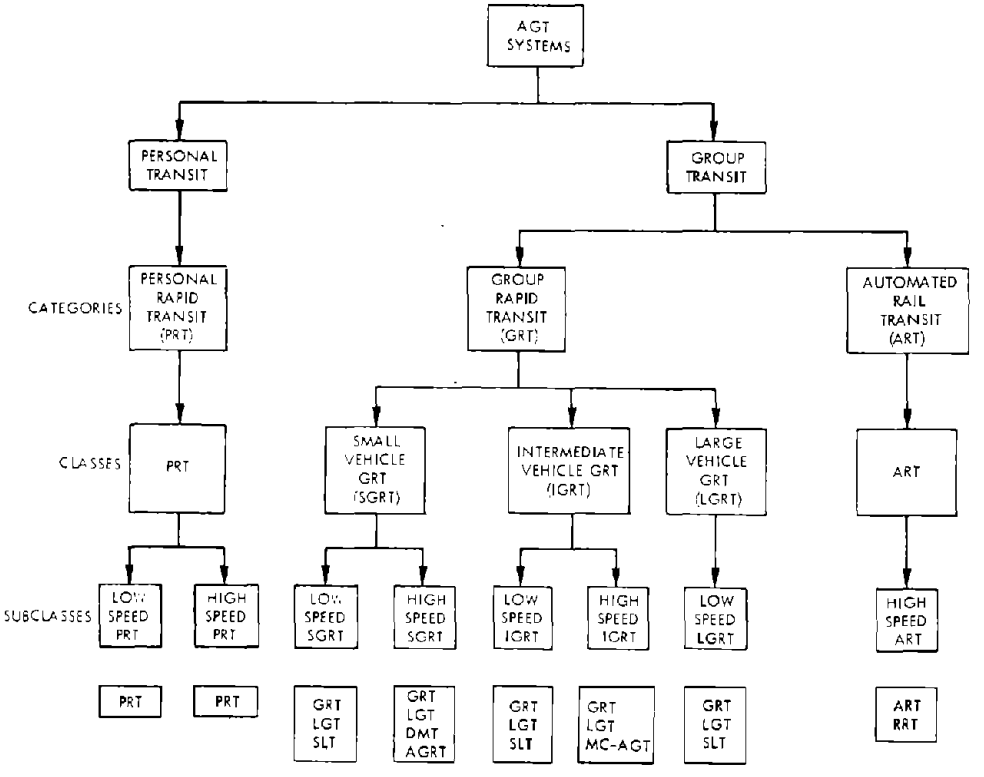


FIGURE 5. POPULATION TERMS VS. STRUCTURE

city is, as the name implies, a link characteristic - not a network characteristic. Therefore, its value in estimating the passenger-carrying capability of a system is questionable and depends strongly on network characteristics. In addition, if theoretical link capacity based on published vehicle capacity and minimum operating headway is used as the primary classification parameter, such anomalies as placing PRT systems in the same class with BART can occur.

While alternative classifications could be developed, none suggested had sufficient advantage to offset the anomalies encountered.

3. Travel Demand Models

Travel demand can be characterized in several ways, regardless of the situation under consideration. Demand, in this case, is the total movement of persons within a specified analysis area, including trips having only one end in the analysis area.

A significant travel demand characteristic is the size of the analysis area. For the purposes of the AGT Systems Operation Studies, analysis area sizes vary from major portions of entire metropolitan areas to localized parts of small-area activity centers; that is, from hundreds of square miles to less than one square mile.

Aggregate trip-making volume is another important characteristic of a demand analysis area. The average daily number of trips in a demand analysis area, for example, is a measure of this type. Disaggregation of demand magnitude by specifying magnitudes for each of several smaller time intervals results in a third demand characteristic: temporal distribution. Disaggregation by subdividing the overall demand analysis area into smaller units and then specifying demand magnitudes between or within pairs of areal units allows a demand analysis area to be described in terms of spatial distribution - another major demand characteristic.

Within the context of AGT-SOS, modal split characteristics are not considered. Instead a set of generalized transit demand models which have representative temporal and spatial amplitude distribution have been defined. The relative ability of alternate system deployments to serve these demands is then measured using a simple diversion curve approach to reject those trips which cannot reasonably be expected to use the AGT system.

An examination of potential AGT system application areas, along with the characteristics discussed above, suggests a top-level classification of demands into two groups: metropolitan areas (or substantial portions of metropolitan areas) and activity centers (small areas of high travel intensity).

At least two alternative demand modeling approaches may be considered: abstract models of composite demand analysis areas may be formulated, or data from individual areas may be used directly with little modification.

The second demand modeling approach seemed more suitable for the types of analyses planned in the AGT-SOS project. This approach involves selecting

an actual demand situation with characteristics similar to those desired, and then obtaining, modifying, and using data which describe that demand. Two major advantages are: first, the assurance that the model represents at least one real travel demand environment; and second, the avoidance of the averaging process used in the formulation of a composite demand model. The detailed characteristics that make each demand situation unique can be obscured during composite demand model synthesis.

The freedom remains, of course, to choose each representative locale on the basis of its aggregate demand characteristics and to modify the resulting demand model as necessary to include other characteristics.

The analysis of a wide range of AGT system types and networks requires a variety of travel demand models. More than one demand model for each of the two major demand classes (metropolitan areas and activity centers) is needed. The combination of system types, network types, and demand types chosen for analysis, however, must be limited to a manageable number.

The travel patterns in a metropolitan area are strongly influenced by the presence of one or more Central Business Districts. A convenient way of expressing relative CBD trip attraction is to calculate the percentage of all daily work trips which terminate in the CBD. Another useful spatial distribution measure is the relative amount of "reverse commutation;" that is, the number of people residing in the city and working in the suburbs. This measure can be computed as the percentage of all daily work trips of central city residents to the urbanized ring outside the central city.

If high and low values are considered for each of the two spatial distribution measures, a total of four basic demand models are defined: low CBD orientation and low reverse commutation; low CBD orientation and high reverse commutation; high CBD orientation and low reverse commutation; and high CBD orientation and high reverse commutation. The first type, in which both measures are low, suggests a homogenous metropolitan area. If the demand is also of low density, a capital-intensive, fixed-route system is not appropriate. If the demand is high density, the actual demand served will be some subset of total demand which is represented by one of the other three types. Therefore, the low/low combination has not been modeled.

Activity center demands have been subclassified on the basis of the nature of the associated activity. The following activity center types are among those for which AGT systems have been suggested: Central Business District, university, airport, medical center (possibly combined with a university), zoo, shopping center, recreation area, business or industrial complex, stadium, and exposition.

The CBD, university, and airport travel demands appear to encompass the most likely deployments of moderately complex AGT systems in future activity center applications. The analysis of CBD deployments is particularly important due to the number of cities planning Downtown People Mover systems. The choice of two CBD types with different demand magnitudes enables a more complete analysis of CBD systems, while a single demand for each of the other two activity center types should be sufficient. The total of four activity center demand model types provide a representative variety of demand magnitudes, spatial distributions, and temporal distributions.

It was decided to choose a metropolitan area of each type from among the largest 35 Standard Metropolitan Statistical Areas (SMSA's) in the United States. The Urban Data Book lists populations, land areas, and journey-to-work data (among other information) for each SMSA. Table 2 is a compilation of SMSA land areas where each SMSA is subdivided into smaller components. The following abbreviations are used in that and other tables:

- SMSA - Standard Metropolitan Statistical Area
- R&SU - Rural and Scattered Urban
- UA - Urbanized Area
- UR - Urbanized Ring
- CC - Central City
- CCR - Central City Ring
- CBD - Central Business District

Table 3 is a similar listing of SMSA populations, based upon 1970 Census data. Next, Table 4 indicates work trip volumes between selected portions of each SMSA. Above each column are abbreviations for the area of residence, followed by the area of employment, for the work trips listed below. As noted, the three largest SMSA's (Chicago, Los Angeles, and New York) are eliminated from the totals and averages presented.

Table 5 summarizes four important characteristics of each Urbanized Area: land area, population, CBD orientation, and reverse commutation. The 35 Urbanized Areas are ranked in descending order for each characteristic. From this data, a candidate list for each model type has been extracted. For this purpose, "high" refers to a characteristic measure above the mean of all 35 UA's, while "low" refers to a value below the mean. Means of 10.06 percent for CBD orientation and 8.49 percent for reverse commutation place the first 16 UA's (in both CBD orientation and reverse commutation) in "high" categories. The following UA's satisfy the simultaneous requirements of low CBD orientation and high reverse commutation:

- San Jose
- Milwaukee
- Miami
- Los Angeles
- Detroit
- Baltimore
- Tampa-St. Petersburg
- Phoenix
- Kansas City
- Providence
- Cleveland

Detroit is the preferred choice for this type of demand model. The Detroit CBD attracts a substantial number of work trips - even though CBD trips constitute a small percentage of all Urbanized Area work trips - providing a good demand environment for analyzing CBD-oriented AGT systems in the presence of strong reverse commutation.

TABLE 2. LAND AREAS OF 35 LARGEST SMSA'S

SMSA NAME	LAND AREA (SQ. MILES)						
	TOTAL SMSA	SMSA		URBANIZED AREA		CENTRAL CITY	
		R & SU	UA	UR	CC	CCR	CBD
ATLANTA	1,727	1,292	435	303	132	130.770	1.230
BALTIMORE	2,259	1,949	310	232	78	77.473	0.527
BOSTON	987	343	644	598	46	45.000	1.000
BUFFALO	1,591	1,377	214	173	41	40.223	0.777
CHICAGO*	3,720	2,443	1,277	1,054	223	221.450	1.550
CINCINNATI	2,150	1,815	335	257	78	77.213	0.787
CLEVELAND	1,519	873	646	570	76	74.942	1.058
COLUMBUS	1,494	1,259	235	100.4	134.6	133.664	0.936
DALLAS - FT. WORTH	6,171	5,101	1,070	599	471	468.900	2.100
DAYTON	1,708	1,484	224	185.7	38.3	37.500	0.800
DENVER	3,660	3,447	213	118	95	94.094	0.906
DETROIT	1,952	1,080	872	734	138	136.880	1.120
HOUSTON	6,286	5,750	536	139	397	392.510	4.490
INDIANAPOLIS	3,080	2,699	381	29	352	349.700	2.300
KANSAS CITY	2,767	2,274	493	254	239	238.234	0.766
LOS ANGELES*	4,069	2,497	1,572	1,060	512	509.240	2.760
LOUISVILLE	908	698	210	150	60	57.650	2.350
MIAMI	2,042	1,783	259	225	34	33.605	0.395
MILWAUKEE	1,456	999	457	362	95	94.003	0.997
MINNEAPOLIS - ST. PAUL	2,107	1,386	721	614	107	105.470	1.530
NEW ORLEANS	1,975	1,791	184	98	86	84.800	1.200
NEW YORK*	2,136	--	2,425	2,125	300	295.977	4.023
PHILADELPHIA	3,553	2,801	752	624	128	125.460	2.540
PHOENIX	9,238	8,850	388	140	248	246.967	1.033
PITTSBURGH	3,049	2,453	596	541	55	54.450	0.550
PORTLAND	3,650	3,383	267	178	89	88.600	0.400
PROVIDENCE	679	435	244	182	62	61.510	0.490
ST. LOUIS	4,118	3,657	461	400	61	60.645	0.355
SAN ANTONIO	1,960	1,737	223	39	184	182.990	1.010
SAN DIEGO	4,262	3,881	381	168	213	212.675	0.325
SAN FRANCISCO - OAKL.	2,478	1,797	681	582	99	97.872	1.128
SAN JOSE	1,300	1,023	277	161	116	114.600	1.400
SEATTLE	4,229	3,816	413	300	113	112.487	0.513
TAMPA - ST. PETERSBURG	1,303	1,011	292	152	140	135.170	4.830
WASHINGTON	2,352	1,857	495	434	61	59.620	1.380
TOTAL	88,010	74,101	13,909	9,642	4,267	4,225.7	41.223
AVERAGE	2,750	2,316	435	301	133	132.1	1.288

*Excluded from Totals and Averages

TABLE 3. POPULATIONS OF 35 LARGEST SMSA'S

SMSA NAME	POPULATION (1970)						
	TOTAL SMSA	SMSA		URBANIZED AREA		CENTRAL CITY	
		R & SU	UA	UR	CC	CCR	CBD
ATLANTA	1,390,000	217,222	1,172,778	675,778	497,000	494,571	2,429
BALTIMORE	2,071,000	491,219	1,579,781	673,781	906,000	903,431	2,569
BOSTON	2,754,000	101,425	2,652,575	2,011,575	641,000	637,300	3,700
BUFFALO	1,349,000	262,406	1,086,594	623,594	463,000	461,172	1,828
CHICAGO*	6,978,000	263,422	6,714,578	3,345,578	3,369,000	3,364,174	4,826
CINCINNATI	1,385,000	274,486	1,110,514	659,514	451,000	447,525	3,475
CLEVELAND	2,064,000	104,120	1,959,880	1,208,880	751,000	745,790	5,210
COLUMBUS	916,228	126,209	790,019	250,642	539,377	537,482	1,895
DALLAS - FT. WORTH	2,318,134	302,506	2,015,628	737,976	1,277,652	1,272,631	5,021
DAYTON	850,266	164,324	685,942	442,484	243,458	242,032	1,426
DENVER	1,230,000	182,689	1,047,311	532,311	515,000	511,880	3,120
DETROIT	4,204,000	233,416	3,970,584	2,457,584	1,513,000	1,506,572	6,428
HOUSTON	1,985,000	307,137	1,677,863	446,863	1,231,000	1,206,951	24,049
INDIANAPOLIS	1,111,000	290,741	820,259	77,259	743,000	733,298	9,702
KANSAS CITY	1,256,000	154,213	1,101,787	599,787	502,000	500,209	1,791
LOS ANGELES*	7,041,000	--	8,351,266	5,182,266	3,169,000	3,146,850	22,150
LOUISVILLE	826,553	87,157	739,396	377,943	361,453	348,292	13,161
MIAMI	1,268,000	48,339	1,219,661	884,661	335,000	331,726	3,274
MILWAUKEE	1,404,000	151,543	1,252,457	535,457	717,000	714,539	2,461
MINNEAPOLIS - ST. PAUL	1,814,000	109,577	1,704,423	960,423	744,000	738,125	5,875
NEW ORLEANS	1,046,000	84,272	961,728	369,728	592,000	586,611	5,389
NEW YORK*	11,571,883	--	16,206,841	8,310,841	7,896,000	7,705,092	190,908
PHILADELPHIA	4,822,000	800,934	4,021,066	2,071,066	1,950,000	1,906,535	43,465
PHOENIX	968,000	104,643	863,357	281,357	582,000	577,675	4,325
PITTSBURGH	2,401,000	554,958	1,846,042	1,326,042	520,000	517,056	2,944
PORTLAND	1,007,000	182,074	824,926	444,926	380,000	376,990	3,010
PROVIDENCE	914,000	118,689	795,311	455,311	340,000	338,440	1,560
ST. LOUIS	2,363,000	480,056	1,882,944	1,260,944	622,000	621,413	587
SAN ANTONIO	864,014	91,501	772,513	118,224	654,289	651,014	3,275
SAN DIEGO	1,358,000	159,677	1,198,323	504,323	694,000	690,382	3,618
SAN FRANCISCO - OAKL.	3,108,000	120,150	2,987,850	1,910,850	1,077,000	1,050,844	26,156
SAN JOSE	1,067,000	41,727	1,025,273	581,273	444,000	431,726	12,274
SEATTLE	1,425,000	186,893	1,238,107	654,107	584,000	579,951	4,049
TAMPA - ST. PETERSBURG	1,012,594	148,693	863,901	370,098	493,803	486,995	6,808
WASHINGTON	2,862,000	380,511	2,481,489	1,724,489	757,000	751,895	5,105
TOTAL	55,413,789	7,063,507	48,350,282	26,229,250	22,121,032	21,901,053	219,979
AVERAGE	1,731,681	220,735	1,510,946	819,664	691,282	684,408	6,874

*Excluded from Totals and Averages

TABLE 4. JOURNEY-TO-WORK DATA FOR 35 LARGEST SMSA'S

SMSA NAME	DAILY WORK TRIPS WITHIN SMSA (THOUSANDS)											
	CC-CBD	CC-CCR	CC-UR	CC-UA	UR-CBD	UR-CCR	UR-UR	UR-UA	UA-CBD	UA-CCR	UA-UR	UA-UA
Atlanta	28	129	39	196	23	110	133	266	51	239	172	462
Baltimore	29	226	67	322	15	86	141	242	44	312	208	564
Boston	36	162	51	249	50	152	559	761	86	314	610	1010
Buffalo	21	98	38	157	15	55	147	217	36	153	185	374
Chicago *	160	1064	205	1429	81	277	916	1274	241	1341	1121	2703
Cincinnati	22	104	37	163	21	78	110	209	43	182	147	372
Cleveland	29	177	64	270	41	165	244	450	70	342	308	720
Columbus	29	138	38	205	12	57	42	111	41	195	80	316
Dallas-Ft. Worth	54	260	29	343	10	88	82	180	67	348	111	526
Dayton	11	60	12	83	11	55	69	135	22	115	81	218
Denver	28	147	27	202	13	75	108	196	41	222	135	398
Detroit	51	306	161	518	33	181	623	837	84	487	784	1355
Houston	84	372	34	490	17	74	51	142	101	446	85	632
Indianapolis	47	187	33	267	4	8	10	22	51	195	43	289
Kansas City	19	143	40	202	13	87	101	291	32	230	171	433
Los Angeles *	80	928	373	1381	51	445	1160	1656	131	1373	1533	3037
Louisville	26	79	25	130	16	54	70	140	42	133	95	270
Miami	10	72	57	139	12	94	217	323	22	166	274	462
Milwaukee	31	189	62	282	12	61	122	195	43	250	184	477
Minneapolis-St. Paul	52	196	57	305	35	128	207	370	87	324	264	675
New Orleans	50	126	22	198	15	35	72	122	65	161	94	320
New York *	750	2410	254	3414	100	470	1785	2355	850	2880	2039	5769
Philadelphia	79	565	74	718	37	144	540	721	116	709	614	1439
Phoenix	17	172	29	218	3	33	58	94	20	205	87	312
Pittsburgh	29	170	31	180	38	66	321	425	67	186	352	605
Portland	18	101	25	144	11	59	89	159	29	160	114	303
Providence	11	90	25	126	9	49	88	146	20	139	113	272
St. Louis	13	162	40	215	16	138	292	446	29	300	332	661
San Antonio	28	173	18	219	2	34	15	51	30	207	35	270
San Diego	16	220	37	273	4	63	116	183	20	283	153	456
San Francisco-Oakland	111	278	56	445	61	126	469	656	172	404	525	1101
San Jose	8	74	58	140	3	40	152	195	11	114	210	335
Seattle	25	181	28	234	11	96	117	224	36	277	145	458
Tampa-St. Petersburg	15	127	26	168	5	43	58	106	20	170	84	274
Washington	59	211	49	319	74	157	430	661	133	368	479	980
Col. Total	1086	5645	1389	8120	645	2691	5883	9219	1731	8036	7272	17039
Average	33.9	176.4	43.4	253.8	20.2	84.1	183.8	288.1	54.1	260.5	227.3	541.8

* Excluded from Totals and Averages

TABLE 5. RANKED DATA SUMMARY FOR 35 LARGEST SMSA'S

Rank	Urbanized Area Size (Square Miles, Land Area)		Urbanized Area Population (Thousands of Persons)		CBD Orientation (% of Urbanized Area Work Trips/Urbanized Area to CBD)		Reverse Commutation (% of Urbanized Area Work Trips Central City to Urbanized Ring)	
1	New York	2,425	New York	16,207	New Orleans	20.31	San Jose	17.31
2	Los Angeles	1,572	Los Angeles	8,351	Indianapolis	17.65	Milwaukee	13.00
3	Chicago	1,277	Chicago	6,715	Houston	15.98	Miami	12.34
4	Dallas - Ft. Worth	1,070	Philadelphia	4,021	San Francisco - Oakland	15.62	Los Angeles	12.28
5	Detroit	872	Detroit	3,971	Louisville	15.56	Columbus	12.00
6	Philadelphia	752	San Francisco - Oakland	2,988	New York	14.73	Detroit	11.88
7	Minneapolis - St. Paul	721	Boston	2,653	Washington	13.57	Baltimore	11.88
8	San Francisco - Oakland	681	Washington	2,481	Columbus	12.97	Indianapolis	11.42
9	Cleveland	646	Dallas - Ft. Worth	2,016	Minneapolis - St. Paul	12.89	Buffalo	10.16
10	Boston	644	Cleveland	1,960	Dallas - Ft. Worth	12.74	Cincinnati	9.95
11	Pittsburgh	596	St. Louis	1,880	Cincinnati	11.56	Tampa - St. Petersburg	9.49
12	Houston	536	Pittsburgh	1,846	San Antonio	11.11	Phoenix	9.29
13	Washington	495	Minneapolis - St. Paul	1,704	Pittsburgh	11.07	Louisville	9.26
14	Kansas City	493	Houston	1,678	Atlanta	11.04	Kansas City	9.24
15	St. Louis	461	Baltimore	1,580	Denver	10.30	Providence	9.19
16	Milwaukee	457	Milwaukee	1,252	Dayton	10.09	Cleveland	8.89
17	Atlanta	435	Seattle	1,238	Cleveland	9.72	Minneapolis - St. Paul	8.44
18	Seattle	413	Miami	1,220	Buffalo	9.63	Atlanta	8.44
19	Phoenix	388	San Diego	1,198	Portland	9.57	Portland	8.25
20	Indianapolis	381	Atlanta	1,173	Milwaukee	9.01	San Diego	8.13
21	San Diego	381	Cincinnati	1,111	Chicago	8.92	Chicago	7.58
22	Cincinnati	335	Kansas City	1,102	Boston	8.57	New Orleans	6.88
23	Baltimore	310	Buffalo	1,085	Philadelphia	8.06	Denver	6.78
24	Tampa - St. Petersburg	292	Denver	1,047	Seattle	7.86	San Antonio	6.67
25	San Jose	277	San Jose	1,025	Baltimore	7.80	Seattle	6.11
26	Portland	267	New Orleans	962	Kansas City	7.79	St. Louis	6.05
27	Miami	259	Tampa - St. Petersburg	864	Providence	7.35	Dallas - Ft. Worth	5.51
28	Providence	244	Phoenix	863	Tampa - St. Petersburg	7.30	Dayton	5.50
29	Columbus	235	Portland	825	Phoenix	6.41	Houston	5.38
30	Dayton	224	Indianapolis	820	Detroit	6.20	Philadelphia	5.14
31	San Antonio	223	Providence	795	Miami	4.76	Pittsburgh	5.12
32	Buffalo	214	Columbus	790	St. Louis	4.39	San Francisco - Oakland	5.09
33	Denver	213	San Antonio	773	San Diego	4.39	Boston	5.05
34	Louisville	210	Louisville	739	Los Angeles	4.31	Washington	5.00
35	New Orleans	186	Dayton	686	San Jose	3.78	New York	4.40

The next list is of Urbanized Areas with high CBD orientation and low reverse commutation:

- New Orleans
- Houston
- San Francisco-Oakland
- New York
- Washington
- Minneapolis-St. Paul
- Dallas-Fort Worth
- San Antonio
- Pittsburgh
- Denver
- Dayton

Of these, Washington is preferred due to its high CBD orientation, very low reverse commutation, and moderately large size.

The following cities are those with both high CBD orientation and high reverse commutation:

- Indianapolis
- Columbus
- Cincinnati
- Louisville

For this demand model type, Cincinnati is the preferred representative area. This selection is based upon Cincinnati's relatively high population density, CBD attraction comparable to other areas, and GM TSD's possession of (and previous work with) home interview survey data for the Cincinnati area.

The following four activity center demand types have been selected for use in the AGT-SOS project:

- CBD line haul
- CBD circulation
- University
- Airport

Candidate cities for the two CBD demand models have been limited to those most likely to implement Downtown People Mover systems in the near and intermediate future. At the time this selection was made, seven cities had received favorable responses to their DPM proposals.

o Baltimore	16,000 riders/day
o Cleveland	46,500 riders/day
o Detroit	39,450 to 65,500 riders/day
o Houston	25,601 riders/day
o Los Angeles	58,100 riders/day
o Miami	40,200 riders/day
o St. Paul	48,000 riders/day

A CBD with low demand was chosen by observing which of the seven CBD's had a relatively low (but not the lowest) demand. Houston's projected daily ridership meets these conditions quite well. A high-demand CBD was chosen in a similar fashion. That is, the highest demand has been eliminated and the second highest selected. Since Detroit CBD demand projections range from a pessimistic estimate of 39,450 to an optimistic estimate of 65,500 riders per day, an average of 52,475 was assumed. Therefore, Detroit was considered a representative high-demand CBD. In addition to these differences in daily demand magnitude, other factors make these two CBD's useful as representatives of CBD demand. The projected demand for the Houston DPM consists of primary trips which originate outside the CBD and use the people mover to reach their final destination after transferring at parking lots or bus terminals. On the other hand, the projected demand for the Detroit people mover consists primarily of secondary trips which have both origin and destination within the CBD. DPM for Houston is essentially a line-haul service between multimodal transfer points and employment sites while the proposed Detroit DPM is intended to serve more of a circulation function.

In order to permit direct comparisons of system deployments designed for different demands, three values of demand magnitude for the CBD circulation (Detroit) application and two values for the CBD line-haul (Houston) application have been specified.

For university and airport travel demand models, the opportunity exists to utilize data pertaining to areas in which AGT systems are presently operating. West Virginia University at Morgantown, West Virginia has, therefore, been selected as a representative university travel demand situation. Dallas/Fort Worth Regional Airport has been chosen for use in the formulation of an airport demand model, since other airports with automated systems have less complex guideway network configurations. The demand patterns exhibit distinctive peaking features with the university demand peaking at most stations each hour while the airport demand peaks randomly at individual stations.

Trip matrix format is uniform among all of the demand models and is compatible with computer programs in the UMTA Transportation Planning System (UTPS) package.

The university demand model is based on projected five-minute station-to-station student trip matrices for the planned six-station Group Rapid Transit system at West Virginia University in Morgantown. The projected data was used in conjunction with observed daily ridership totals because no actual origin-to-destination data was available for the existing Morgantown system.

a. University Demand: The university application deployment to be analyzed in the SOS program consists of an alternative network linking the three stations of the existing Morgantown system. Therefore, the first step in generating the demand model for the university application was to modify the projected six-station demand by eliminating trips to and from the three stations not included in the representative network.

The magnitude of daily travel represented by the resulting three-station demand matrices was compared to existing daily ridership totals observed in recent operation of the Morgantown system. The demand projection was found to be higher than the existing daily ridership for the three-station system. In order to more closely model the demand for the existing system configuration at Morgantown, the modified demand projection matrix was scaled to adjust the demand magnitude to correspond to the daily ridership observed. Figure 6 illustrates the university demand model showing the variation in demand magnitude for 15-minute intervals during a service day. It shows the significant micropeaking which is characteristic of the university application.

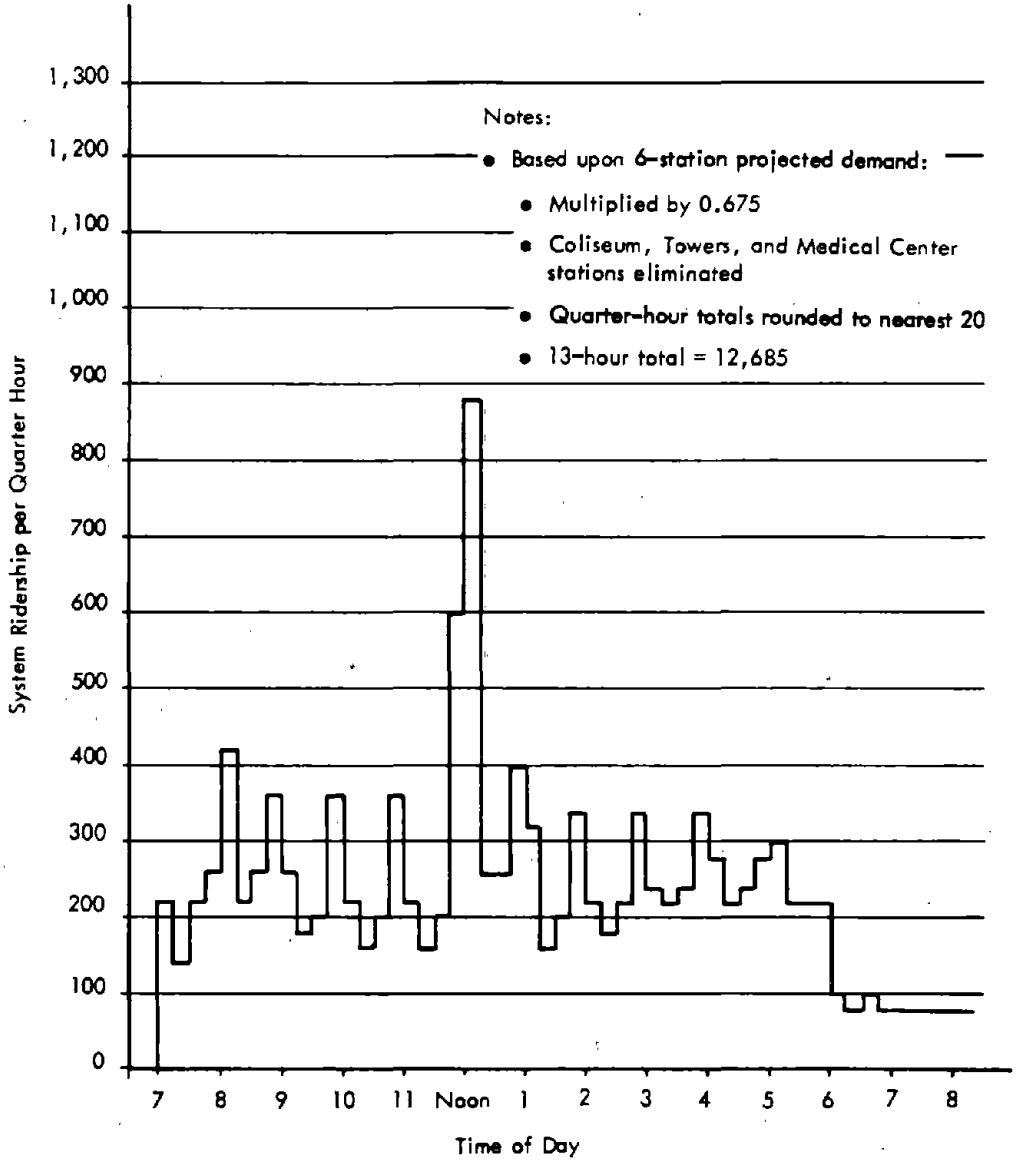


FIGURE 6. DEMAND PROFILE FOR THE 3-STATION MORGANTOWN AGT SYSTEM

b. Airport Demand: The airport demand model is based on data from a 1974 passenger flow study of the Airtrans system operating at the Dallas/Fort Worth Regional Airport. The data consist of turnstile counts at each of 14 passenger stations, taken over 15-minute intervals during three peak periods. Demand for off-peak intervals was estimated based on total trips made during each of the three eight-hour work shifts. Turnstile counts - actual counts or estimates - do not specify the station-to-station demands as needed for analysis purposes. Therefore, it was necessary to approximate the station-to-station demand by assigning trips which enter at each station to exit at the other stations in proportion to the total number of exiting passengers at each station.

Figure 7, the observed demand profile for the Airtrans system as reported in the Passenger Flow Study, indicates that the recorded 15-minute trip levels are well in excess of the average number for each shift. The demand for the unrecorded 15-minute intervals must be significantly lower than the recorded levels to result in the given shift averages. The demand for 15-minute intervals during the off-peak periods was assumed to first decrease then gradually build up to the next peak. It was further assumed that the slope of the off-peak demand fluctuations is approximately equal to the greatest hourly variation in demand during the adjacent peak period. This assumption, coupled with the constraint that the shift total be reproduced, led to the estimates of off-peak 15-minute interval demand as presented in Figure 8.

Figure 9 shows the demand magnitudes, aggregated over half-hour intervals, which result from the O-D distributions for the period between 7:00 a.m. and 8:00 p.m. Half-hour intervals proved to display similar characteristics to the quarter-hour intervals; consequently, the half-hour was selected as the basic time interval to be used for further analysis.

For modeling purposes it is desirable to minimize the number of different O-D matrices. Using the demand profile of Figure 9 as a base, modifications were made to reduce the number of unique half-hour intervals to be represented while retaining the peaking characteristics of the airport application. In general, the time intervals for which data was estimated, rather than observed, were aggregated. The resultant demand model is illustrated in Figure 10.

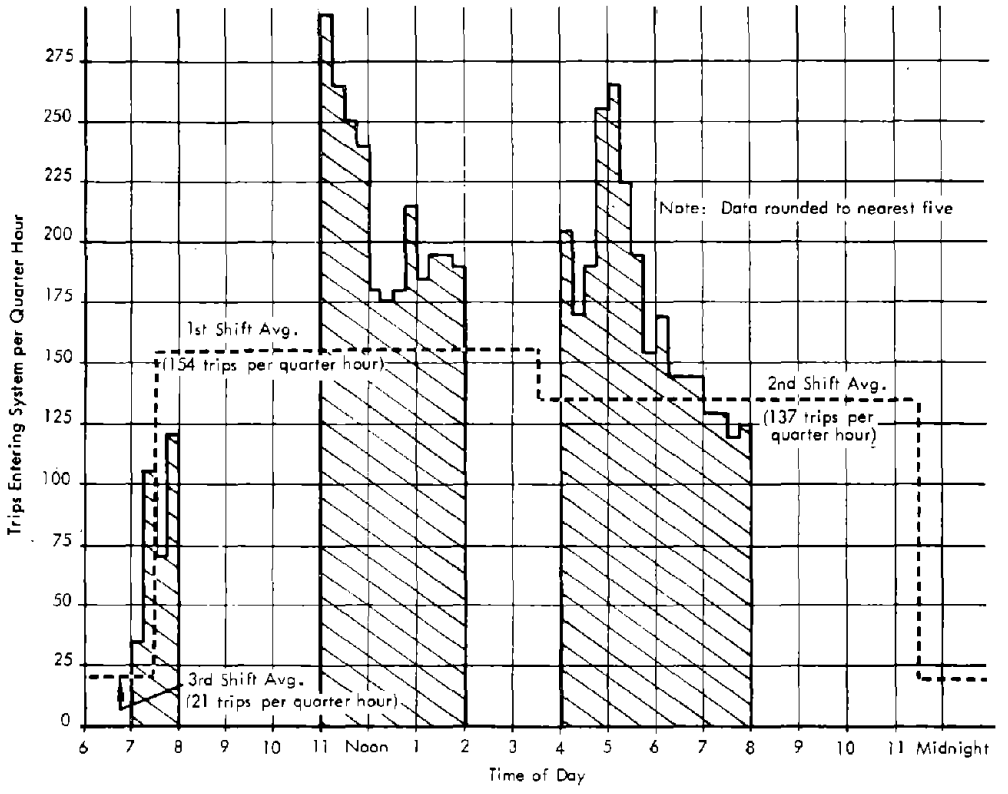


FIGURE 7. AIRTRANS DEMAND PROFILE (1974 PASSENGER FLOW STUDY)

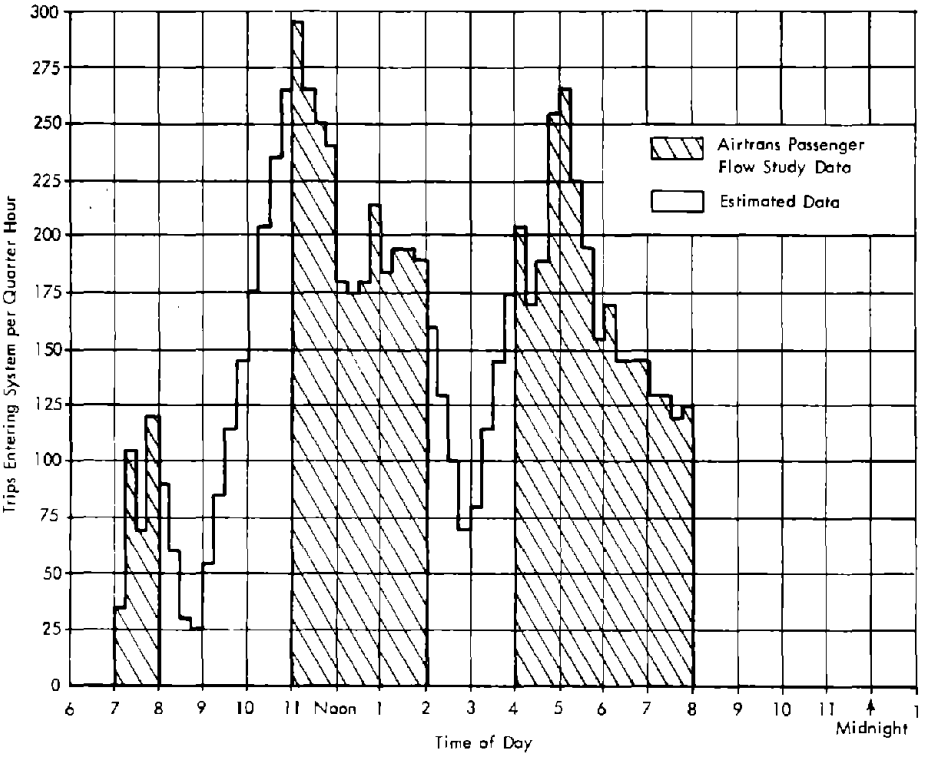


FIGURE 8. AIRTRANS DEMAND WITH OFF-PEAK ESTIMATE

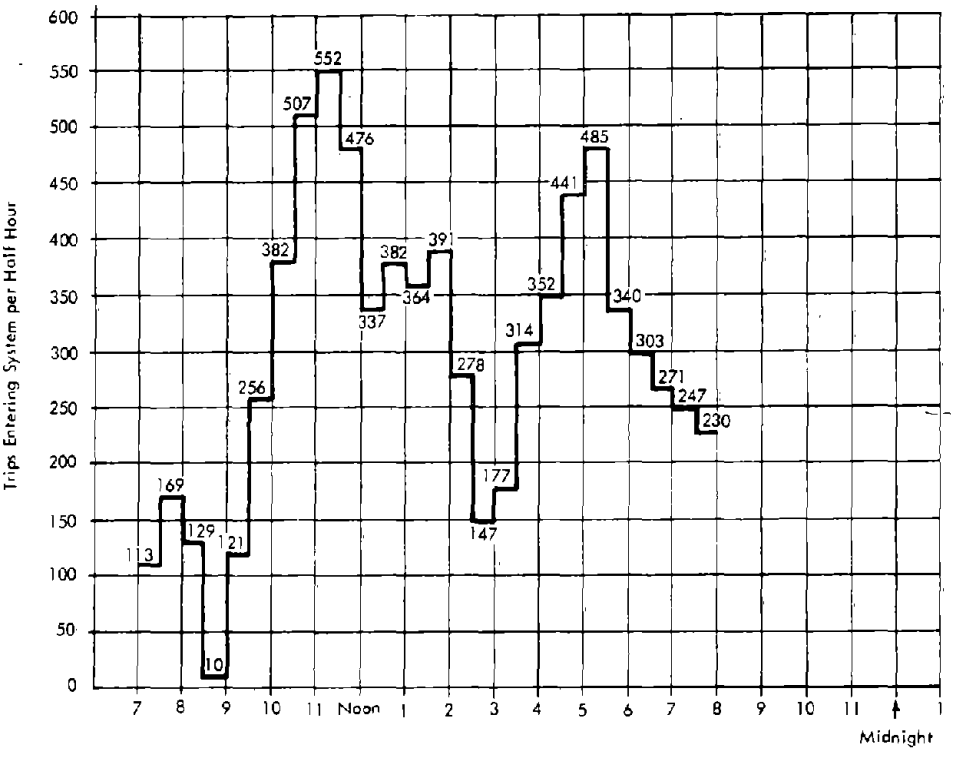


FIGURE 9. AIRTRANS DEMAND, HALF-HOUR AGGREGATES

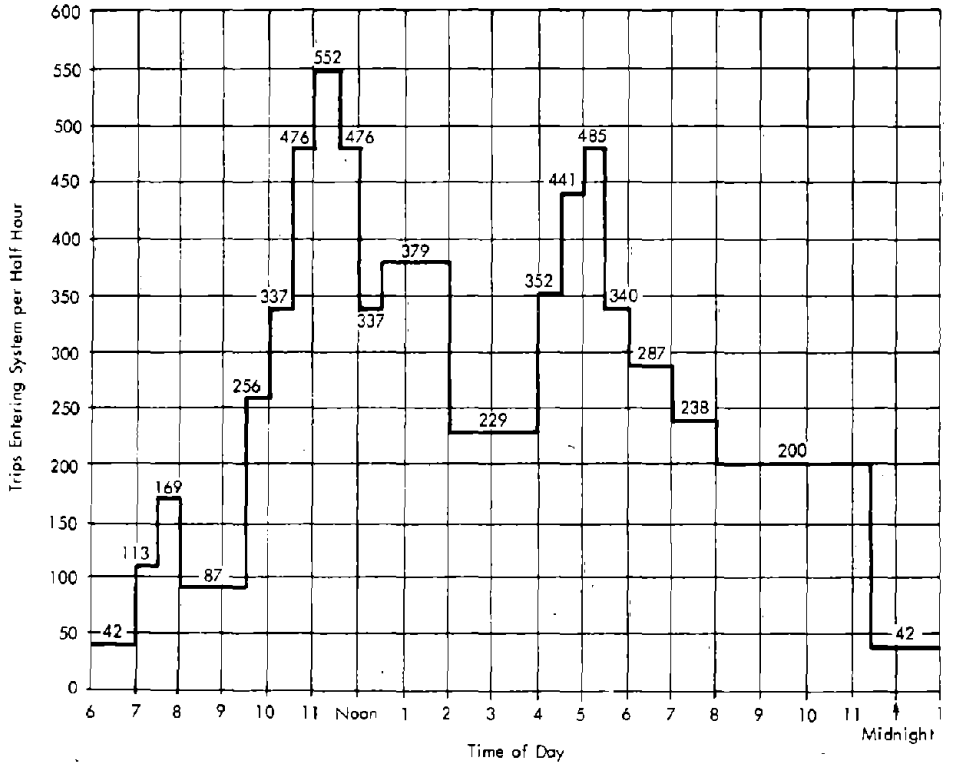


FIGURE 10. AIRPORT DEMAND MODEL

c. CBD Circulation Demand: Three CBD circulation demand models representing a low-, medium-, and high-demand CBD application were generated. The three demand models differ only in the magnitude of travel and are based on demand information for the Detroit CBD.

No information has been found which describes the spatial distribution of demand in the Detroit CBD as a function of time. An estimated profile of people mover demand is reproduced in Figure 11. The average value of the demand estimate for each hour was used to produce Figure 12 which shows the percentage of all estimated people mover trips which occur in each hour of the 12-hour service day. At the right side of the figure, a profile of peak-hour trips is given by quarter-hour intervals.

The range of people mover ridership estimated by SEMTA and shown in Figure 11 was used to define the three CBD circulation demand models.

d. CBD Line-Haul Demand: Two CBD line-haul demand models representing a low-demand and a high-demand CBD application were generated. The two demand models differ only in the magnitude of demand. The models are based on demand information for the Houston CBD. Parking trips (pedestrian trips to and from parking lots within the CBD) occur during the hours of 6:00 to 9:00 a.m. and 4:00 to 7:00 p.m. while circulation (secondary) trips occur during the interval from 9:00 a.m. to 4:00 p.m. Identical spatial distributions are reported for the two parking trip intervals, and a different spatial distribution is reported for the circulation trips.

According to the Houston DPM proposal, a large percentage of the projected people mover ridership in the peak period consists of metropolitan area bus patrons who would use the automated system for a portion of their trip. DPM demand estimates presented in the Houston proposal are listed by trip purpose for each hour of the 13-hour service day in Table 6. The table also shows the percentage of total daily trips on the automated system which occurs during each hour of the service day. Figure 13 displays the resulting demand profile. This profile illustrates the general form of the CBD line-haul demand model.

e. High CBD Orientation, High Reverse Commutation Metropolitan Area Demand: The demand model for this application area is based on a 1965 home-interview survey of travel behavior in the Cincinnati Metropolitan Area. The survey tape was obtained from the Ohio-Kentucky-Indiana Regional Council of Governments and contains 261,226 records which define travel among the region's 460 traffic analysis zones.

Figure 14 shows the demand profile generated for total travel in the Cincinnati region. The data indicate that preferred times for trip initiation tend to be on the hour and half-hour. This may indicate an actual trend in travel behavior, but the preference is probably exaggerated to some extent by the quantization of time by survey respondents. This uncertainty sug-

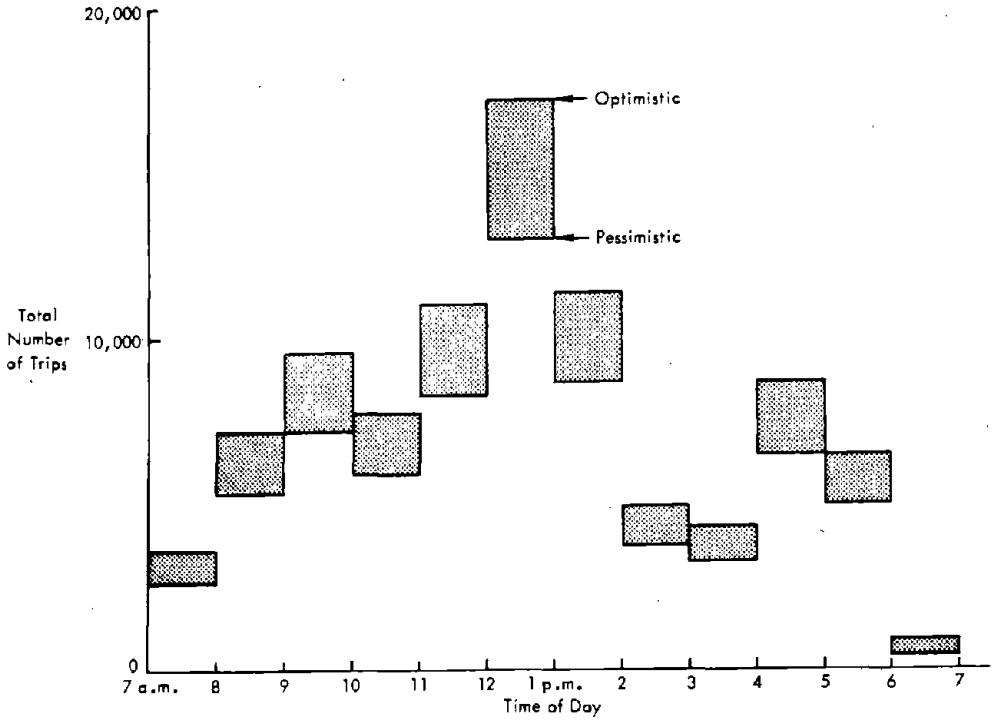


FIGURE 11. DETROIT PEOPLE MOVER, ESTIMATED PROFILE

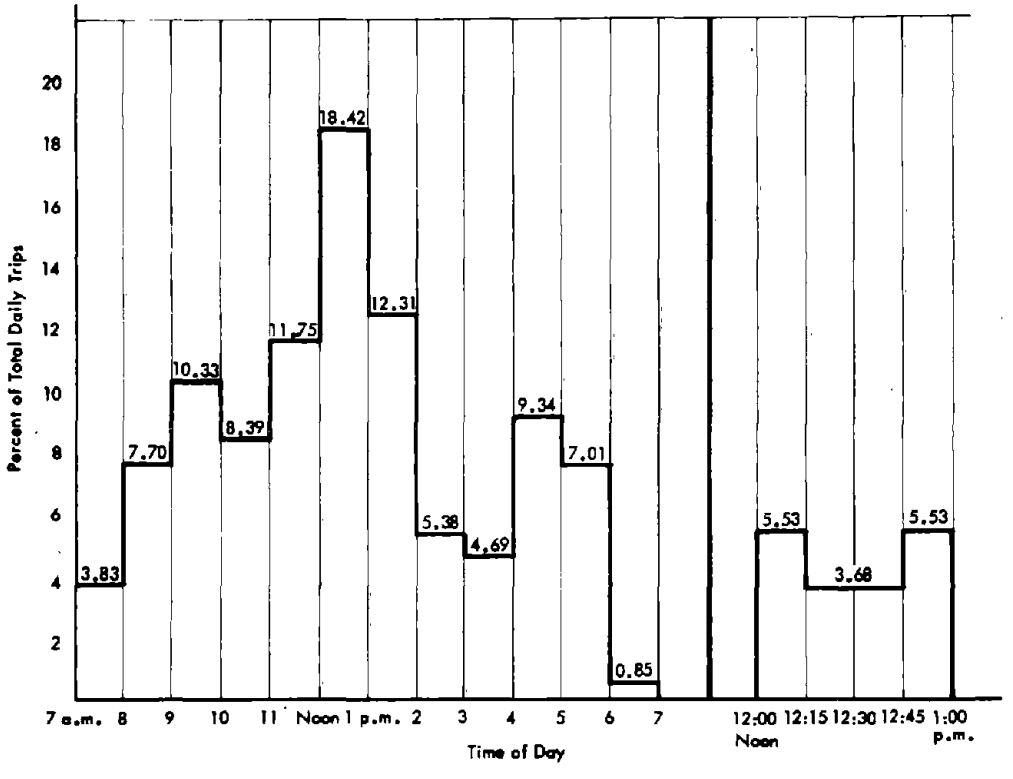


FIGURE 12. DETROIT PEOPLE MOVER, TRIP PERCENT/HOUR

TABLE 6. HOUSTON CBD DEMAND DATA

Hour	Parking		Circulation		Bus Transfer		Evening		Total	
	# Trips	% of Total	# Trips	% of Total	# Trips	% of Total	# Trips	% of Total	# Trips	% of Total
12-1 a.m.										
1-2										
2-3										
3-4										
4-5										
5-6										
6-7	81	0.32			1260	4.92			1341	5.24
7-8	416	1.62			6494	25.37			6910	26.99
8-9	124	0.48			1939	7.57			2063	8.06
9-10			129	0.50					129	0.50
10-11			217	0.85					217	0.85
11-12			625	2.44					625	2.44
12-1 p.m.			961	3.75					961	3.75
1-2			836	3.27					836	3.27
2-3			663	2.59					663	2.59
3-4			544	2.13					544	2.13
4-5	404	1.58			6030	23.55			6434	25.13
5-6	205	0.80			3061	11.96			3266	12.76
6-7	12	0.05			186	0.73			198	0.77
7-8							283	1.11	283	1.11
8-9							283	1.11	283	1.11
9-10							283	1.11	283	1.11
10-11							283	1.11	283	1.11
11-12							281	1.08	281	1.08
Total	1242	4.85	3975	15.53	18970	74.10	1413	5.52	25600	100.00

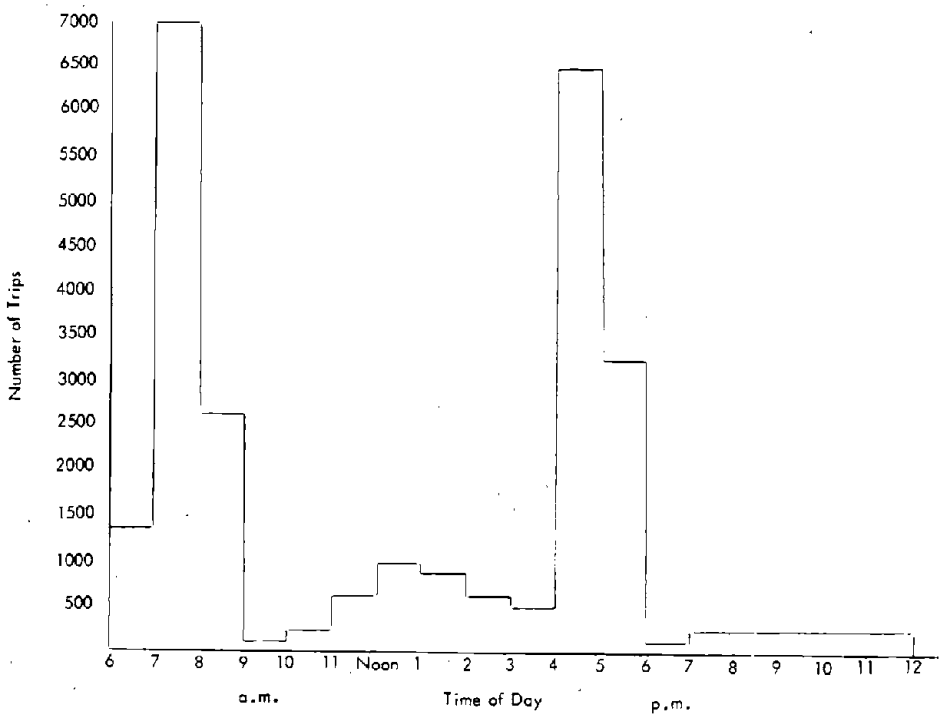


FIGURE 13. CBD LINE-HAUL PROFILE

gests that the time interval over which demand is aggregated for analysis purposes should not be shorter than one-half hour. A smoothed profile for total travel in the Cincinnati metropolitan area is shown in Figure 15. Demand profiles, which have been smoothed in the same way, showing CBD attraction and CBD production are presented in Figures 16 and 17, respectively.

To represent the basic differences in spatial distribution the demand model for each metropolitan area application consists of four origin-destination (O-D) matrices which describe the demand distribution during the morning peak, midday, afternoon peak, and evening periods. Spatial variations could be represented by a larger number of matrices at the expense of increased data storage and computer run time requirements. However, as the interval over which the data is aggregated becomes small, the matrices become very sparce. The use of four matrices in the demand models balances the requirements of adequate detail and data storage.

Figure 18 illustrated the form of the demand model for the high CBD orientation high reverse commutation metropolitan area application. In order to smooth the data somewhat, demand has been aggregated over one-hour intervals. The intervals over which the peak period matrices apply were extended so that the change from one matrix to another occurs during a period when the demand magnitude is not changing significantly. The various matrices apply during the following periods:

- o Morning peak period 5:00 a.m. to 10:00 a.m.
- o Midday period 10:00 a.m. to 2:00 p.m.
- o Afternoon peak period 2:00 p.m. to 7:00 p.m.
- o Evening period 7:00 p.m. to 5:00 a.m.

The magnitude of demand is changed each hour by scaling the appropriate matrix.

f. Low CBD Orientation, High Reverse Commutation Metropolitan Area Demand: The demand model for this application area is based on a 1965 home-interview survey of travel behavior in the seven-county Detroit metropolitan area. The survey tape was obtained from the Southeastern Michigan Council of Governments and contains 307,148 records which define travel among the region's 1446 analysis zones.

The form of the demand model for the Low CBD Orientation, High Reverse Commutation Metropolitan Area Application is illustrated in Figure 19. As in the previous case, the intervals over which the peak period matrices apply were extended so that the change from one matrix to another occurs during a period when the demand magnitude is not changing significantly. The four matrices apply during the following periods:

- o Morning peak period 5:00 a.m. to 10:00 a.m.
- o Midday period 10:00 a.m. to 2:00 p.m.
- o Afternoon peak period 2:00 p.m. to 7:00 p.m.
- o Evening period 7:00 p.m. to 5:00 a.m.

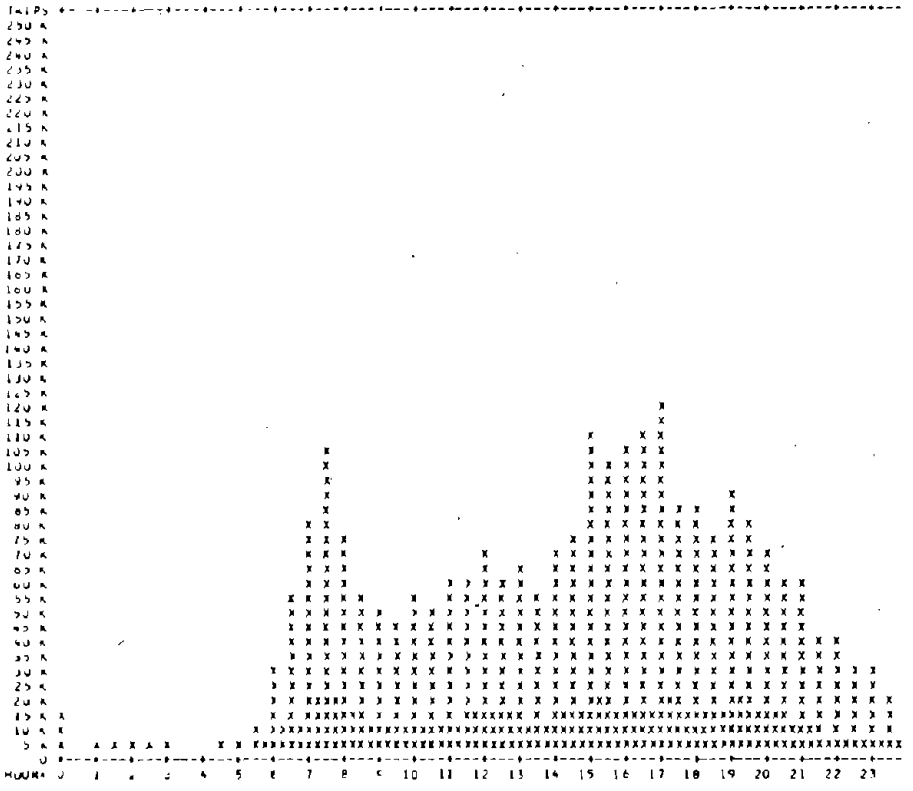


FIGURE 14. TOTAL CINCINNATI TRAVEL

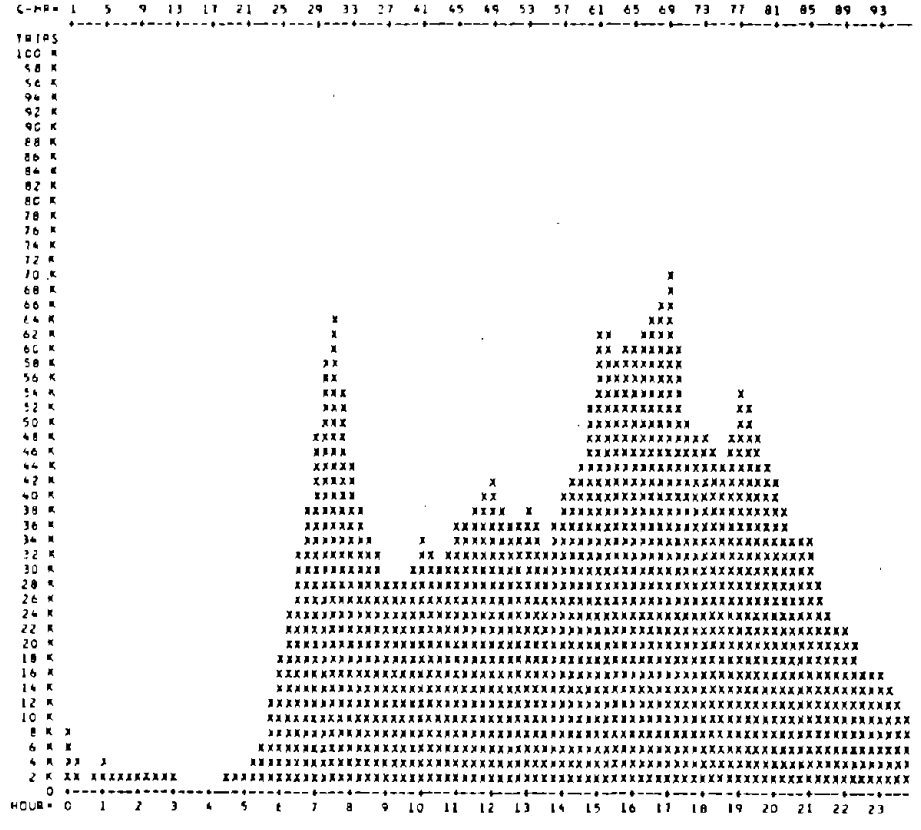


FIGURE 15. SMOOTHED CINCINNATI PROFILE

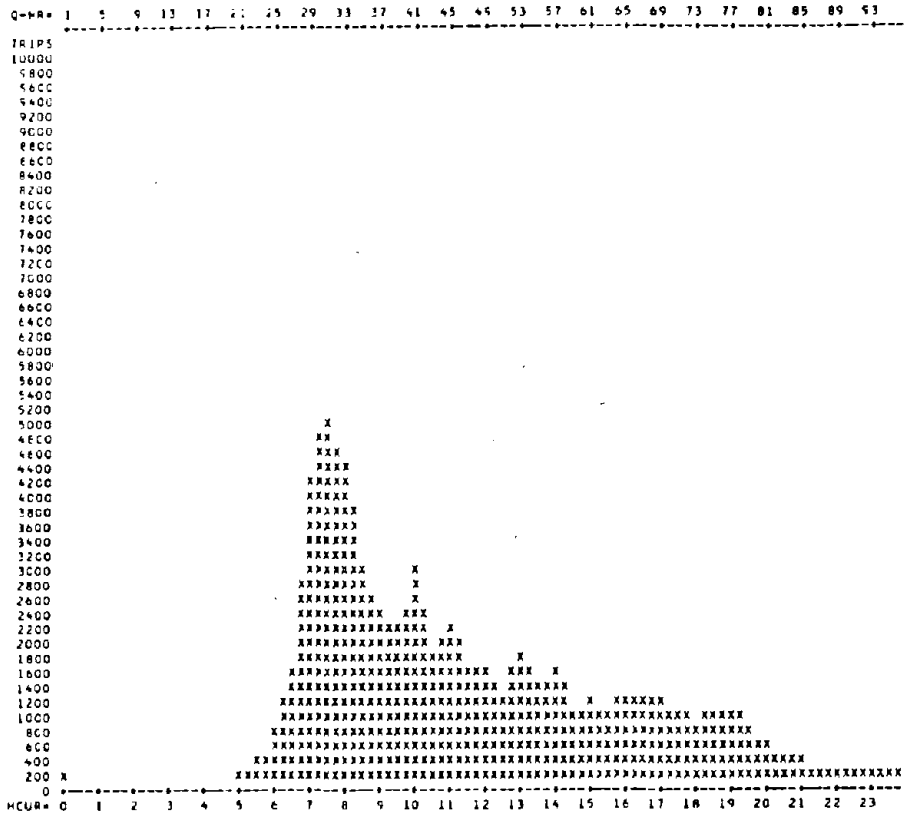


FIGURE 16. CINCINNATI CBD ATTRACTION PROFILE

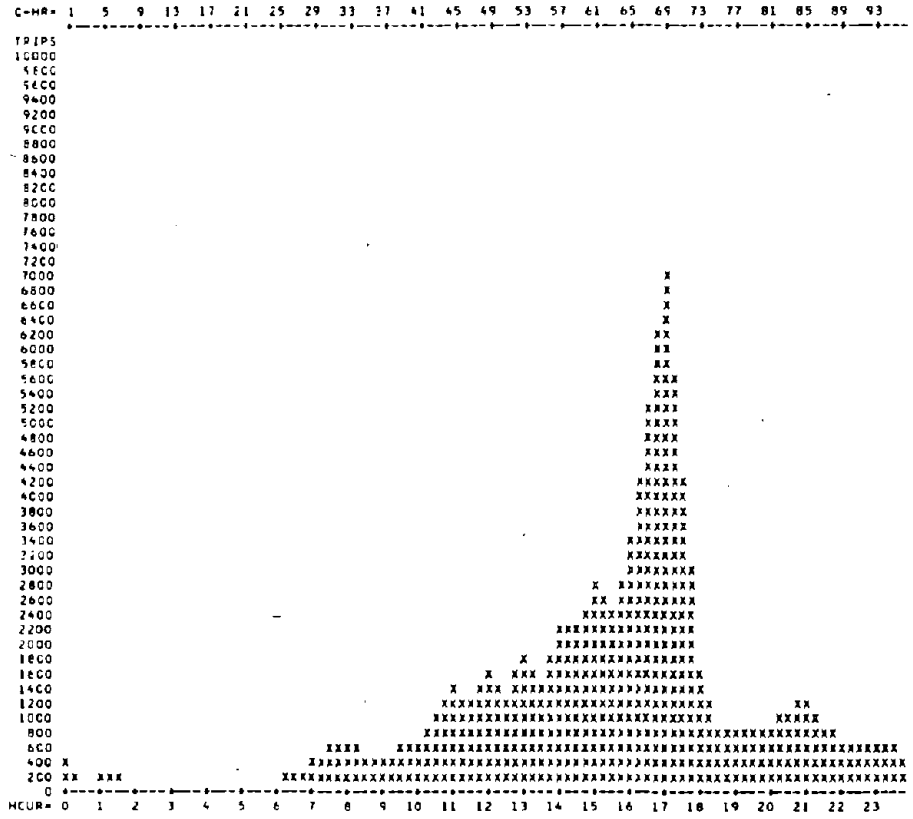


FIGURE 17. CINCINNATI CBD PRODUCTION PROFILE

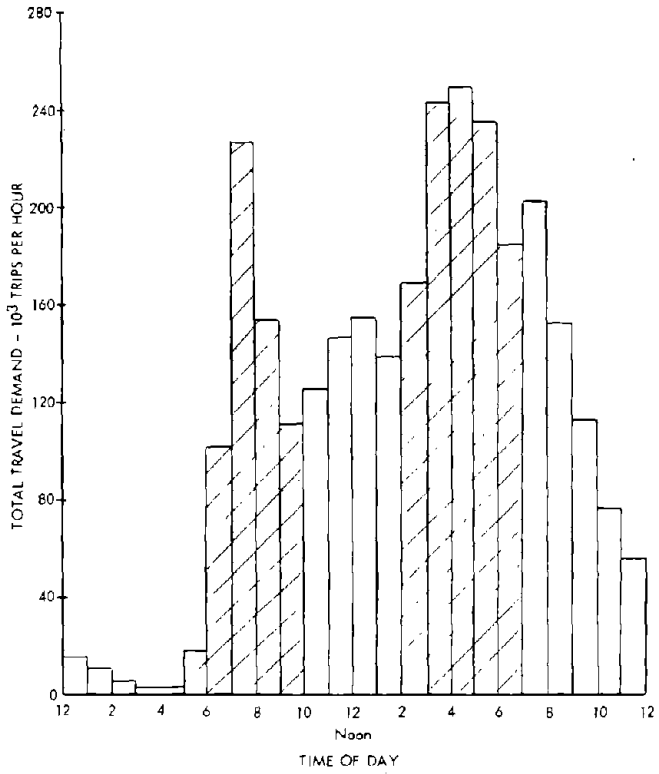


FIGURE 18. HIGH CBD, HIGH REVERSE PROFILE

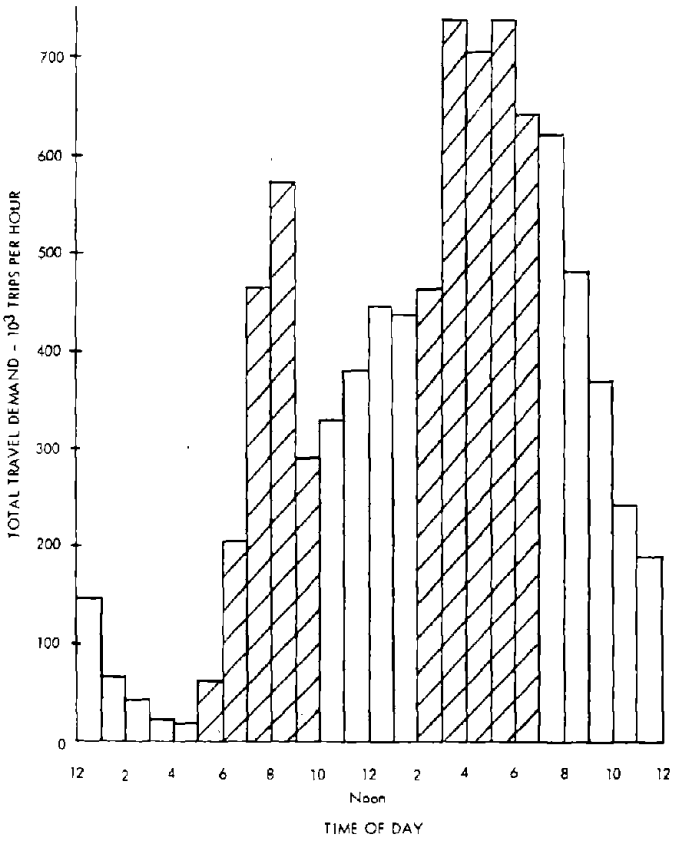


FIGURE 19. LOW CBD, HIGH REVERSE PROFILE

The magnitude of demand is changed each hour by scaling the appropriate matrix.

g. High CBD Orientation, Low Reverse Commutation Metropolitan Area Demand: The demand model for this application area is based on a 1968 home-interview survey of travel behavior in the metropolitan Washington, D.C., area. The survey tape was obtained from the Metropolitan Washington Council of Governments and contains 149,905 records which define travel among the region's 1207 traffic analysis zones.

The form of the demand model for the High CBD Orientation, Low Reverse Commutation Metropolitan Area Application is illustrated in Figure 20. The four demand matrices apply during the following periods:

o	Morning peak period	5:00 a.m. to 10:00 a.m.
o	Midday period	10:00 a.m. to 2:00 p.m.
o	Afternoon peak period	2:00 p.m. to 7:00 p.m.
o	Evening period	7:00 p.m. to 5:00 a.m.

The magnitude of demand is changed each hour by scaling the appropriate matrix.

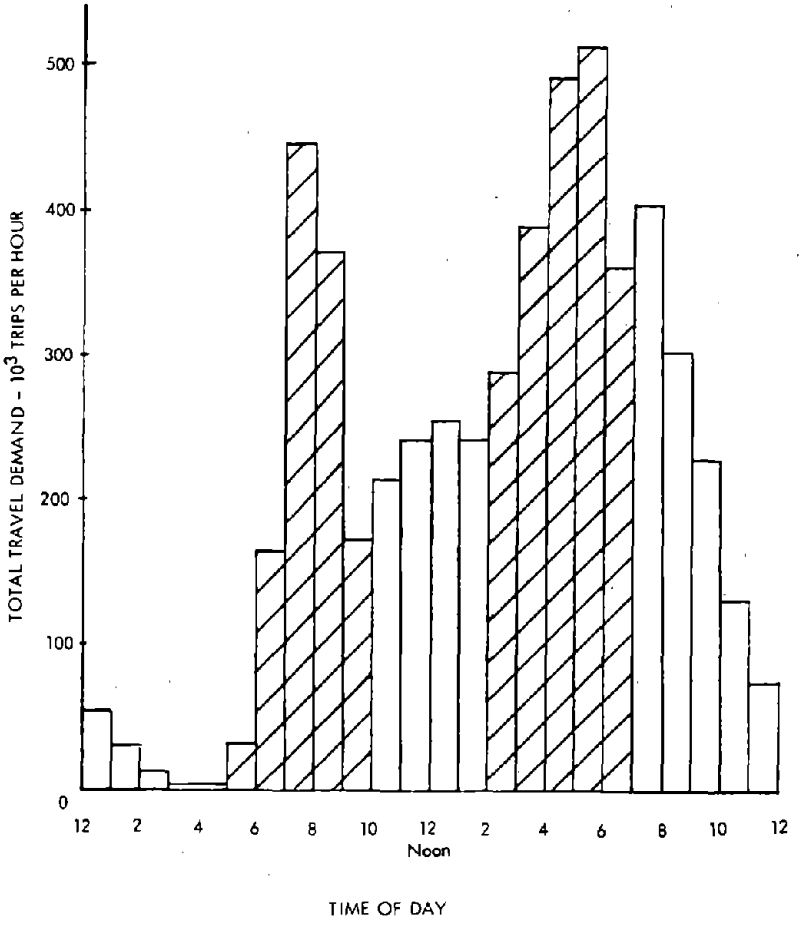


FIGURE 20. HIGH CBD, LOW REVERSE PROFILE

4. Network Types

Each operationally distinct portion of a network can be classified into one of three basic simple network types:

1. Shuttle - A guideway on which bidirectional motion occurs during normal operation and which is defined by a single curve connecting two distinct end points.
2. Loop - A guideway on which motion is unidirectional during normal operation except possibly on short segments at stations or at end of runs, and which is defined by a closed path.
3. Grid - Any guideway on which vehicles are presented with a choice of paths during normal operation.

Only one vehicle may operate on a simple shuttle network and no headway or merge control is required. More than one vehicle may operate on a simple loop or a simple grid at the same time; however, headway control is required to prevent collisions and, in the case of a simple grid, some form of merge control must be used.

Subcategorizing these network types is useful in defining detailed network configurations. The following definitions and abbreviations have been adopted:

1. Shuttle (S) refers to a simple shuttle as defined above and also to any network consisting of two or more simple shuttles, either following the same path or different paths. If passing sections are added to a shuttle, the network becomes a grid since vehicles are presented a choice of paths. Headway and merge control are required to safely utilize such passing sections.
2. Loop (L) is used to refer only to a single simple loop, as defined above, which is elongated to the extent that it encircles no area and thus provides a line-haul type of service.
3. One-Way Loop (L1) is used to refer to a single simple loop which does encircle an area and provides a one-directional circulation service.
4. Two-Way Loop (L2) is used to refer to two simple loops contiguously deployed which do encircle an area. Circulation service in two directions is thus accommodated.
5. Multiple Loop (ML) is used to refer to any network consisting of two or more simple loops which does not qualify as a two-way loop network.
6. Fully Connected Grid (FG) is used to refer to a simple grid as defined above if no network constraint prevents a vehicle currently at one station from proceeding to any other station in the network in a manner which does not require the vehicle to retrace any one- or two-directional portion of guideway.
7. Partially Connected Grid (PG) is used to refer to any simple grid which is not a fully connected grid.

This partitioning is applied to networks before the question of off- or on-line stations is considered. Usually a non-grid network (not considering stations) has on-line stations. However, in the deployments which follow, one non-grid network has a station type specified as open, to be determined only after link loads are investigated. In this case, should off-line stations be required, the network should be reclassified as either a fully connected grid or a partially connected grid network.

5. Representative Application

A set of representative system deployments have been selected for system trade-off and comparative analyses. Each deployment consists of a specific system, demand and network type. Since ten system, seven demand, and seven network types have previously been identified, there are 490 possible deployment combinations from which to choose.

Several major criteria were considered in establishing the starting set of representative applications.

1. The RFP establishes a lower bound of 18 representative applications for full-scale analysis.
2. Activity center applications are emphasized since they represent the class of near term deployments.
3. High speed SGRT systems are de-emphasized to limit overlap with the current AGRT programs.
4. The applications are intended to allow the evaluation of the applicability of similar system types to a variety of problems and the comparison of the performance of alternative system types and deployment approaches for similar problems.

The selection process is of necessity somewhat subjective and arbitrary but the final selections provide a fairly broad cross section of system types and deployment approaches. This set, of course, can be extended both by selecting additional combinations and by expanding the set of nominal system, demand, and network models.

Table 7 displays the system deployment scenarios currently planned for analysis in the AGT-SOS project. Table 8 lists representative applications by name.

TABLE 7. DEPLOYMENT SCENARIOS

SYSTEM TYPES		DEPLOYMENT SCENARIO									
		LOW SPEED							HIGH SPEED		
				CBD CIRCULATION			CBD LINE HAUL				
		UNIVERSITY	AIRPORT	LOW DEMAND	MEDIUM DEMAND	HIGH DEMAND	LOW DEMAND	HIGH DEMAND	METRO AREA HIGH CBD HIGH REVERSE	METRO AREA LOW CBD HIGH REVERSE	METRO AREA HIGH CBD LOW REVERSE
SLT	SGRT						L1				
	IGRT		ML	S	L1, L2	L1					
	LGRT	S				L1	ML, L1	L1			
ART									PG		PG
GRT	SGRT										FG
	IGRT								ML, FG	FG	
PRT						FG				FG	

S - SHUTTLE
L - CLOSED LOOP
L1 - OPEN LOOP ONE WAY
L2 - OPEN LOOP TWO WAY
ML - MULTIPLE LOOPS
PG - PARTIALLY CONNECTED GRID
FG - FULLY CONNECTED GRID

TABLE 8. REPRESENTATIVE APPLICATIONS

Deployment Descriptor	System Type Vehicle	Speed	Network Type	Demand Type
SLT-1	LGRT	Low	Shuttle	University
SLT-2	IGRT	Low	Multiple loop	Airport
SLT-3	IGRT	Low	Open loop, one-way	CBD circulation, medium demand
SLT-4	IGRT	Low	Open loop, two-way	CBD circulation, medium demand
SLT-5	IGRT	Low	Open loop, one-way	CBD circulation, high demand
SLT-6	LGRT	Low	Open loop, one-way	CBD circulation, high demand
SLT-7	IGRT	Low	Shuttle	CBD circulation, low demand
SLT-8	LGRT	Low	Multiple loop	CBD line-haul, low demand
SLT-9	LGRT	Low	Open loop, one-way	CBD line-haul, low demand
SLT-10	SGRT	Low	Open loop, one-way	CBD line-haul, low demand
SLT-11	LGRT	Low	Open loop, one-way	CBD line-haul, high demand
ART-1	ART	High	Partially connected grid	Metropolitan Area - high CBD, high reverse commutation
ART-2	ART	High	Partially connected grid	Metropolitan Area - high CBD, low reverse commutation
GRT-1	IGRT	High	Multiple loop	Metropolitan Area - high CBD, high reverse commutation
GRT-2	IGRT	High	Fully connected grid	Metropolitan Area - high CBD, high reverse commutation
GRT-3	IGRT	High	Fully connected grid	Metropolitan Area - low CBD, high reverse commutation
GRT-4	SGRT	High	Fully connected grid	Metropolitan Area - high CBD, low reverse commutation
PRT-1	PRT	Low	Fully connected grid	CBD, high demand
PRT-2	PRT	High	Fully connected grid	Metropolitan Area - low CBD, high reverse commutation

a. Shuttle Loop Transit Representative System Deployments: Eleven SLT system deployments are analyzed in the SOS program. SLT is a low-speed, guideway transit system deployed in an activity center demand environment having any of the various shuttle- or loop-type networks which involve no operational switching. An SLT system typically provides either a line-haul service between a small number of destinations or acts as a circulator between sub-areas of some larger area.

A low-speed Large Vehicle Group Rapid Transit (LGRT) system deployed using a shuttle or loop network is one of the subcategories of SLT systems which is analyzed. This subclass is characterized by maximum velocities in the range of 13-54 km/h, minimum operating headways in the range of 50-110 s, and minimum traveling units which accommodate from 70 to 109 passengers. Five specific deployments are analyzed using this subclass.

A low-speed LGRT is applied to the demand environment of West Virginia University at Morgantown, West Virginia. The system uses two contiguous shuttle guideways to serve three stations. The application is shown in Figure 21. System statistics are:

Total Lane Length	-	6.8 km
Double Guideway Length	-	3.4 km
Number of Stations	-	3
Type of Stations	-	On-Line

A low-speed LGRT is applied to the demand environment of the Dallas/Fort Worth Regional Airport. The system uses three guideway loops to serve sixteen stations as shown in Figure 22. Initial analysis has indicated that the center loop must provide two-directional service, to meet the transfer time requirement. System statistics are:

	1-way Center Loop	2-way Center Loop
Total Lane Length	16.6 km	25.4 km
Double Guideway Length	0 km	8.8 km
Single Guideway Length	16.6 km	7.8 km
Number of Stations	16	
Type of Stations	On-Line	

A low-speed LGRT is applied to the high demand environment of the Detroit CBD. The system uses a simple guideway loop to serve eleven stations as

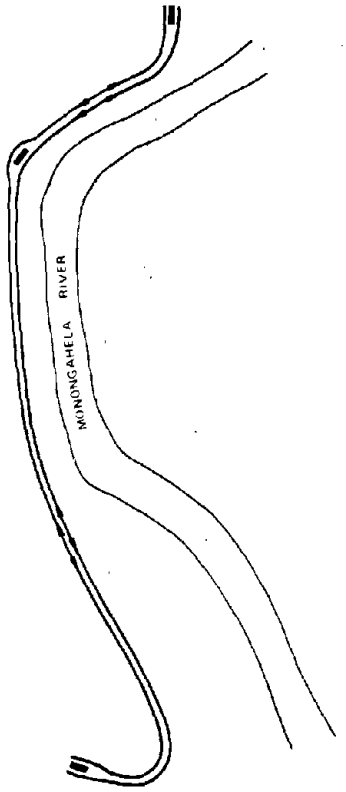


FIGURE 21. LOW SPEED LGRT, UNIVERSITY

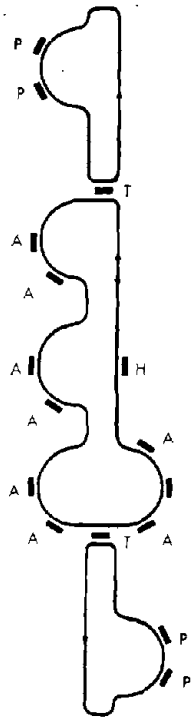


FIGURE 22. LOW SPEED LGRT, AIRPORT

shown in Figure 23. System statistics are:

Total Lane Length	-	3.7 km
Single Guideway Length	-	3.7 km
Number of Stations	-	11
Type of Stations	-	On-Line

A low-speed LGRT is applied to the low demand environment of the Houston CBD. The system uses two guideway loops to serve ten stations as shown in Figure 24. End-to-end line-haul service is accomplished with one transfer. System statistics are:

Total Lane Length	-	3.6 km
Single Guideway Length	-	3.6 km
Number of Stations	-	10
Type of Stations	-	On-Line

A low-speed LGRT is applied in this demand environment using an alternate network configuration. The network, shown in Figure 25, is a single guideway loop which is geometrically open at both ends and which collapses to line-haul service through the business area. System statistics are:

Total Lane Length	-	3.6 km
Double Guideway Length	-	0.9 km
Single Guideway Length	-	1.8 km
Number of Stations	-	8
Type of Stations	-	On-Line

A low-speed Intermediate Group Rapid Transit (IGRT) system deployed using a shuttle or loop network is another of the subcategories of SLT systems which are analyzed. This subclass is characterized by maximum velocities in the range of 13-54 km/h, minimum operating headways in the range of 15-60 s, and minimum traveling units which accommodate from 25 to 69 passengers. Four specific deployments are analyzed using this subclass.

A low-speed IGRT is applied to the low demand environment of the Detroit CBD. The system uses four shuttle guideways placed end-to-end forming a circulator which serves eleven stations as shown in Figure 26. System statistics are:

Total Lane Length	-	3.8 km
Single Guideway Length	-	3.8 km
Number of Stations	-	11
Type of Stations	-	On-Line

Two low-speed IGRT applications are made in the medium demand environment of the Detroit CBD. One of the systems, shown in Figure 27, uses a single guideway loop to provide one-directional circulation service to eleven stations. The other system, shown in Figure 28, uses two guideway loops deployed to provide two-directional circulation service to the same eleven stations. System statistics are:

	System of Figure 3-7	System of Figure 3-8
Total Lane Length	3.7 km	7.4 km
Single Guideway Length	3.7 km	0
Double Guideway Length	0	3.7 km
Number of Stations	11	11
Type of Stations	On-Line	On-Line

A low-speed LGRT is applied to the high demand environment of the Detroit CBD. The system uses a simple guideway loop to serve eleven stations as shown in Figure 29. System statistics are:

Total Lane Length	-	3.7 km
Single Guideway Length	-	3.7 km
Number of Stations	-	11
Type of Stations	-	On-Line

A low-speed Small Vehicle Group Rapid Transit (SGRT) system deployed using a shuttle or loop network is the third subcategory of SLT systems which is analyzed. This subclass is characterized by maximum velocities in the range of 13-54 km/h, minimum operating headways in the range of 3-15 s, and minimum traveling units which accommodate from 7 to 24 passengers.

Two deployments are analyzed using this subclass.

A low-speed SGRT is deployed in the low demand environment based on the Houston CBD.

A second low-speed SGRT is deployed, using the same network, in the high-demand environment based on the Houston CBD.

The network, shown in Figure 30, uses a single guideway loop which is geometrically open at both ends and which collapses to line-haul service through the business area. System statistics are:

Total Lane Length	-	3.6 km
Double Guideway Length	-	0.9 km
Single Guideway Length	-	1.8 km
Number of Stations	-	8
Type of Stations	-	On-Line

b. Automated Rail Transit Representative System Deployments: Two ART system deployments are analyzed in the SOS program. ART is a high-technology rail transit system deployed in a metropolitan area demand environment having a maximum velocity greater than 54 km/h. Minimum operating headways are 60s or more, and a minimum traveling unit accommodates 110 or more passengers. Limited use of operational switching is made. ART systems typically provide radial or corridor line-haul service.

An ART will be applied to the demand environment based on metropolitan Cincinnati. The ART system uses the partially connected grid network shown

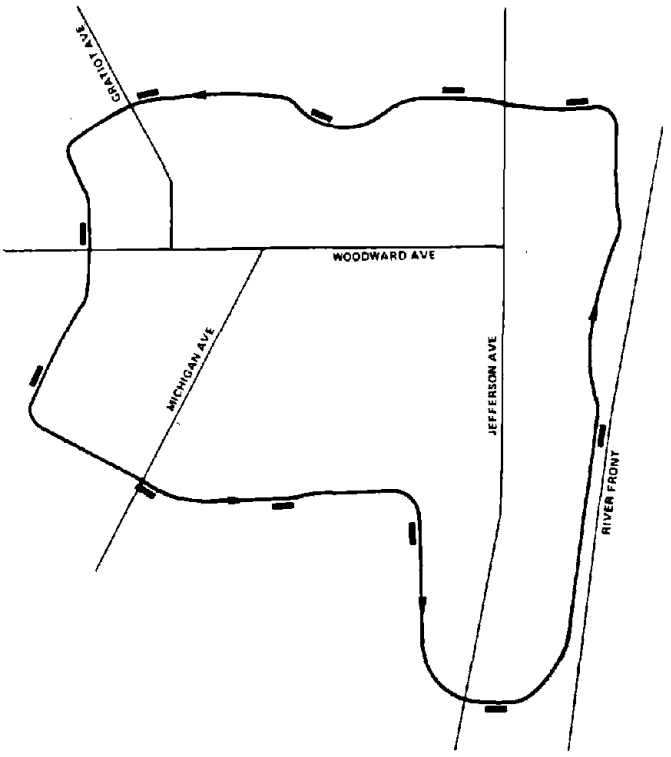


FIGURE 23. LOW SPEED LGRT, CBD CIRCULATION

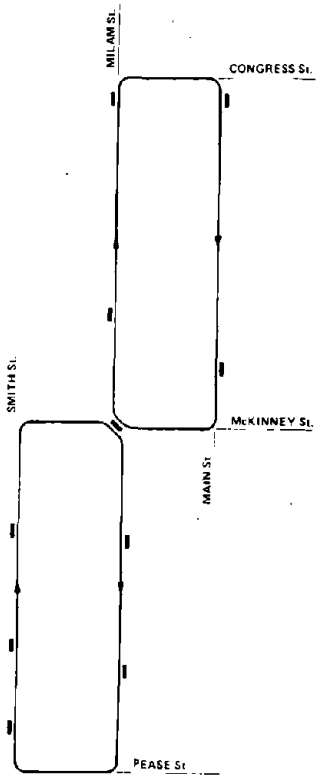


FIGURE 24. LOW SPEED LGRT, LINE HAUL, LOW DENSITY

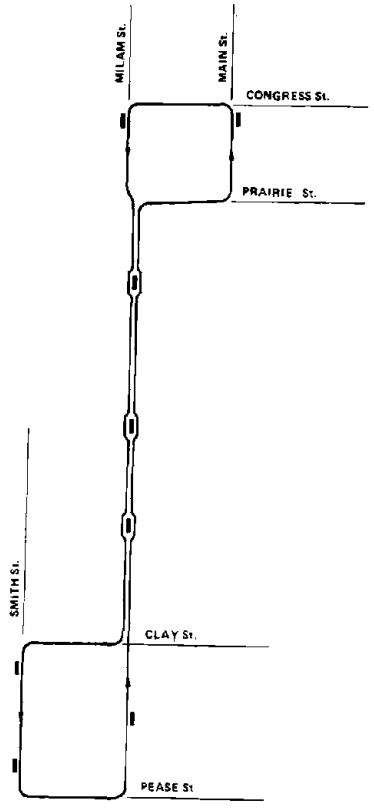


FIGURE 25. LOW SPEED LGRT, LINE HAUL, LOW DENSITY ALTERNATE

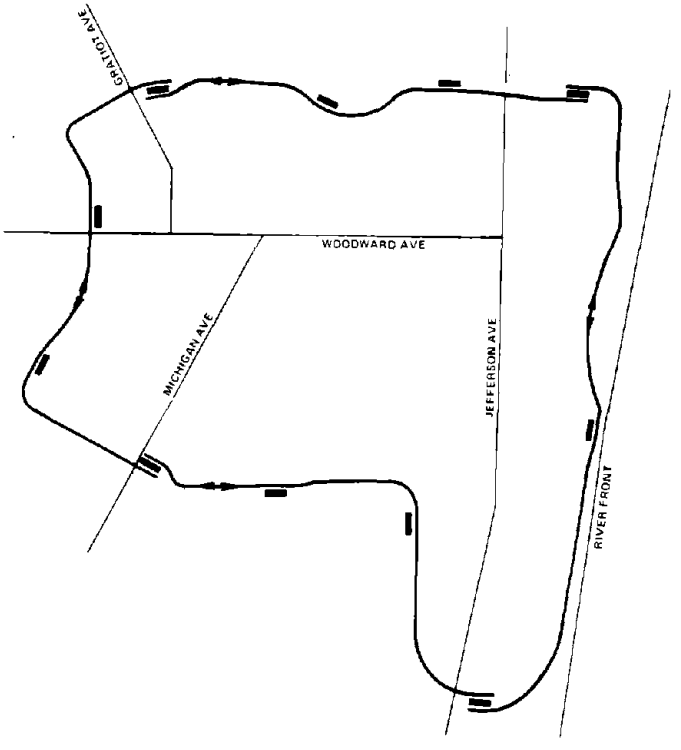


FIGURE 26. LOW SPEED LGRT, CBD CIRCULATION, LOW DEMAND

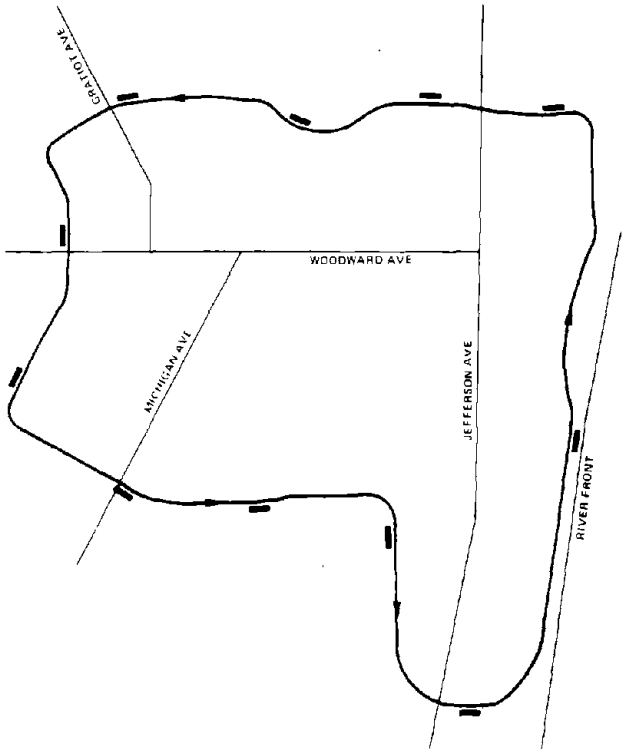


FIGURE 27. LOW SPEED IGRT, CBD CIRCULATION, MEDIUM DEMAND

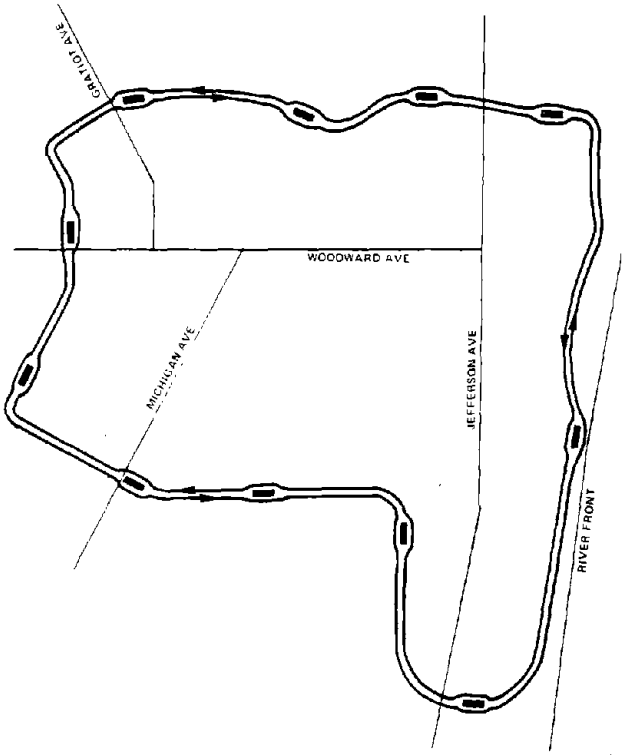


FIGURE 28. LOW SPEED IGRT, CBD CIRCULATION, MEDIUM DEMAND, ALTERNATE

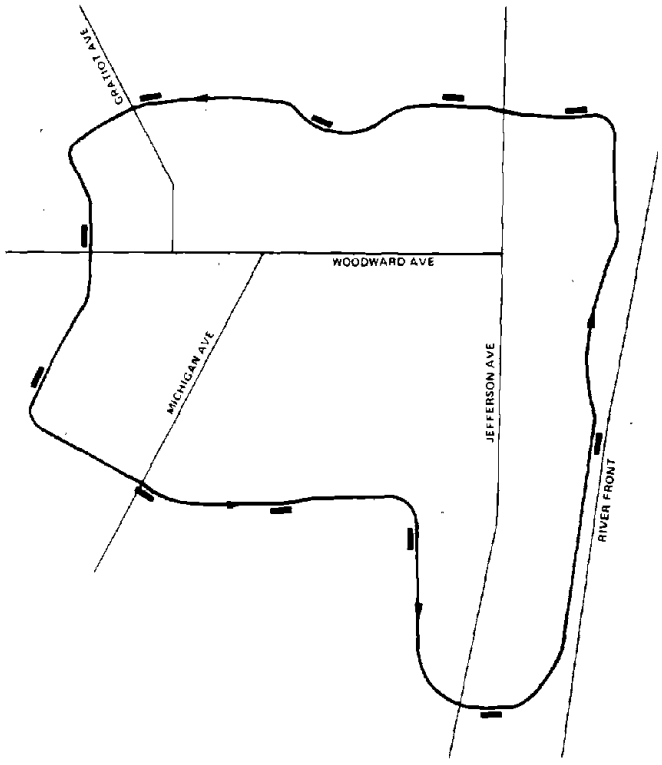


FIGURE 29. LOW SPEED IGRT, CBD CIRCULATION, HIGH DEMAND

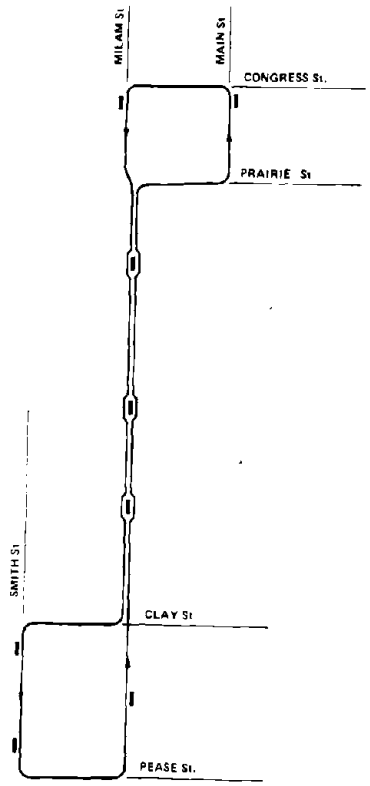


FIGURE 30. LOW SPEED SGRT, LINE HAUL, LOW AND HIGH DEMAND

in Figure 31. Each link represents two-directional guideway, and the Y junctions have switching only in the direction pictorially implied. System statistics are:

Double Mainline Guideway Length	-	49 km
Number of Diverges	-	3
Number of Merges	-	3
Number of Stations	-	28
Type of Stations	-	On-Line

An ART is applied to the demand environment based on metropolitan Washington, D.C. The ART system uses the partially connected grid network shown in Figure 32. Each link represents two-directional guideway, each Y junction has switching only in the direction pictorially implied, and + junctions have no switching capability. System statistics are:

Double Mainline Guideway Length	-	161 km
Number of Diverges	-	5
Number of Merges	-	5
Number of Stations	-	83
Type of Stations	-	On-Line

c. Group Rapid Transit Representative System Deployments: Four GRT system deployments are analyzed in the SOS program. GRT as used in this report includes all multiple-party, multiple-stop, guideway transit systems except those which qualify as SLT systems.

Two high-speed IGRT applications in the demand environment based on metropolitan Cincinnati are analyzed. One of the system applications, shown in Figure 33, uses a multiple-loop network to provide line-haul service to 28 stations. Passenger transfers are made between vehicles operating on different loops. The other system application, shown in Figure 34, uses a fully connected grid network to provide line-haul service to the same 28 stations. In both cases, the stations may be either on- or off-line. In both figures, each link represents two-directional guideway and, in the case of Figure 34, each Y junction has full switching capability. System statistics not including off-line station guideway and switch requirements are:

Double Mainline Guideway Length	49 km	49 km
Number of Full Y Junctions	0	3
Number of Stations	28	28
Type of Stations	On- or Off-Line	On- or Off-Line

A high-speed IGRT is applied to the demand environment based on metropolitan Detroit. The system, as shown in Figure 35, uses a coarse density, area-wide, fully connected grid network to serve 50 stations. The stations may be either on- or off-line. Each link represents two-directional guideway, and all Y and + junctions have full switching capability. System statistics not including off-line station guideway and switch requirements are:

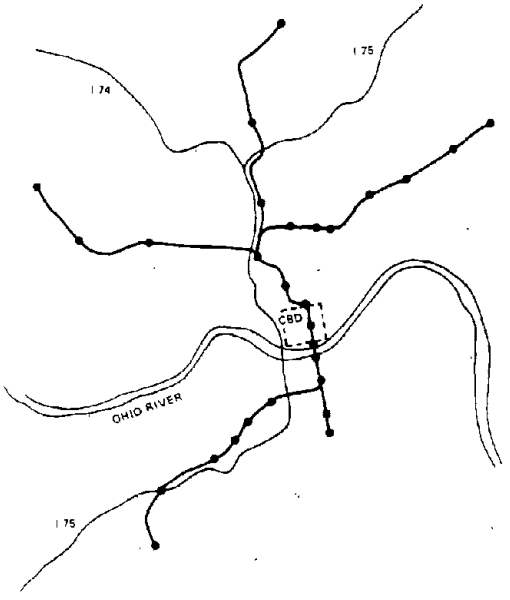


FIGURE 31. ART, CINCINNATI

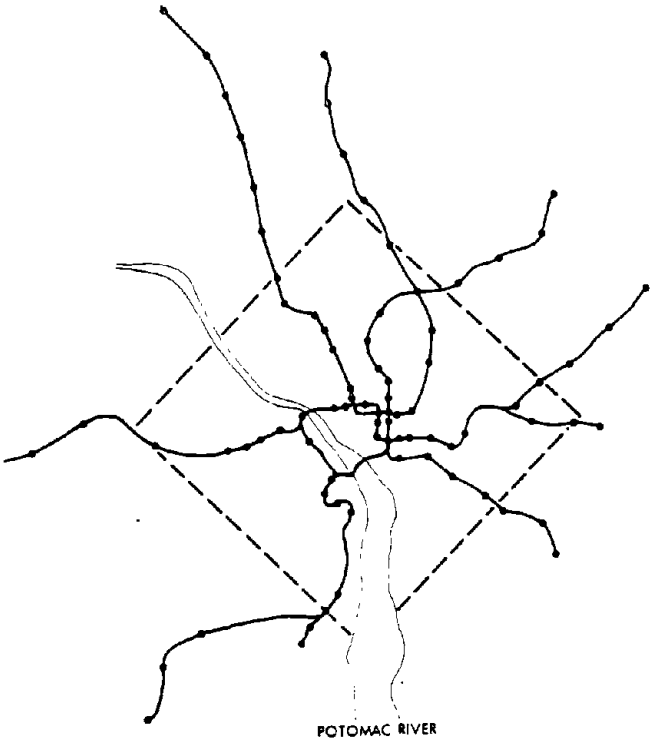


FIGURE 32. ART, WASHINGTON, D.C.

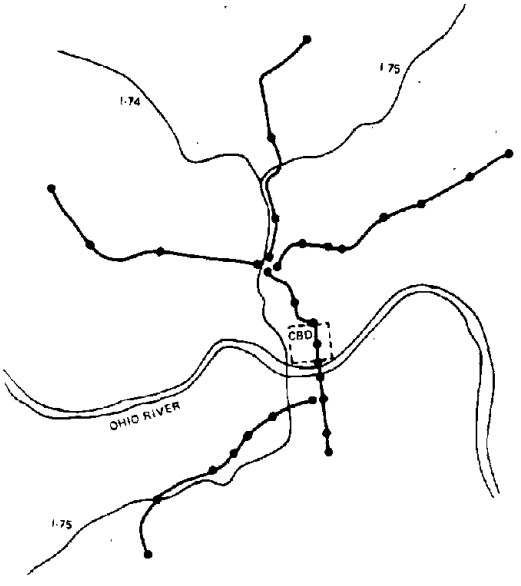


FIGURE 33. IGRT, HIGH SPEED, CINCINNATI, MULTI-LOOP

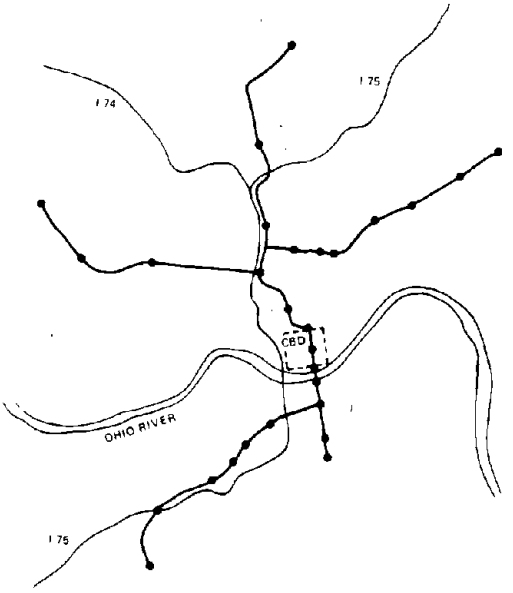


FIGURE 34. IGRT, HIGH SPEED, CINCINNATI, GRID

Double Mainline Guideway Length	-	219 km
Number of Y Junctions	-	6
Number of + junctions	-	13
Number of Stations	-	50
Type of Stations	-	On- or Off-Line

A high-speed IGRT is applied to the demand environment based on metropolitan Washington, D.C. The system, as shown in Figure 36, uses a radial line-haul, partially connected grid network to serve 83 stations. The stations may be either on- or off-line. Each link represents two-directional guideway, each Y junction has switching only in the direction pictorially implied, and + junctions have no switching capability. System statistics not including off-line station guideway and switch requirements are:

Double Mainline Guideway Length	-	161 km
Number of Diverges	-	5
Number of Merges	-	5
Number of Stations	-	83
Type of Stations	-	On-Line

d. Personal Rapid Transit Representative System Deployments: Two PRT system deployments are analyzed in the SOS program. PRT is a very high-technology, grid transit system which provides single-party, point-to-point service. It may be deployed in either a CBD or a metropolitan area demand environment, using an area-wide, fully connected grid network with a high station density.

A low-speed PRT is applied to the high demand environment based on the Detroit CBD. The system uses an area-wide, fully connected grid network to serve 14 off-line stations as shown in Figure 37. System statistics not including off-line station guideway and switch requirements are:

Total Lane Length	-	5.5 km
Single Guideway Length	-	5.5 km
Number of Diverges	-	4
Number of Merges	-	4
Number of Stations	-	14
Type of Stations	-	Off-Line

A high-speed PRT is applied to the demand environment based on metropolitan Detroit. The system uses a medium density, area-wide, fully connected grid network to serve 82 off-line stations as shown in Figure 38. Each link represents two-directional guideway and all Y and + junctions have full switching capability. System statistics not including off-line station guideway and switch requirements are:

Double Mainline Guideway Length	-	260 km
Number of Y Junctions	-	15
Number of + Junctions	-	16
Number of Stations	-	82
Type of Stations	-	Off-Line

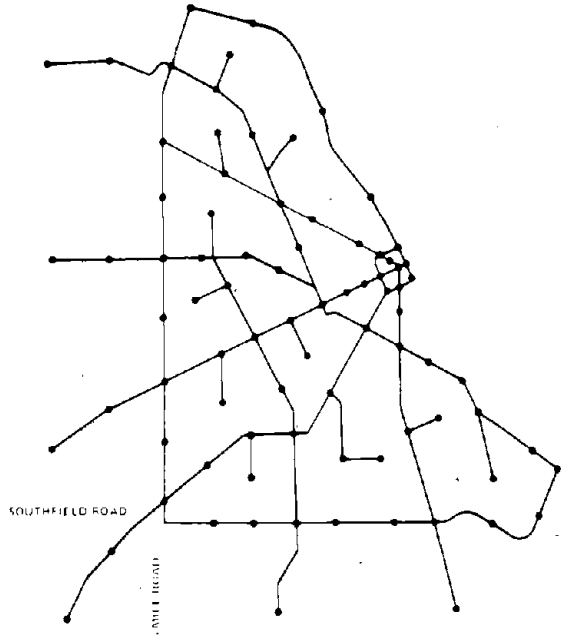


FIGURE 35. IGRT, HIGH SPEED, DETROIT, GRID

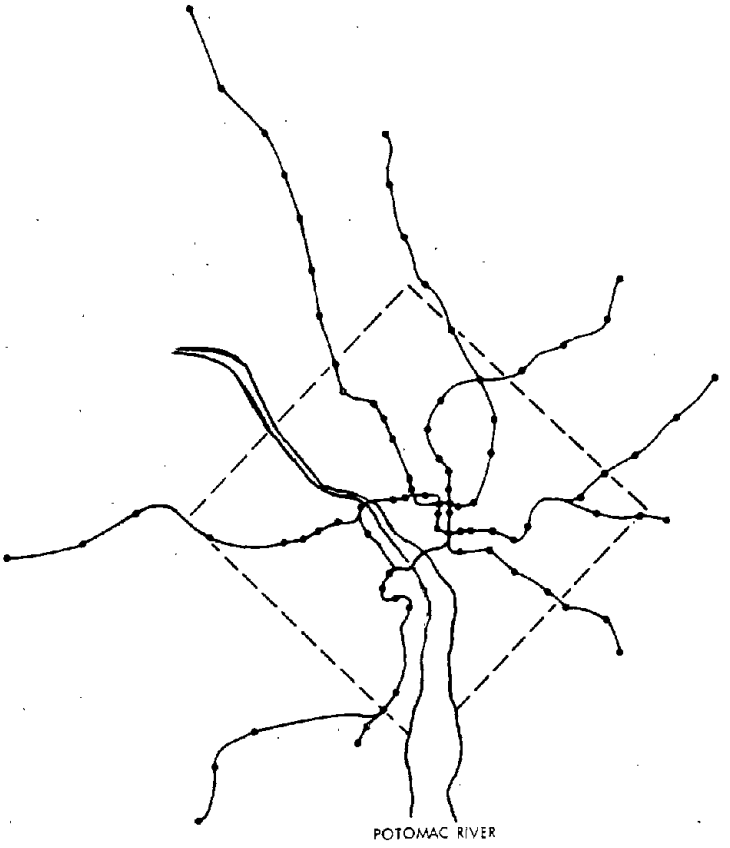


FIGURE 36. IGRT, HIGH SPEED, WASHINGTON, D.C., GRID

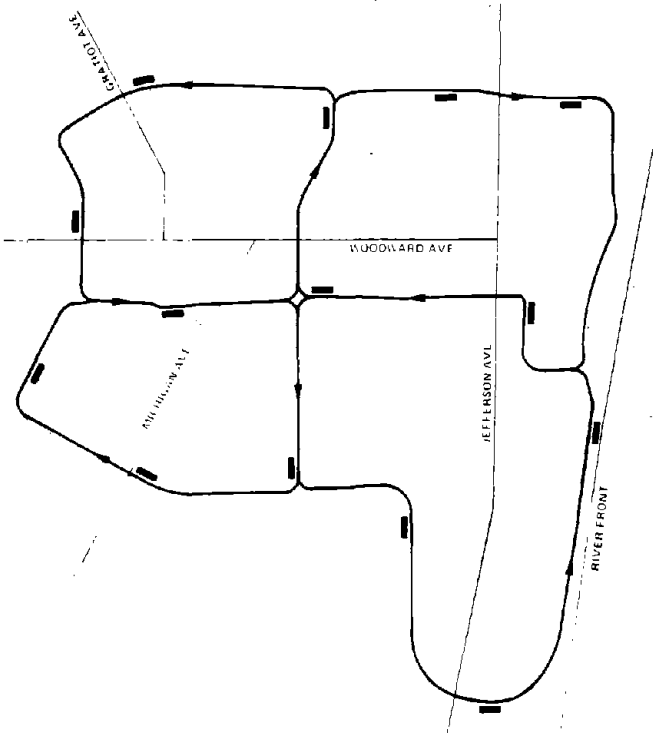


FIGURE 37. PRT, DETROIT CBD, HIGH DEMAND

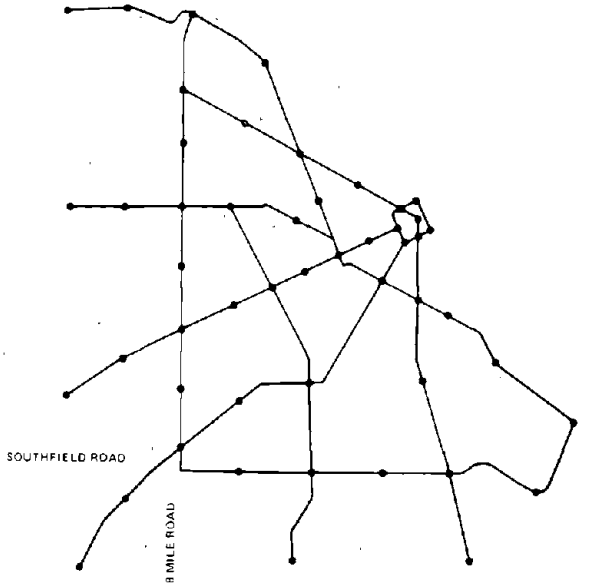


FIGURE 38. PRT, METROPOLITAN DETROIT

E. COMPUTER SOFTWARE

To perform the necessary analyses of the representative applications, a set of computer programs which provide the ability to simulate and evaluate the various aspects of AGT system performance has been developed. There are seven major modelling programs.

1. An event simulation of the operation of an individual station in terms of the movement and queuing of both passengers and vehicles. (Detailed Station Model or DSM)
2. A continuous (or delta t) simulation of the dynamics and interactions of strings of vehicles when traversing a link, merge, or intersection under synchronous or asynchronous control and FIFO or priority merge strategies (Detailed Operational Control Model or DOCM).
3.. An event simulation of the operation of a deployed AGT system in terms of the movement of individual vehicles and passengers over a network of guideway links and stations (Detailed Event Simulation Model or DESM).
4. A continuous (or delta t) simulation of a deployed AGT system in terms of rates of flow of vehicle capacity and passengers over a network of guideway links and stations (System Planning Model or SPM).
5. A processor which develops capital and operating cost estimates for system deployments by applying detailed unit costs and economic factors to deployment parameters and data on operations from the simulators (System Cost Model or SCM).
6. A processor which operates on subsystem and component reliability numbers and trip and vehicle delay data from simulations of system operation with induced failures to produce vehicle and passenger based availability measures. In addition, it determines total fleet size necessary to provide a specific operational fleet size with a predefined probability (System Availability Model or SAM).
7. A processor which maps zone-to-zone trip demand through a coarse model of the station access modes of walking, private auto and conventional bus fleet onto an arbitrary set of station locations. This model estimates the contribution of off-guideway travel to trip time and cost and generates an equivalent station-to-station trip demand for use in the simulation of system operation (Feeder System Model or FSM).

In addition to these major processors, a set of software modules to aid the entry of input data and support the display and evaluation of output results graphically are under development.

The organization of the software set and data base is illustrated in Figure 39. The nominal models discussed previously constitute the Input and Description Files. Each program has an input processor which operates on these and run time user inputs to establish the particular data set that the model processor requires. Model processor output is generally in the form of time samples or other disaggregate statistics. These raw statistics outputs are then operated on by an output processor associated with the program to

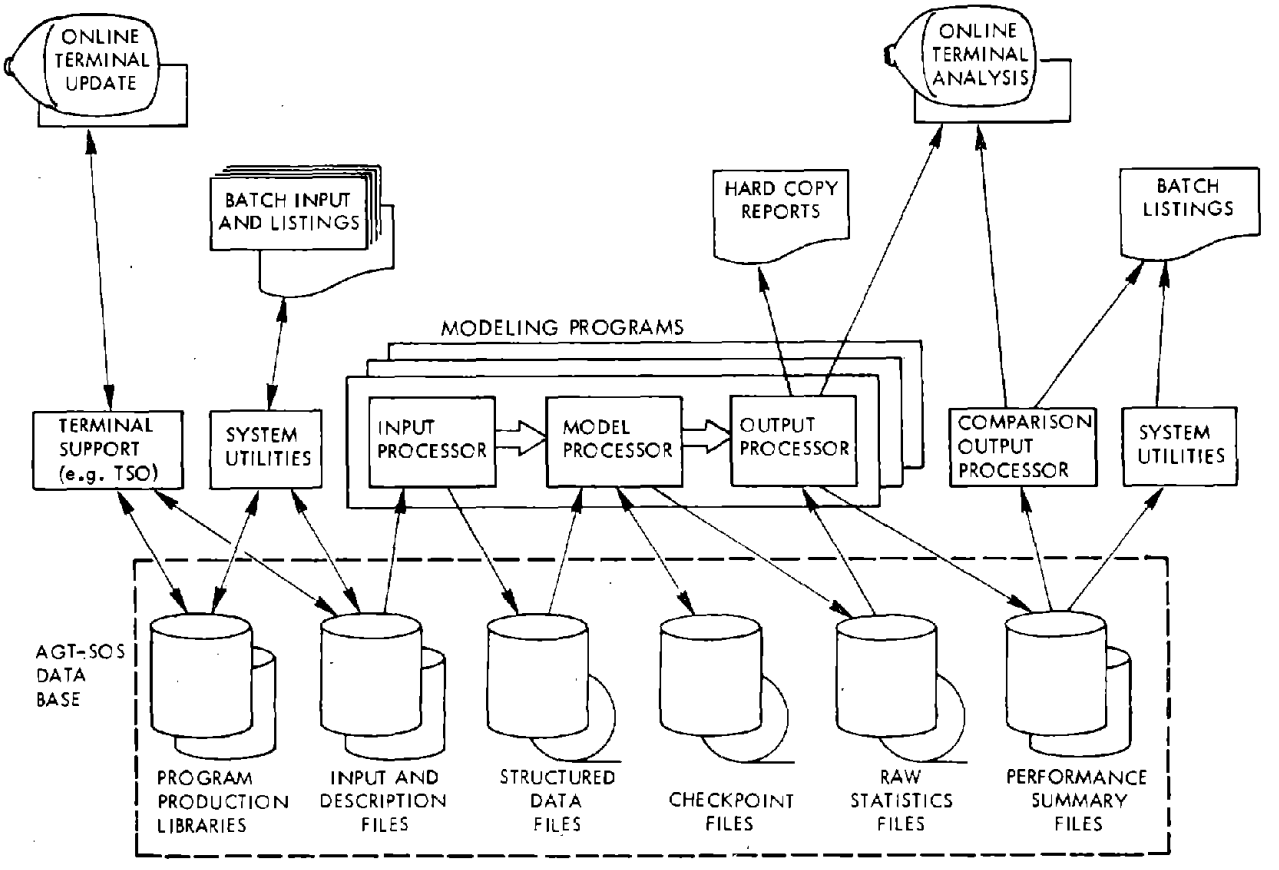


FIGURE 39. SOFTWARE AND DATA BASE ORGANIZATION

establish performance summary data. The same data can be reaggregated in many ways through subsequent runs of the output processor or by use of other sub programs to generate graphic displays of system or subsystem operation. Run time overrides provide the analyst with the ability to modify the characteristics of the nominal models for specific analysis tasks. New Input and Description files can be generated to describe alternative system, demand or network characteristics as necessary.

Descriptions of the functional and design details of the major computer programs are contained in the software functional and technical specifications listed in Appendix A.

F. SYSTEM ANALYSES

Figure 40 is a schematic representation of the relationship of the analysis process to the developmental and planning functions of AGT-SOS. The work done to date is documented in deliverable reports numbered one through five on the figure. The execution of the analysis steps under control of the Analysis Requirements and Plan has started. Presently, the system tradeoff analyses are being performed for each representative application. A three-

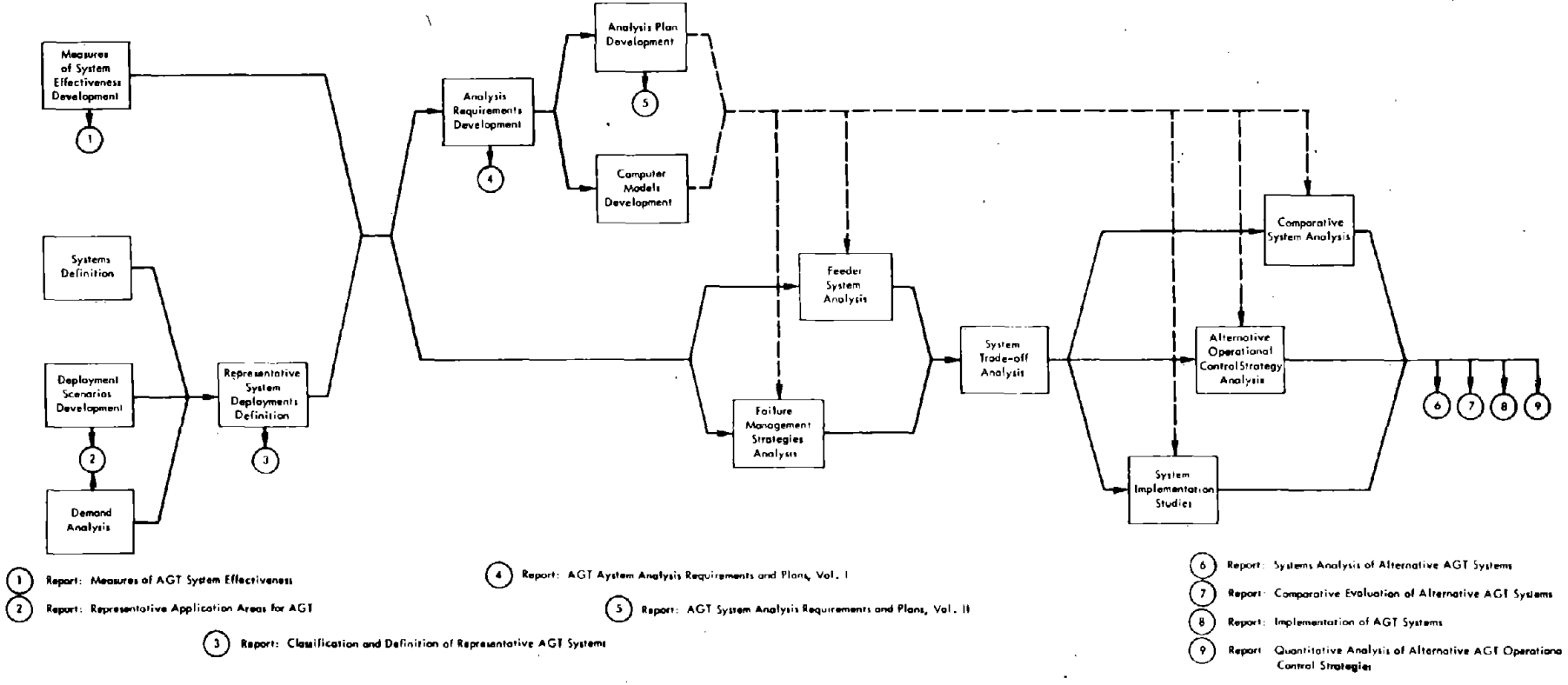


FIGURE 40. ANALYSIS PROCESS SCHEMATIC

volume report will summarize these analysis efforts for each system deployment type. The report set consists of the following analysis documents:

1. Analysis of SLT Systems in a Variety of Applications
2. Analysis of GRT Systems in a Variety of Applications
3. Analysis of PRT Systems in a Variety of Applications
4. Analysis of ART Systems in a Variety of Applications

The first volume of each series provides a summary of the analysis. Volumes II and III of the report series will contain the detailed study results and a description of the analysis techniques applied and data sources employed for the effort respectively.

The structure of the tradeoff analysis tasks is depicted in Figure 41. The objective of each of these tasks is discussed briefly below.

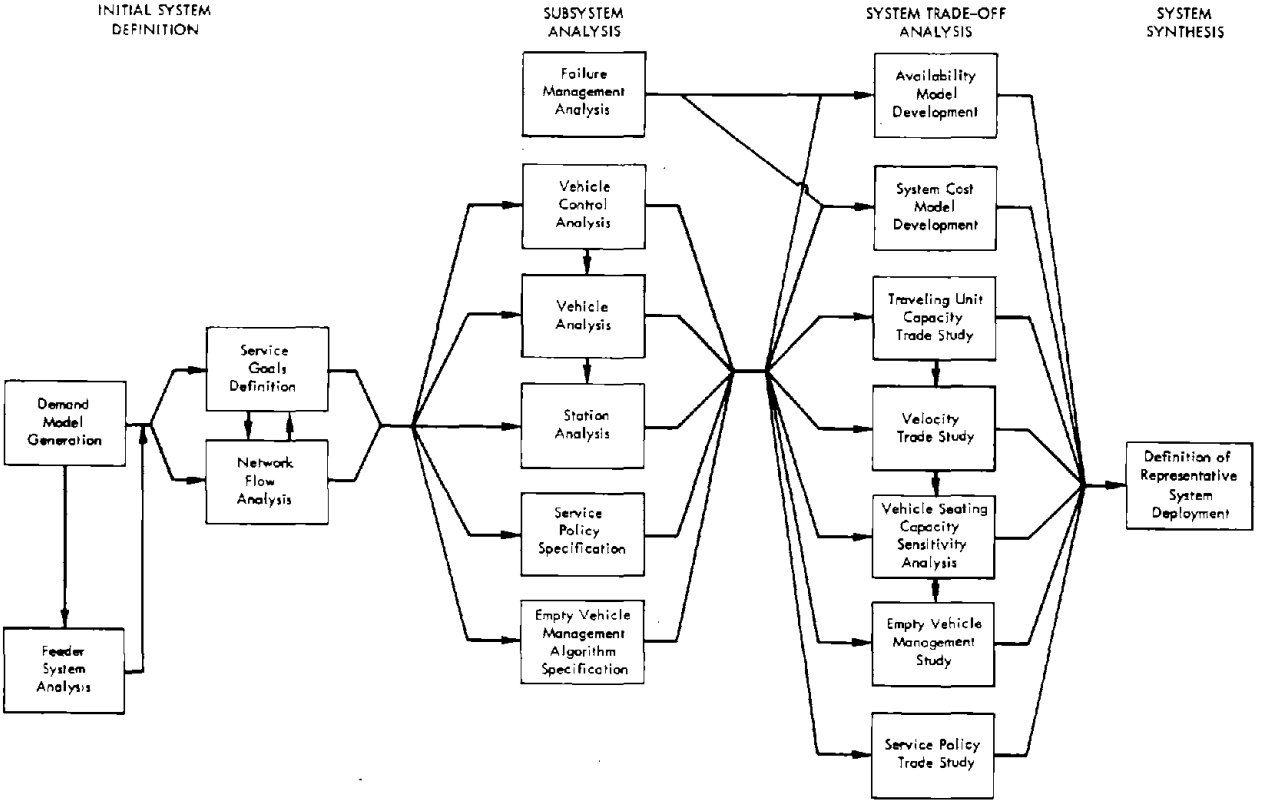


FIGURE 41. ANALYSIS TASK STRUCTURE

1. Demand Model Generation

The objective of this task is to develop a set of zone-to-zone demand matrices to represent the temporal and spatial variations in demand for each application area. The zone-to-zone demand models resulting from this task are mapped onto the various networks as part of the Feeder System Analysis.

2. Service Goal Definition

The objective of this task is to establish minimum (or maximum) acceptable levels for selected measures as trade-off criteria. A secondary purpose is to ensure compatibility among system deployments designed for the same application to facilitate comparison among systems. Currently, four measures (average trip speed, vehicle-based availability, energy consumption, and noise) are specified as constraint measures. As the analysis proceeds, measures may be added or deleted if they provide a more significant indication of system operational sensitivity to parameter variations.

3. Network Flow Analysis

The objective of this task is to determine if the selected system deployment is a reasonable one to be analyzed in the specific demand environment. System characteristics such as the range of vehicle capacities and train consists and network characteristics such as link loads and passenger transfer requirements are considered in this analysis task to determine if the system/network combination is adequate to satisfy the demand.

4. Vehicle Control Analysis

The objective of this task is to determine headway measurement characteristics and constraints, both functional and hardware, necessary to establish the system performance limits and cost and availability data for each deployment. A further objective is to establish the headway policy and resulting headway equation parameters to be used.

5. Vehicle Analysis

The objective of this task is to establish vehicle characteristics (nominal capacities, number of seats, dimensions, weights, velocities, acceleration/deceleration profiles, propulsion power and energy requirements) for use in subsystem analysis, cost model development and system level studies.

6. Service Policy Specification

The objective of this task is to select service policies to be considered during peak and off-peak periods in the system trade studies. This task includes the specification of alternate routes for fixed-route/fixed-schedule studies. Demand-responsive, demand-activated, and demand-stop service policies are examined as well as fixed route/fixed schedule policies.

7. Empty Vehicle Management Specification

The objective of this task is to specify the specific empty vehicle management algorithms for consideration within each AGT system deployment.

8. Station Analysis

The objective of this task is to develop functional designs and analytical relationships among the station design parameters and measures to aid in sizing stations. Station analysis is approached as a two-part study. First, the passenger areas are analyzed assuming that the passenger-vehicle interface does not constrain passenger flow. Then, the functional requirements of vehicle areas are determined. These guidelines are used later in the Traveling Unit Capacity study to specify station configurations.

9. Availability Model Development

The objective of this task is to model the mechanization of the representative deployments in terms of availability factors (failure rates, redundancies, levels of quality, failure response strategies, and delay consequences), and to develop availability-factor relationships.

10. Cost Model Development

The objectives of this task are to develop the relationships required to estimate fixed and variable unit costs and to establish unit cost and cost parameter inputs to the SCM to support the trade studies.

11. Traveling Unit Capacity Trade Study

The objectives of this task are to evaluate the operational and cost implications of vehicle size and cruise speed for single vehicle and train operation and to generate sensitivity data for use in selecting a final representative system configuration. A further objective is to select the combination of vehicle capacity, train consist, cruise speed, and station configuration which produces the best balance among the measures of service, cost, availability, and environmental impact. This task brings together the results of the vehicle analysis task and the station analysis and examines alternative subsystem designs in a system context.

12. Vehicle Seating Capacity Sensitivity Study

Seating capacity is a policy decision, and as such, seating sensitivity information is required for use by planners to assess the implications of such decisions. The objective of this task is to establish the sensitivity of capital cost, energy consumption, and percent standing to variations in the number of seats per vehicle.

13. Service Policy Trade Study

The objectives of this task are:

1. The determination of the effects of alternative service policies on operating cost, energy consumption, and total trip time.
2. The identification of the service policy which results in the best balance among operating costs, energy utilization, and total trip time.
3. The establishment of the relationship between vehicle load factor and the related measures of cost and energy consumption.

14. Empty Vehicle Management Study

The objective of this task is to identify the empty vehicle management strategy which results in the best balance among operating cost, energy utilization, and total trip time for each service policy considered in the service policy trade study.

15. Definition of Representative System Deployment Mechanization

The objective of this task is to provide a complete description of each system deployment in terms of specific values of system design parameters and measures.

System flexibility in terms of the ability of the system to serve excess demand and further, the aspects of system design which are most sensitive to demand variation will be characterized.

16. Feeder System Analysis

The objectives of this task are:

1. Comparison of the performance and cost of alternative feeder systems designed to serve equal percentages of the AGT demand in the various feeder service test problems.
2. Selection of a feeder system alternative for each deployment.
3. Evaluation of the feeder system performance and utilization measures.

17. Failure Management Analysis

The objectives of this task are:

1. To develop a description of each deployment in terms of component and subsystem reliability.
2. To establish, through simulation, the vehicle and passenger delay consequences of subsystem failures with various failure response strategies implemented.
3. To establish cost/availability tradeoff data.
4. To evaluate for each deployment system availability in terms of both vehicle and passenger delays.

G. WORK TO COME

The remaining effort on the AGT-SOS project can be grouped into four areas:

1. the remaining Trade Off Analyses
2. the Comparative Analyses
3. data base generation and operation
4. dissemination of information

1. Trade Off Analyses - This work is in progress. When it is completed, each of the 19 representative applications will have been subjected to what essentially is a design tradeoff process. Specific mechanizations will have been established and exercised through simulation to establish parametric sensitivity data. An investigation of the implications of alternative vehicle control and dynamic entrainment policies will be performed within the context of one of the Metropolitan Area GRT deployments.

2. Comparative Analysis - This work has a twofold purpose; first, the performance of alternative systems and mechanizations will be compared within similar deployments; and second, the parametric sensitivity data will be investigated with the intent of defining a set of linear models of the form $M_R = M_N + (P_R - P_N) \times S_N$ where:

M_R is a resultant vector of measure values

M_N is the vector of measure values for some nominal deployment configuration

P_R is a vector of parameter values for which a set of measure values is desired

P_N is the vector of parameter values for the nominal deployment configuration

S_N is a sensitivity matrix which relates changes in parameter values to a change in measure values for the nominal deployment

The purpose of these linear models is to provide quick-look estimates of major performance measures for proposed deployments which are similar to one of the nominal deployments without the need for extensive simulation. The specific parameter/measure relationship to be modeled, range of accuracy, and the number of such models to be developed are a function of the data being developed in the tradeoff analyses.

3. Data Base Generation and Operations

The computer software, nominal models, representative application configurations, and analysis results constitute a data base. This data base is continuously expanding as both analysis and software development proceed. A set of user aids to simplify the generation of future deployment data and the cross referencing and reevaluation of existing analysis results are under development. These aids make use of interactive and graphic display techniques to extend the utility of AGT-SOS results and software.

4. Dissemination of Information

For a project with the purpose of AGT-SOS to be effective, it is necessary to make information on the project techniques and results available to as many potential users as possible. The intent is to establish a two-way flow of information and also to make the analysis tools and techniques widely available. The information flow mentioned is two-way so that results and conclusions are made available to the industry in a timely manner and evaluations by users of the accuracy, generality, and utility of both raw data and results can be used to direct future extensions of the basic work.

To accomplish this dissemination of information, two workshops are planned under this contract. One is scheduled in the near future to evaluate and comment on the SLT Analysis Report. A second is scheduled near the end of the contract (early to mid-1979) to serve as a complete review of results and software operations.

H. SUMMARY

The AGT-SOS project is an across-the-board study of the applicability and capability of automated guideway transit systems. In the course of the study, representative system types, networks and demands have been delineated and a set of representative combinations selected for investigation. A software set which provides a generalized capability to model the performance, cost, and availability characteristics of such deployments has been developed.

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APPENDIX A

AGT/SOS DOCUMENTS

Title	EP #
Classification and Definition of AGT Systems	77002
Representative Application Areas for AGT	77054
Measures of AGT System Effectiveness	77004
System Analysis Requirements and Plan, Volume I (Requirements)	77019
Update	77019A
Update	77019B
Update	77019C
System Analysis Requirements and Plan, Volume II (Plan)	77012
Update	77012A
Update	77012B
Software Standards	76056A
Feeder System Model Functional Specification	76065
Detailed Station Model Functional Specification	77008
Detailed Operational Control Model Functional Specification	77009
Discrete Event Simulation Model Functional Specification	77057
System Planning Model Functional Specification	77010
Update	77010A
System Cost Model Functional Specification	77048
System Availability Model Functional Specification	77043
Feeder System Model Technical Specification	77014
Update	77014A
Detailed Station Model Technical Specification	77081
Detailed Operational Control Model Technical Specification	77082
Discrete Event Simulation Model Technical Specification	77083
System Planning Model Technical Specification	77032
Update	77032A
System Cost Model Technical Specification	77055
Update	77055A
System Availability Model Technical Specification	77056
Update	77056A
Data Base Functional Specification	78003

PAPER 2

Systems Safety and Passenger Security

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SYSTEMS SAFETY AND PASSENGER SECURITY

A SYSTEM LEVEL STUDY PROJECT

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ABSTRACT. A study project on "Systems Safety and Passenger Security" in the AGTT Program is approximately half way through its contract period. Interim reports have been delivered to the Government on the plans, programs and preliminary findings of six tasks dealing with passenger security, evacuation and rescue, safety and convenience services, passenger value structure models, deceleration and jerk standards, and security and safety workshops.

An experimental evaluation of a CCTV security surveillance system has been started in New York with the cooperation of the Transit Authority and TA Police Department.

A two-phased survey of community attitudes on passenger safety and security has started in New York in association with the CCTV experiment.

Experimental trials in a specially instrumented "cube-van" truck have been completed, and the data are being used to establish maximum acceptable levels of deceleration and jerk for seated human subjects, and design requirements for a high retention seat.

Work is continuing in preparing AGT system safety and security guidebook materials and in preparing for a Security and Safety Workshop to be conducted at DOT/Transportation Systems Center in the Fall of 1978.

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INTRODUCTION

An explicit objective of UMTA's Automated Guideway Transit Technology (AGTT) Program is to provide system designers and urban planners with guidance data and analytical tools applicable to a broad spectrum of automated guideway technologies, ranging from simple loops and shuttles, to GRT, PRT, Dual Mode and ART systems.

This paper describes the objectives, scope, plans and progress of one system level study project in the AGTT program. The project will generate guidelines and planning information that can be used to assure the actual and perceived safety and security of passengers in AGT systems.

Existing AGT systems, servicing as they do special populations and operating mostly in restricted non-urban settings, have not encountered serious security and safety problems. However, security and safety is currently a major problem for most large urban transit systems. The reduction in numbers of system personnel in AGT systems--drivers, conductors, station and ticket booth attendants, and the increase in numbers of unmanned stations and driverless small vehicles will add greatly to the problems of providing passenger services and of ensuring passenger safety and security in the urban environment. Such services include, for example, protection from harassment, delivery of emergency aid, evacuation and rescue during system breakdown or disaster, and provision of information needed by passengers to use the system effectively.

The designers of short headway, multiple small vehicle systems also need more information on the limits of emergency decelerations that the general public can tolerate without the risk of being thrown from their seats and receiving bodily injury. Urban planners and transportation officials need more guidance and information on the security and safety expectations, characteristics and attitudes of the potential AGT passenger. With this information, planners will be able to better predict passenger satisfactions with different features of AGT systems, in relation to their current use of transit systems for different purposes, at different times of day or week and in differing urban environments.

The scope of this project was defined by the Government as follows:

> "The Contract will require six major efforts (each identified as an item in this work statement). The first item will involve study and experimentation to determine more effective methods and procedures for reducing crime and vandalism, and preparation of a comprehensive guidebook on the methods and procedures for reducing crime and vandalism. The second effort will involve

writing a comprehensive guidebook on methods and procedures for safely evacuating and rescuing passengers from AGT vehicles and guideways in emergency situations. The third effort will involve writing a comprehensive guidebook on passenger safety and convenience services (i.e., helping lost children, providing directions for lost or confused passengers, etc.). The fourth effort will model the potential AGT passenger with perceived safety, security, ridership and public acceptance as basic parameters. The fifth effort will involve experimentally determining maximum emergency deceleration and jerk levels and development of seat design parameters. The sixth effort will involve holding a workshop on the methods and procedures to enhance passenger safety and security developed under this procurement. On the basis of the responses obtained in these workshops, the guidebooks shall be revised where required."

The diversity of the six tasks addressed in this single procurement presents a serious challenge to the range of technical expertise and experience of any single organization. Dunlap and Associates, Inc., joined forces, therefore, with the University of Virginia and with the Vought Corporation; first to respond to the procurement request and now to execute the project.

APPROACH

The Government has defined in broad terms the overall approach to be followed in conducting this project. The sequences of activities anticipated by the Government for each of the six work items or tasks, and their interrelationships, are shown schematically in Figure 1. The Item 1 crime countermeasure experiment will contribute to the development and validation of the value structure model of Item 4, and the workshop of Item 6 will contribute directly to the products of Items 1, 2 and 3.

In meeting these general requirements, we have adopted a three-pronged approach to the organization and performance of this project.

The first part of this approach is concerned with the systematic collection of data about AGT passenger requirements for security, safety and convenience services, the development and evaluation of design or procedural solutions to crime and passenger problem scenarios, the holding of workshops and presentation of Task 1, 2 and 3 findings in the form of guidebooks.

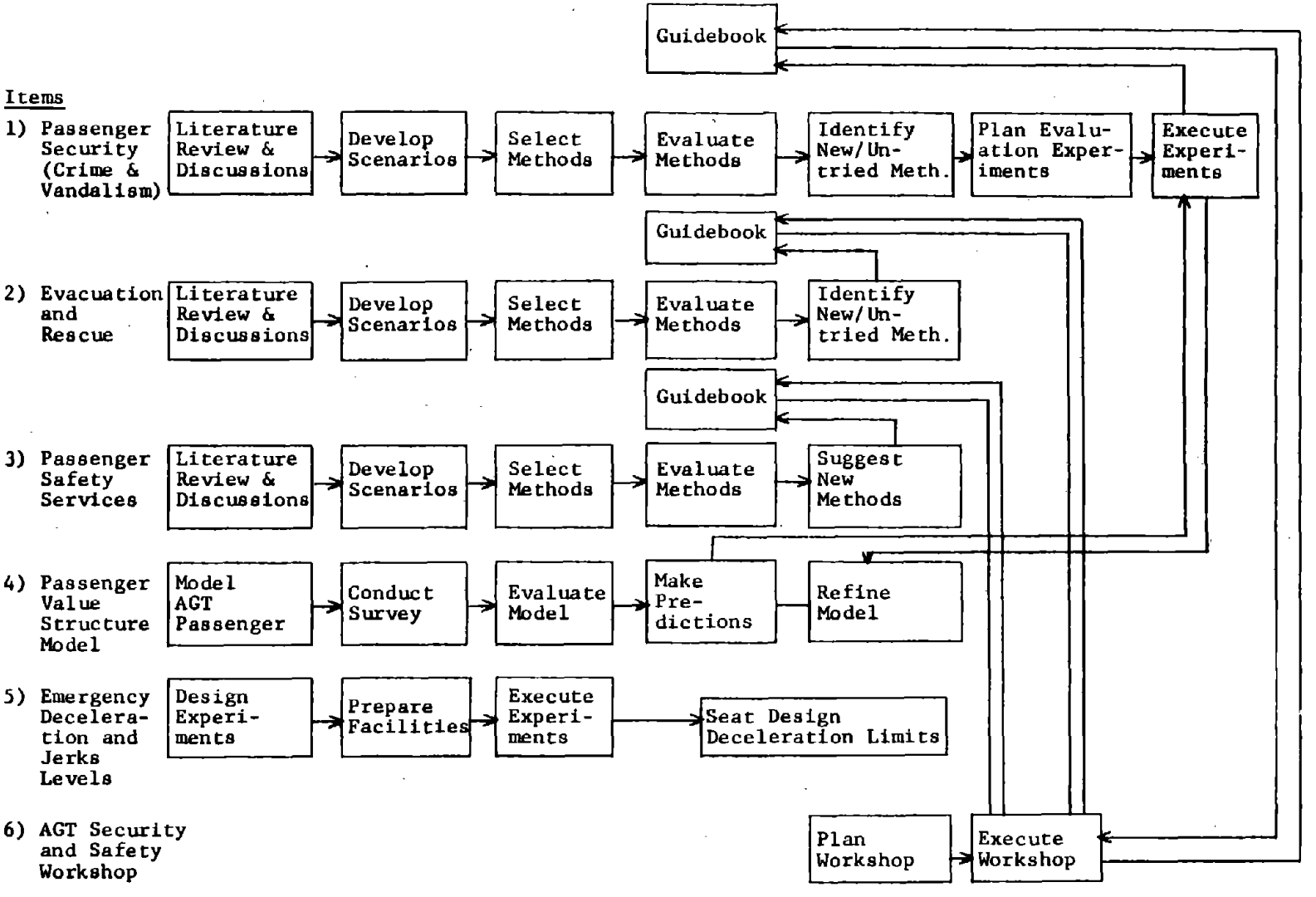


FIGURE 1. STUDIES OF SYSTEM SAFETY AND PASSENGER SECURITY

The second part is concerned with the measurement and prediction of passenger attitudes toward AGT system safety and security, and of passenger ridership behavior. The technical approach to Task 4 requires different kinds of data and utilizes sophisticated subjective measurement techniques, data analysis and mathematical modeling skills.

The third part involves experimentation with human subjects under carefully controlled conditions to establish in Task 5 acceptable emergency deceleration and jerk levels for seated AGT passengers.

Each part of the approach requires somewhat different technical capabilities and results in different products--guidebooks, computerized passenger value model and system deceleration performance standards and seating specifications.

As prime contractor, Dunlap and Associates, Inc., is responsible for the overall management and coordination of the work effort and the on-time delivery of the required products. Each of the three contractors has prime responsibility and makes the major contribution to two of the six tasks and supports other team members' effort in the other areas where most appropriate.

At times, all three contractors participate in joint activities common to several work items--such as computerized literature search, visits to transit properties and the workshops. At other times, they work separately on their particular tasks.

STATUS

Figure 2 is a Gantt Chart that shows the approximate delivery dates of the required interim, draft and final products of each of the six tasks. The project is approximately at the half-way point in the two-year contract period and, with the exception of a delay on the Task 5 deceleration and jerk experiment due to bad weather, the delivery of all products is on schedule.

The remainder of this paper presents brief descriptions of the principal activities to date and the status of work on each of the six tasks.

Joint Activities

Early in the project, Tasks 1, 2 and 3 shared in an extensive computerized literature search of six major file sources:

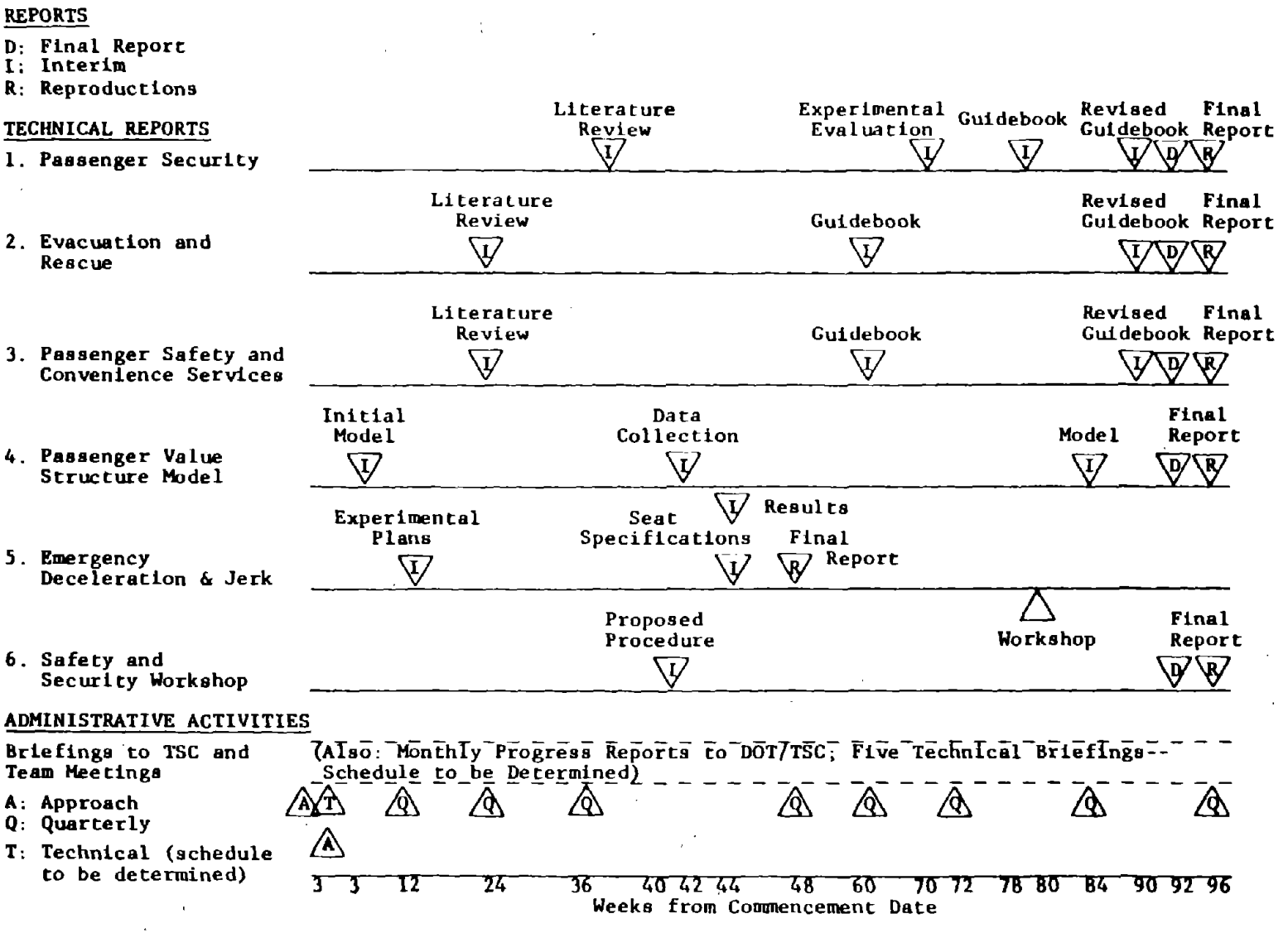


FIGURE 2. PROJECT ORGANIZATION CHART

- Computerized Engineering Index (COMPENDEX)
- National Technical Information Services (NTIS)
- Smithsonian Science Information Exchange (SSIE)
- Transportation Research Information Systems Network (TRISNET)
- National Aeronautics and Space Administration (NASA)
- Defense Documentation Center (DDC)

The researchers on each of the tasks supplemented this common effort with explorations of local sources unique to each task--unpublished technical literature, vendor literature, management and professional journals, even newspaper reports and articles.

Additional information on passenger security (Task 1), evacuation and rescue (Task 2) and passenger safety and convenience services (Task 3) was obtained during joint visits to old and new transit properties and in meetings with transit officials and other experts.

Project representatives visited Sea-Tac and the Monorail in Seattle, BART and MUNI in San Francisco, AIRTRANS at Dallas/Fort Worth Airport, Toronto Transit Commission, CTA in Chicago, PATH, NYCTA and Roosevelt Island Aerial Tramway in New York, PATCO in Philadelphia, WMATA in Washington and Morgantown PRT in West Virginia.

The staff of Tasks 1, 2 and 3 consolidated the information from the literature surveys and site visits and developed comprehensive descriptions of the state-of-the-art and current practices in each of the three problem areas.

Independent Activities

Task 1: In the case of this task (passenger security), the staff first analyzed the information by four crime categories--crimes against the person, crimes against personally carried property, crimes against station property, and crimes against the public.

They next developed scenarios for crimes in each category which described representative situational variables and values or descriptors for both "extreme" and "typical" situations. The realism of the scenarios and the appropriateness of the values chosen for each variable were "verified" against the judgments of experienced transit security officials. The

various crime countermeasures employed on transit systems were also categorized as passive, semi-active and active; related to station, vehicle, guideway or collateral site design or to operational features; and identified as a device or hardware, as a station or vehicle design characteristic, as personnel or operations related or as related to land use and locale. The appropriateness of countermeasures in each major category were evaluated for future AGT systems applications.

Cost information, both monetary (capital/operating) and social (passenger/transit authority acceptability) was also developed for selected countermeasures, and expert judgments were collected on their relative effectiveness against different categories of crime. A systematic procedure has been developed for selecting and integrating the crime countermeasures most suitable for a planned transit system.

In addition to these analytic activities, the Task 1 staff searched for a suitable and available transit site for conducting a field evaluation of a countermeasure applicable to AGT systems. With the cooperation of Transit Police Chief Sanford D. Garelik of NYCTA, the evaluation of an experimental closed circuit television surveillance system has been started and data on crime, ridership and perceptions of passenger security are being collected both at an experimental site in Queens and at a matching control site in Brooklyn.

Tasks 2 and 3: The staffs of these two tasks (evacuation and rescue, and safety and convenience services) related the information collected from literature searches and site visits about passenger problems and response agency practices to knowledge of current and proposed AGT system designs and applications. They then developed scenarios depicting realistic emergencies and passenger problems on differing types of AGT systems in differing environments and climates.

To keep the number of scenarios developed for Task 2 manageable and to assure that the scenarios selected were both realistic and representative, a selection process consisting of four steps was followed:

1. Combination of similar scenarios into common variables.

2. Selection of a few discrete examples to represent a range of situations.

3. Indication of probability of occurrence so that emphasis can be placed upon problems that occur most frequently.

4. Indication of the level of hazard or difficulty associated with the situation so that emphasis could be placed on situations with the greatest threat to the well-being of the passengers.

This scenario selection process identified eleven variables which are likely to influence the selection of evacuation and rescue methods and procedures. These variables range from the severity of the situation to the climatic conditions that exist. For example, guideway elevations can range from those of deep subways to tall aerial structures. Rather than consider all possible values, the values were categorized into two to four ranges. This categorization was based upon characteristics of the various AGT system technologies, possible applications and likely evacuation and rescue methods.

Situations requiring passenger evacuation or rescue were developed by selecting values from each of the scenario variables. In addition, qualitative assessments were made of the degree of hazard or difficulty of rescue associated with aspects of a scenario, as well as judgments of the likely frequency of occurrence. Table 1 gives an example of a complete situation.

Information collected about response agency practices is being used also to select evacuation and rescue methods and procedures appropriate to AGT systems and to evaluate their effectiveness in resolving scenarios of AGT emergency situations.

Task 3: In the case of this task, the number of possible scenarios depicting passenger safety and convenience problems was reduced to a representative and realistic set by a three-step process:

1. Selection of "worst" case and "typical" case scenarios to cover the range of intermediate situations.

2. Weigh each scenario selection based upon the "probability of occurrence," thereby providing more emphasis or detail for those events which are more likely to occur.

3. Weigh each scenario selection based upon the degree of hazard to passenger safety or passenger inconvenience. Hazardous situations and events which create the greatest degree of passenger inconvenience will therefore receive higher priority.

TABLE 1. CONSTRUCTION OF A SAMPLE SCENARIO

Actual Condition: On a fine spring day, an explosion at an electrical substation causes a loss of power to an AGT system. One of the vehicles stranded by the power outage is near the end of a bridge 27 feet over a river. Twenty people, including two elderly women, are aboard the vehicle. The technology of the AGT system is similar to that at the Dallas/Fort Worth Airport.

Scenario Construction:

Scenario Variable	Actual Condition	Corresponding Variable Value
Severity of Emergency	Power Outage	Less Critical Emergency
Guideway Type	Wide, Flat Running Surface with Exposed Power Rails	Safe for Walking Power Off
Guideway Elevation	Twenty-seven Feet Above Ground	Elevated--3,000 Feet or Less
Terrain/ Geography	Over a River	Virtually Inaccessible to Conventional Vehicles
Passenger Group Size	Twenty Passengers	Ten to One Hundred
Passenger Condition	Able Bodied Except for Two Elderly People	Able Bodied and Ambulant with Assistance
Distance from Station or System Access	One Hundred Feet to At-grade Guideway at End of Bridge	Within Walking Distance
Weather Conditions	Warm Spring Day	Dry and Mild
Ambient Lighting	Mid-day Sun	Adequate
Attendant on Vehicle	No	No
Vehicle Egress Constraints	End Doors on Vehicle Allow Acess to Guideway Running Surface	None

Through a systematic approach of combining each problem with the different situation variables (location, system condition, trip variables, weather, etc.), hypothetical scenario situations were conceived. In several cases, the situation variables had no real influence on a specific problem, hence the number of scenario possibilities were reduced. The remaining scenarios were then studied with respect to frequency of occurrence, and the potential passenger hazards or inconveniences that may occur. Fortunately, the more frequently occurring problems are typically the less hazardous to the passenger. For example, the occurrences of lost/confused passengers, lost articles, malfunctioning ticketing equipment, soiled cars, etc., are frequent, but these usually result in only annoyances or delays and do not create a serious hazard to the passengers. Situations associated with fires, serious illness/injuries and uncontrolled entries into the guideway are less frequent but pose immediate dangers. In these cases, the need for almost instantaneous detection and response is critical to prevent serious injuries or loss of life.

Scenarios were developed for each significant and unique problem area defined. As noted, two scenarios were generated for each identified problem. One illustrates a realistic "worst case" set of situations, while the other denotes a more "typical" problem area. The "worst case" scenario is not the absolute worst set of circumstances that could theoretically occur. Sound judgment was used to rule out the ridiculous combinations. Cost makes it impractical to fully accommodate 100 percent of all possible problems. These scenarios should make the designer aware of rather infrequent but possible situations that may occur. If the "worst case" situations can be accommodated, the associated "typical" scenario cases should be resolved with relative ease. The "typical" situations in this case refer to those routine problems that may occur on an almost daily basis, e.g., lost/confused passengers, equipment malfunctions, lost articles, etc.

Currently, the adequacy of these scenarios is being investigated. Various problem detection and response methods and procedures are being applied to each scenario and evaluated for effectiveness.

In AGT systems, it is the area of DETECTION that becomes the really unique and important aspect of passenger service and safety. In non-AGT systems, the detection and correction of many routine passenger service problems are by onboard operators and/or station attendants. With the absence of these personnel in an AGT environment, other means of detection and resolution are required. The problems themselves are typically not unique to AGT transit systems nor are the situation variables all that different from conventional transit operations. Whether the problem occurs onboard a vehicle or in

a station, at day or night, during adverse weather, or with the system crowded or empty, detection becomes the first order of importance. Furthermore, the response to a problem, once detected, may not differ greatly from currently used practices, except for some unique equipment and personnel variations. For example, if a person is injured in an unattended station or vehicle, once detected, the response will typically be the same in all systems--that is, dispatching medical assistance. In a conventional system, the station attendant would most likely be the detection source, whereas in an AGT system, other means would be required. Roving transit personnel, CCTV, special sensors, and passengers serve as current modes of detection in present AGT systems. These are supplemented by readily accessible radio/telephone communication to central control. Functions currently being handled by vehicle or station personnel on conventional transit systems will have to be accommodated with special equipment or transferred to central control and resolved via radio, telephone, P/A, CCTV or by dispatching the required personnel.

Task 4: The staff of this task have conducted critical reviews of the literature on perceived safety and security and on user reactions to the characteristics of transportation systems. While actual and perceived crime levels are often related, they are not always so. There are four situations of correspondence between perceived and actual safety and security. A system may be safe and be seen as such, or may be correctly perceived as unsafe. However, the discrepancies between perception and fact are particularly interesting: the unsafe system that is viewed as safe, and the safe system with a reputation for being unsafe. The staff found the literature on passenger perceptions of crime and security to be minimal. The perceived effectiveness of countermeasures had hardly been studied at all. There are few enough papers on the actual effects of countermeasures on crime levels. Most countermeasures have never been systematically evaluated.

The staff have also developed models of the role of perceived safety in "modal choice" and of the processes whereby impressions are formed of transit passengers' safety and security. A theory about perceived safety and security places this construct in a set of propositions relating it to real world situations, to other psychological constructs, and to behavior or action. These propositions or statements may be realized through various alternative models, and several models are necessary to describe the information processing or decision making involved in using a transportation system.

The theory will be realized as a sequence of models which may be entered into a digital computer to simulate the effects of changing specific features of the transportation system. The general nature of these models is shown in TABLE 2.

TABLE 2

OVERVIEW OF MODELS

MODELS	PURPOSE	TYPE
System	To Describe Features, Aspects	Scenarios, Conceptualizations
Perception of System	To Describe Salient Features	Dimensional and Clustering Models
Response to System	To Predict Rated Safety and Security	Regression Model with Salient Attributes Weighted to Maximize Prediction
Behavior	To Predict Percentage of Users and Non-users Feeling Safe and Secure and to Predict Ridership	Population Cover Approach: Probabilistic Use of Regression Equations with Distributive Properties

A large data gathering effort is underway to assess parameters of the various models discussed above. An overview of the data acquisition plan is shown in TABLE 3. A survey will be administered both before and after the experimental modification of the transit stations referenced earlier in Task 1. A closed-circuit television system is being installed to monitor the platform and station areas. The survey is designed to elicit reactions of the respondents about perceived safety and security on the transit system in general as well as at specific places and times of day. User and non-user perceptions of various other aspects of the system and its operation will also be obtained.

Two other sources of data are also involved. Panels of respondents will be assembled to provide in-depth information concerning their perceptions of crime, their evaluations of crime scenarios, and their reactions to proposed countermeasures designed to prevent crimes or facilitate the apprehension of criminals. These panels will also assess various features of proposed AGT systems.

The final data source will be site visits to areas identified by survey respondents as safe or unsafe. Information will be collected about the physical characteristics of the stations, the socioeconomic characteristics of the areas, and on a variety of system features. Informal interviews of station users will be conducted as needed.

Task 5: This task (deceleration and jerk) calls for a series of experimental trials to determine the maximum acceptable levels of deceleration and jerk for seated human subjects. In planning the experiment, consideration has also been given in the test design not only to motion variables but also to seat orientation, seat angle, seat covering and cushioning, and the use of arm and foot rests. These motion and seating variables and their interactions are thought to be the important variables that must be considered in establishing design standards for safe emergency stops on AGT systems.

A "cube-van" truck has been used to simulate an AGT vehicle. It was fitted with a transit seat and data recording instruments. During the experimental trials, the braking mechanism of the truck was controlled automatically by a LeBow Model 7610 Brake Test Instrument, which provided adequate test repeatability and met the required deceleration and jerk limits.

The tests were conducted on an airport taxiway first at Hanscom Field in Bedford, Massachusetts, and later at Otis Air Force Base on Cape Cod. The tests were limited to normal populations of seated adults (i.e., no children, handicapped or elderly) and employed only straight line decelerations of the vehicle.

TABLE 3

DATA ACQUISITION--TASK 4

SURVEY

Administered to General Public; Requires OMB Approval

Two Waves of Distribution:

- Before Experimental Change
- After Experimental Change

Target Groups: Both Users and Non-users

PANELS

Paid; No OMB Approval Required

To Judge Scenarios

To Evaluate Features--Proposed and Actual

To React to Countermeasures

SITE VISITS

To Evaluate System Features

To Interview Terminal Occupants

- Interview Schedule Informal and Flexible
- Does Not Require OMB Approval

In separate trials, the seat pan and back were tilted back in increments up to approximately 12 degrees to determine if tilting of this type aids passenger retention during deceleration. The orientation of the seat was also shifted through 135° (from forward) to determine the effects of these angles on the maximum deceleration levels. Arm rests and foot rests were also examined to determine their effectiveness in restraining passenger movement.

One of the experiments determined the effect of jerk on the maximum acceptable deceleration level. In addition to the use of switches imbedded in the seat to measure passenger movement, this experiment was filmed at the speed of 64 frames per second to identify precisely how and when passenger movement occurred.

Throughout this study, particular attention was paid to the protection of the well being of the human subjects. Large, medium and small sized individuals of both sexes were recruited for the experiments. A safety committee critiqued the test set-up prior to the running of any test subjects. The safety precautions were successful in that there were no mishaps throughout the conduct of the experiment.

Task 6: This task involves the planning and conduct of a Security and Safety Workshop to assess the practicality of the material that will be prepared in guidebook format in Tasks 1, 2 and 3. Three guidebooks are being developed and a separate workshop will be conducted for each one. The workshops will each last 1-1/2 to 2 days, and will be held consecutively over a one-week period. Every workshop will be limited to approximately a dozen people drawn from industry, Government and research institutions. In addition to evaluating the guidebook materials and suggesting revisions, the workshop participants will be asked to prognosticate on the security and safety of future (urban) AGT systems.

The workshops are planned for 16-20 October 1978 at the Transportation Systems Center in Cambridge. An information package for advance mailing and provisional lists of participants have been prepared.

One participant in each workshop will be asked to prepare, in advance, a written preliminary critique of the draft guidebook, and act as moderator and discussion leader.

During the workshops, comments and recommendations will be recorded on a "storyboard" display as a reminder during the discussions and for use later in modifying the draft guidance materials. The final creative effort of each workshop will be a discussion of future trends in system safety and passenger security and the predictions of the safety and security problems of urban AGT systems and their recommended countermeasures.

CONCLUSION

At the mid point of the contract period, the project team is successfully prosecuting the study, in accordance with the required approach.

Certain logistic or administrative delays have occurred but, overall, the project is on schedule. The approach has proved feasible, the schedule appears reasonable, and preliminary reports point to the accomplishment of significant research findings and the ultimate delivery of practical guidance materials directly relevant to urban AGT systems.

PAPER 3

Vehicle Longitudinal Control and Reliability

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THE VEHICLE LONGITUDINAL CONTROL AND RELIABILITY PROJECT

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Abstract - The Vehicle Longitudinal Control and Reliability Project is a research and development undertaking to evaluate automated guideway transit (AGT) longitudinal control systems and to determine the best compromise between the conflicting requirements of performance, safety, cost, weight, and reliability. The project is organized into three areas of endeavor: technology studies, experimental program, and project documentation. This paper describes this project's objectives, organization, current status and sets forth some preliminary results.

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Introduction

The Vehicle Longitudinal Control and Reliability Project has been established to investigate alternative longitudinal control technologies and to determine ways to improve reliability which are applicable to a wide variety of automated guideway transit systems.

The Vehicle Longitudinal Control and Reliability Project is a project within the Subsystem and Component Technology Development subdivision of UMTA's Automated Guideway Transit Technoloty Program (AGTT).

The Automated Guideway Transit Technology (AGTT) program is a comprehensive, broadbased, critical technology development program derived from the Urban Mass Transportation Administration's experience with automated transportation systems. The program is oriented toward the analyses of systems and the development of system elements which may be used in a variety of advanced urban transportation systems. For this reason, it represents the identification and selection of new research and development initiatives which will provide the direction for new systems development into the future.

The objectives of the AGTT program are to:

- o develop a comprehensive AGTT network simulation capability applicable to a wide variety of different AGT system concepts and application;
- o carefully explore the service and operation costs of AGT systems in a variety of applications;
- o identify, develop, and test the technology required to substantially extend the mean time between failures (MTBF's) which result in guideway blockage and explore manual and automatic methods to effect rapid stalled vehicle removal while minimizing the number of operation personnel;
- o study the technology requirements for fractional-second headway, small (4 to 6 seat) vehicle PRT systems, and develop and test essential subsystems;
- o generate the technical and operating data required to develop rational decisions concerning further AGTT program activities;
- o reduce the technical and financial risks involved in the development and deployment of automated systems; and
- o develop a national data base for use by system designers and developers, local planners, and government officials to assist them in preparing performance specifications for such systems.

Vehicle longitudinal control is one of two subsystems, the other being Vehicle Lateral Control and Switching, which have been identified as being particularly crucial to the successful operation of automated transit systems.

PROJECT OBJECTIVES

The VLCR project is focused on the improvement of the performance and reliability of the longitudinal control subsystem used in the overall system. This focus is set forth by the project's overall objectives of:

1. Reducing cost and complexity while increasing the reliability and maintainability of AGT longitudinal control subsystem.
2. Providing a comprehensive experimental evaluation of the performance of improved longitudinal control systems.
3. Developing and demonstrating techniques for enhancing reliability by methods such as complexity reduction, maintainability improvement, component improvement, fail-operational and fail-degradable design, and the determination of the cost impacts of such designs.

4. Establishing reasonable goals for longitudinal control system component reliability.
5. Developing specific cost and performance requirements for longitudinal control systems for a range of headways including operation at K-factors less than one.
6. Demonstrating potential performance improvements achievable through rapid control system reaction to failures and closed-loop emergency braking.
7. Developing functional and performance specifications for longitudinal control systems for AGT systems using automatic entrainment or platooning.
8. Performing an analytical and experimental evaluation of an automatic coupling and decoupling system suitable for trained vehicle operations and failed vehicle pulling and pushing.
9. Establishing design concepts and specifications for automatic coupling systems which meet the requirements of AGT vehicles in a cost-effective manner.
10. Performing an analytical assessment of the platooning concept and establishing platooned vehicle operation.
11. Developing a comprehensive longitudinal control data base.

These objectives are to be met through a program of technology studies, experimental evaluation, and documentation.

The technology studies, which account for approximately 50% of the project budget, consist of:

1.) Longitudinal Control Studies
2.) Reliability Enhancement Studies
3.) Entrainment and Platooning Studies.

Each of these studies consists of appropriate combinations of literature and technology review, specification, mechanization, analysis, design and simulation.

The remaining 50% of the Project budget is targeted for the Experimental Program. The objective of the Experimental Program is to provide validation of the models used in the technology studies to predict performance and reliability. Performance improvements which might be achieved through use of advanced technology may be extrapolated using the results of the models.

The main thrust of the experimental program is directed toward demonstrating moving block protection systems which operate at short headways according to both vehicle follower and point follower control philosophies. Also, the system performance benefits of using a non-brickwall vs. brickwall operating policy will be demonstrated.

As one of the VLCR major objectives is the dissemination of information, the project team will participate in workshops, conduct a seminar on the project results and sponsor a demonstration of the unique technology developed, as well as providing normal project documentation.

PROJECT TEAM

The VLCR contract was awarded to the Transportation Technology Division of Otis Elevator Company (OTIS-TTD) in March 1977. As prime contractor, OTIS-TTD has the responsibility for overall project management, program execution, data base generation, and documentation. In August 1977, OTIS-TTD was awarded the Vehicle Lateral Control and Switching (VLACS) Project contract, the other Subsystem Development Project within the Automated

Guideway Transit Technology Program. This provides for coordination of the work on the VLCR and VLACS projects, which will result in a comprehensive study of both longitudinal and lateral control systems for automated transit systems being performed.

The VLCR project team is comprised of several subcontractors and consultants. The team members and their responsibilities are as follows:

Otis	-Team leader, prime contractor responsible for VLCR Project, including integration/incorporation/evaluation of subcontractor tasks.
Charles Stark Draper Laboratory (CSDL)	-Longitudinal Control Technology Evaluator; PRT system VLC and reliability, platooning VLC, closed-loop braking mechanization.
Pullman-Standard (P-S)	-Nominal vehicle design; reliability inputs; closed-loop braking test.
United Technologies Research Center (UTRC)	-Entrainment and coupling.
Mitsubishi Heavy Industries (MHI)	-Review of CVS program.
General Research Corporation (GRC)	-Cost model, weight model.
Frank C. Smith & Associates	-Reliability enhancement consultant.
Dr. A. Yen	-Technology review; past experimental program review.

VLCR PROJECT REQUIREMENTS

The VLCR project will address the development of wheeled vehicle longitudinal control and reliability technology which is applicable to longitudinal control subsystems for automated guideway transit. There are four system categories:

Shuttle - Loop Transit (SLT)
Group Rapid Transit - Large (GRT_L)
Group Rapid Transit - Small (GRT_S)
Personal Rapid Transit - (PRT)

These categories were arrived at after careful review of physical as well as operational parameters.

The physical parameters considered were: size, passenger capacity, and weight. The operational parameters were: velocity. headway, safety assurance, spacing control philosophy, and operating policy (see Table 1).

Shuttle - loop transit systems use relatively large vehicles which follow unvarying paths and make little or no use of switches. The vehicles may be

TABLE 1

VEHICLE CATEGORIES

CATEGORY	MINIMUM HEADWAY (SECS)	MAXIMUM LINE SPEED (KM/HR)	ENERGY UTILIZATION KW-HR / VEH.KM	NO. OF PASSENGERS	EMPTY VEHICLE WEIGHT (NEWTONS) / PER PASSENGER	SIZE (METERS)		
						LENGTH	WIDTH	HEIGHT
SLT (NOMINAL)	>60 (90)	25-100 (50)	2.0	20-120 (80/30)*	45 000 - 135 000 (110 000) / 1 300	7.5 - 12.0 (11.0)	2.5 - 3.0 (2.75)	3.0 - 3.75 (3.5)
GRT_L (NOMINAL)	15-60 (20)	25-100 (65)	1.4	20-50 (30/20)*	35 000 - 90 000 (55 000) / 1 750	4.5 - 7.5 (6.0)	1.8 - 2.2 (2.0)	2.5 - 3.5 (3.0)
GRT_S (NOMINAL)	3-15 (5)	25-80 (65)	0.60	6-25 (15/10)*	13 000 - 65 000 (45 000) / 2 225	3.5 - 5.0 (4.3)	1.8 - 2.2 (2.0)	2.4 - 2.8 (2.5)
PRT (NOMINAL)	<3 (0.5)	30-75 (50)	0.15	(2-6) (4)**	4 450 - 13 000 (6 500) / 1 550	2.2 - 3.0 (2.5)	1.2 - 1.8 (1.5)	1.5 - 1.8 (1.8)

* Total Vehicle Capacity, Seated and Standing/Number of Seats

** All Seated

used singly or coupled into trains. Headways are of such a magnitude that fixed block protection systems are normally used.

Group rapid transit systems are classified into two categories, Group Rapid-Transit - Large (GRT_L), Group Rapid Transit - Small (GRT_S). GRT_L systems use intermediate to large size vehicles, and operate with headways as short as 15 seconds. These systems may employ some switching. GRT_S systems use intermediate to small vehicles, operate with headways as small as 3 seconds, use extensive switching and off line stations.

Personal Rapid Transit (PRT) systems use small vehicles, operate with headways as small as 0.5 seconds, make use of extensive switching and off-line stations.

For the purposes of this study, systems which require headways less than 15 seconds require moving block protection. A moving block protection system employs the concept that a safe stopping distance is projected in front of each vehicle and moves with the vehicle. If this projection touches a preceding vehicle an emergency stop is initiated.

Also systems which employ moving block protection operate according to a point-follower or vehicle-follower control philosophy. The essential differances are shown in Figure 1. A system which uses a vehicle-follower control philosophy, Figure 1A, bases the spacing between vehicles upon the difference between the positions of the preceding (P) vehicle and the trailing (T) vehicle according to a function, h (operating policy), which multiplies the trailing vehicle's velocity.

A point-follower control philosophy, Figure 1B, is essentially a model or reference following system. The reference is generated according to the desired line velocity (V_L) and the spacing is governed by an integer number of the headway policy multiplied by the line velocity.

In general as the passenger capacity of an individual vehicle decreases, the overall capacity achievable through a given guideway segment is achieved through reduction of the spacing between vehicles. This reduction of spacing requires additional complexity in the longitudinal control system. The longitudinal control system design problem is further complicated through the passenger ride quality constraints, see Table 2. These constraints limit both service acceleration and jerk and emergency acceleration.

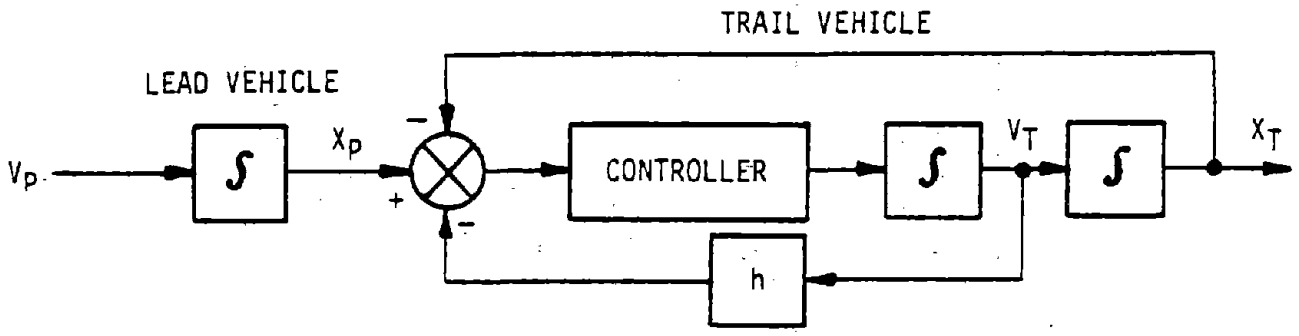
The overall longitudinal control design problem is: given the basic vehicle dynamics, construct a reliable low cost control system which is capable of implementing one or more of the following operating policies; constant separation, constant time headway, constant K factor or limited collision velocity.

A longitudinal control system is configured by the interconnection of the technology options given in Table 3. Several technology choices are available for selection by the designer to satisfy each function.

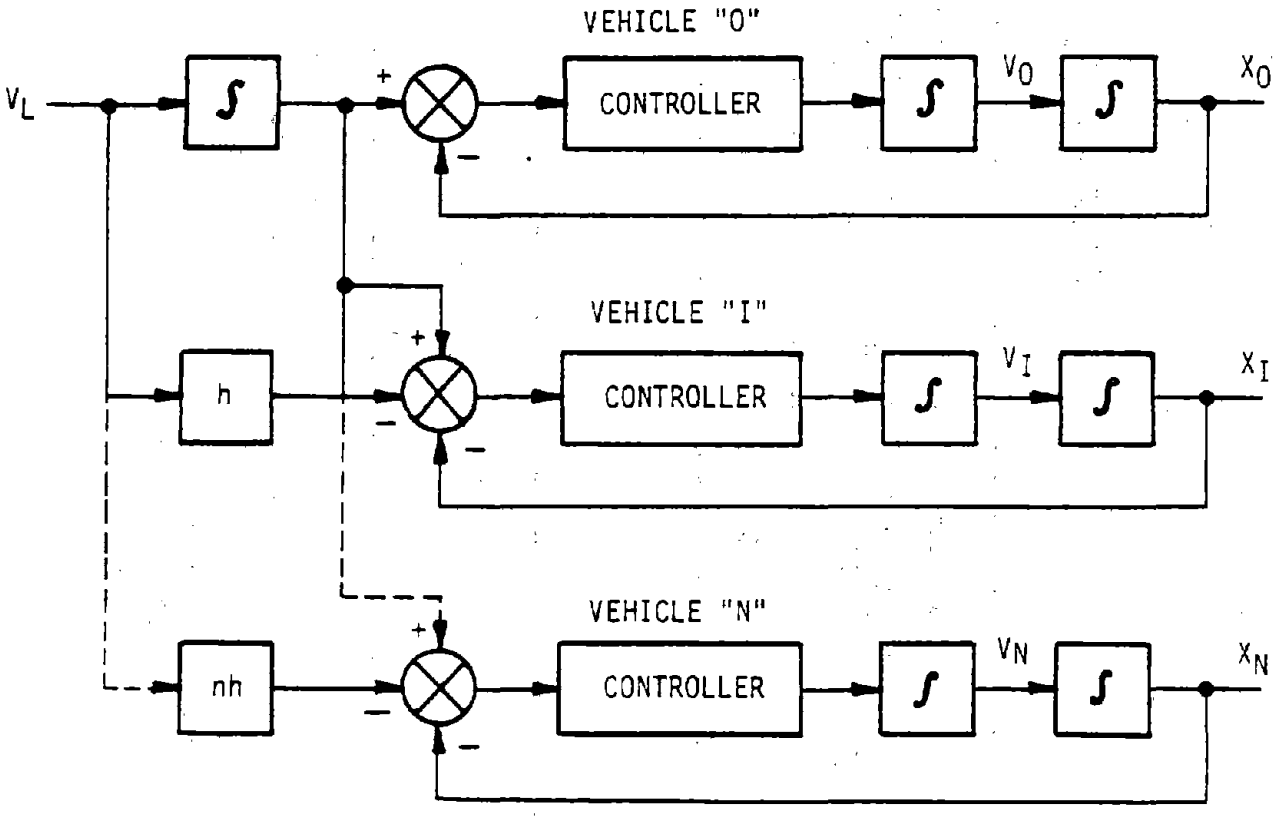
These choices are made after consideration of performance, reliability, weight, and cost. The evaluation of each of these factors must include consideration of the effects of the operational environment which is specified in Table 4.

PROJECT TASKS

Six major tasks have been identified to accomplish the project objectives. These tasks are described in the following paragraphs.



(A) GENERIC VEHICLE FOLLOWER



(B) GENERIC POINT FOLLOWER

FIGURE 1 GENERIC CONTROL PHILOSOPHIES

TABLE 2

NOMINAL VEHICLE
PERFORMANCE GOALS

Category	Maximum Acceleration (g)			Maximum Jerk (g/sec.)			Capital Cost[1] (Dollars/Veh.)
	Longitudinal		Lateral	Longitudinal		Lateral	
	Normal	Emergency		Normal	Emergency		
SLT	.15	.20	.10	.15	-	.07	125,000[2]
GRT Large Vehicle	.15	.25	.10	.15	-	.07	100,000[3]
GRT Small Vehicle	.15	.25	.10	.15	-	.07	80,000[3]
PRT	.15	.40	.10	.20	-	.07	15,000[4]

1. 1975 dollars.
2. Production run of 20 vehicles.
3. Production run of 200 vehicles.
4. Production run of 2,000 vehicles.

TABLE 3 TECHNOLOGY OPTIONS

Function	Longitudinal Control Technology Choices
Power Collection	- AC/DC, single and three phase, voltage level
Power Conditioning	- Variable frequency, variable voltage, variable frequency and voltage
Propulsion	- Linear induction motor, rotary induction motor, rotary direct current motor, linear synchronous motor, power train
Suspension	- Rubber tire on concrete, steel wheel on rail, Hovair
Communications	- Time, frequency, space multiplexed
Control Computation	- Microprocessor, other
Service Braking	- Motor thrust reversal, non-regenerative, regenerative
Failure Detection & Management Computations	- Microprocessor, other
Emergency Brakes	- Mechanical, electrical with mechanical backup
Parking Brakes	- Mechanical
Sensors	- Tachometers, antenna transpositions, fixed monuments, acoustic, radar, light, infrared, magnetic
Collision Attenuators	- Energy absorbing bumpers

TABLE 4 NOMINAL VEHICLE OPERATIONAL ENVIRONMENT

Climate

Wind:	18 m/sec (40 mph) with gusts up to 29 m/sec (60 mph)
Rainfall:	5 cm (2 inches)
Sleet:	1.3 cm (0.5 inches)
Glaze accumulation:	0.76 cm (0.3 inches)
Snowfall accumulation:	25 cm (10 inches) to 60 cm (24 inches)
Temperature range:	-35° C (-30° F) to 50° C (120° F)

Guideway

Grades:	6% maximum
Superelevation:	10% maximum

Electromagnetic

The system shall be capable of operating in the electromagnetic environment (airport, radio and television stations, power transmission lines, and power plants) found in large cities.

Task 1 - Technology Evaluation Model Development - In this task, detailed performance measures and goals will be developed for each Longitudinal Control System Category. These will be used during the analysis and design implementation studies as a basis for comparison of alternative approaches. Detailed weight, cost, and reliability models will be structured for each system category which encompass the range of technology functions of Table 3, and will permit assessment of the sensitivity of selected parameters versus goals. These models will enable the retrieval of information for selected single thread and enhanced reliability designs and the determination of the effects of automatic training and platooning in terms of cost, weight, and reliability.

Also as part of this task strawman vehicles will be designed which show the vehicle envelope, major component space claim and overall relationship of all technology choices.

Task 2 - Vehicle Longitudinal Control Design - This task involves a survey and evaluation of existing VLC systems and the analysis, selection, and design development of single-thread systems for each vehicle category. These designs will provide baseline information for the technology evaluation models and for reliability enhancement studies. Typical subtasks include identification of wheeled vehicle dynamics, major component non-linearities, performance of linear analyses, response evaluations, and sensitivity analyses.

The single-thread system design will be sufficient to support the analysis to be performed to determine performance, reliability, cost and vehicle weight.

Task 3 - Reliability Enhancement Studies - This task includes an extensive survey of reliability enhancement techniques employed in past U.S. Government and industrial programs, a compilation of information obtained from the industry and operating properties on failure mechanisms, maintenance practices, and operating characteristics and costs. This will be followed by an analysis of reliability enhancement techniques in selected key compnent areas where such enhancement can be cost-effective, as well as an analysis of the effects of redundancy to provide fail-operational/fail-degradable operation. A system is fail-operational if in the event a component fails, the system is configured to allow continued operation with no loss in performance. A system is fail-degradable if in the event a component fails, the system is configured to allow continued operation with some bounded loss in performance.

Task 4 - Entrainment and Platooning Studies - This task will evaluate the effects of automatic entrainment and platooning on longitudinal control systems. The entrainment studies include performing a survey of the current techniques and equipment, analyses, specification, and the conceptual design of automatic coupling system for each system category. The survey of AGT systems which currently use entrainment will determine the existing performance characteristics, and requirements for safety, longitudinal control, and couplers. This task will also provide analysis and design for the associated vehicle train longitudinal control. A specific coupler and control system design for a small GRT class will be implemented, tested, and demonstrated during the Experimental Program. Similarly, the platooning studies will include performing the survey, analysis, and synthesis of platooning concepts. These concepts will be evaluated via modelling and simulation.

The model used will be validated via experiments conducted during the Experimental Program.

The size, weight, and cost of couplers and the additional training control components, as well as equipment for platooning, will be evaluated via use of the technology evaluation models.

Task 5 - Experimental Program - The experimental program will be conducted primarily at the OTIS Denver test track shown in Figure 2, which consists of approximately 764 meters (2500 ft) of guideway configured in a collapsed loop with 18.3m (60 ft) radii turns.

The experimental program is partitioned into two distinct parts which are separated by the test program design review. The tasks required to be performed prior to the design review consist of: a) performing a literature search to obtain information on test procedures, instrumentation techniques, test activities and test results, from current and past domestic and foreign, AGT experimental programs, b) preparing a detailed test program implementation plan and safety plan and c) preparing design documentation for the test program hardware and software.

After the design review, the design, implementation and tests of the hardware and software will be performed. This effort will be culminated with a demonstration of the concepts proposed during the studies. The experimental program is intended to provide validation of the analyses and design techniques employed in the design studies and provide feedback to the cost, weight, and reliability assessments via the technology evaluation models.

As the state of the art of fixed block system design and implementation is well entrenched and proven, the experimental control system will use moving block protection and be able to operate according to vehicle-follower and/or point-follower longitudinal control philosophies. The basic system will provide flexibility to evaluate and/or demonstrate operation according to headway policies which are based upon brickwall and non-brickwall criteria.

Couplers will be added to the vehicles and control laws implemented which will allow evaluation of automatic coupling for train formation and failed vehicle retrieval.

Platooning concepts will also be demonstrated within the overall constraints imposed by the experimental system.

The test system implementation will include the guideway, wayside computer system, vehicle state measurement system, wayside/vehicle communications, two real vehicles and a real time simulator capable of simulating 3 additional vehicles. This implementation will allow operation of an equivalent five-vehicle string around the track at operational headways approaching the fractional second regime.

Task 6 - Data Base Development and Guideline Specification Requirements - This task will provide a comprehensive data base on longitudinal control and reliability which documents the results of the VLCR project, including surveys of previous foreign and domestic programs. In addition to the written reports, the data base will contain copies of all simulations and software developed in the generation of the included data.

A comprehensive set of guideline specifications and requirements applicable to the longitudinal control systems, reliability enhancement, and entrainment and platooning techniques will be prepared. The guidelines will

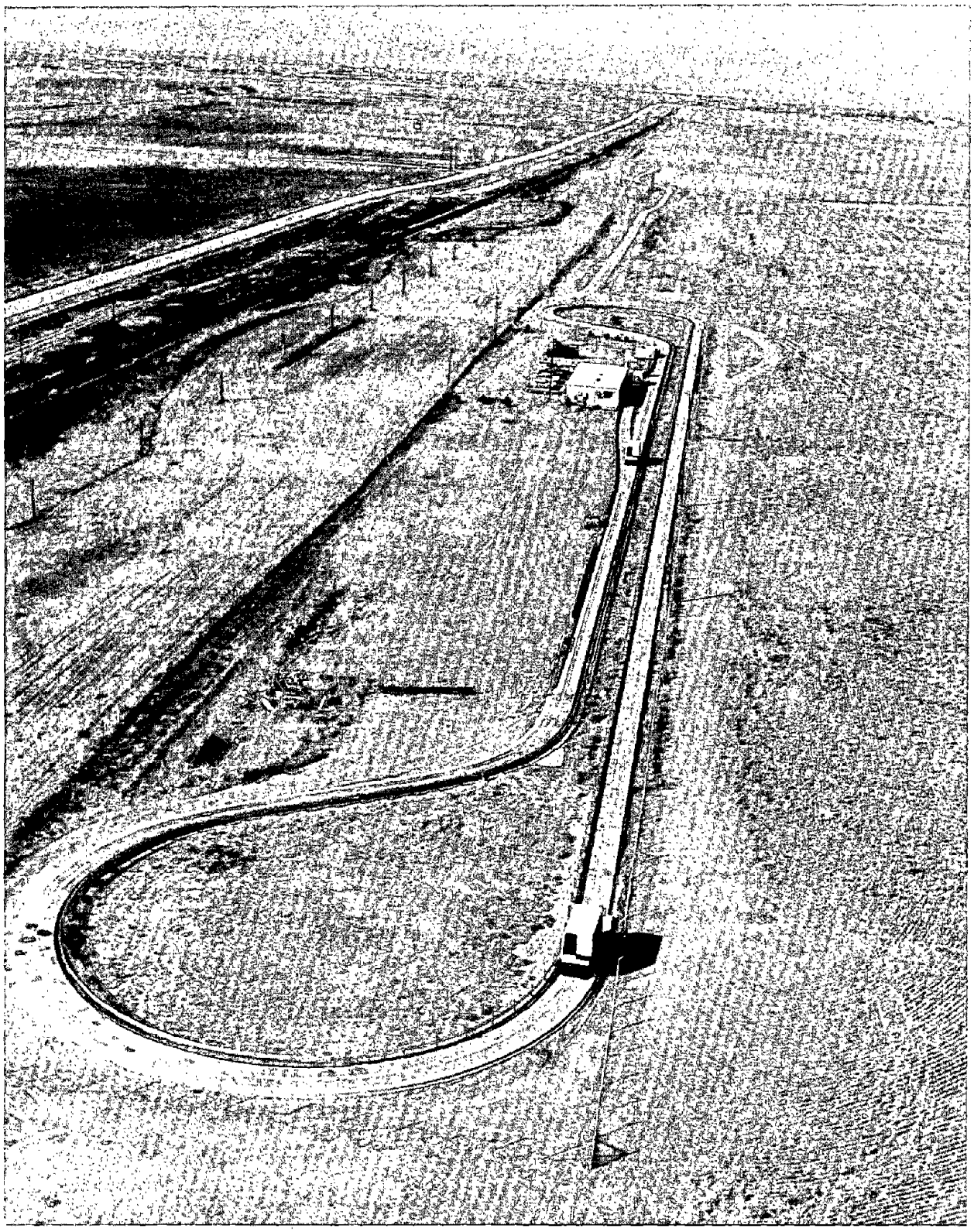


FIGURE 2 OTIS - DENVER TEST TRACK

include performance, cost, reliability, and system characteristics for each of the major VLC design types. System parameters will be shown for both demonstrated values and values determined as achievable by the analytical programs using technology alternatives. The guidelines will be limited to the system level in order that they can be easily read and followed and, therefore, become a useful tool for system developers, planners, and local public bodies interested in developing specifications for AGT systems.

PROJECT STATUS

The following paragraphs describe the status of the VLCR project at the end of the third quarter.

Task 1 - Technology Evaluation Model Development - A comprehensive list of performance measures has been developed. These measures prescribe the quality of performance required of vehicle longitudinal control subsystems for the four AGT system categories. The approach used in developing these measures begins with the transit system operational objectives. These operational objectives are used to determine constraints on the longitudinal control system and then the subsystem parameters whose values determine, directly or indirectly, the extent to which the system-level operational objectives are met.

Currently an effort to determine specific values (performance goals) that the performance measures must have in order that the system/subsystem component achieve a quality of performance consistent with higher level operational objective is in process.

The other part of this task requires the development of models which can be used to perform the bookkeeping required to assess baseline cost, weight and reliability of the longitudinal control concepts as well as being used in tradeoff studies. In order to provide a unified approach to model construction a functional tree was designed for the overall Transit System. Although VLCR is only interested in the longitudinal control subsystem, the tree contains other functions such as guideways, stations, and system supervision.

Using the applicable portions of the functional tree, cost, weight, and reliability models have been designed, coded, and are available for use. Typical of the models is the cost and weight model. A block diagram is shown in Figure 3. During the construction of the VLCR model, care was taken to provide interfaces with other models as shown outside the dashed line. As can be seen the cost model calculates life-cycle cost based upon investment costs, maintenance cost, and energy cost. A sample output of the Investment Cost Factors plus weight is shown in figure 4. Other outputs which are available are maintenance cost, aggregate (lane km) cost, disaggregate (lane km) cost, disaggregate unit vehicle costs, and items which contribute to 60% of the maintenance cost.

As an aid to the cost, weight, and reliability efforts, nominal vehicle designs for the four categories of AGT systems are being generated. A typical design for an SLT Rubber Tired Vehicle is shown in figure 5. For each vehicle category, outline drawings showing length, width, height, seating arrangement and placement of major longitudinal control system and vehicle components placement are being generated.

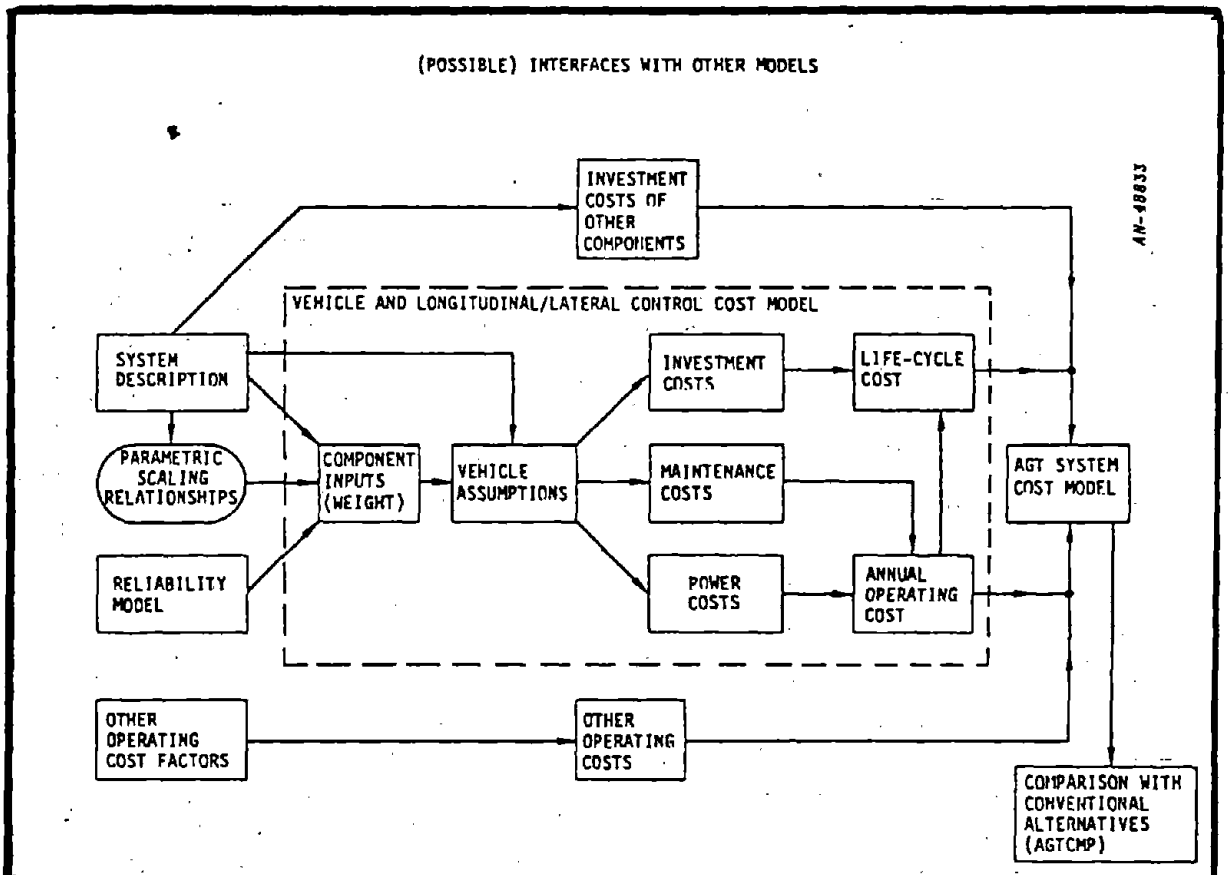


FIGURE 3 COST MODEL BLOCK DIAGRAM

INVESTMENT COST FACTORS PLUS WEIGHT

ID NUMBER	CATEGORY	INVESTMENT COST (1976) (DOLLARS)	INVESTMENT NUMBER (PER VEH OR PER LN MI)	INITIAL SPARES FACTOR	MAINT. EQUIP. COST	MAINT. EQUIP. NUMBER	LIFE EXPECTANCY	WEIGHT (KGS.)
1	VEHICLE SYSTEM (EXCLUDING CONTROL)	100000	1	.100	10000	2	20	454
2.2.1.1	COMMUNICATION SUBSYSTEM	500	1	.050	-0	-0	20	2
2.2.1.1.1	COMMAND COMMUNICATIONS	500	1	.050	-0	-0	20	2
2.2.1.2	INTERLOCK AND INTERCONNECT	2000	2	.050	-0	-0	20	7
2.2.1.3.1	MEASUREMENT SUBSYSTEM	100	1	.050	-0	-0	20	5
2.2.1.3.2	LONGITUDINAL STATE CONTROLLER	200	1	.050	-0	-0	20	5
2.2.1.3.3A	POWER CONDITIONER	120	1	.050	-0	-0	20	5
2.2.1.3.3B	MOTOR	130	2	.050	-0	-0	20	5
2.2.1.3.3C	DRIVE TRAIN	50	1	.050	50	1	10	5
2.2.1.3.4	SERVICE BRAKING SUBSYSTEM	400	2	.050	-0	-0	20	5
2.2.1.3.5	ENERGY REGENERATION SUBSYSTEM	500	1	.050	-0	-0	20	5
2.2.1.4	SAFETY ASSURANCE SUBSYSTEM	4000	1	.050	-0	-0	20	5
2.2.1.5.1	LATERAL SUSPENSION	1000	1	.050	-0	-0	20	5
2.2.1.5.2	LATERAL RETENTION	1000	1	.050	-0	-0	20	1
2.2.1.5.3	SWITCHING SUBSYSTEM	1000	1	.050	-0	-0	20	1
2.2.1.5.4	STEERING SUBSYSTEM	1000	1	.050	-0	-0	20	1
2.2.1.5.5	LATPEL STATE CONTROLLER	500	1	.050	-0	-0	20	1
2.2.1.5.6	LATERAL MEASUREMENT SUBSYSTEM	500	1	.050	-0	-0	20	1
2.2.1.6.1	LONGITUDINAL CONTROL EQUIPMENT	3000	1	.050	-0	-0	20	2
2.2.1.6.2	LATERAL CONTROL EQUIPMENT	3000	1	.050	-0	-0	20	2
2.2.1.7	FAULT MONITORING SUBSYSTEM	7000	1	.050	-0	-0	20	5
2.2.1.8	ON BOARD CONTROL INTEGRATION	1	1	.050	-0	-0	20	0
2.2.2.1.1	COMMAND COMMUNICATIONS	15000	1	.050	-0	-0	25	
2.2.2.5.1	LATERAL SUSPENSION	1000	1	.050	-0	-0	25	
2.2.2.5.2	LATERAL RETENTION	1000	1	.050	-0	-0	25	
2.2.2.5.3	SWITCHING SUBSYSTEM	1000	1	.050	-0	-0	25	
2.2.2.5.4	STEERING SUBSYSTEM	1000	1	.050	-0	-0	25	
2.2.2.6.1	LONGITUDINAL CONTROL EQUIPMENT	500	1	.050	-0	-0	25	
2.2.2.6.2	LATERAL CONTROL EQUIPMENT	500	1	.050	-0	-0	25	
3	GUIDEWAY	10000000	1	.000	-0	-0	50	

FIGURE 4 COST AND WEIGHT MODEL OUTPUT

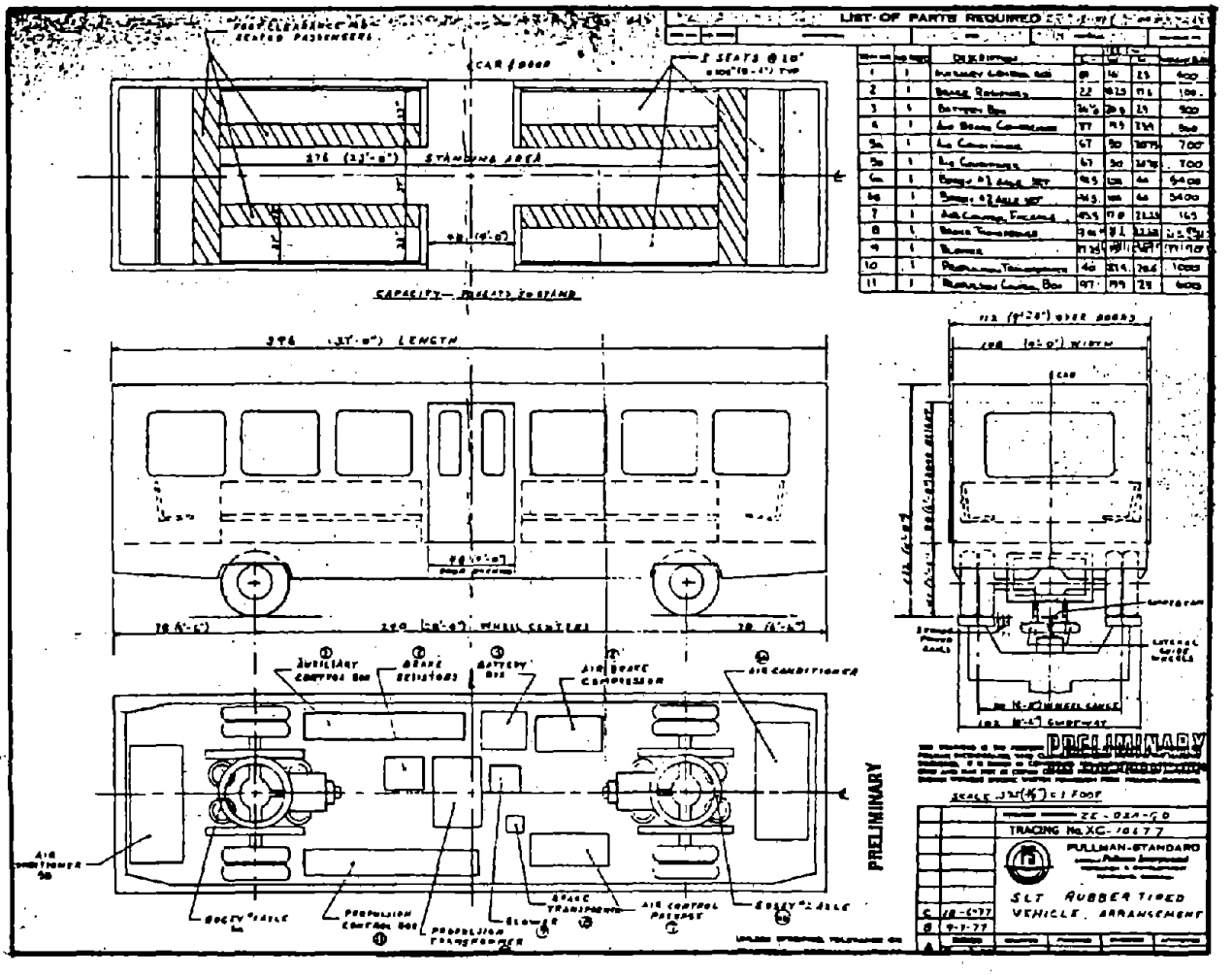


FIGURE 5 PRELIMINARY SLT RUBBER TIRED VEHICLE

Task 2 - Vehicle Longitudinal Control Studies - The primary emphasis in the Vehicle Longitudinal Control Studies was placed upon the technology review, operation policy development, wheeled vehicle dynamics, and design of longitudinal control systems which are capable of short headway operation.

The technology review effort is divided into the development of a classification matrix for existing systems and into a control technology review. The classification matrix has, as main entries, system description, control classification, operating policy, principal control technologies and includes top level reliability and cost data. At present 10 systems have been classified: 6 SLT, 2 GRT and 2 PRT.

In the area of control technology a review of the various choices which are available for selection by the designers to satisfy the need for propulsion, power conditioning, measurements, communications, etc. is in process. Information has been supplied by Mitsubishi Heavy Industries which describes their Computer Controlled Vehicle Systems installed and operated at Higashimurayama and at the Osaka World Exposition.

Operating policy specifies the relationship between vehicle spacing and velocity. Primarily an operating policy is chosen to meet a particular headway objective. Three relationships are required to be developed:

1. Minimum possible separation which is based on ideal service and emergency jerk and acceleration constraints, as well as failure detection and reaction time.
2. Achievable separation which takes into account measurement errors, variation in braking rates and reaction times, and maneuvers, as well as the effects of wind and grade.
3. Actual separation which is the policy implemented by the control.

Figure 6 illustrates a typical build up from the minimum possible separation to minimum safe, which is the lower boundary of the achievable separation. Another very important consideration is chosing a brickwall or non-brickwall safety criteria.

As the effective headway becomes shorter, it is necessary to consider incorporating closed loop braking which will minimize the effect of wind and grade as well as adopting a non-brickwall safety criteria.

The choice of an operating policy directly affects system capacity as illustrated in Figure 7.

As the VLCR project is charged with developing longitudinal control systems which use wheeled vehicles, it was necessary to identify the vehicle dynamics. The generic wheeled vehicle dynamic model which is being used is shown in Figure 8. In addition to the usual model parameters of mass, wind resistance, drag, the model includes factors which describe the wheel dynamics and the interaction of the tire with the guideway. This model has been coded and is being used in all simulations.

Given the vehicle dynamics, the longitudinal control system must provide all of the functions shown in Figure 9. This model includes modules which describe, propulsion, longitudinal controller, braking, safety assurance, communications and measurement systems. As the analysis progresses the linear models for each of the blocks will be replaced with non-linear models which include saturation, quantization, hystereses etc. as applicable.

Linear analyses are being performed using these models together with simulation studies which use the non-linear model to determine system response and sensitivities to parameter variation.

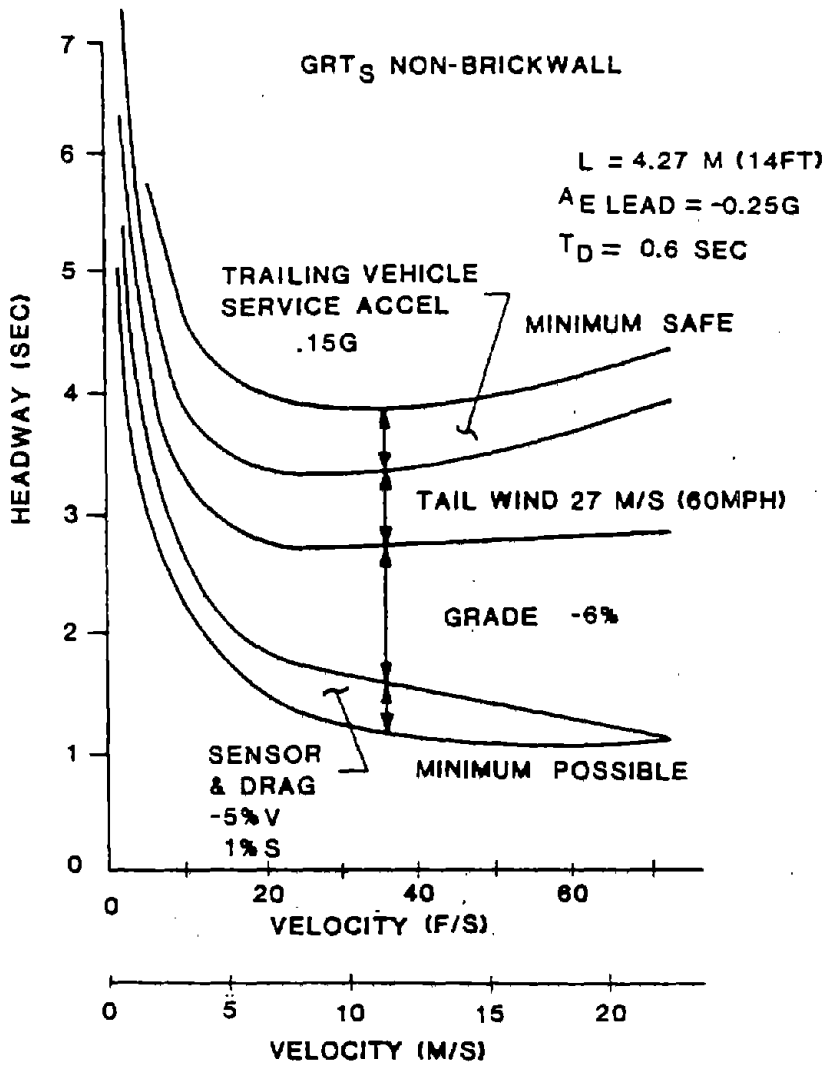


FIGURE 6 MINIMUM SAFE HEADWAY

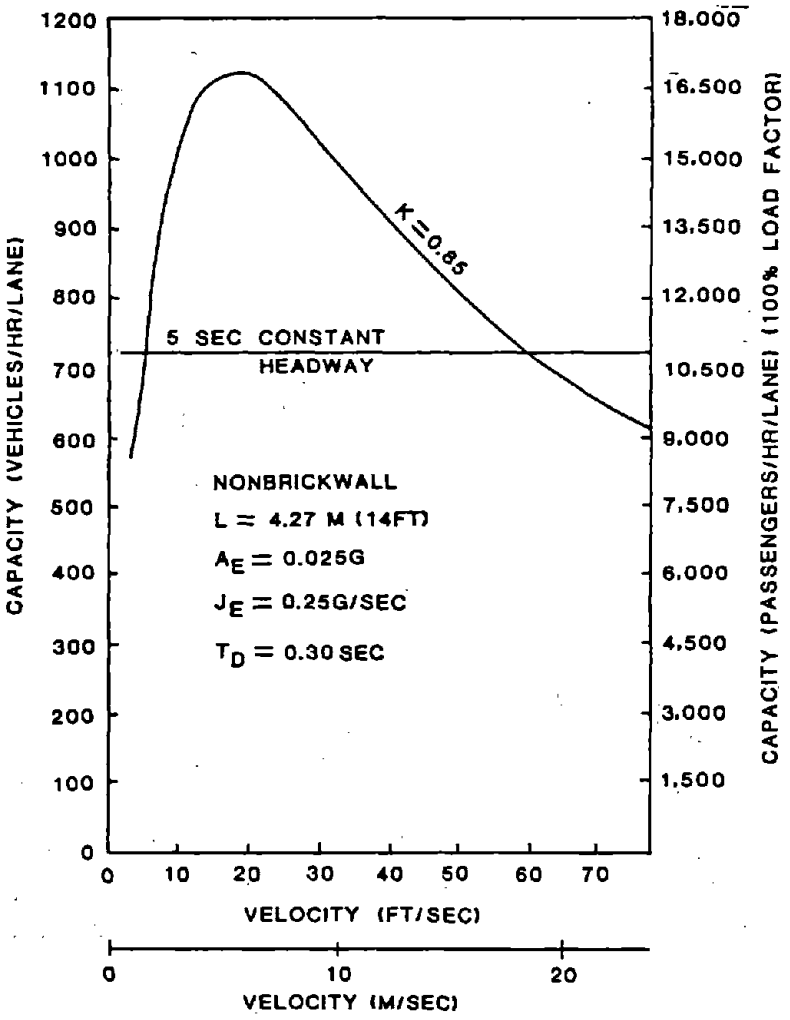


FIGURE 7 TYPICAL CAPACITY VS VELOCITY CURVE

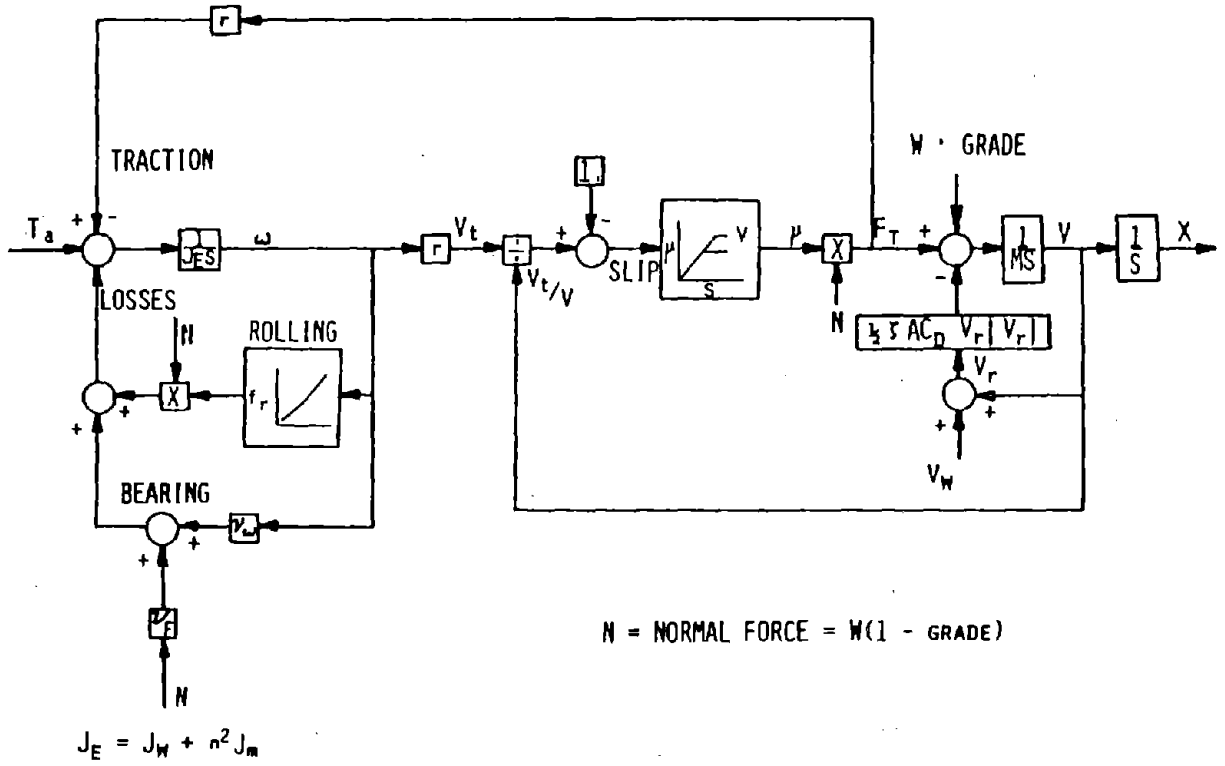


FIGURE 8 GENERIC VEHICLE DYNAMICS MODEL

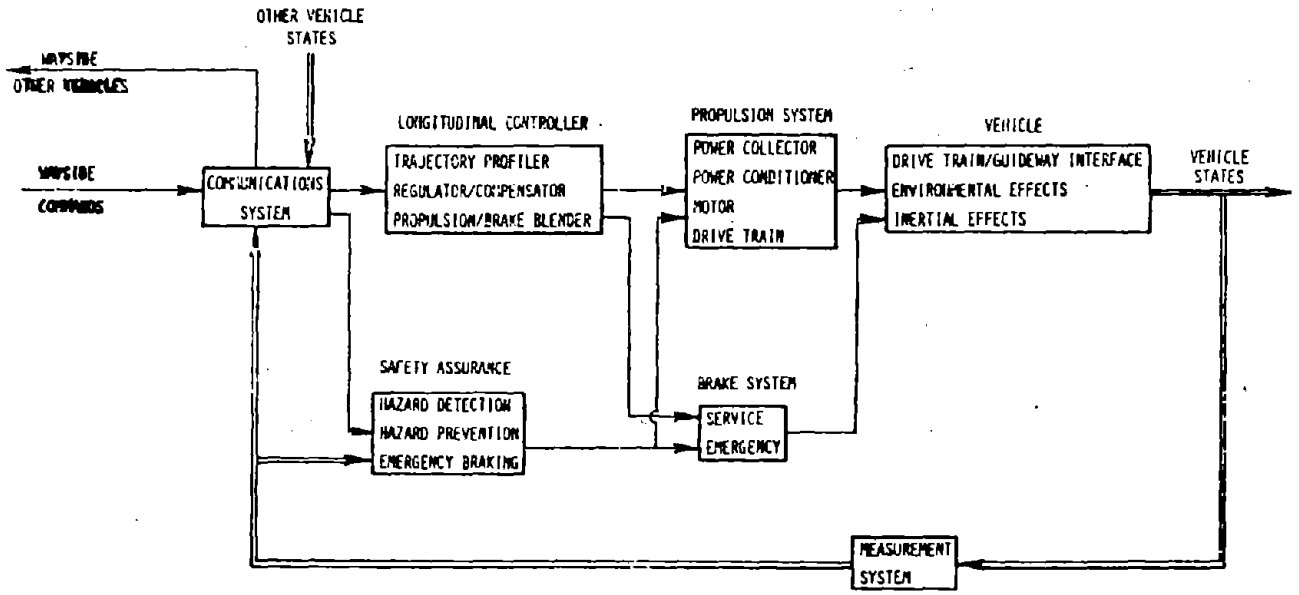


FIGURE 9 FUNCTIONAL VEHICLE LONGITUDINAL CONTROL MODEL

Analyses are also in process to determine wayside control laws and the effects of operating policy on stability, performance and ride quality for short headway operation. Enforcing the ride quality constraints while attaining the required system performance is one of the major problems of longitudinal control system design. Alternative control schemes which are capable of meeting the performance requirements are:

- o Target Follower of Mitsubishi Heavy Industries
- o State Constrained Approach proposed by APL
- o Target Tracking Approach proposed by CSDL
- o Reference Following Approach proposed by OTIS.

A typical simulation run using the Target Tracking Approach , Figure 10, shows an overtake maneuver with the lead vehicle changing speed. In Figure 10(A), the trailing vehicle initial conditions with respect to the lead vehicle are 112 m (367 ft) and 10 m/s (32.8 f/s); at approximately 8 seconds into the run the lead vehicle accelerates from 5 m/s (16.5 f/s) to 10 m/s (32.8 f/s). The overtake maneuver is accomplished within the acceleration and jerk constraints. Likewise figure 10(C) shows another run where the lead vehicle decelerates from an initial velocity of 10 m/s (32.8 f/s) to a final velocity of 5 m/s (16.4 f/s). Again the overtake maneuver is performed within the acceleration and jerk constraints.

There are other schemes which could also be evaluated but at this time no published information has been found.

Task 3 - Reliability Enhancement Studies - To date the reliability enhancement studies have been involved in (1) evaluating all the existing enhancement techniques, (2) determining the applicability to AGT systems, (3) determining the cost, weight and performance impacts of the various techniques, (4) recommending an enhanced reliability design for all four classes of AGT systems, (5) and finally modifying the detailed implementations for the four system categories to include the recommended reliability enhancements.

The reliability enhancement techniques naturally fit into three categories:

1. Component enhancement where enhancement techniques depend primarily on component selection, screening and testing, derating and proper design specification.
2. Subsystem enhancement where redundancy is the major consideration.
3. System enhancement which relates primarily to maintenance procedures both scheduled and unscheduled.

In order to produce a baseline for comparative analysis, a reliability analysis was performed on the 2 single thread designs, SLT, GRT_L that were produced in task 2. The result is an estimate of the inherent reliability for the VLC system which meets the performance and safety requirements.

Since an AGT system is very complex it is very difficult to analyze every component or even subsystem. Therefore Frank C. Smith, a consultant, identified the major causes of shut down or unscheduled maintenance figure in operating AGT properties, Figure 11. As suspected a few items cause 70% of all unscheduled maintenance.

Current work is involved in examining and analyzing the generic VLC designs to eliminate the failures modes indicated by this list. This work consists of performing a failure modes and effects analysis, FMEA, weight and cost analysis and developing a maintenance plan for each category, currently only SLT. From the lists, it can be observed that most of the problem areas are generic to all system categories and many of the SLT solutions will carry

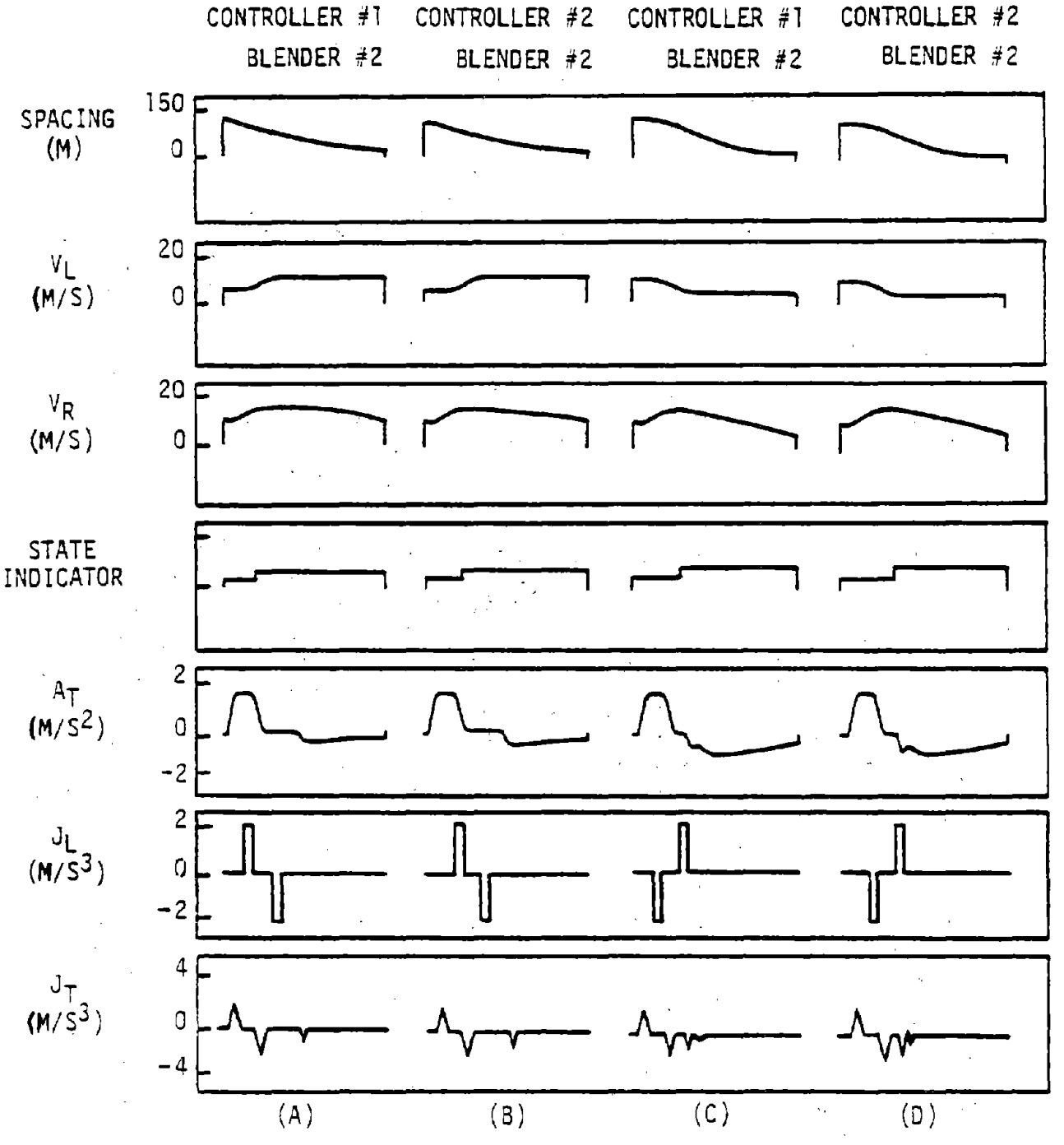


FIGURE 10 PERFORMANCE DATA - TARGET TRACKING APPROACH

SYSTEM "A"
MOST FREQUENT FAILURES

SUBSYSTEM	% TOTAL
VEHICLE FLEET	78.
COMMUNICATIONS/FARE	9.
SOFTWARE/COMPUTERS/OTHER	13.
TOTAL	100.

SYSTEM "A"
TOP EIGHT U/S MAINTENENCE ITEMS

ITEM	% TOTAL
COLLECTOR BRUSHES	38
BRAKE PADS	15
RETAINER SHOES	14
VALVES	14
PUMPS	9
TIRES	8
BEARINGS	4
TOTAL	100

SYSTEM "A"
TOP NINE "PROBLEM AREAS"

ITEM	% TOTAL
FARE COLLECTION	22.
BRUSHES	10.
VALVES	7.
VEHICLE UNCONFIRMED	6.
BRAKE PADS	6.
VEHICLE DOOR MECH.	5.
SOFTWARE	4.
RADIO	4.
HYDRAULIC PRESSURE	4.
TOTAL	68.

FIGURE 11 TYPICAL FAILURE DATA

over directly to the GRT_L and GRT_S. Because of the large network involved and the consequences of many vehicles, the PRT system is being treated as a separate effort.

Task 4 - Entrainment and Platooning Studies - The entrainment literature review has been completed and an annotated bibliography of significant citations prepared. Entrainment technology was reviewed via a questionnaire which was sent to seven transit properties for their response. The intent of the questionnaire was to obtain data in five basic areas consisting of the mechanical and electrical characteristics of existing couplers, the procedures employed for the formation of trains, data on the transit cars, operational experience with couplers (particularly the documentation of problem areas), and the maintenance history of the couplers.

Based upon this survey and extensive discussions with various coupler manufacturers, a number of areas have been identified which will likely require extensive development beyond the present state-of-the-art to meet the particular needs of AGT vehicles. Three of the most critical development items are the draft gear, a coupler positioning device and the electrical coupler.

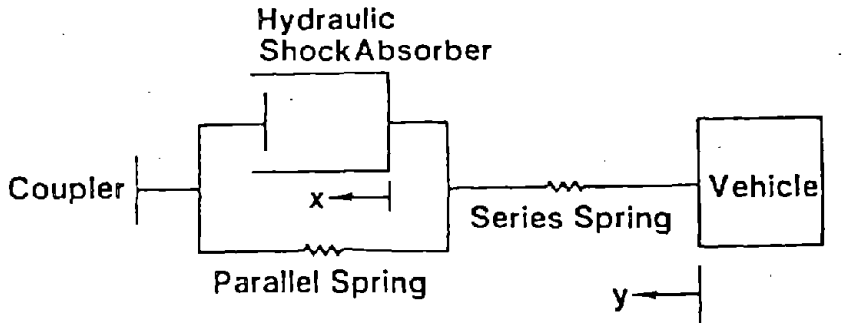
As standing passengers are permitted, limits have been established which constrain the maximum allowable acceleration and jerk. The draft gear must be designed to absorb the impact energy which occurs during coupling in a manner which will produce acceptable accleration and jerk levels. However, there exists a conflicting requirement that the draft gear be sufficiently firm to control the relative motion of trained vehicles, i.e., to prevent the development of relative oscillatory motion between coupled cars.

No existing draft gear can meet these conflicting requirements. Therefore a composite draft gear is being studied which will consist of a variable orifice hydraulic shock absorber in series with a rubber cushion. The selection of the appropriate draft gear characteristics is being done through the use of a computer simulation based upon the draft gear model shown in figure 12.

The studies have resulted in the identification of the vehicle and guideway parameters that affect coupler gathering range, the development of procedures for calculating gathering range and coupler swing angle, a simplified analysis and the time-domain analysis of the draft gear to determine appropriate draft gear characteristics and the evaluation of the resulting acceleration and jerk produced at various impact velocities.

The most significant factors which affect coupler gathering range and swing angle required to permit unattended vehicle coupling are shown in figure 13. These factors are minimum guideway radius, vehicle wheelbase, the location of the coupler pivot, the coupler length, vehicle length and width, and the minimum permitted lateral displacement of the vehicle centerline with respect to the guideway centerline. The factors are all considered in a computer program which has been developed to aide in the study efforts.

Studies are also in process which are aimed at evaluating the longitudinal control problems involved in performing the coupling maneuver. These studies will typically evaluate the effects of measurement errors, measurement quantization, effects of failure, and knowledge of the initial conditions. A simulation is being constructed which will use the generic nonlinear wheeled vehicle model together with its on board control system,



Significant Parameters

A-Piston Area
A_o-Orifice Area
C_d- Orifice Flow Coefficient
K_p-Parallel Spring Constant
K_s- Series Spring Constant
L-Maximum Shock Absorber Stroke
M- Vehicle Mass
β - Fluid Bulk Modulus
ρ-Fluid Desity

FIGURE 12 DRAFT GEAR MODEL

- R,guideway radius
- WB,vehicle wheelbase
- CP,coupler pivot location
- DG,coupler length
- L,vehicle length
- W,vehicle width
- δ,$\mathbb{Q}$ offset

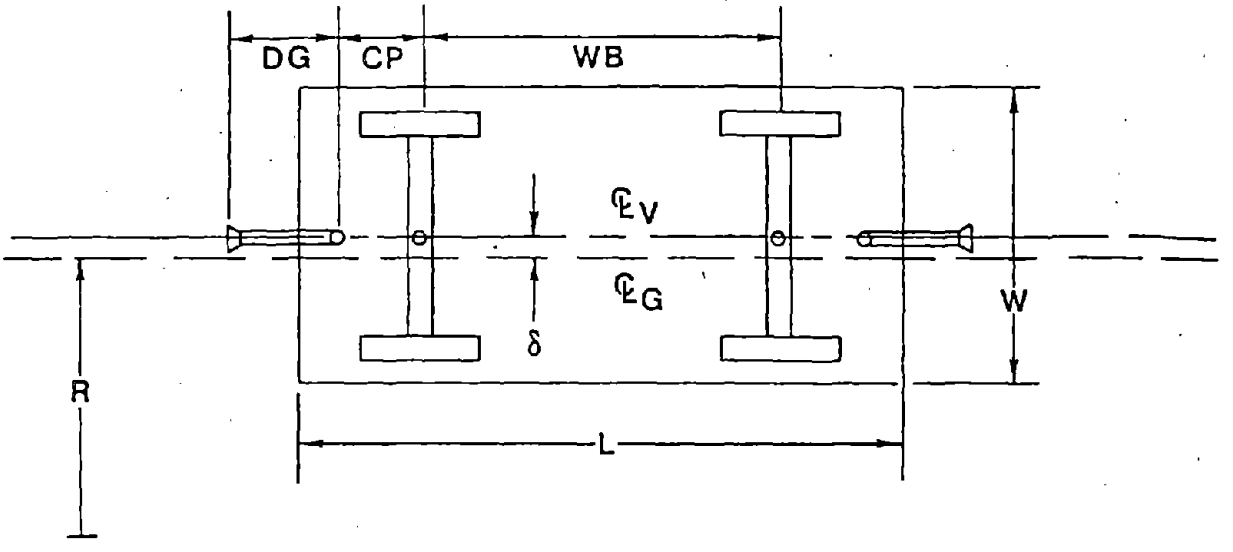


FIGURE 13 FACTORS AFFECTING COUPLER SWING AND GATHERING RANGE

communications, measurements, and control law.

The Platooning Studies have just begun with the literature search. As of this reporting date the Project Team has not been able to identify any previously published work on platooning. However, several control schemes can be postulated for forming platoons in a station area. Providing the required vehicle state measurements with the required accuracy and allowable time delay is the major implementation problem.

Task 5 - Experimental Program - Work in this task has been primarily in the areas of technology review and experimental program planning. Related tasks which have been completed are: the OTIS test track has been extended to form a loop, and minor modifications to the test vehicles have been made in order to be compatible with the test track guideway interface.

Task 6 - Data Base and Guideline Specifications - The Data Base contains five categories of information: annotated bibliographies, system descriptions, technology review, deliverable documentation and trade off studies, and a cross reference catalog.

As of the first of this year the annotated bibliographies contain a review of entrainment technology which contains 71 entries and a listing of the 330 entries in the VLCR library at OTIS.

Various system descriptions are available which have been accumulated through published literature. These include various reports on UMI Type II Tourister AGT System at King's Dominion, WEDway People Mover at Walt Disney World, Passenger Shuttle System at Tampa, ACT System at Fairlane Town Center, Tunnel Train System at Houston Intercontinental Airport, and Satellite Transit System at the Seattle-Tacoma International Airport. Also included are the reports on the Computer Controlled Vehicle Systems prepared by Mitsubishi Heavy Industries, and various reports on the Morgantown System, Washington Metro, Bart, and Airtrans.

Several reports on performance measures and goals, longitudinal control, braking, reliability, safety, entrainment and platooning technology and cost modelling are contained in the technology review catalog.

Under the deliverable and trade off studies are the VLCR contract, the OTIS proposal, project plan, monthly progress letter reports and quarterly progress briefings. Copies of all software and software documentation used on this project will also be included.

Finally the cross-reference catalog will contain an author index of all VLCR documents which are included in the data base as well as a subject index.

PAPER 4

Vehicle Lateral Control and Switching (VLACS) Project Descriptions

Gordon Haines
Otis Transportation Technology Division
United Technologies Corporation

VEHICLE LATERAL CONTROL AND SWITCHING (VLACS) PROJECT DESCRIPTION

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ABSTRACT

The Vehicle Lateral Control and Switching (VLACS) Project has been established by the Urban Mass Transportation Administration under the Automated Guideway Transit Technology program. In this project, various automatic steering and switching systems will be evaluated for performance, cost, weight, and reliability and for their applicability to a wide variety of transit vehicle types. The project tasks include a review of existing VLACS technologies, detailed mathematical modeling, analysis and simulation, detailed hardware studies, experimentation with alternative designs, and development of guideline specifications for VLACS systems.

This paper describes project objectives, required tasks, and deliverable reports which will be prepared. The project status after the first quarter of work is summarized. The final project reports and the VLACS data base developed in this project will thoroughly document the findings of the project tasks and provide guidelines for the specification and selection of VLACS technologies for various automated guideway transit applications.

INTRODUCTION

The Vehicle Lateral Control and Switching (VLACS) project has been established to investigate alternative steering and switching systems applicable to a wide variety of automated transit vehicle types. This project is part of the Automated Guideway Transit Technology (AGTT) program which is a comprehensive, broadbased, critical technology development program derived from the Urban Mass Transportation Administration's experience with automated transportation systems. The program is oriented toward the analyses of systems and the development of system elements which may be used in a variety of advanced urban transportation systems. For this

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reason, it represents the identification and selection of new research and development initiatives which will provide the direction for new systems development into the future.

The objectives of the AGTT program are to:

- develop a comprehensive AGT network simulation and capability applicable to a wide variety of different AGT system concepts and applications;
- carefully explore the service and operating costs of AGT systems in a variety of applications;
- identify, develop, and test the technology required to substantially extend the mean time between failures (MTBF's) which result in guideway blockage and explore manual and automatic methods to effect rapid stalled vehicle removal while minimizing the number of operating personnel;
- study the technology requirements for fractional-second headway, small (4- to 6-seat) vehicle PRT systems, and develop and test essential subsystems;
- generate the technical and operating data required to develop rational decisions concerning further AGTT program activities;
- reduce the technical and financial risks involved in the development and deployment of automated systems; and
- develop a national data base for use by system designers and developers, local planners, and government officials to assist them in preparing performance specifications for such systems.

Vehicle lateral control is one aspect of automated guideway transit technology which has been identified as particularly crucial to the successful operation of automated transit systems. The VLACS project tasks include a review of existing lateral control and switching technology, detailed mathematical modeling, analysis and simulation, detailed hardware studies, experimentation with alternative designs, and development of guideline specifications for VLACS systems.

Three types of steering systems for rubber-tired transit vehicles will be investigated:

1. Mechanical sensing without power steering (herding). (Figure 1)

2. Mechanical sensing with power steering. (Figure 2)

3. Electromagnetic (wire-follower) sensing. (Figure 3)

The first type of steering system is a passive wall-follower system in which the vehicle follows a vertical surface of the guideway and the forces required to steer the wheels are generated through mechanical steering linkages without power assist. The second type is an active wall-follower system in which a sensor detects vehicle lateral displacement from a vertical wall of the guideway. This measurement is used to generate steering commands to a power steering system which steers the vehicle. The third type (wire-follower) also uses power steering to generate required

steering forces; however, the vehicle position reference is a transmission wire laid in the guideway. An antenna array on the vehicle senses vehicle position errors relative to the wire reference. Steering commands are generated from this position error signal. All three steering types must incorporate mechanical positive retention of the vehicle to the guideway in switch areas.

PROJECT OBJECTIVES

The objectives of the VLACS project are to:

- Reduce the cost, complexity and weight and increase the life, reliability, maintainability, ride quality, and switching capability of VLACS systems.
- Develop specific performance requirements and guidelines for lateral control and switching systems for cruise speeds of 20 to 50 mph, for SLT, GRT, and PRT vehicles in trained and untrained configurations.
- Develop and evaluate baseline VLACS hardware designs reflecting project objectives.
- Provide experimental data to demonstrate capability of VLACS system and subsystem designs to meet performance requirements including line speed switching.

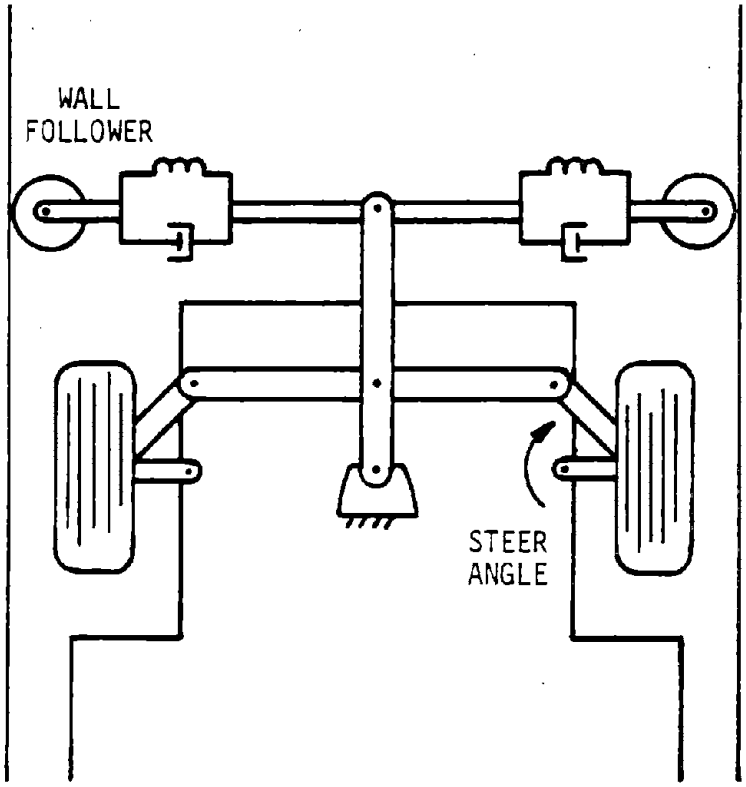


FIGURE 1. MECHANICAL SENSING WITHOUT POWER STEERING

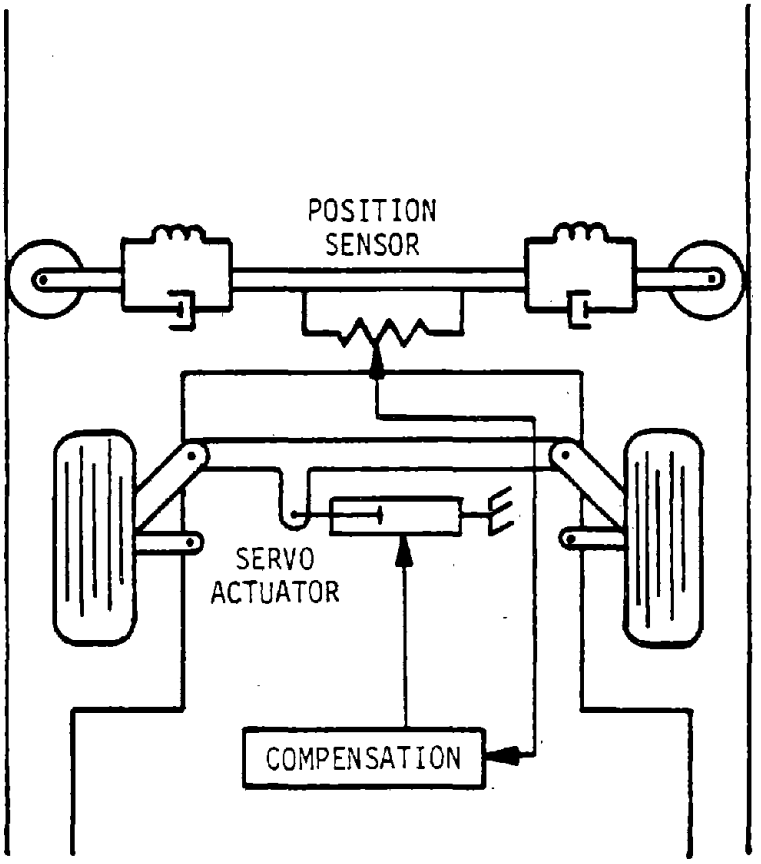


FIGURE 2. MECHANICAL SENSING WITH POWER STEERING

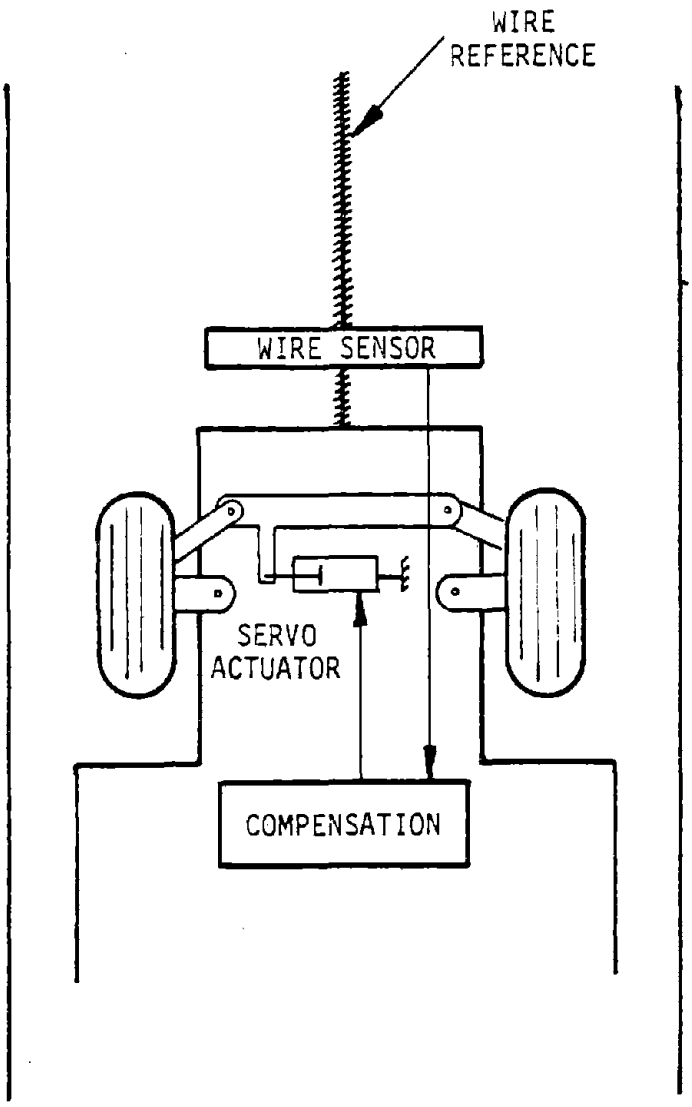


FIGURE 3. ELECTROMAGNETIC SENSING WITH POWER STEERING

- Provide a comprehensive analytical evaluation of contact (mechanical) and non-contact (wire-follower) lateral guidance approaches.

- Perform an assessment of the positive retention capabilities of automatic switching systems.

PROJECT TEAM

The VLACS contract was awarded to the Transportation Technology Division of the Otis Elevator Company (OTIS-TTD) in August, 1977. As prime contractor, OTIS-TTD has responsibility for overall project management, VLACS analysis and design, hardware implementation studies, experimental program execution, data base generation, and documentation. OTIS-TTD has also been awarded the Vehicle Longitudinal Control and Reliability (VLCR) Project contract (another Automated Guideway Transit Technology program sponsored by the Urban Mass Transportation Administration). With coordinated work on the VLACS and VLCR projects, a comprehensive study of both lateral and longitudinal control systems for automated transit systems is being performed.

Several subcontractors have been included on the VLACS project team. The United Technologies Research Center (UTRC) is developing detailed mathematical dynamic models of vehicles and the VLACS systems for use in control system studies and ride quality analyses. The General Research Corporation (GRC) is developing VLACS technology evaluation models used to evaluate cost and weight trade-offs for VLACS systems. The GRC VLACS model is integrated with the VLCR cost and weight model to provide a complete model for both lateral and longitudinal control systems. Mitsubishi Heavy Industries, Ltd. of Japan is providing technical information on the lateral and longitudinal control techniques used in several Japanese transit systems. Technical data on tire characteristics is being supplied by the Firestone Tire and Rubber Company. Several consultants have been included in the VLACS project team to provide technical information on wire-follower steering, vehicle dynamics, and vehicle design.

VLACS SYSTEM REQUIREMENTS

Vehicle Categories

Lateral control and switching systems for the vehicle categories summarized in Table 1 will be investigated in the VLACS project. Dynamic performance goals for each vehicle class are summarized in Table 2. These classes cover a wide spectrum of vehicle types having various applications. The primary emphasis of VLACS technology is on bottom supported vehicles with rubber-tired suspension systems. Different steering and switching systems may be developed for each vehicle class.

TABLE 1

VEHICLE CATEGORIES

CATEGORY	MINIMUM HEADWAY (SECS)	MAXIMUM LINE SPEED (KM/HR)	ENERGY UTILIZATION KW-HR / VEH.KM	NO. OF PASSENGERS	EMPTY VEHICLE WEIGHT (NEWTONS) PER PASSENGER	SIZE (METERS)		
						LENGTH	WIDTH	HEIGHT
SLT (NOMINAL)	>60 (90)	25-100 (50)	2.0	20-120 (80/30)*	45 000 - 135 000 (110 000) 1 300	7.5 - 12.0 (11.0)	2.5 - 3.0 (2.75)	3.0 - 3.75 (3.5)
GRT_L (NOMINAL)	15-60 (20)	25-100 (65)	1.4	20-50 (30/20)*	35 000 - 90 000 (55 000) 1 750	4.5 - 7.5 (6.0)	1.8 - 2.2 (2.0)	2.5 - 3.5 (3.0)
GRT_S (NOMINAL)	3-15 (5)	25-80 (65)	0.60	6-25 (15/10)*	13 000 - 65 000 (45 000) 2 225	3.5 - 5.0 (4.3)	1.8 - 2.2 (2.0)	2.4 - 2.8 (2.5)
PRT (NOMINAL)	<3 (0.5)	30-75 (50)	0.15	(2-6) (4)**	4 450 - 13 000 (6 500) 1 550	2.2 - 3.0 (2.5)	1.2 - 1.8 (1.5)	1.5 - 1.8 (1.8)

* Total Vehicle Capacity, Seated and Standing/Number of Seats

** All Seated

TABLE 2

NOMINAL VEHICLE
PERFORMANCE GOALS

Category	Maximum Acceleration (g)			Maximum Jerk (g/sec.)			Capital Cost[1] (Dollars/Veh.)
	Longitudinal		Lateral	Longitudinal		Lateral	
	Normal	Emergency		Normal	Emergency		
SLT	.15	.20	.10	.15	-	.07	125,000[2]
GRT Large Vehicle	.15	.25	.10	.15	-	.07	100,000[3]
GRT Small Vehicle	.15	.25	.10	.15	-	.07	80,000[3]
PRT	.15	.40	.10	.20	-	.07	15,000[4]

1. 1975 dollars.
2. Production run of 20 vehicles.
3. Production run of 200 vehicles.
4. Production run of 2,000 vehicles.

Positive Retention

The VLACS systems must provide positive (mechanical) retention of the vehicle to the guideway. This requirement significantly affects switching system designs since fail-safe locking mechanisms with position verification must be incorporated into the switching system design. Positive retention must be provided in the event of any of the following lateral control system failures:

- Traction or guidance tire failure.
- Mechanical failure of the steering or suspension system.
- Loss of power to the steering actuator.
- Loss of command to the steering actuator.
- Incorrect steering command.

Other failure modes which affect the VLACS designs are being investigated.

Steering System Requirements

The types of steering systems which are being investigated are the passive wall-follower, active wall-follower, and wire-follower configurations described above. The steering systems may be applicable to one or more of the vehicle classes identified in Table 1. The vehicle size and weight, maximum line speed, and turn radius for each system is considered in the VLACS system design for each vehicle class. Lateral ride quality for each configuration is compared to International Standards Organization (ISO) lateral vibration standards which establish a required level of performance for the lateral control systems. Lateral displacement tolerances of the vehicle must be compatible with the vehicle and guideway width; the VLACS systems must prevent the vehicle from making other than that contact necessary for power collection, communication, and guidance.

Switching System Requirements

The VLACS switching systems being investigated must provide two functions. First, the steering system reference which is used to guide the vehicle on the desired path through a switch zone must be switched to the proper configuration. Secondly, positive retention devices which assure positive vehicle retention to the guideway must be switched. In some configurations, these two functions may be combined into one hardware element such that distinction between the two functions is not necessary. However, in some VLACS systems, separate hardware elements are used to effect switching of the steering reference and the retention devices.

Several constraints have been imposed upon the switching systems:

- Switches must be suited for turnouts in either direction.
- Switches must be suited for turnouts from or onto curved tracks, including tracks of minimum radius.
- Switch configurations must be suitable for vehicles to switch at line speed.
- Switch configurations must permit two consecutive vehicles at minimum headway to pass through alternative branches of the switch.
- Switch configurations must permit vehicles operating at minimum headway to pass through any sequence of switch paths.

Fail-safe locking devices with position verification must be included as part of the switching systems to assure that positive vehicle retention is maintained through the switch zones.

Operational Environment

The VLACS systems must operate in an environment which is typical of that in which automated transit systems must operate. Details of operational environment specification are included in the VLACS project Statement of Work.

PROJECT TASKS

To meet the VLACS project objectives, major project tasks have been identified. Figure 4 shows the interrelationship of these tasks. From the program requirements and objectives, a Project Implementation Plan has been developed. The following paragraphs provide a brief description of the work being performed in each task.

Technology Evaluation Model Development

In this task, the performance measures and goals set forth in the Statement of Work are used as a framework for the development of detailed performance measures and goals for each class of VLACS. This provides a frame of reference for the analysis and design implementation studies and provides a basis for comparison of alternative approaches. Detailed weight and cost models are structured for each VLACS configuration selected for each AGT class encompassing the three basic alternative guidance configurations. The weight and cost models are coordinated with the VLCR project to provide overall vehicle weight and cost predictions for each vehicle class. The technology evaluation models enable retrieval of information for the selected design approaches and variations of VLACS systems including single and trained vehicle operation.

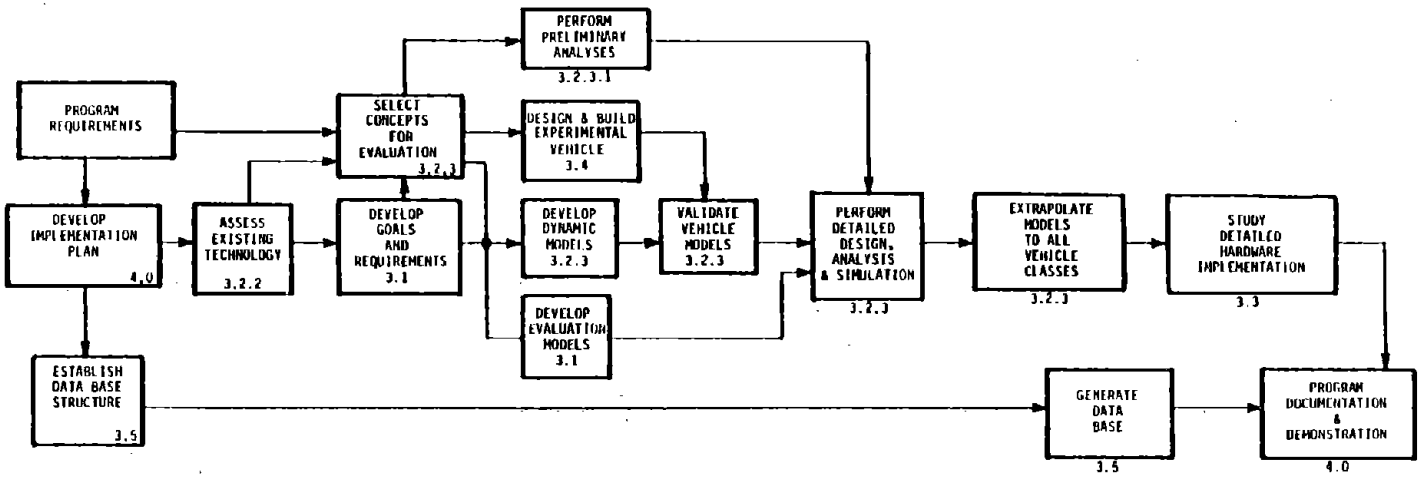


FIGURE 4 VLACS PROJECT TASK FLOW

Vehicle Lateral Control and Switching Technology Review, Design, & Analysis

This task includes a survey and evaluation of existing VLACS configurations, selection and development of VLACS designs for each vehicle class of VLACS system performance, and analysis and detailed dynamic simulation model development. This task will provide detailed design, cost, weight, and reliability information for technology evaluation models.

This task also includes control and stability analysis, ride quality analyses, and control system simulation studies. Vehicle and control system dynamic models will be developed and validated using test results from the experimental program. These models will be structured according to the generalized block diagram of a lateral control system shown in Figure 5 and will include mathematical models of vehicle dynamics, suspension, steering system, and tire characteristics. VLACS designs will ultimately be selected for each vehicle class after consideration of control performance, safety, cost, weight, and reliability as related to the project objectives described above.

Detailed Hardware Implementation Development

This task includes design trade-off studies to select and define VLACS elements down to the component level to satisfy the VLACS systems specifications and requirements developed for each vehicle class. The trade-offs are made with consideration for cost, reliability, maintainability, and useful life in the implementation of each function of the VLACS systems. There is iterative feedback between this task, the VLACS design and analysis task, and the experimental program to arrive at component-level designs. The contractor will perform the component level design activities and will draw heavily upon the detailed dynamic simulation model outputs to substantiate component design requirements and characteristics. Inputs will also be obtained via measurement and description of existing automated transit systems. Detailed designs will be described by specifications, block diagrams, drawings, cost breakdowns, weight breakdowns, and reliability analyses. This task provides the final input to the technology evaluation models for each of the selected VLACS designs.

Experimental Program

The experimental program consists of a combination of laboratory and full-scale test vehicle evaluations. The laboratory tests are being conducted to establish the performance and transfer characteristics of vehicle structural elements, suspensions, vehicle inertial effects, steering sensors (both wall-follower and wire-follower), and steering actuation systems. A special rubber-tired VLACS test vehicle, which includes double-ended and/or single-ended Ackermann steering and 2-wheel and/or 4-wheel drive, is being constructed. This vehicle illustrated in Figure 6 will be used to evaluate wire-follower steering control, active wall-follower control, safety, cost, reliability, and system-level considerations for each major VLACS design type. The guidelines will be a useful tool for system developers, planners, and local public agencies interested in planning for automated transit system deployment.

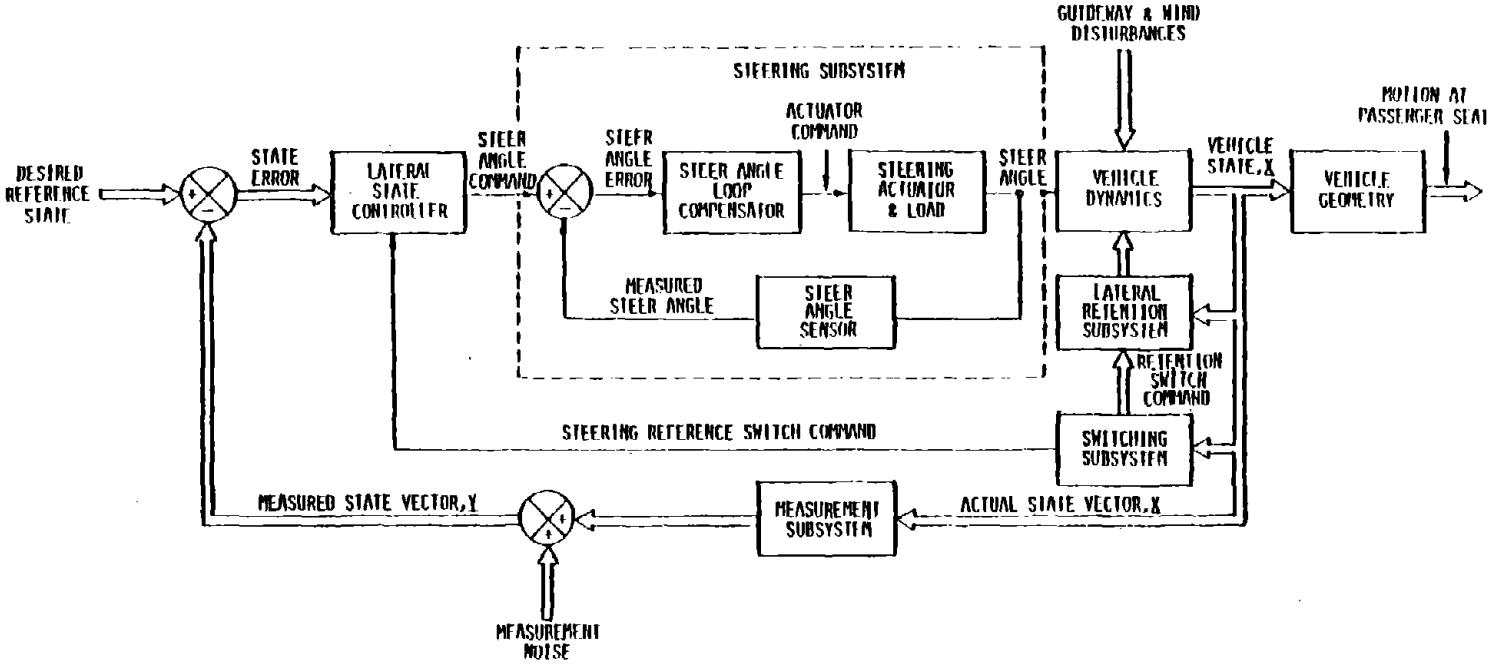


FIGURE 5 GENERALIZED BLOCK DIAGRAM OF A LATERAL CONTROL SYSTEM

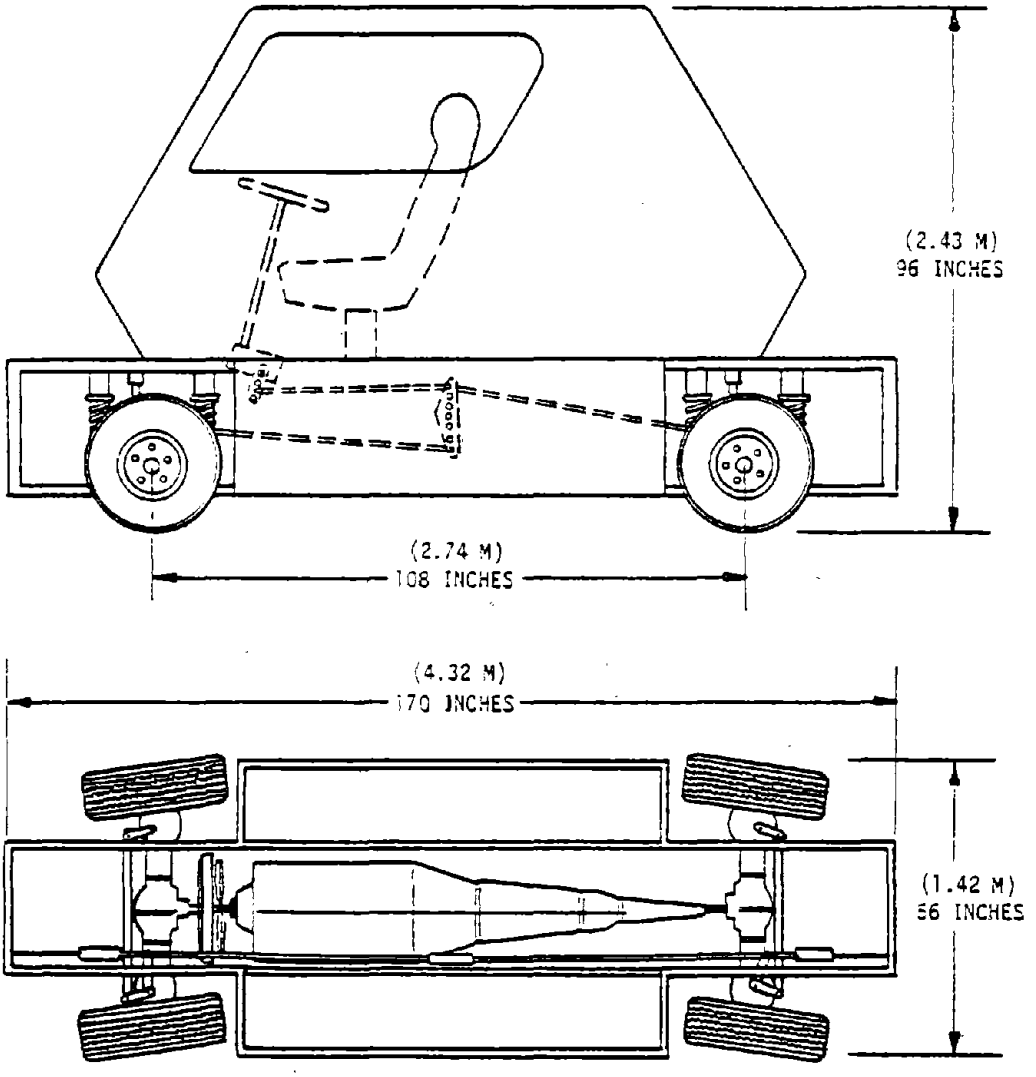


FIGURE 6. VLACS TEST VEHICLE

The prime purpose of the VLACS experimental vehicle is to provide test data for vehicle mathematical model validation. The vehicle is being instrumented with transducers and recording devices to measure steering angles, roll angles, spring displacements, accelerations, etc. The test program starts with model validation tests at the subsystem and subassembly level followed by dynamic tests of the complete vehicle and lateral control system. Most of the dynamic tests will be performed at the OTIS-TTD test track in Denver, Colorado, shown in Figure 7. The test program will conclude with the Government demonstration and design review at the end of the VLACS project.

Data Base Development and Guideline Specifications and Requirements

This task encompasses the development of a comprehensive data base on vehicle lateral control and switching systems which documents the results of the VLACS project. In addition to written material, the data base will contain copies of all simulations and software developed in the generation of the included data. A comprehensive set of guidelines, specifications, and requirements applicable to the VLACS systems for each AGT vehicle will be prepared. The guidelines will include performance, safety, cost, reliability, and system-level considerations for each major VLACS design. The guidelines will be applicable at the system level so that they can serve as a useful tool for system planners, developers and public agencies interested in the deployment of automated guideway transit systems.

Final Reports

Formal reports on the results of the project tasks will be prepared and included in the VLACS data base. These documents will be available to the public as they are prepared and approved for release. Study progress reports will be prepared describing work in the following areas:

- Technology Review
- Technology Evaluation Models
- Design and Analysis Studies
- Detailed Hardware Implementation Studies

A final VLACS project report will also be prepared to summarize the results of the project tasks.

PROJECT STATUS

The following paragraphs describe the status of the VLACS project at the end of the first quarter. The project interim and final reports will document the results of all VLACS project activities.

Performance Measures

A preliminary set of performance measures for VLACS systems has been

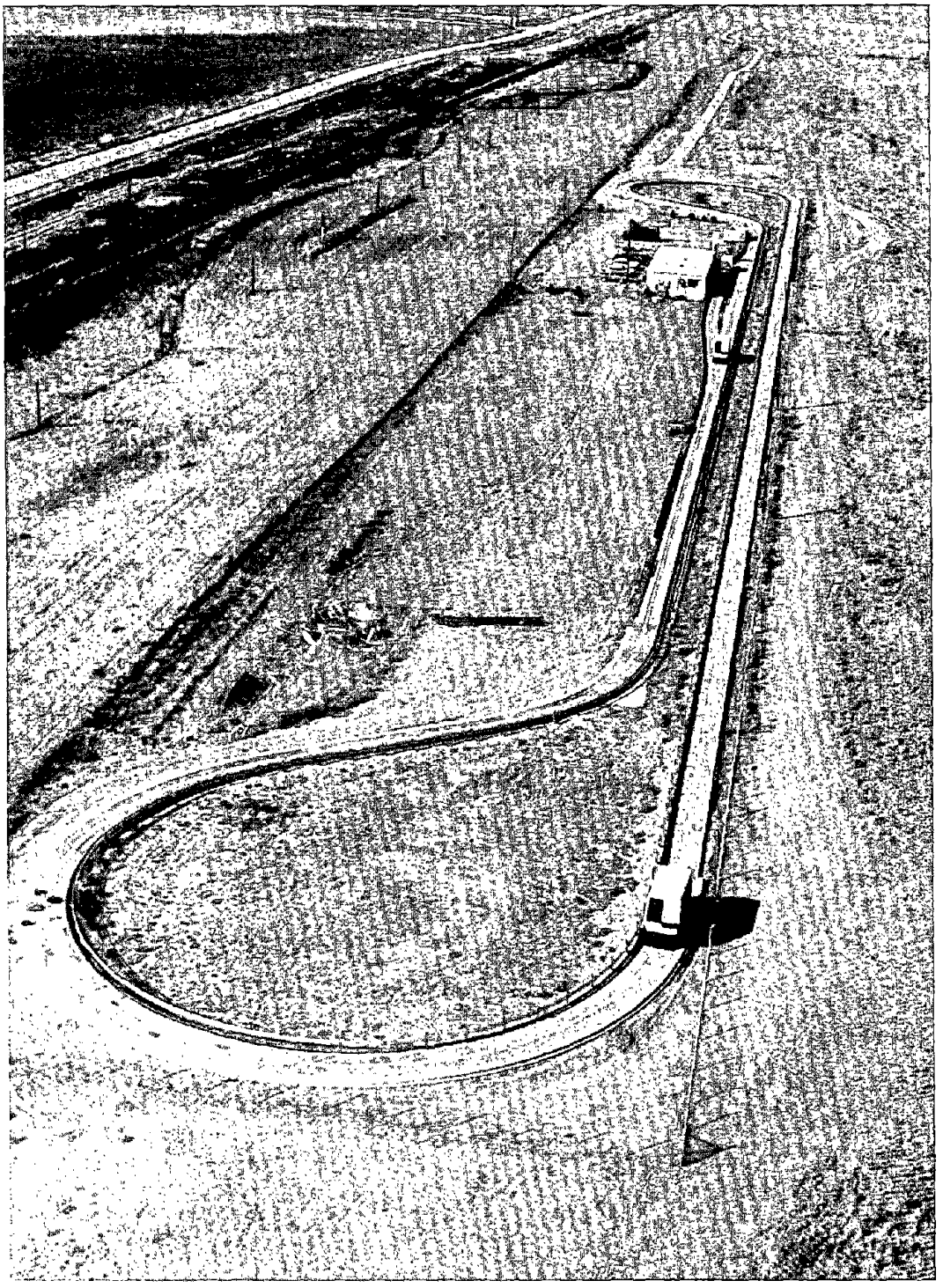


FIGURE 7 OTIS-TTD TEST TRACK, DENVER, COLORADO

defined. For these performance measures, performance goals will be established based on the performance of existing systems and performance requirements established by the VLACS project statement of work. These performance measures and goals will be the basis of the performance evaluations of various VLACS system configurations. The final VLACS performance measures and goals will be included in the deliverable report on Technology Evaluation Models developed under this project.

Technology Review

A review of VLACS technology has been initiated. This effort has included a survey of lateral control and switching techniques used on existing transit systems. A classification structure for steering and switching systems has been defined so that the VLACS systems surveyed can be classified into categories. A matrix which uses this classification structure to summarize the characteristics of nineteen transit systems has been completed. This matrix and the classification structure will be included in the deliverable report on the VLACS Project Technology Review.

The design and analysis of VLACS systems requires extensive mathematical modeling of vehicles and steering systems. As part of the VLACS technology review, a survey of dynamic models which have been used in previous lateral control system studies has been initiated. The results of this model survey will also be included in the Technology Review.

Design and Analysis

The design and analysis task efforts have concentrated on the development of mathematical models and definition of the coordinate system to which these models are referenced. A vehicle and control system model has been defined and used for some preliminary control system studies. Parameters which must be measured on the test vehicle for model validation have been defined. The models developed for control system studies and ride quality analyses will be documented to the project deliverable report on the VLACS design and analysis. This report will also document the results of control system studies which use the models and simulations.

Experimental Program

Fabrication of the VLACS test vehicle to be used for model validation has been initiated. The frame and drive train for the vehicle have been assembled. Preliminary design of the wire-follower sensor has been completed and fabrication of a prototype antenna array has been initiated. Current efforts are concentrating on the selection of transducers for instrumentation and the design of the automatic steering system for the test vehicle. Work on the experimental program test implementation plan will be started in the near future to define the scope of testing to be performed. Results of the model validation tests will be documented in the design and analysis reports as part of the mathematical model description.

CONCLUSIONS

By completing the VLACS project tasks and meeting the project objectives, a comprehensive study of alternative lateral control and switching systems for a variety of automated guideway transit system types will be performed. The final project reports and the VLACS data base will thoroughly document the findings of the project tasks and provide guidelines for the specification and selection of VLACS technology for various automated guideway transit applications.

PAPER 5

AGT Guideway and Station Technology

Robert D. Stevens
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AGT GUIDEWAY AND STATION TECHNOLOGY PROJECT

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ABSTRACT. This project is a part of the U.S. DOT automated guideway transit (AGT) technology program. The objective of the project is the development of guideway, station and weather protection concepts which will reduce the cost of and the implementation time associated with these AGT subsystems. Work on the project was initiated in July 1977 and is scheduled to be finished by August 1979. The project includes a review of existing technology, the development of design guidelines, and the development and evaluation of concepts for AGT guideways, station and weather protection methods and procedures.

All of the effort in this project is being devoted to preparing outputs which will aid planners, designers, administrators and others as they consider AGT systems and their application to satisfy specific transportation needs in an urban area. The outputs will include a description of the guideways and stations found at existing AGT system installations and of weather protection methods and procedures used both at AGT systems and in the related transportation fields including railroads, highways and airports. Cost, time and evaluation models will be produced as tools for comparing different AGT guideway and station configurations. A guideway-vehicle interaction model will be provided as a tool for evaluating this interaction and as an aid in designing AGT systems to achieve a desired ride quality level. Guidelines for the design and implementation of AGT guideways and stations will be provided. Finally, concepts for AGT guideways, stations and weather protection methods will be identified. These concepts will offer potential benefits over those currently in use.

INTRODUCTION

To date a number of automated guideway transit (AGT) systems have been designed, built, operated and maintained. Most of these systems have been deployed in either airport or amusement park settings. They range in size from systems with approximately 360 m (1,200 ft) of guideway and a few vehicles to those with guideways of over 21 km (13 mi) and more than 50 vehicles. A number of AGT installations are currently in the planning stage. In the United States, most of these installations are in connection with the Downtown People Mover Program. In these urban locations, the issues of site integration

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and public acceptance become more critical than in the more remote or less dense locations found in most previous applications.

To further the development of AGT, the United States Department of Transportation Urban Mass Transportation Administration has established the Automated Guideway Transit Technology (AGTT) Program. The objective of the AGTT program is to address among others the technological, operational, environmental and cost aspects of AGT systems and to find solutions to problems which have been identified. The program includes three generic types of AGT systems. These are shuttle-loop transit (SLT), group rapid transit (GRT) and personal rapid transit (PRT).

The AGTT program includes a number of projects. One of these--the AGT Guideway and Station Technology Project--is the subject of this paper.

This paper is organized such that the remainder of the introduction sets forth the project objectives, the project contents, the project participants, the project schedule and the project outputs. The majority of the paper follows the introduction and deals with the nature of the research work being carried out in this project. Included in this part is a description of the approaches being used in the project and some results from the work to date. The project approach and accomplishment section is followed by a brief conclusions section.

Project Objective

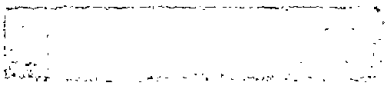
The Guideway and Station Technology Project has as its primary objective the establishment of guideway, weather protection and station concepts which will result in lower cost AGT installations. Other objectives include the improvement of the site integration and aesthetics of AGT guideways and stations, the establishment of design guidelines and requirements for AGT guideways and stations, and the development of evaluation, cost and time models and of a data base for AGT guideways and stations.

Project Contents

The project work program is grouped into four technical areas. These include models and data base, guideways, stations and weather protection. The models and data base area includes the development of evaluation, cost and time models and a guideway and station data base.

The guideway work includes a review of existing AGT guideways, an analysis of AGT guideway-vehicle dynamics, the development of guideway design guidelines and requirements and the development of guideway concepts. The station work includes a review of existing AGT stations and several selected conventional rail rapid transit stations, the development of AGT station design guidelines and requirements and the development of AGT station concepts.

In the weather protection area, the work involves a review of existing weather protection problems and techniques used in both AGT and non-AGT applications, the development and analysis of weather protection concepts and the testing of weather protection concepts.



Project Participants

The team assembled to carry out this project includes De Leuw, Cather & Company, ABAM Engineers Incorporated, Massachusetts Institute of Technology and special consultants Thomas J. McGean and H. William Merritt. Although the project work structure has been broken down to use personnel from the participating firms in various study groups, each participating firm has certain key responsibilities.

De Leuw, Cather is responsible for overall project management and administration and for the evaluation models, station and weather protection task areas. ABAM is responsible for the guideway review, guidelines and concept work. MIT is responsible for the guideway-vehicle dynamics model. The special consultants are assisting in several areas but most significantly in the weather protection tasks and in the contracting methods portions of the guideway and station tasks.

Schedule

Work on this project started July 11, 1977 and is scheduled for completion not later than August 11, 1979. The anticipated level of effort over this 25-month period is nearly 15 person-years. The majority of the work is expected to be completed by May 1979.

Products

The outputs of this project will include a description of the guideways and stations found at existing AGT system installations and of weather protection methods and procedures used both at AGT systems and in the related transportation fields including railroads, highways and airports. Cost, time and evaluation models for comparing different AGT guideway and station configurations and a guideway-vehicle interaction model for achieving the desired level of ride quality will be produced. Guidelines for the design and implementation of AGT guideways and stations will be provided. Concepts for AGT guideways, stations and weather protection methods will be identified. All of these products will be oriented to provide the planners, designers, administrators and others interested in AGT with useful tools to assist in the planning of AGT systems. These outputs will be reflected in the project final report.

The final report will consist of an executive summary and seven technical report volumes. The seven report volumes will include the AGT Weather Protection Review, AGT Guideway and Station Technology Review, AGT Guideway and Station Design Guidelines, AGT Guideway-Vehicle Dynamic Model, AGT Guideway and Station Technology Evaluation Models, AGT Guideway and Station Design Concepts and AGT Weather Protection Concepts.

PROJECT APPROACH AND ACCOMPLISHMENTS

As described in the introduction, the work of this research project is divided into four major tasks. In this section, the objectives of each task, the approach being used to address each task, the anticipated results of the

work and the results available to date are described. The material is set forth in the following order: models and data base, guideways, weather protection and stations.

Models and Data Base

The models to be developed under this project include the cost model, the time model and the evaluation model. The purpose of these models is to establish a basis for evaluating guideway and station concepts that will be developed in this project and for use as appropriate elsewhere by others.

Cost Model: An interactive computer cost model will be developed to be used as a basic planning tool for guideways and stations. While the model will not provide sufficient detailed cost information for bidding a guideway or station, it will provide for cost comparisons, for example, of various guideway concepts over a given route or of a given guideway concept over various routes. The input to the model will include site conditions, the type and amount of guideway, the number and type of stations, geographic location, schedule, and various financial data including interest rates and inflation factors. The model will include a data base of estimated capital costs for guideway and station components. The model will also include operations and maintenance costs associated with guideways and stations. The model will combine the input data with the cost data to provide outputs for a specific condition. The output will include capital and annualized costs.

Time Model: The second model being developed is the implementation time model. This model will evaluate differences in implementation times--both those associated with different guideway and station concepts and those resulting from a change in construction sequence.

The implementation time model will portray in sequence the events leading from the start of construction of a guideway and station through to completion and acceptance of the construction work. The model will be in the form of a CPM model with three levels of networks. The first level network will be used to identify the basic site-dependent and site-independent events involved in the construction of an urban AGT guideway section and station. Each successive level will be used to subdivide events into their subevents. While the actual model network will be prepared in detail, only the first level network will have default times associated with it. The outputs of the time model will include the identification of each event, early and late start dates, early and late finish dates, total and free float time and a project implementation bar chart.

Evaluation Model: An evaluation model is being developed to provide an orderly and systematic method for evaluating guideway and station concepts. The evaluation model will make use of performance measures and goals. The performance measures to be used include capital cost, operations and maintenance cost, implementation time, environmental impact and safety and security. Each performance measure will be subdivided into its components. A goal will be established for each performance measure component. The goals will be either quantitative or qualitative consistent with the nature of the performance measure.

An existing AGT system will be used to establish a baseline for each performance measure component. Goals will be established based on what appears reasonable to achieve in this project to improve guideways and stations. Concepts will then be evaluated against the goals.

Data Base: This project involves the development of a data base on AGT guideways, station and weather protection. The data base serves as a collection point for all material generated in this research effort. The data base will include the results of library searches which have been conducted to identify bibliographies of reference material related to AGT guideways, to stations and particularly to weather protection. For each reference source identified, an abstract is being prepared which identifies the work, key words and a description of the contents. On completion of the project, the data base will be delivered to UMTA.

Guideways

The guideway task has as its objective the development of guideway concepts to reduce AGT guideway costs and implementation time. The work in this task includes the guideway review, guideway-vehicle dynamic models, guideway design guidelines and guideway concepts. This work is closely related to and integrated with the weather protection, stations and models work carried out in the other task areas of this project.

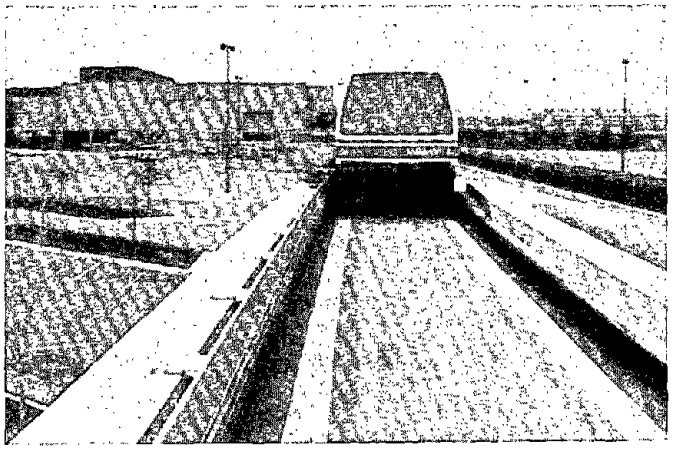
Guideway Review: The guideway review work has resulted in the preparation of inputs to a draft report on AGT guideways and stations. This report will review existing AGT systems and examine how vehicle technology has influenced the guideway. The review differs from other AGT assessment programs in that it investigates all existing AGT systems simultaneously and attempts to draw conclusions from the different systems. The review asks the fundamental question: "What happened to AGT from the guideway point of view?" It investigates the impact of vehicle selection and vehicle size on the guideway as well as the decisions that have been made regarding building codes, tolerances and other related items as they affect the design and cost of AGT guideways.

Since the number of deployed AGT systems is rather small, there is considerable scatter in the data which makes development of definitive conclusions difficult. Trends, however, are identified in the review. These are briefly summarized below:

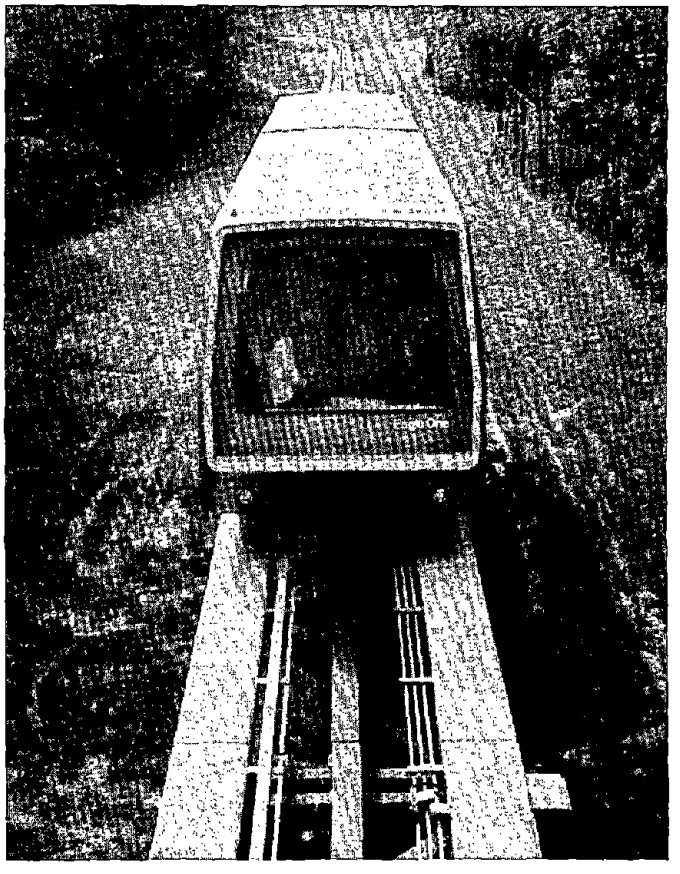
1. Guideway selection to date is heavily influenced by the vehicle rather than the development of the guideway technology.

2. Attempts to optimize the guideway and the vehicle system concurrently have been limited to a few applications. In these technologies, significant overall cost savings were realized through complete system optimization.

3. For bottom supported rubber-tired systems, there is a general trade-off between guideway width and guideway depth. The primary influencing factor in this trade-off is the selection of the vehicle steering concept. This can be seen by comparing the Ford and the Westinghouse guideways as shown in Figure 1.



Ford Fairlane



Westinghouse - Busch Gardens

Figure 1
Vehicle/Guideway Interface

4. No consistent pattern for guideway cost data exists, which makes a direct comparison of the guideway types difficult. Furthermore, it is nearly impossible to isolate cost data for specific subareas such as tolerances or finish.

5. Existing codes may serve as effective design guidelines. However, professional interpretation of these codes is needed to avoid certain built-in pitfalls resulting from the original intent of the code to serve some structure other than AGT guideways.

6. A comparison of all of the guideway functions and subsystem interfaces allows the rapid identification of potential guideway shapes. A process of combining guideway and vehicle functions can be used as an initial step in the generation of guideway cross sections for concept development.

Guideway-Vehicle Dynamics: AGT system ride quality requirements are a significant influence on system design. Three research tasks have been initiated to develop guidelines and data to aid in designing an AGT system with acceptable ride quality in a cost-effective manner:

1. Assessment of ride quality data and specifications.

2. Development of analytical tools for designing AGT systems to meet ride quality requirements.

3. Formulation of a methodology and parametric data to aid design.

The primary goals and results achieved to date in these tasks are summarized in the paragraphs that follow. The topics covered, in order, are ride quality data and specifications, analytical design tools and design methodology and data.

A review of ride quality specifications for, and ride data measured on, existing AGT systems has been completed. This review has indicated that the most extensive data available on newly constructed systems has been measured on the Airtrans system at the Dallas-Fort Worth Regional Airport. For this system, ride quality has been measured and compared with the International Organization for Standardization (ISO) Specification 2631. This system was found to meet an ISO eight-hour exposure limit specification for operation on straight sections of track and a one-hour exposure limit specification on curved sections of track. The levels of ride at Airtrans are comparable to those achieved by a midsized automobile traveling at 80 km/h (50 mi/h) over a U.S. highway quality road.[1]

To provide additional data on the ride quality levels achieved by existing AGT systems, direct measurements of the ride quality on two operating AGT systems will be performed. One set of tests will be conducted at Morgantown

1. A.J. Healey, "Ride Quality Assessment for the Airtrans System," Transportation Research Record (1977).

in association with Dunlap Associates. These test data will be correlated with data obtained from passenger surveys indicating the degree of ride acceptability.

Using the existing and newly measured ride quality data which have been correlated with passenger acceptance as a basis, recommendations will be developed for use of ride quality criteria in AGT system design.

Analytical tools to aid in designing vehicle guideway systems to meet specified levels of ride quality are being developed. These tools are based upon computer simulation models developed for the dynamic interactions between vehicles and guideway structures such as described in a previous study.[2] In these models, lateral and vertical dynamic models of AGT vehicles are coupled with a guideway model which includes dynamic deflections due to vehicle traveling loads and surface irregularities (roughness, joint offset, angular misalignment and camber) to compute vehicle motions and accelerations and guideway dynamic loads as vehicles traverse the structure. Analysis of the vehicle accelerations provides data which may be compared directly with ride quality specifications such as the ISO specification. Using these computer simulations in an iterative manner, baseline designs may be evaluated and parametric studies conducted to determine a cost-effective method of providing acceptable ride quality. The simulation programs provide a basis for evaluating the changes in ride quality which occur when: (1) vehicle suspension, mass body and automatic steering system parameters are altered; (2) guideway structural properties are altered including span cross section properties and the use of continuity across beam joints; and (3) guideway construction tolerances relating to the lateral guidance and vertical support surface profiles are altered to provide improved (or degraded) profiles with their associated increases (or decreases) in cost.

The validity of the computer simulation models for computing AGT system ride quality will be assessed by directly comparing the analytical predictions with data measured on an operational system. Inputs to the computer simulation model will include guideway structural parameters derived from guideway drawings, guideway surface profile and surface irregularity parameters derived from survey data, vehicle design data derived from vehicle drawings and vehicle operational parameters. The outputs predicted by the model in terms of both acceleration time traces and processed data in terms of ISO specifications will be compared with experimental data to assess the validity of the computer models. The comparison between the analytical and experimental data will provide a basis for performing modifications to the simulation programs so that useful design tools can be developed.

A methodology as well as specific design trade-off data will be developed using the validated computer programs as a basis. The methodology consists of a set of guidelines outlining the use of the simulation programs through an iterative design process to aid in selection of system parameters to meet ride

2. J. Snyder, D.N. Wormley, H.H. Richardson, "Automated Guideway Transit Systems: Vehicle Elevated Guideway Dynamics," U.S. Department of Transportation, Urban Mass Transportation Administration, Washington, D.C., 1975, UMTA-MA-11-0028-75-1.

quality specifications. Parametric data for several typical types of AGT systems to indicate the sensitivity of ride quality to primary vehicle and guideway design parameters will be developed to provide specific guidelines with respect to design.

Guideway Design Guidelines: The guideway design implementation guidelines include three aspects: the general and site requirements, the technical design criteria and the urban site integration considerations. The general and site requirements will examine specific AGT system characteristics and their associated placement and envelope considerations. The general and site requirements, together with definitions of AGT types and the AGT system functional requirements, are the prime considerations in establishing the urban installation requirements. The technical criteria will present detailed guidelines for the design of the guideway structure. These criteria are intended to augment existing codes to provide a comprehensive overview of guideway design. The urban site integration guidelines will provide illustrations of guideway integration into typical urban situations which might be encountered in the deployment of an AGT system. These site integration guidelines will take the form of a guidebook of potential solutions for actual installation conditions which an AGT deployment may encounter.

Guideway Concepts: The development of concepts is the core of the entire project and guideway concepts is the core of the guideway task. The intent here is to develop guideway cross sections and evaluate their applicability to AGT. The emphasis of the concept development program is on cost reduction and on product improvement. The concept development program will begin with the identification of guideway cross sections. The cross sections will then be taken through a design process which will include a continual evaluation of both the applicability of the section and the section ability to meet the cost goals. Ultimately, the cross sections will be developed into full guideway structures complete with the supporting super- and substructures. The output of the concept development program will provide basic data for the models and for concept definition sheets.

The concepts will be developed with constraints that closely represent an actual AGT installation environment. Care will be taken not to impose excessive restrictions on the developmental process. The design procedure will be geared to allow the freedom of design necessary to meet the project objective of lower cost guideways.

The generation of a guideway concept will draw on the material resulting from the guideway review and the design guidelines and general requirements subtasks as well as the weather protection task. A number of guideway cross sections will be defined. Section development will be carried further only after an initial capital cost estimate and screening is conducted. An evaluation against the mandatory functional requirements for an AGT system will then be made to avoid examining extraneous sections in excessive detail. The design procedure will be further restrained by site requirements and design criteria. Some concepts will pass all of the reviews and be developed to the point where a thorough concept definition exists. Each concept will have associated with it a description of the structure and potential utilization of the concept, the concept applicability to the different AGT types (SLT, GRT and PRT) and relevant data for the cost and time implementation models.

A parallel and related program will investigate the impacts of guideway deployment in various urban, commercial and suburban situations. Beginning with the identification of specific site situations, typical solutions will be developed for SLT, GRT and PRT options. The objective of the site integration solution is to produce the most unobtrusive guideway installation. Obtrusiveness will be measured by visual impact, noise, and various environmental considerations such as light blockage or disruption to storefronts.

Ultimately, this parallel program will be tied into the main program through the development of a few simulated site deployment scenarios. Several actual guideway concepts will be evaluated for their applicability to the site scenario and a method of selecting a preferred system will be demonstrated.

The output will be guideway concepts which can be implemented more economically than existing guideways; a description of the concepts and methods to implement several of them into specific sites will be included.

AGT Weather Protection

The objective of this portion of the Guideways and Station Technology Project is to identify and develop methods of improved performance and/or reduced cost with regard to AGT weather protection. For this project, weather protection is defined as the control or elimination of the adverse effects of weather upon the designed operation of AGT systems under varying climatic conditions.

This task focuses on bottom-supported, rubber-tired AGT systems in a winter weather environment. Weather-related problems associated solely with vehicle operation, exclusive of the guideway-vehicle interface, are not included. Wind, heat, sand, rain and lightning, though significant guideway design considerations, are not considered in detail in the weather protection portion of this project.

This task includes the review, identification, development and testing of winter weather protection methods and concepts. Upon completion of the review phase, concepts judged to warrant further investigation will be identified, analyzed and developed. Selected concepts will then be tested either in the laboratory or in a field application.

The review effort has been completed and will be documented in the AGT Weather Protection Technology Review report. The review encompassed both AGT and non-AGT transportation systems including railroad, airport and highway. The latter were included due to their more extensive winter weather experience and their functional similarities with AGT systems.

AGT Weather Protection Review: The review consisted of a literature search and interviews with personnel at operating AGT systems and manufacturers. The literature search produced few references on the subject of AGT weather protection. A wealth of reference material, however, was found on highway winter weather problems, controls and research and, similarly, on airport runway and rail system winter weather experience. An annotated bibliography of over 100 winter weather related references was compiled through these searches.

The survey of existing AGT operating experiences focused on the Ford Fairlane, Morgantown, Westinghouse test tracks, Dallas-Fort Worth Airtrans and Toronto Zoo systems. Though the latter is not an automated system, its design and operating characteristics are similar to those of an SLT AGT system and it provides operating experience in a severe winter environment. A summary of the winter weather provisions at these locations is given in Table 1.

Table 1

AGT SYSTEMS WINTER WEATHER PROVISIONS

	Ford	Morgan-town	Westing-house	Airtrans	Toronto Zoo
GUIDEWAY TRACTION SURFACE					
Primary	Electric 645 W/m^2 (60 W/ft^2)	Hydronic 645 W/m^2 (60 W/ft^2)	Selective electric (60 W/ft^2)	Ethylene glycol spray	Sand/ urea pellets
Backup	Snow blower	Snow blower	-	-	Snow blower
Snow Tolerance	2.5 cm (1 in)	None	4.5 cm (1.8 in)	-	2.5 cm (1 in)
Prediction	Monitor forecasts	Independent weather service	Detector	Airport weather forecasts	Monitor forecasts
RAILS					
Primary	Methanol spray	Heated ethylene glycol spray	Electric heat	Ethylene glycol wipers	-
Backup	Manual scrape	Manual scrape	-	-	Manual broom underneath
Collectors	-	Heated	-	-	-
SWITCHING	-	On board heated	-	-	Switch pit heated

The remainder of this section on weather protection presents some of the findings from the review of existing AGT systems followed by those from non-AGT transportation systems.

Based on the AGT systems reviewed, three areas were found to present the greatest potential for winter weather problems: (1) icing of signal and power rails; (2) loss of traction due to ice, snow, sleet or freezing rain; and (3) freezing and jamming of guideway switches. A discussion of each of these problems follows.

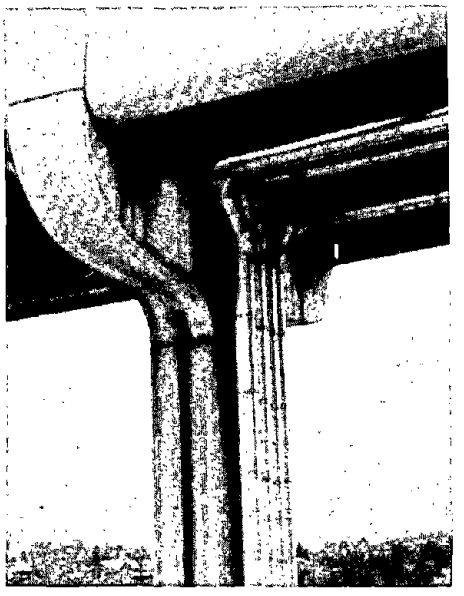
Icing of signal and power rails was found to be the most critical operational problem. Icing may occur even without precipitation; with precipitation, the problem may be compounded. Signal and power flow to the vehicle can be interrupted by a thin frost formation on the rails. Such an interruption typically results in automatic stopping of vehicles and possibly a system shutdown.

The icing problem is combatted in a number of ways: rail shape and configuration, electric heating of rails, application of anti-icing or de-icing chemicals and manual ice removal. Experience has indicated that some rail shapes and configurations are less prone to ice formation. Electric heating, using a wire along the rail, has proven the most positive countermeasure. Spraying and wiping of rails from automated or manually operated vehicles is equally common. Ethylene glycol, methanol and UCAR are some of the chemicals used. Manual frost and ice removal methods are not only laborious and crude, but extend system downtime. Two of the AGT systems employ in-house manufactured ice scrapers, one using a modified metal bracket at the end of a common fiberglass bicycle safety flag and the other employing a plexiglass scraper blade at either end of a polyvinyl chloride pipe. While vehicle-mounted scrapers have been tested, results to date have not been satisfactory.

Maintaining traction between AGT vehicle tires and the guideway is a second operational problem. From a safety standpoint, it is the most critical problem. In rubber-tired systems, traction is necessary for normal acceleration, deceleration and emergency braking. It governs headway and safety. Freezing rain, sleet, snow and ice all have an adverse effect on surface traction. The severity of this effect depends on the individual system's guideway geometry (running surface shape and steepness of grade), vehicle steering concept, vehicle speed, headway and service constraints (tolerance of service degradation). Several methods are employed in an attempt to maintain traction. These include embedded heating, abrasives and chemicals, snow blowers and an assortment of manual measures.

Embedded heating is provided by both electric resistance wire and hydronic piping systems. Such systems require prediction of weather conditions sufficiently in advance to allow heating to overcome inherent thermal lag times and to minimize activation time and thus energy consumption. Figure 2 shows the hydronic piping system being installed in the guideway at Morgantown and distribution pipes attached to a column serving a completed elevated section of the Morgantown guideway.

All of the AGT embedded heating systems installed to date have been designed to provide a heat density of 645 W/m^2 (60 W/ft^2). The Fairlane guideway heating employs a control system which allows alternating heating of adjacent sections to provide a lower average heat output and to reduce energy consumption if weather conditions allow. Westinghouse experimented with a load sharing power supply which turned on the heating system only when the



Distribution Pipes to Elevated Section

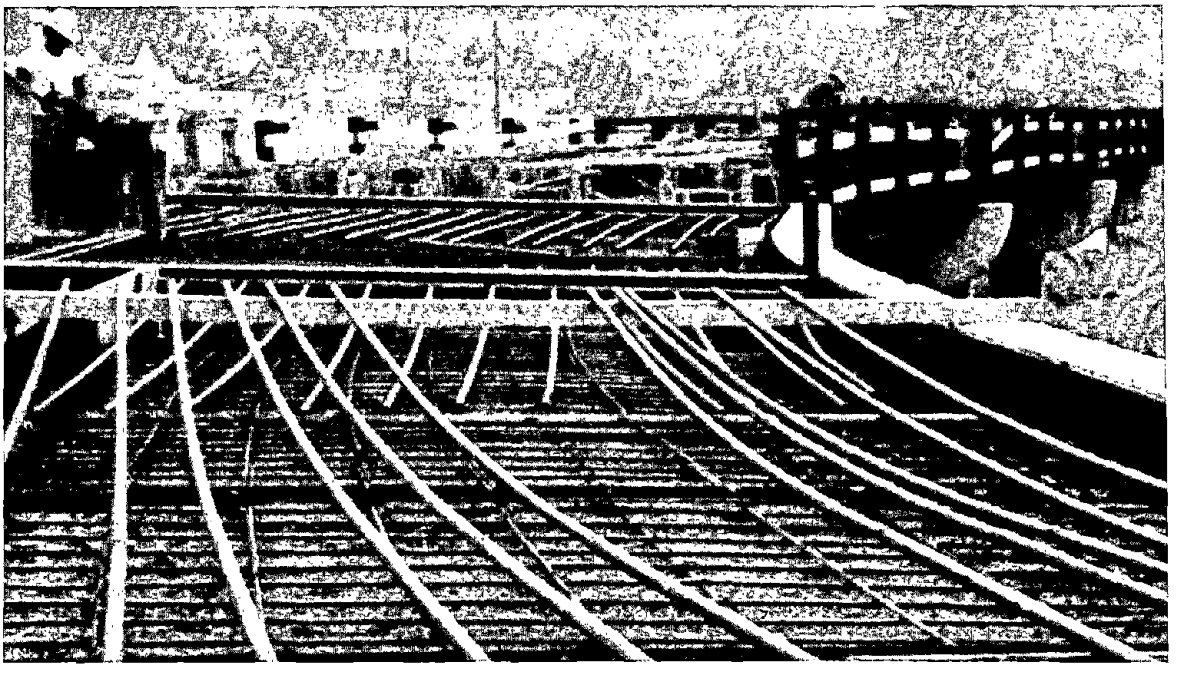


Figure 2
Morgantown Embedded Pipe Heating Systems

vehicle was not drawing propulsion power. This approach lowered the effective heat density to an average of 516 W/m^2 (48 W/ft^2) and proved inadequate in the Pittsburgh area. Nevertheless, this approach offers a potential to reduce power demand charges significantly. Westinghouse has experimented with automatic activation of guideway heating by a three-element moisture/temperature sensor. Testing of this device, however, was not definitive enough to determine whether the added costs associated with the controls are offset by labor and energy operating cost savings.

Urea pellets and sand are used successfully to improve guideway surface traction. In a less severe winter weather climate, ethylene glycol is sprayed on the guideway to melt ice. The ethylene glycol, however, tends to create a slippery traction surface on bare pavement. In the Airtrans system where this is used, the pavement has a grit-epoxy coating on the traction surface. This tends to mitigate the resulting slipperiness.

Blowers used to remove snow from existing AGT guideways range from large, vehicle-mounted, multistage snow blowers down to small walk-behind blowers. In all cases when blowers are used, preference was indicated for the smaller units. Manual methods to reduce snow and ice are also used. These vary from physically shoveling snow and chipping ice to the use of portable propane torches and weed burners to melt snow and particularly ice.

Winter weather has not been a problem for existing AGT system switches. This is due primarily to the design of installed switching systems, which are either inherently winter tolerant or provided with appropriate heaters.

Non-AGT Transportation System Weather Protection Review: The following paragraphs address the results from the review of non-AGT transportation systems winter-related experiences. These experiences are presented in the following order: (1) power rails, (2) traction, (3) switches and (4) detection devices.

Among non-AGT transportation systems, only the rail industry offers related experience with power rail type winter problems. This experience is concentrated at conventional rapid transit systems. Here it was found that in one case where an underriding power rail is used, there are minimal winter icing difficulties. Most United States rapid transit systems, however, employ an overriding power rail configuration and experience icing problems. In these cases, one or more of the following three methods are used to combat ice formation on the power rail: electric heating, mechanical scraping and anti-icing chemicals.

Electric heating of power rail utilizes tubular heaters or silicone rubber heaters. The heaters are installed in a pattern which produces alternating heated and unheated sections along the rail. Mechanical scraping by vehicle mounted scraper shoes is frequently coupled with increased vehicle deployment on the systems. This method is typically employed during precipitation to prevent ice from bonding to the rail. Once bonded to the rail, ice is extremely difficult to remove by mechanical means alone. The anti-icing chemical, Penetone, is being used by some rapid transit systems when conditions favorable to ice formation are anticipated. In one case, a glycol

paste is manually applied to the energized rail during sleet conditions to prevent icing of the power rail.

The second topic in the non-AGT transportation system review was traction. Traction is concerned with maintenance of adequate surface friction for vehicle operation. The non-AGT transportation system methods used to maintain surface traction may be categorized as mechanical, abrasive, chemical, thermal and tire modifications. The findings on these methods are presented sequentially below.

Mechanical equipment used include plows, blowers, sweepers, loaders and air jets. In general, the mechanical methods have been found effective for snow removal but ineffective in removing ice.

A variety of plows are employed depending upon depth of snow, speed of the removal vehicle and method of snow displacement. Plow blades are edged with tungsten carbide, steel, rubber or plastic. Plows are mounted either in front of or underneath the vehicle. The underbody mounted scrapers and conventional construction type graders are reportedly effective in removing hard packed snow and even ice, under favorable conditions.

Blowers are employed to cast snow clear of the pavement or tracks and to load dump trucks for removal to dump sites. Such blowers are most favored where space is available to cast the snow and with accumulations of dry snow. Though wet snow can be handled, some multistage units have a tendency to clog with it.

Sweepers are used at airports for cleanup after plowing and for removal of slush and debris. Conventional front-end loaders and conveyor-type units are used to transfer snow into dump trucks for off-site disposal.

Air jets from high volume fans or jet engines are used at airports and on rail systems to remove accumulated snow. These units discharge air at 160 to 1040 km/h (100 to 650 mi/h). Compressed air lances are also used by rail systems to clear switch areas.

Abrasives are employed by all three non-AGT transportation industries to improve traction. Rail propulsion vehicles incorporate rail sanding provisions to provide traction on wet and slippery rails. Ice, per se, is eliminated on the running rails by melting due to wheel-rail pressure. Sand, cinders and stone are used on highway systems. Tests by Pennsylvania State University indicate that all of these are similar in friction-creating capabilities. Though generally supplanted by chloride chemicals on highways, abrasives still find continued use on secondary roads especially in colder northern areas. In airport applications, sand must be bonded to the ice to avoid turbo-jet engine ingestion damage. This is accomplished in several ways: heating the sand before application, spraying a thin film of water over applied sand or applying sand together with a de-icing chemical to soften the surface of the ice for sand embedment.

Chemicals are used by non-AGT systems to improve traction by preventing the formation of an ice bond with the pavement (anti-icing), melting ice already formed (de-icing) and preventing the accumulation of snow pack. The chemicals used may be grouped into chloride and non-chloride categories.

The chloride chemicals, sodium chloride and calcium chloride, are commonly used on highways to melt snow and ice. Whereas their use is prohibited at airports due to their corrosive effect on aircraft, use of chloride chemicals as an anti-icing agent is emphasized in the highway industry. Calcium chloride is more expensive than sodium chloride, but is growing in use due to its continued effectiveness at lower ambient temperatures. Mixes of sodium and calcium chloride are being used to take advantage of these properties. The literature contains many articles on the environmental, vehicle corrosive and structural deterioration effects of salt. Procedures and materials have been developed to reduce the latter two effects; but the environmental impact is a site-specific evaluation.

Some of the non-chloride chemicals addressed in non-AGT snow/ice control literature include urea, sodium formate, tetrapotassium pyrophosphate (TKPP), formamide, glycols, mixes of the foregoing and proprietary solutions such as UCAR. As mentioned earlier, airport prohibitions against chloride chemicals have resulted in their focusing on non-chlorides. Urea and urea-glycol solutions are common airport use control chemicals. UCAR was also developed for airport use. Slipperiness created by the melted snow or even the ice control chemical can be counteracted by grooved runway pavement or a light application of abrasives. Another chemical approach tested is the use of hydrophobic pavement coatings to mitigate pavement ice adhesion. Though not generally employed, hydrophobic chemicals have been demonstrated as feasible for highway application.

Non-AGT transportation industry thermal methods to provide winter traction include portable and stationary snow melters used in conjunction with mechanical snow removal equipment, portable heaters, embedded systems and infrared fixtures.

Snow melters are generally employed where snow disposal is a problem. Portable units incorporate a melting tank, burner and fuel tank. These units are towed or self-propelled to the site. Snow is loaded into the unit by mechanical equipment. Melt water is discharged into the street gutters or other storm drainage system. Stationary pit units are used where storage space for snow is lacking or where snow hauling is either impractical or too costly.

Portable heaters range from hot jet engine exhaust units to open flame burners similar to weed burners. Application of these heaters is limited.

Embedded thermal systems may be categorized as electrical or piped. They are typically installed at toll plazas, ramps, overpasses and bridges. Electrical units employ either MI (mineral insulated) cable or a resistance wire assembly embedded 3.8 to 5.1 cm (1.5 to 2 in) below the pavement surface. Embedded system pipes are typically 5.1 cm (2 in) below the surface.

Steam, light weight oil, hot mineral water, ethylene glycol and propylene glycol have all been used as the heat transfer liquid in embedded pipe systems. Except in the case of hot mineral water, these installations require a furnace to heat the liquid. Embedded pipe systems also require pumps, valving and other associated controls. A 1974 study by General Motors Corporation which analyzed heating of a 1.6 km (1 mi) dual-mode transit system guideway indicates that pipe systems are less costly to install and operate than embedded electric systems.[3] This study indicates that the annual fuel and energy costs of these two systems are of major cost significance and that electrical heating system energy costs are some 20 times greater than embedded pipe systems, with electric power demand charges accounting for 90 percent of this cost.

A recent development in embedded systems is the use of heat pipes to transfer heat to the pavement. The heat pipe is a sealed isothermal unit incorporating a wick and vaporized heat transfer fluid without use of pumps. Heat pipes have been demonstrated in an embedded pavement system using earth energy as a heat source, and suggested for use with boiler heated and solar energy heat sources. Its use in elevated roadways has not yet been established as feasible.

Infrared snow melting has been employed successfully at parking areas, building entrances and ramps. It has not been used in any extensive road-type application. It is not effective in melting accumulated snow or ice, but is typically activated by a snow sensor to melt falling snow before any buildup occurs. Compared to embedded heating systems, its lag time between activation and melting is extremely short. The 1974 General Motors study referred to earlier indicates, however, that in a dual-mode transit guideway application, infrared system installation, operation and maintenance costs would exceed both embedded electric and pipe system costs.[4]

Tire modification is the last method employed by non-AGT transportation systems to provide winter traction. Tire modifications include snow tires, studded tires and chains. Tests indicate that snow tires are of little value on ice and are less effective than studded tires or chains on snow. Use of the latter two tire types results in increased pavement wear once the snow/ice layer has been removed.

In the area of non-AGT system winter experience with switch devices, only railroad industry equipment and experiences approximate AGT-related configurations. Both thermal and non-thermal methods are employed to keep rail switches clear of ice and snow.

The most common thermal switch heating method employed is the use of tubular electric heaters, especially in the rail rapid transit industry. The oldest method is the use of portable open flame, kerosene burning pots. Propane, oil or natural gas burning open flame melters are also used. The

3. B.B. Manzano, "Determination of Method for Snow, Ice and Sleet Removal, Dual Mode Transit System," U.S. Department of Transportation, Urban Mass Transportation Administration, Washington, D.C., January 1974, TSD-R-740001, 64 p.
4. Ibid.

fuel is either piped from a central distribution system or from separate tanks at remote locations. Hot air heating of switches is also effectively employed. A burner, using oil, propane or natural gas, heats air which is ducted to the switch rails. Portable jet engines mounted on a railroad flat car have also been used to clear switches with high velocity hot air; experimentation with stationary pulse-jet hot air sources has also been performed for remote site application.

The most common non-thermal method of clearing railroad switches is manual clearing with broom and shovel. A number of rail yards employ compressed air lances connected to a central distribution system or supplied from car mounted compressors. The Canadian National Railway recently developed an air curtain unit to keep switches clear of falling snow. This non-thermal unit ducts 160 km/h (100 mi/h) air from a trackside high volume, low pressure electric fan to nozzles along and between the tracks. It is reported to offer significant installation, energy and maintenance cost savings as compared to oil and propane-fired melters.[5] The Canadian Pacific Railway has successfully employed a rotary steel brush sweeper and blower to remove fallen snow from switch areas. Rail rapid transit systems' increased vehicle traffic procedures help to keep switches free of snow and ice accumulation

Finally, the area of snow/ice detection was explored with the goal of providing background for potential automatic operation of AGT heating devices and energy conservation. Railroads employ temperature sensors and snow sensors to activate switch heaters; rapid transit systems surveyed, however, had no confidence in snow detectors used. Infrared snow melting systems employ snow sensors to turn on lamps. Highway systems have tested and employ similar sensors to activate motorist warning signs. One of the major problems to be resolved for AGT application is the long lead time required by embedded heating systems. Embedded pavement heating systems require one and one-half to four hours lead time depending upon temperature conditions. Typically, even snow sensors which advertise anticipatory capabilities cannot predict precipitation more than 15 to 30 minutes in advance, and even then reliability or accuracy of such a warning may be lacking.

Stations

The station task has as its objective the development of station concepts which will reduce AGT station costs and AGT station implementation time. To accomplish this objective, the station work is organized to include a review of existing AGT stations and selected conventional rapid transit stations, the development of AGT station design guidelines and requirements including site integration studies and the development of AGT station components.

Station Technology Review: The review of existing AGT stations and selected conventional rapid transit stations is being carried out to identify the existing state of station technology. The review includes the identification of the characteristics at each existing AGT installation. Characteristics

5. "Keeping Switches Snow-Free with Air," Railway Age, CLXXVIII, 5, March 14, 1977, p. 26.

being described include the nature of the site, the location with respect to surrounding developments, design criteria, the nature of the station components, the impact of materials used on station design, the method of construction, and contractual means used to obtain the design and construction of the station.

The station components being reviewed include interface with the guideway, platform characteristics, passenger control area including fare collection and station access, ancillary spaces such as electrical and mechanical spaces, passenger amenities, accommodation for elderly and handicapped, orientation graphics and communication facilities and provisions for safety and security.

The gathering of the review data for both existing AGT stations and selected rail rapid transit stations has just been completed. The results will be set forth in the AGT Guideway and Station Technology Review report. A summary of some of the findings from the review effort are set forth below to provide a general overview of the station findings.

A number of AGT stations have been designed and built in the United States. Many of these stations have been provided as an integral part of another facility, such as an airport terminal, a shopping center, a hotel or an amusement park or zoo facility. Very few free-standing stations have been built in urban areas for AGT. Most of the existing stations have single-sided platforms. Also, since most of the systems have a limited number of stations, communication of information to the passenger is not too complex. Several AGT stations are shown in Figure 3.

Some of the stations are open air with canopies and windscreens. Others are enclosed by nature of their location within an airport or other facility. A few of the stations include fare collection equipment; others have turnstiles to control access to certain locations while others have no control. Some of the stations use automatic sliding doors of various configurations to control patron access to vehicles while others have no control between station platform and the vehicle doors.

Some of the stations have vertical access provided by stairs, escalators or elevators while others are at grade level or as extensions of building floors have their vertical access via building stairs, escalators or elevators.

Although most of the existing stations are on-line, a few AGT systems include off-line stations. One such system has stations with multiple berthing positions at multi-sided platforms.

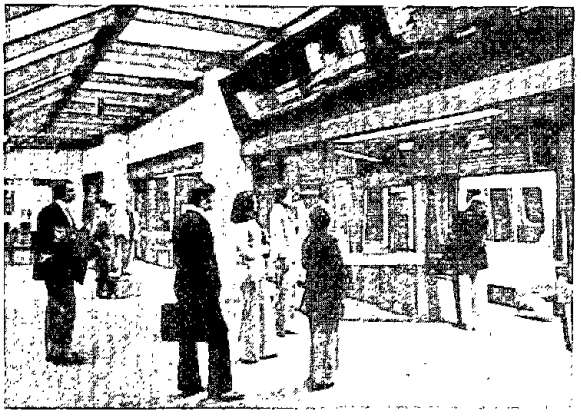
Station Design Guidelines: The purpose of this effort is to develop general requirements and design guidelines for AGT stations and to study station site integration and aesthetics. General requirements will be developed for stations for the classes of AGT systems included in this project. The general requirements will form a preliminary design specification and will define the functional and performance requirements for AGT stations.



Fairlane - Hotel Lobby



Morgantown - Free Standing



Airtrans - Airport



Pearlridge - Shopping Center

Figure 3
Various AGT Stations

Design guidelines will be developed in the form of design criteria. The criteria will result from the review of existing design criteria for both conventional rapid transit stations and existing AGT stations. The guidelines as identified will be used in developing new station concepts and in evaluating existing stations. They will also be available for use by station designers.

The station site integration and aesthetics study will result in illustrations of various ways to integrate AGT stations into existing and typical urban sites. Specific sites will be selected and renderings and models will be used to illustrate concepts for implementing stations in existing buildings and on existing rights-of-way.

Station Concepts: New station concepts and suggested contracting and management concepts for obtaining stations will be developed in this task. The objectives here are to reduce overall station costs and to reduce implementation time. Costs to be considered include fabrication, installation, finishing, operating and maintenance. Specific methods to contract for stations will be recommended.

CONCLUSIONS

Through the review effort of this project, the existing state of technology as it relates to AGT guideways, stations and weather protection has been described. This review will form a data base for AGT planners, designers and other interested parties and will serve as the basis for further phases of this project.

The development of the guideway and station guidelines work is under way. The results of this effort will provide a basis for the design of future AGT systems as well as the development of new concepts under this project.

The concepts development effort has just been started. This effort will result in revisions to existing concepts and new concepts for AGT guideways, stations and weather protection. These concepts will aid in lowering the overall cost of AGT systems, thereby making AGT an even more viable urban transit alternative than it is at the present time.

PAPER 6

The Development of Measures of Service Availability

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THE DEVELOPMENT OF MEASURES OF SERVICE AVAILABILITY

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ABSTRACT: Transit system failures impact system operations and economics in many ways: maintenance requirements, spare parts inventory requirements, reserve fleet requirements, maintenance fleet requirements, and service interruptions. The concept of service availability treats this latter effect--the service interrupting effects of system failures as viewed by the passengers. The transit industry seeks to control service interruptions to some level which is acceptable to the passengers. Hence, service availability measures are necessary to guide these control actions and gauge their effectiveness.

Service availability has always been a concern in the design and operation of a transit system. However, the direct passenger service orientation was not explicitly utilized. Rather, the emphasis was on equipment performance--specifically equipment reliability and restorability measures. As new transit systems evolved, the experience of existing systems was utilized to establish desired reliability and restorability goals. Implicit in this approach was the assumption that improvements in these two parameters was tantamount to an improvement in service availability. Because of the similarity of applications and technology, this assumption was valid and the quantification of actual passenger-oriented service availability was unnecessary.

AGT systems, however, evolved to meet different service requirements: frequent service, short headways, high equipment utilization, and little tolerance to failure. Furthermore, both applications and competing technologies varied widely. Establishing performance requirements and measuring achieved performance levels requires the explicit treatment of passenger service levels--specifically expected delay patterns.

Many models have been proposed to relate passenger delay potential and system failure characteristics. However, these are unsuitable for general use for different technologies and/or different transit system applications. An important conclusion is that no single measure or model will suffice in this role. Rather, each application and technology will require the derivation of specific control measures and values in response to specific passenger delay criteria.

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THE DEVELOPMENT OF MEASURES OF SERVICE AVAILABILITY *

INTRODUCTION AND BACKGROUND Transit system failures impact system operations and economics in many ways: maintenance requirements, spare parts inventory requirements, reserve fleet requirements, maintenance fleet requirements, and service interruptions. The concept of service availability treats this latter effect--the service interrupting effects of system failures, as viewed by the passengers. The transit industry seeks to control service interruptions to some level which is acceptable to the passengers. Hence, service availability measures are necessary to guide these control actions and gauge their effectiveness.

The role of a service availability measure is that of a transfer function relating the failure characteristics of a transit system to some service parameter or group of parameters with which a passenger identifies good or bad service. Traditionally, this linkage has not been treated in an explicit, quantitative manner. As we gained failure experience from existing transit system operations, improved passenger performance was assumed to follow improvements in the reliability of equipment and improved techniques to restore equipment operating following a failure. The emphasis was on reducing equipment downtime. To a large degree, this approach was satisfactory. The transit systems of concern were technologically similar and were being applied in similar transport demand situations--conventional rapid transit systems. Hence, in the traditional sense, service availability was tantamount to equipment availability and the measures utilized reflected this situation. In the specification, design, and compliance testing phases of a new system, system and subsystem failure rates and restore times (MTBF and MTTR) were utilized as control measures. During transit system operations, measures were selected which similarly reflected the reliability of equipment operation; for example, percent trains on time, schedule effect, and train removals.

In more recent times, say the last ten years, there has been a re-examination of this approach in an attempt to control system performance by more direct correlation to passenger service levels. This was prompted by several factors.

(1) Further improvements in equipment reliability were becoming difficult and expensive to achieve. Hence, an objective determination of actual service improvements was required to assess the benefits of such actions.

(2) Much more emphasis was being placed on "passenger service". Perhaps this was necessary to "sell" new transit system applications. Perhaps it was brought on by Government concerns in evaluating capital

*The material upon which this paper is based was developed under Contract No. DOT-TSC-1283, part of UMTA's AGRT program.

expenditure options. Whatever the cause, the effect was the realization that we did not know how well existing systems were performing and, hence, could not judge if and how improvements could be made in new applications.

(3) New technologies (the AGT class of systems) were being introduced in applications quite different from existing rapid transit systems. These systems offered characteristically different failure modes and service interrupting effects. Hence, to evaluate these alternate technologies and control their failure performance over their life cycle, it became obvious that service availability considerations would have to be made on a plane higher than specific system failure characteristics.

The concept of service availability, that is, a passenger-oriented view of transit systems performance, conceptually, circumvents these problems. Practically, however, the use of service availability depends on its utility as an effective control means. This paper discusses several forms of passenger-perceived service together with an examination of the implications of these in a performance control process.

SERVICE AVAILABILITY--USER PERSPECTIVE As defined above, service availability in its generic form is a measure of the impingement of failures on the transportation service provided by a transit system as viewed by the users of that system. In other words, service availability, as a measure of transit system performance, seeks to relate the failure characteristics of a transit system to some service parameter or group of parameters to which a passenger associates with service goodness (or badness). From the system operating standpoint, system failures evidence themselves as temporary losses in ability to transport passengers in the normal manner. To the passenger, this off-normal performance fosters a lack of confidence in the system's ability to perform in the "normal" manner; a lack of service predictability which is necessary to comfortably utilize the services provided.

The actual parameters of service degradation to which a passenger relates have not been absolutely defined. A passenger's perception of reliable, predictable service may take many forms; examples are:

- Reliability of destination achievement
- Waiting time
- In-transit delays
- Missed connections
- Seat availability
- Trip-time variance.

To this list might be added effects of failure such as perceived safety, congestion, comfort, and other parameters which are equally nebulous. Literally, pages could be filled with alternate expressions which have been used at one time or another to describe the passenger perceived impact of

system failures. The only useful point which would be served, however, would be to further underscore the fact that passenger attitudes with respect to system failures and their effects are not completely understood.

In view of the fact that the transit community (including planners, designers, A/E firms, operators, etc.) does not fully comprehend how the passenger "measures" the impact of failures, and in view of the fact that such knowledge is necessary to establish the dimensions by which failure characteristics must be measured, it becomes necessary to assume this passenger measure. In this regard, the consensus opinion of the transit industry is that passengers respond negatively to trip delays--in terms of type, frequency, duration, and location. While this is an assumption, it is quite reasonable and affords the translation of many attitudes into theoretically measurable quantities. Accepting this thesis, however, does not imply a consensus of how these parameters are valued in a passenger's assessment of performance. Simply, the levels of delay frequency and/or duration which are considered to constitute bad performance do not enjoy a consensus opinion within the transit industry. Figure 1 illustrates examples of the types of theories proposed.

In general, the curves depicted in this figure illustrate an increasing level of annoyance as the delay duration increases. Curve I illustrates a linear relationship which implies that a passenger views a single delay of two units exactly as he would two delays of one unit each.

Curve II illustrates the theory that passengers are insensitive to "short" delays. Hence, one is concerned only with delay events which are longer than some predetermined "tolerable" level. This theory sounds plausible, but introduces the problem of defining a "tolerable" delay. While there is agreement that the tolerable delay is a function of trip parameters such as trip type, purpose, and normal travel time, there is no general agreement as to the value to be applied.

Curve III represents the theory that a passenger's annoyance factor increases at a rate greater than the increase in delay duration. A delay of two units is more than twice as bad as a delay of one unit. Using this theory, one has to weight failure occurrences by their duration to gain an overall performance measure. This theory is also plausible. We can all relate to instances where this type of response was present.

Curve IV illustrates an opposite viewpoint--a theory which says a delay event causes an initial surge of annoyance, the rate of which diminishes as the delay duration increases. Like the previous theories, this too is plausible. A passenger subjected to a delay initially does not know if it will be long or short and his annoyance sensors may always be tuned to expect the worst. Again, we can relate to the feeling from our own experience.

Curve V represents a theory which can be like any of the previous ones except that it assumes that passengers do not evaluate delays in a continuous fashion. Rather, they are insensitive to delay duration over selected ranges.

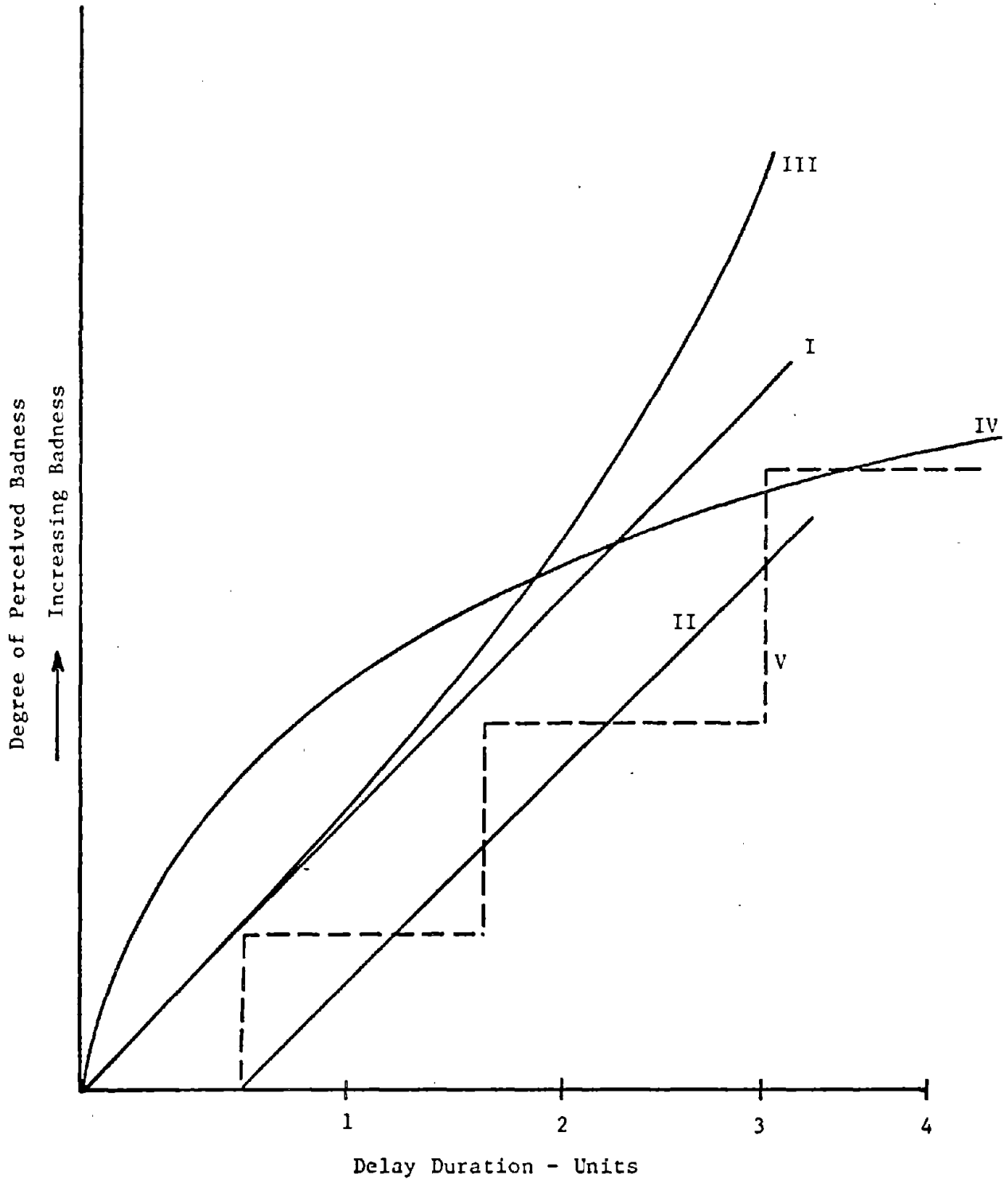


FIGURE 1. ALTERNATE THEORIES OF PASSENGER PERCEPTION OF TRIP DELAYS

For example, a 3-minute delay might be viewed with the same annoyance as a 5-minute delay; or a 25-minute delay may be considered equivalent to a 30-minute delay. Again, this is a plausible theory; one which we can support on the basis of our own experience.

From these theories, we can see that the limits of tolerable delay can take many forms and values. In addition to these variations, the location and type of delay are also considered influential in a passenger's perception of service. Typically, passengers can experience delays induced by system failures in one of two ways:

(1) By being aboard a vehicle which is stopped or slowed due to a failure

(2) By being denied normal access to the transit system at a station due to a failure.

If one considers that passengers perceive only the excess trip time resulting from delays, the above distinctions are not significant. If, however, stations are exposed to severe weather conditions, one might well "weight" station delays higher than en-route delays.

Alternatively, station delays afford the passenger an option of aborting the trip, an option which does not exist if the passengers are delayed en-route. Hence, one might choose to attach a premium to these latter delays. Significance may also be attached to the type of en-route delay encountered. Failures which require passengers to stop may be perceived differently from those which merely reduce vehicle velocity--particularly if the system uses tunnels or elevated structures.

Hence, it can be seen that "delay", as a measure of passenger-perceived service, can take many forms and values. This consideration drives the necessary conclusion that a service availability control process must be capable of functioning within these variations.

THE SERVICE AVAILABILITY CONTROL PROBLEM The use of such passenger-oriented measures has obvious advantages for comparing performance among systems in a given application and, to some degree, comparing performance among systems in a different application. However, such measures do not aid the control process. We do not control passenger delays directly. Furthermore, if we did, the problems of measuring these passenger delay parameters would make it extremely difficult to verify compliance with established goals. Therefore, passenger-oriented measures, while establishing the desired output characteristics of a transit system, cannot be used as a direct control measure. This latter measure must be equipment performance oriented--specifically addressing allowable failure frequency and duration. To maintain the proper passenger orientation, the allowable failure characteristics must be derived from or otherwise related to desired passenger delay goals.

This conclusion implies that need for a system failure model, or "off-normal" performance model which relates system failure characteristics and

passenger delay results. By exercising such a model, one can translate desired passenger delay performance goals into allowable system failure characteristics. These latter values can then be used as the primary control measures during system design and operation. Deriving and defining these models has been a high activity area for the last few years. Many forms, in various stages of development, can be found in the literature.

With certain liberties, these models can be classified into three types:

Type I. Measures of the classical availability form

$$\text{Availability} = \frac{\text{Successful time}}{\text{Total operating time}},$$

where the elements of the fraction may be expressed in terms of system hours, vehicle hours, or passenger hours.

Intended Meaning: Likelihood of being in a successful state of any random time during use.

Type II. Measures of the classical dependability form

$$\text{Dependability} = \text{probability of delay-free trip} = \text{availability} \times \text{reliability}$$

$$= \frac{\text{successful trips}}{\text{total trips}},$$

where the elements are generally computed on a per trip basis for either vehicles or passengers.

Intended Meaning: Likelihood of not incurring a delay during a given period of use (generally one trip).

Type III. Measures of the expected delay form

$$\text{Expected delay} = \text{probability of delay} \times \text{average duration of delay},$$

where the elements are generally computed on a passenger trip or vehicle-trip basis.

Intended Meaning: Average delay of a passenger on a typical trip.

Figure 2 illustrates, for a hypothetical, simple system, the impact on mean-time-between-failure (MTBF) and mean-time-to-restore (MTTR) exerted by each of these types of measures.

Within each of these categories, numerous levels of detail and complexity are represented. Each of these models may be valid for a specific system situation. However, all of these models are deficient for general applicability. On the equipment side, they do not comprehend all the system

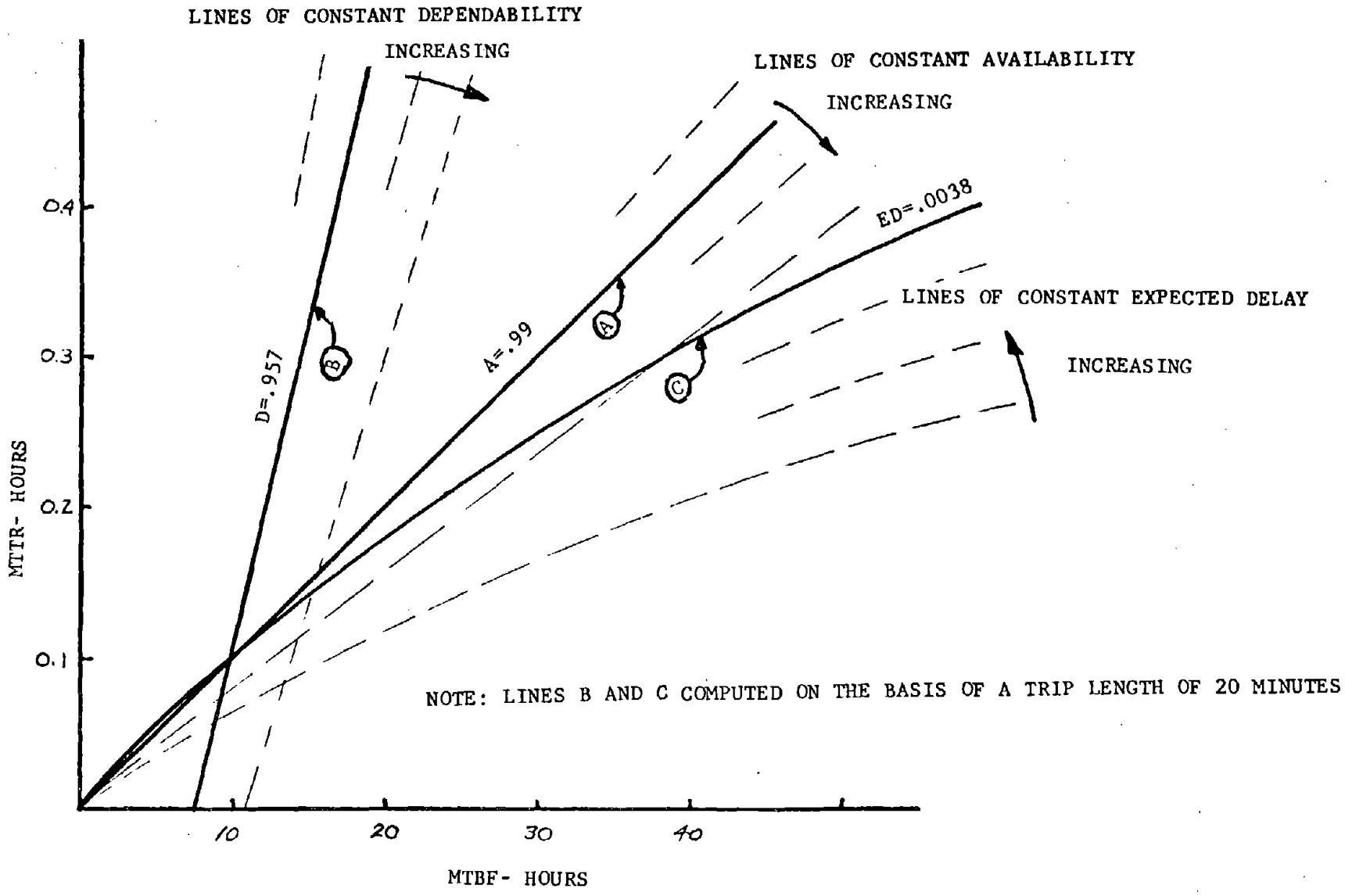


FIGURE 2. SAMPLE RELATIONSHIP AMONG VARIOUS SERVICE PERFORMANCE MEASURES AS APPLIED TO A SIMPLE HYPOTHETICAL SYSTEM

characteristics which can influence delay; and on the passenger side, they do not reflect all the types of delay criteria which may be desired.

By studying these models and the effort behind them, by examining the system performance parameters addressed, by examining the parametric alternatives which may exist in any application, and by examining the passenger delay impact of each of these alternatives, a conclusion can be reached that no single model can suffice for the range of passenger delay criteria and/or system operating and failure strategies which may exist for AGT system application.

If the conclusion cannot be supported on the basis of the alternative passenger delay criteria discussed previously, which may be imposed singly or in various combinations, an examination of the system characteristics which can influence these delay parameters will further encourage support.

(1) Failure rate - the expected number of failures in some unit of time.

(2) Failure duration - the time during which the failed state exists.

(3) Failure type - classified by the effect of the failure on the ability of the system to deliver required capacity in the vicinity of the failure. For example, failures may result in a blockage, in operations at velocities less than the normal velocity, or in operations with less than the required number of vehicles.

(4) Failure location - the location of the failure relative to the general system configuration. This is important where failure tolerance is provided.

(5) System failure tolerance - the ability of the system to limit the impact of certain failure situations by bypassing or otherwise disconnecting the failure affected area. This feature determines the extent to which a specific failure disturbs total system performance.

(6) System operation under failure - the manipulation of deployed vehicles following a failure.

(7) Passenger trip demands - in terms of the quantity of trip requests per unit time.

(8) Trip origin-destination patterns.

(9) System capacity - more appropriately, excess capacity to recover from failure.

(10) Options for introducing additional capacity to recover from a failure.

(11) Time of failure - this is not a primary variable but one where impact is reflected in all those above which are functions of time.

As implied by this list, the delay mechanism is very complex. Furthermore, the precise system performance with respect to each of these variables is system specific. Hence, the implication is that each system (for example, competing for a given application) will require its own "model" to translate its peculiar characteristics into passenger delay parameters. This process, conceptually at least, affords a maximum latitude to the system supplier in manipulating the performance characteristics of their particular systems to derive cost effective approaches within established passenger delay constraints.

From a practical viewpoint, two questions remain, however:

(1) What is involved in developing an appropriate model?

(2) Can the approach be integrated into the normal procurement/control process?

In response to the first question, in a general sense, the evaluation of each of these variables on system performance requires some form of simulation; that is, some method of imposing failures on a normally operating system and "counting" the passenger delay impacts which result. By doing this, a sufficient number of times to effectively cover the range of system variables proposed, allowable values for these variables can be derived in response to a given passenger delay criterion. For complex systems, computer simulation techniques are mandatory. For "simple" systems, however, where normal operation can be "visualized", manual techniques can be used. These simple systems consist of shuttle loops, line-haul systems, connected loops, and similar types of transit systems. It is significant that the current operational AGT systems fit this category. Furthermore, it is likely that the near future system (the Downtown People Mover Systems) will fit this category.

The second question is not so simply addressed. However, as discussed in the next section, the procurement process can function without losing control; some departure from existing procedure will be required.

THE SERVICE AVAILABILITY CONTROL PROCESS As indicated previously, traditional system performance has been specified in terms of allowable failure characteristics for system and/or subsystem. Under the service availability concept, these types of specifications would be in a form which identified an acceptable level of service (LOS) to the passengers; e.g.,

- Probability of incurring a delay on an average trip
- Probability of incurring a station delay
- Probability of incurring an en-route delay
- Probability of incurring an en-route stoppage
- Average delay associated with the previous delays

- Average delay encountered on average trip
- Cumulative number of delays expected for an average passenger over some period of time
- Cumulative delay experienced by an average passenger over some period of time
- Exclusive combinations of the above.

The precise form and value of the service availability criterion are Buyer's decisions--based on his goals and insight into passenger expectation and sensitivities.

When the Buyer selects these passenger delay criteria, he chooses a specific degraded level of service which he has determined to be acceptable to the system passengers during those times when the AGT system is experiencing abnormal operation.

During the process of establishing the service availability specification, the simplified analysis* can be used to judge the reasonableness of the specific values selected. However, these analyses require information regarding the specific operating and failure characteristics of the system being analyzed--information which will only be available upon receipt of the proposals during the next phase of the AGT system's life. Therefore, to test the reasonableness of the service availability specification requires that the Buyer make educated assumptions for the unknown system parameters, based on his general knowledge of the range of specific system characteristics available or anticipated.

Only after receiving the proposals from the Suppliers can the Buyer assess whether or not a Supplier's proposed system meets the service availability requirements. To do this requires that the Supplier provide, in his proposal, all information necessary to perform detailed analyses. This requirement for information must, therefore, be a part of the Performance Specification, together with an explanation of how the information will be utilized to evaluate conformance of the proposed system with the specified service availability measure. This information should include a general operating scenario in which the Supplier describes the normal operating characteristics of his proposed system together with a general discussion of perturbations; i.e., off-normal performance, due to failures. Included would be a discussion of failure management strategies and other special characteristics of his proposed system to enhance service availability. Additionally, the Buyer should request a summary failure mode and delay effect analysis (FMDEA). This analysis provides the "data" required for evaluating the service availability aspects of the proposed system. The FMDEA should list the following for each "aggregate failure mode":

(1) Brief identification of the failure mode

* A methodology for assessing delay characteristics for simple systems was developed during Contract No. DOT-TSC-1283. It has yet to be tested with real-world data, however.

(2) The type of failure, for example

(a) Failures which cause vehicle to stop
(b) Failures which cause vehicles to proceed at reduced speed
(c) Failures which require the system to operate with a reduced number of vehicles

(3) The effect of the failure on the operating capability of the system

(4) The effect of the failure on the passenger-trip service capability of the system (e.g., which trips are affected by the failure)

(5) A mean duration of the failure

(6) The predicted failure rate.

After evaluating the proposals for all aspects of the system, the Buyer selects a winner and a contractual agreement is drawn up. This contractual agreement will not include requirements to prove conformance to the passenger service availability requirements of the Specification. Rather, the equipment and/or system MTBF and MTTR criteria submitted by the Supplier in the proposal will be the criteria used in the contract for system acceptance. This provides for a clear and workable set of acceptance values which can be verified during system testing. The process involved in arriving at these acceptance values assures the Buyer that if the equipment meets the MTBF's and MTTR's, the system will perform as he desires from the standpoint of passenger level of service.

PAPER 7

Independent Study of Personal Rapid Transit

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INDEPENDENT STUDY OF PERSONAL RAPID TRANSIT

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ABSTRACT. This paper summarizes the findings of an Independent Study of Personal Rapid Transit (PRT) conducted by the Aerospace Corporation for UMTA. PRT findings included a review of existing hardware and software systems - Aerospace, CVS, Aramis, Cabtrack and Cabintaxi - for applicability to future American PRT systems. Also, environmental and energy impacts of PRT were estimated and compared with alternate forms of AGT and conventional urban transportation modes using data on energy consumption by type of fuel, land use needs, visual intrusion, air pollution emissions and noise burden. A general methodology demonstrating the feasibility of PRT deployment in an urban environment was defined and applied to the Los Angeles basin area. The Los Angeles basin area study included service, cost, dependability and growth characteristics of PRT systems. Areas where research and development are required to make a future PRT system deployment feasible are described, and an approach to fulfill the noted technology shortfalls is provided.

INTRODUCTION

This presentation summarizes a part of the work performed by The Aerospace Corporation in the "Independent Study of Personal Rapid Transit," UMTA-CA-06-0090-77-1. The study included the following four categories:

1. Review of Available Technology
2. Environmental and Energy Impact Study
3. PRT Deployment Requirements Study
4. Research and Development Activity

Category 3, PRT Deployment Requirements Study, outlined in full below, was discussed only in part due to the time limitations of this paper.

a. Define a general methodology for establishing the feasibility of a PRT system deployment in a given area.

b. Demonstrate the planning methodology application to a specific urban area.

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c. Investigate means of reducing fleet size and improving peak period performance by adjustment of service policy.

d. Study the effects of reliability on systems performance.

Part (a) of Category 3 was included because of its general interest. The planning methodology used relied on computer simulations data developed over the years at Aerospace. Additional subjects considered include network configuration, patronage analysis, system economics, dependability, and evolutionary growth potential related to a typical PRT system application in the Los Angeles basin area.

AEROSPACE

The Aerospace version of Modal-Split Analysis is unique in that a Monte Carlo Simulation Technique is used, utilizing a traveler tape which provides discrete location of thousands of travelers together with income and car ownership by zone.

The method assigns the traveler to modes on the basis of a cost function that includes access time, waiting time, travel time, and traveler preferences in addition to out-of-pocket cost. Because the individual traveler is simulated, his exact origin/destination is known, which allows the determination, in detail, of the entire door-to-door trip.

A significant advantage of this program is that random samples from probability distributions rather than averages are employed for travelers' attributes, and this technique results in a much more realistic population of simulated travelers.

Figure 1 presents an overview of how this Monte Carlo modal split simulation is used to analyze the patronage of a PRT system. One type of input to the simulation model is interzonal data consisting of the number of trips from each origin zone to each destination zone, and distances and travel times by auto between the centroids of the zones. A second type of input is data about each zone specifying its location and shape, the income of travelers originating from the zone, and parking costs for travelers whose destination is within the zone. The third basic type of input relates to characteristics of the PRT system, such as where the stations are located, the travel times between stations, the fare structure for the PRT network, data regarding station access, and waiting and processing times. These three types of inputs feed the Monte Carlo modal split simulation program. The program outputs include modal split, average demand at and revenue from individual stations, and statistical descriptions of which travelers take PRT, which do not, and what factors affect their choices.

Aerospace has developed a PRT Analysis System, Figure 2, which uses the Modal-Split Analysis in conjunction with a number of other programs to furnish guides to the implementation and assessment of alternate PRT networks for urban areas.

In the case where origin and destination demand is predicted, Program GENOD is used in place of the Modal-Split Analysis (MDS). This program

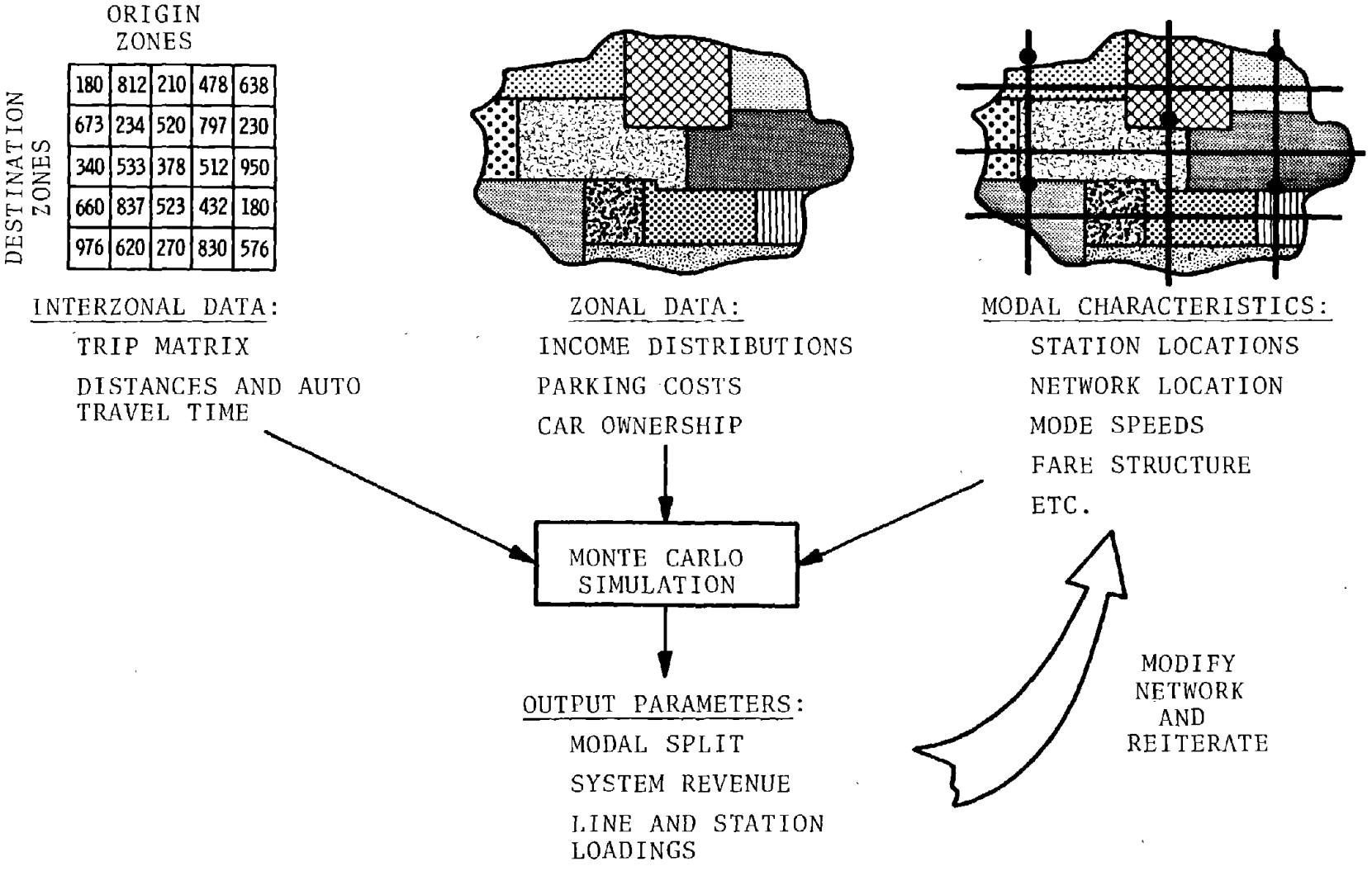


FIGURE 1. INTRA-URBAN MODAL SPLIT MODEL

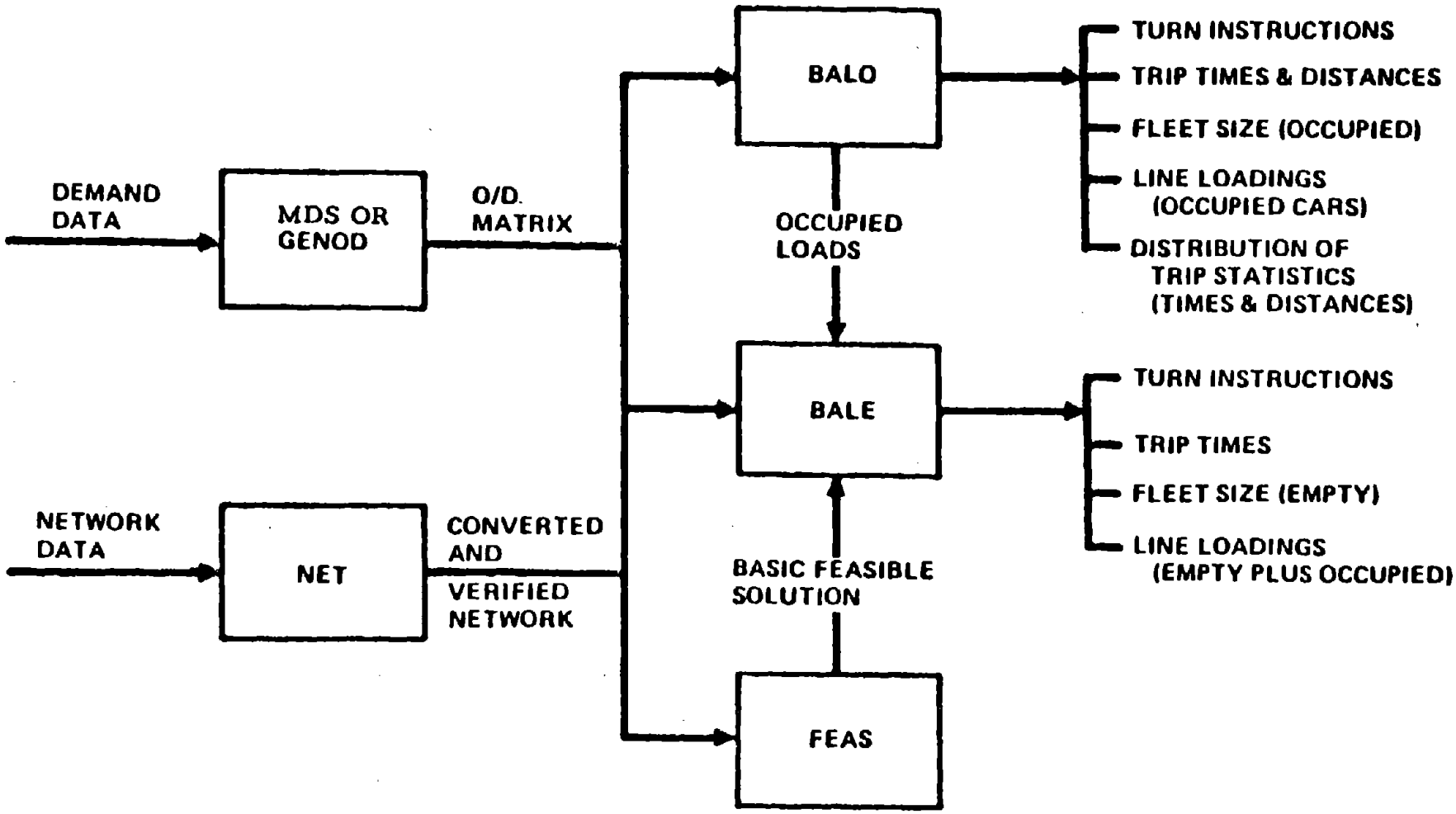


FIGURE 2. PRT ANALYSIS SYSTEM

accepts as input the total number of trips originating at each station in the PRT network as well as the total number of trips reaching destination at each such station in the network and generates an origin/destination matrix.

The NET program accepts as input a detailed description of a PRT network and line speeds, performs a number of validity tests on the data describing the network, and constructs various tables that are used by other parts of the analysis. Upon successful execution of Program NET, the network description tape from NET and the origin/destination tape from Program GENOD or MDS are used by Program BALO to achieve optimal (minimum time) routing of occupied cars (as opposed to the empty cars) consistent with non-overloading of any of the nodes. A major subroutine of this program ROUTE which has been designed in such a way that computation time for minimum-time paths for very large networks is extremely rapid. The method whereby the loads are balanced on the network to avoid overloading of any nodes is to apply a penalty time which is proportioned to the loading of a node. This penalty is added to the transit time for the node and is used as an increased time by Subroutine ROUTE which alters the optimum paths in such a way as to unload those nodes which are approaching overloaded conditions. This penalty is merely a device for changing paths and is not included in the actual times.

Program FEAS is run concurrently with program BALO utilizing the same network tape from Program NET and the O/D tape from Program GENOD to derive a basic feasible solution for the empty vehicle routing problem to be used by Program BALE in obtaining an optimum solution for the routing of empty vehicles.

The basic requirements for a PRT installation to be studied are summarised in Figure 3.

The Los Angeles Basin area, comprised of Los Angeles and Orange Counties, is a broad area which by 1990 is expected to contain a population of 9,925,000 and to generate nearly 32 million person-trips per day. The area is heavily automobile-dependent; about 97% of all trips are presently being made by that mode, and the urban freeways exhibit marked congestion during peak hours. All of these characteristics make the Los Angeles Basin a logical urban arena in which to illustrate the application of PRT planning methodology.

The corridor containing Wilshire Boulevard and extending from Santa Monica to the Los Angeles Central Business District (CBD) has been singled out in past studies as a high-density, high-employment region which the Los Angeles City Planning Department estimates will experience travel flows of about 40,000 persons per peak hour in 1990. The corridor also contains major universities as well as several activity centers which have been singled out for future growth by the Los Angeles City Planning Department. Six major freeways access the corridor/CBD from various directions, and it was decided to investigate a PRT network consisting of a grid covering the corridor together with a series of radial feeder lines located on selected freeways which would permit widespread access and could tend to reduce freeway congestion.

It was assumed that approximately a 364-mile PRT system could be realized, based on extensive cost analysis completed at Aerospace.

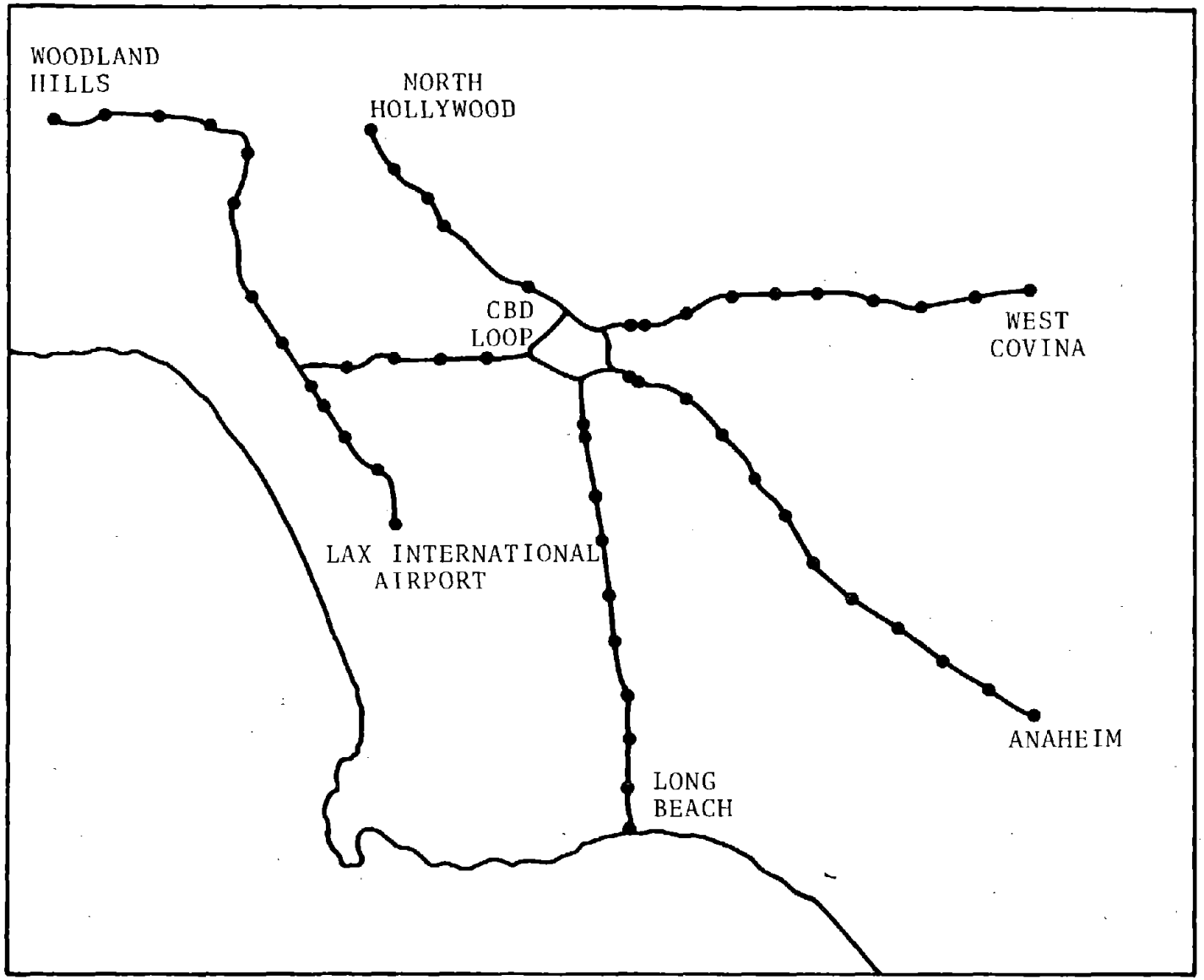


FIGURE 3. LOS ANGELES CBD NETWORK AND STATION LOCATION

Study of the Los Angeles area showed that about two hundred and eight miles of one-way radials would be required to connect the Los Angeles CBD periphery to the areas of Woodland Hills, North Hollywood, West Covina, Anaheim, Long Beach, and International Airport. Hence, about 165 miles of guideway were available for networking the Wilshire Corridor and the Los Angeles CBD.

Demographic and cartographic data were then utilized to design the initial corridor and CBD network and station locations shown in Figures 3 and 4. The network illustrated in Figure 4 contains 108 one-way miles in the corridor and 46 miles in the CBD, making a total of 362 guideway miles.

Stations in the Santa Monica/Wilshire corridor grid were located as near to employment centers or high density dwelling complexes as practicable, with separations averaging about 1/2 mile to permit reasonably short walking access times. Radial station spacing was nominally set at two miles, and parking structures were predicated at each radial station.

An on-site inspection of the selected alignment indicated that initial design assumptions appeared reasonable. The initial system had 194 stations in the Wilshire Corridor, 61 in the CBD, and 51 dual stations on the radials. The assumed speed for most of the corridor/CBD network was 30 feet/sec. The Wilshire-Olympic loop speed was assumed, nominally, as 60 feet/sec, as was the speed on all radials, since this permits trip times competitive with automobile trip times.

The Santa Monica/Wilshire Corridor network shown in Figure 4 connects a number of recognized activity centers, education facilities, and recreational centers. It also represents an intensive and expanding employment region.

Data were obtained on the number of trips destined to each city block, based on existing and planned office space, and these data were used to distribute stations to meet the capacity requirements in each subregion of downtown. The assumed PRT speed for the CBD was 30 ft/sec or about 20 mi/hr. At this speed it is possible to make a coordinated banked turn within the confines of available street widths. With the line speed and station capacity requirements known, platform and siding lengths were obtained, and it was seen that the siding lengths limited the proximity of neighboring stations. To obtain sufficient distributed capacity for the assumed patronage, it was found that a majority of the streets would need one-way PRT lines.

It was noted that if full grade-separation were provided at every intersection of two streets containing PRT lines, the turn ramps (and intersection maneuvering regions on the main lines) would occupy a significant fraction of the linear space and would tend to restrict the space available for station sidings.

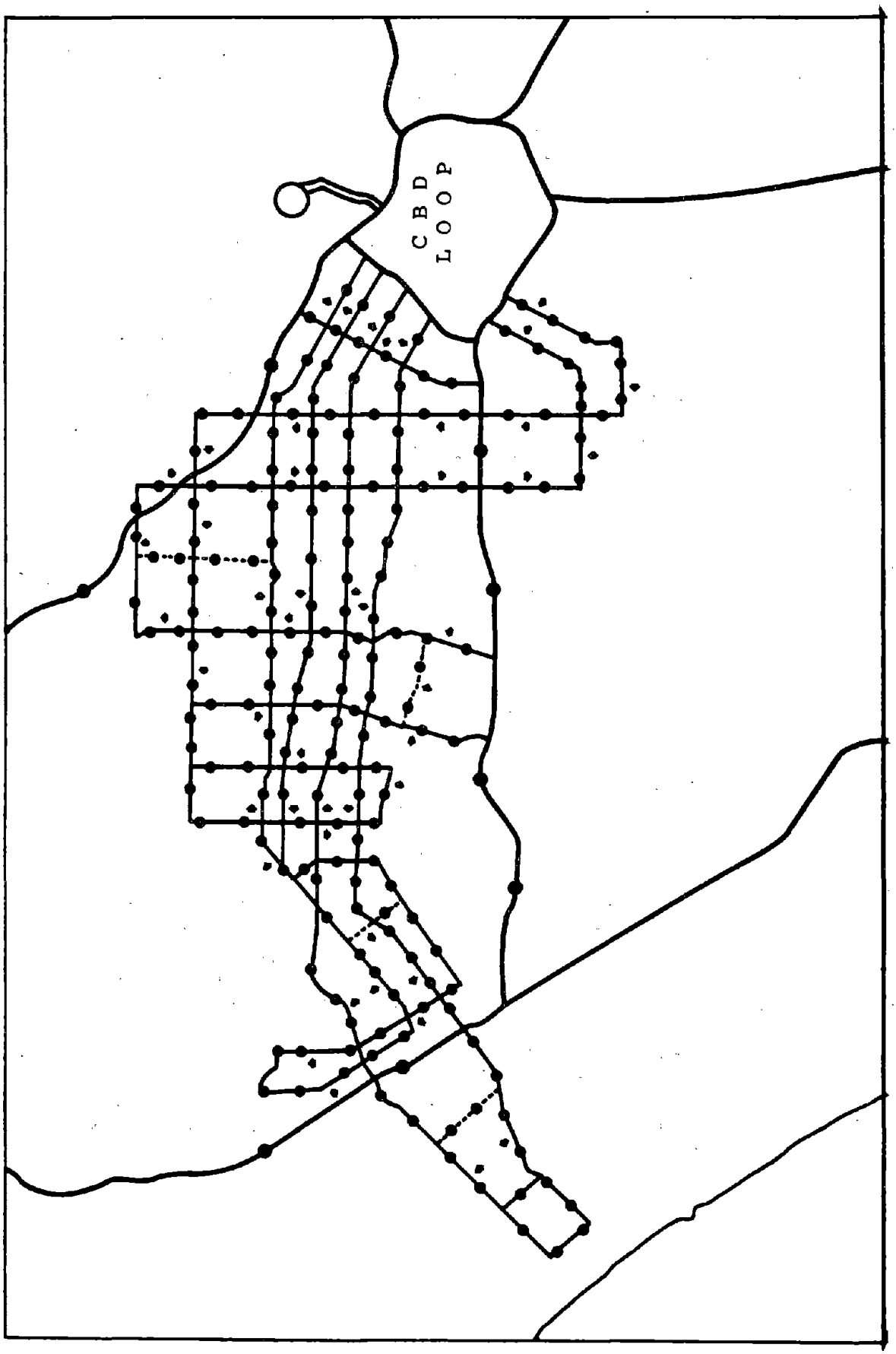


FIGURE 4. SANTA MONICA/WILSHIRE CORRIDOR ALIGNMENT

PRT stations were placed at three parking lots in the downtown area -- at Dodger Stadium, the Convention Center, and Union Station. In addition, there are 58 other downtown stations which, with one exception, are all located along the north-south streets, since these streets have longer blocks. Lines on east-west streets, with short blocks, merely serve as feeder lines to stations.

On the incoming radial lines shown in Figure 5, the line speed is assumed to be 18.2 m/s (about 40 mi/hr), but each line splits up into two 9.1 m/s lines as it approaches the CBD. Each of the utilized east-west streets carries two lines in the same direction, which are assumed to be supported on the same columns, and which have frequent transitions between the two. This is illustrated by showing that the whole network could be constructed at one level without grade-separated crossings. However, a north-south through trip would then be quite tortuous, so a few grade-separated intersections were utilized to facilitate north-south traffic flow.

It is of interest to note that the CBD network is largely at one level and permits easy integration with some planned pedestrian bridges.

The L.A. CBD network described above was utilized, with minor alterations to permit integration with the Wilshire/Santa Monica grid, as the initial downtown system in the present study.

The extensive data base obtained from LARTS,[1] was transformed into formats appropriate for use by the Aerospace PRT modal split program (MDS). The 32 million daily person-trips projected to be made in Los Angeles and Orange Counties in 1990 were screened by a criterion that at least one trip end by within 1/2 mile of the PRT network. This screening produced 10.5 million trips generated by potential PRT patrons, as shown in Table 1.

In order to minimize computation time, a 200,000 trip statistical representation of the 10.5 million potential PRT trips was developed.

As shown in Figure 6 major system variables of fare structure and radial line speed were exercised as independent variables in the modal split simulation to permit parametric insight into impacts on patronage, revenue, and fleet size requirements. Other variables, such as access mode costs, were held constant at established levels in the interest of economy of simulation. Still other variables, such as perceived auto travel cost and availability of kiss-and-ride access, were briefly perturbed to establish the sensitivity of the simulation results to these costs.

A total of twenty simulations were completed, and the general results are summarized in Table 1. All modal split results from the fifth line down have been scaled to account rationally for the fact that those runs had originally

[1] Los Angeles Regional Transit Study, CALTRANS

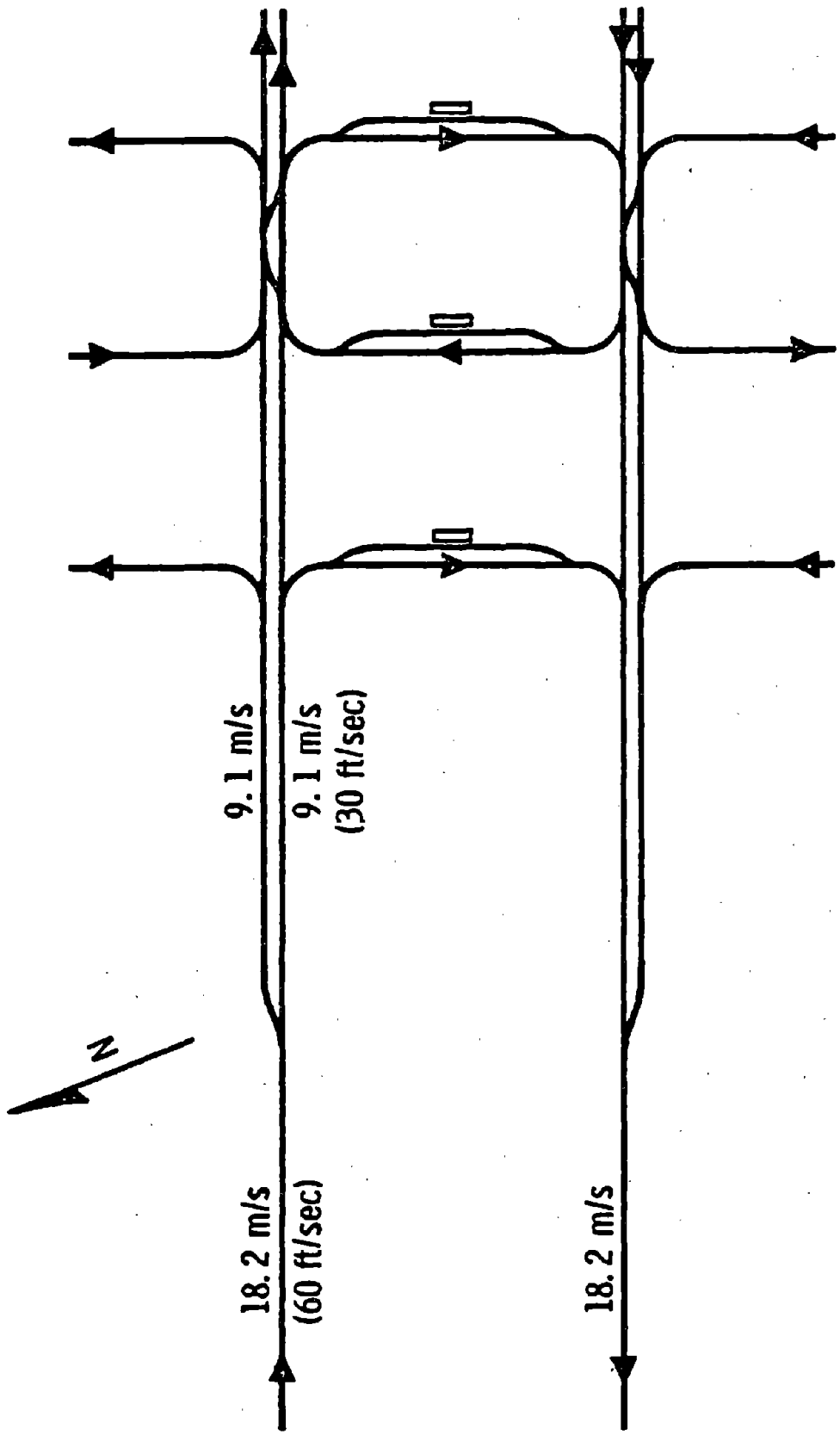


FIGURE 5. CBD INCOMING RADIAL LINES

TABLE 1. PRT MODAL SPLIT SIMULATION RESULTS (LOS ANGELES NETWORK)

TABLE

PRT MODAL SPLIT SIMULATION RESULTS
(LOS ANGELES NETWORK)

Fare Structure ($/Trip)	Line Speeds Net/ Radial (MPH)	Travel Period (Special Condition)	Feeder Parking Charge ($)	Average PRT Trip (Mi.)	Average PRT Speed (Mi/Hr)	Average PRT Time (Min)	PRT Modal Split (%)**	Patronage (10^6 persons) ***	Average Fare Rate ($/Mi.)	ORIGIN ACCESS				Revenue ($/Yr)	O&M Cost ($/Yr)	TOTAL ROUND TRIP COST			
										DAP (%)	KAR (%)	Walk (%)	DAR (%)			$/Trip: PRT Users		$/Trip: Auto Users	
																PRT	AUTO	PRT	AUTO
.25+.07(L-3)*	20/40	24	0	9.24	33.0	16.8	13.7	1.44	.074	75.1	20.7	3.0	1.2	214×10^6					
.25+.07(L-3)	20/40	24	1	9.29	33.0	16.9	12.6	1.33	.074	45.4	46.5	3.9	4.2	227×10^6					
.30+.03L	20/40	24	0	11.02	34.5	19.2	13.9	1.47	.06	78.4	17.6	2.7	1.2	176×10^6		4.22	6.47	6.30	2.92
.30+.06L	20/40	24	0	9.94	33.6	17.8	11.4	1.20	.09	78.3	17.9	2.5	1.3	217×10^6	165.4×10^6	5.15	7.45	6.68	2.68
.30+.09L	20/40	24	0	9.40	33.2	17.0	9.6	1.01	.12	79.4	16.6	2.5	1.5	242×10^6		5.53	7.69	6.85	2.77
.30+.03L	20/40	24	1	11.00	34.3	19.2	12.3	1.30	.06	44.0	47.4	3.8	4.9	189×10^6		4.82	6.45	6.73	2.60
.30+.06L	20/40	24	1	10.00	33.5	17.9	10.5	1.11	.09	47.0	45.1	3.4	4.5	229×10^6		5.31	7.47	7.04	2.76
.30+.09L	20/40	24	1	9.44	33.1	17.1	8.9	0.94	.12	49.8	42.3	3.2	4.6	255×10^6		5.70	7.69	7.29	2.82
.30+.06L	20/60	24	0	10.78	45.8	14.1	12.4	1.31	.09	78.8	17.8	2.3	1.2	234×10^6	278×10^6				
.30+06L	20/60	24 60 mph radials	1	10.82	45.6	14.2	11.3	1.19	.09	46.6	45.8	3.2	4.4	245×10^6	278×10^6				
.30+.03L	20/40	24 60 mph radials Peak-Pk Hr	0	11.2	34.7	19.4	28.9	.30	.06	85.3	12.9	1.0	0.9			5.26	8.38	7.19	3.60
.30+06L	20/40	Peak-Pk Hr	0	10.7	34.3	18.7	24.7	.26	.09	85.4	12.5	1.0	1.1			5.73	8.71	7.40	3.76
.30+.06L	20/40	24 (No KAR)	0	7.01	31.7	13.3	17.5	---	.09	78.8	0	21.2	0.8						
.30+.06L	20/40	24 (No KAR)	1	7.35	31.3	14.1	16.1	---	.09	69.4	0	27.1	3.4						
.30+06L	20/40	24 11¢/mi. auto)	1	9.85	33.4	17.7	10.1	---	.09	48.6	45.9	1.5	3.9						

*L = trip length, miles

**For all 24 period data, the base = 10.54×10^6 person-trips/day

For all peak-peak period data, the base = $1.[illegible] \times 10^6$ person trips/peak-peak hour

***Based on SCAG-76 population projection for 1990

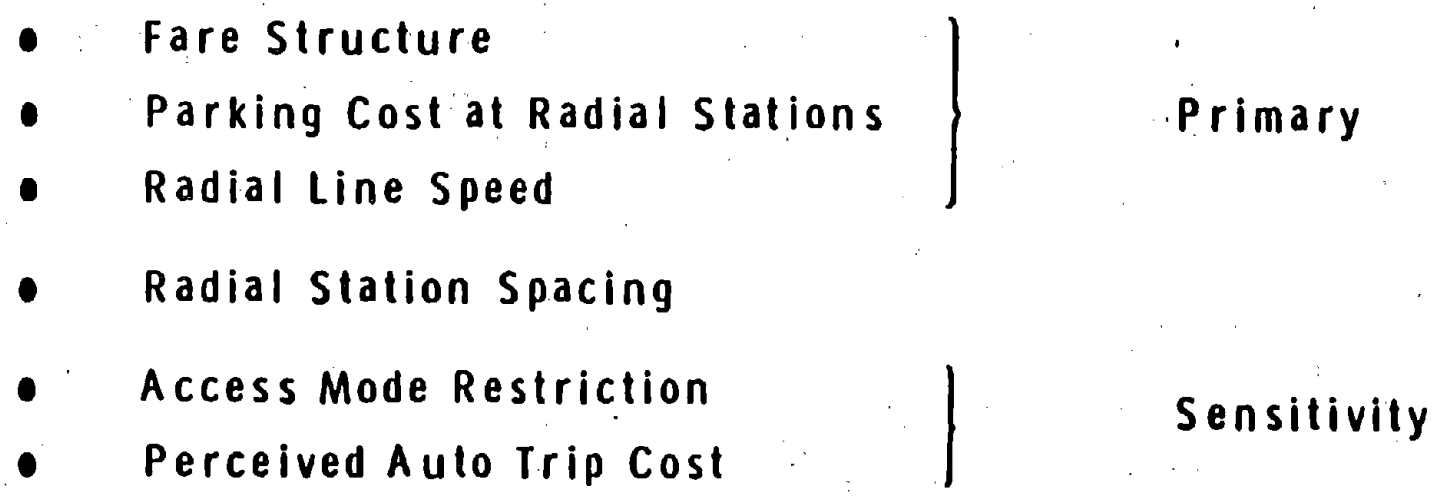


FIGURE 6. SIMULATION INDEPENDENT VARIABLES

included the assumption that all auto parkers in the CBD TAZs paid the full, all-day TAZ parking charge. A multiplying factor of 0.84 was derived by ratioing those original results with results in which the only input change was the assumption that 25% of the parkers paid the full daily charge and 75% paid one fourth that charge, reflecting the fact that most shopping and government facility trips require parking stays of less than two hours.

Most simulations involving fare structure variations were run with both free parking and $1/day parking at the radial station parking structures. This was done to establish the difference in patronage between the two cases and to define the expected revenue increment which might be used to attract private operation of the facilities.

The effects on patronage and system O&M cost of variations in radial line speed were also simulated, and the results are summarized later in this briefing.

Due to lack of peak-hour travel data the PRT analysis program, which was discussed earlier in this briefing, was run only to define the required original destination trip time material. Hence, the required peak-hour fleet size was estimated, as summarized in Table 2, to be about 57,100 occupied vehicles. The related occupancy of the assumed fifteen foot slots would be less than 50%, which is acceptable for traffic management.

According to simulation results, the West Covina radial appears to be the most heavily loaded for the peak hour design case. The heaviest patronage was experienced with the fare case (.3 + .03 x L) dollars per trip length of L miles. The station platforms are seen to range from 33 ft to 99 ft in length, as in Table 3.

As noted earlier, LARTS personnel report that cordon checks show about 70% of peak AM traffic to be inbound, and this ratio has been used to obtain the headway requirements shown in Table 3. Fractional second headway capability is seen to be required on the typical feeder link.

The two stations exhibiting the highest throughput rates are #266, located at the Hollywood Freeway and Magnolia Avenue; and #276, located at the 405 Freeway and Century Boulevard. These throughputs, as in Figure 4, are

$$\frac{1.72 \times 1,459}{1.3} = 1,930 \text{ and } \frac{1.72 \times 1,316}{1.3} = 1,741$$

vehicles per hour, respectively. These stations would require platforms accommodating over 20 berths.

The maximum parking demand for each radial feeder line station is summarized on Table 3 for the peak-peak hour case. The fare case (0.3 + .03 x L) dollars per trip, together with free parking represents the critical design case. Simulations show that imposition of a nominal one dollar parking charge tends to reduce parking demand by about a factor of 60%, and this effect is applied in the Reduced Demand column of Table 4. An estimate of maximum parking facility size, furnished by Column 4 of the table, is based on a requirement of 590 square feet per parking space. It can be seen that, even

TABLE 2. FLEET SIZE FOR L.A. EXAMPLE NETWORK

H-W PRT vehicle trips per five hour peak period =
(Peak hour H-W PRT trip modal split) x (H-W PRT trips per five hour peak period) ÷ (Average H-W trip party size) =

$$\frac{.289 \times 1.40 \times 10^6}{1.15} = .350 \times 10^6$$

Non H-W PRT vehicle trips per five hour peak period =
(PRT peak hour non H-W trip modal split) (Non H-W trips per five hour peak period) ÷ (Average non-H-W trip party size) =

$$\frac{.100 \times 2.70 \times 10^6}{1.70} = .159 \times 10^6$$

Total PRT vehicle trips in average peak hour =

$$(.350 + .159) \times 10^6 = 102{,}000$$

Absolute local peaking factor (LARTS) = 1.28

& $1.28 \times 102{,}000 = 130{,}600$ PRT vehicle trips in Peak-Peak Hour

70% inbound and 30% outbound at peak hours (LARTS)
So $130{,}600 \times .70 = 91{,}400$ to be handled inbound one way.
Simulation shows average peak-hour trip speed and length to be 34 MPH and 22 round trip miles or $\frac{34}{22} = 1.6$ round-trips per hour.
Basic fleet size = $\frac{91{,}400}{1.6} = 57{,}000$ vehicles: (62,700 vehicles including 10% spares)
This results in $\frac{57{,}000}{362}$ vehicles per mile ÷ $\frac{5280}{15}$ fifteen foot slots per mile = 45% slot occupancy.

TABLE 3. CRITERIA USED TO ESTABLISH AVERAGE HEADWAY REQUIREMENTS

Station Number	Station Throughput Vehicles/Hour		Station Size** (Eleven Foot Bay Length)	Vehicle Departures Per Hour		Accumulated Link Flow Rate Vehicles/Hr.	Average Headway Per/Veh. (Seconds)
	Simulated (Based on 10^5 sample)	Scaled*		Simulated (Based on 10^5 sample)	***Scaled		
305	827	1092	9	730	675	675	5.33
304	334	441	5	289	267	942	3.82
303	198	261	3	130	120	1062	3.39
302	508	671	5	407	376	1438	2.50
301	494	652	5	391	361	1799	2.00
300	578	763	7	499	461	2260	1.59
299	741	978	8	607	561	2821	1.28
298	645	851	8	465	430	3251	1.11
297	819	1081	9	616	569	3820	0.94
				771	712	4532	0.79

Typical Radial Feeder Station Characteristics (West Covina Feeder)
(Peak-Peak Hour Case): Fare = .(3 + .03 x L) $ per trip of length L.

* 1.3 persons per vehicle; 1.72 person trips per simulated person trip.

** Based on Figure 3-23

*** Assuming 70% of departures have destinations in network.

TABLE 4. SUMMARY OF MAXIMUM PARKING DEMAND

Radial Station (Station number for maximum parking)	Maximum Demand (Free parking)		Reduced Demand (1$ Parking charges)	*** Typical Structure Sizing Stories & 60,000 ft^2 per story (Based on $1 fee)
	Simulated Parks/hr (10^5 sample	*Scaled Parks/hr	** Scaled Parks/hr	
Long Beach (279)	480	635	298	3 Stories
West Covina (305)	679	898	421	4 Stories
Orange (296)	703	938	439	4 Stories
West S. F. Valley (268)	688	910	426	4 Stories
East S. F. Valley (266)	1186	1569	734	7 Stories
Santa Monica (111)	448	593	278	3 Stories
LAX (276)	1005	1330	622	6 Stories

Maximum Radial Feeder Line Parking Structure Requirements

(Peak-Peak Hour Case)

* Scale factor = 1.72

** Scale factor = 1.72 x 0.60

*** 590 ft^2/parking slot assumed

1.3 persons per vehicle, average

with a one dollar parking fee, the nominal parking structures are not inconsequential. Large multiple story structures would also be needed near the East San Fernando Valley station #266 and Los Angeles International Airport station #276.

The fare was computed by multiplying the fixed cost rate, F, by the average trip length (about ten miles) and then adding a variable cost rate, V, times the trip length L. Thus the fare formula used in the modal split simulations was (10 x F + V x L) cents per occupied vehicle trip of length L miles, with F taken as 3¢ and V taken as 3¢, 6¢, and 9¢ per mile.

The variation in average fare rate with trip length is shown in Figure 7, which also shows the range of average trip length derived from the simulations. The mileage rates shown on the curves are based upon a ten mile average trip length, and all of the fare structures shown would appear to inhibit short trips while favoring trips longer than about five miles.

The nominal PRT fare structure was determined so as to at least permit the recovery of the nominal system operating costs. Based on 357 station platforms, 362 guideway miles, 155 operating vehicles per mile,* 33 miles-per-hour average speed,* 3¢ per KWH electric costs, 20 mph corridor speeds and 40 mph radial speeds, and the operating cost data derived in UMTA-CA-06-0071-76-1, an annual operating cost of about 165×10^6 dollars was developed. As shown later, this equates to about 6¢ per occupied vehicle mile.

The annual estimated operating and maintenance cost associated with the Los Angeles PRT system under study is summarized in Table 5.

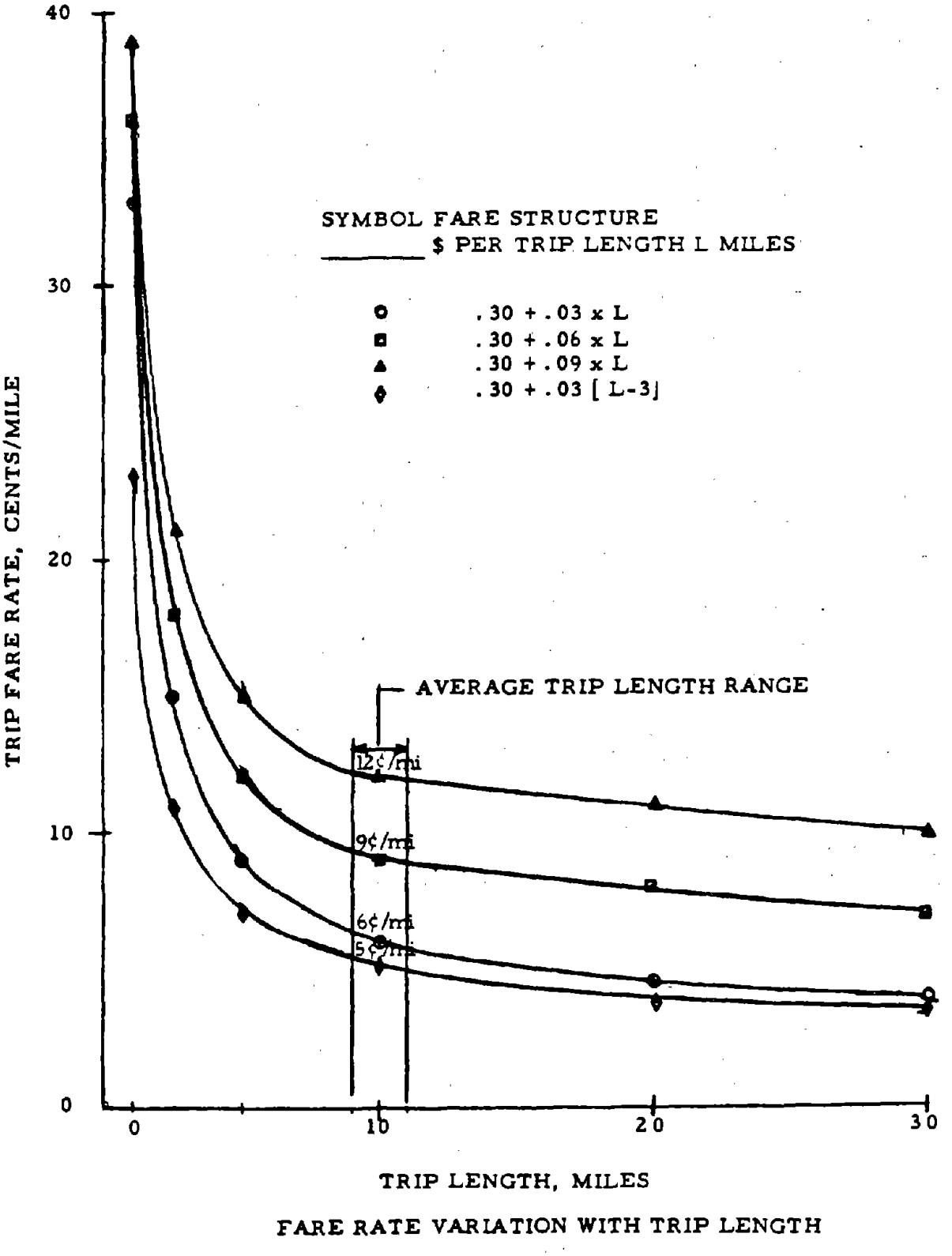
The details of the estimate may be found in Section 2.2 of report UMTA-CA-06-0071-76-1. "Personal Rapid Transit Research Conducted at The Aerospace Corporation."

Major indicators of service quality are the PRT modal split and the number of PRT patrons per day. The variation of these indicators with average (ten mile)** trip fare rate is shown in Figure 8 for the cases of free and one dollar charges for radial parking. Doubling of the fare rate from six cents to twelve cents per mile is seen to reduce passenger service by about 30%. The difference between the PRT trips for the two parking charges becomes less at the higher fare rates probably because the one dollar parking charge becomes a smaller fraction of the perceived round trip cost at the higher rates. Increasing the radial line speed from 40 mph to 60 mph is seen to have a significant positive fleet patronage, but, as will be shown later, the attendant increase in power cost has an adverse impact on system economics in this case.

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*Derived from initial simulations.

**Averaged from simulation results.



FARE RATE VARIATION WITH TRIP LENGTH

FIGURE 7. FARE RATE VARIATION WITH TRIP LENGTH

TABLE 5. O&M COST ESTIMATE

O&M Cost Estimate

L. A. 362-Mile PRT Network (350 Stations)
Case: Fare = 0 + .3 + .03L $/trip of L miles

(Estimate Based on Section 2.2 of Ref. 3-2)

Assumptions: electrical energy cost = 3¢/kwh, propulsion efficiency = .75, 155 operating vehicles/mi, 80% vehicle miles at 40 mph and 20% at 20 mph, 8 operating hours/day, 300 operating days/year, 1976 dollars, 125% empty factor

	$/Year/Guideway Mile
• Fixed Costs	
- Guideway	11,847
- Stations	15,630
- Electronics	60,442
- Staff	15,443
TOTAL	103,362
• Variable Costs	
- Electrical Energy	201,696
- Vehicle Cleaning	16,740
- Vehicle Maintenance	67,630
- Facility O&M	7,580
- GA & O	59,550
TOTAL	353,196
• GRAND TOTAL	457,000

• ANNUAL O&M COST $\$165.4 \times 10^6$ for 362 mile system
(not including radial parking structure operation of ~ 5×10^6 $/year)

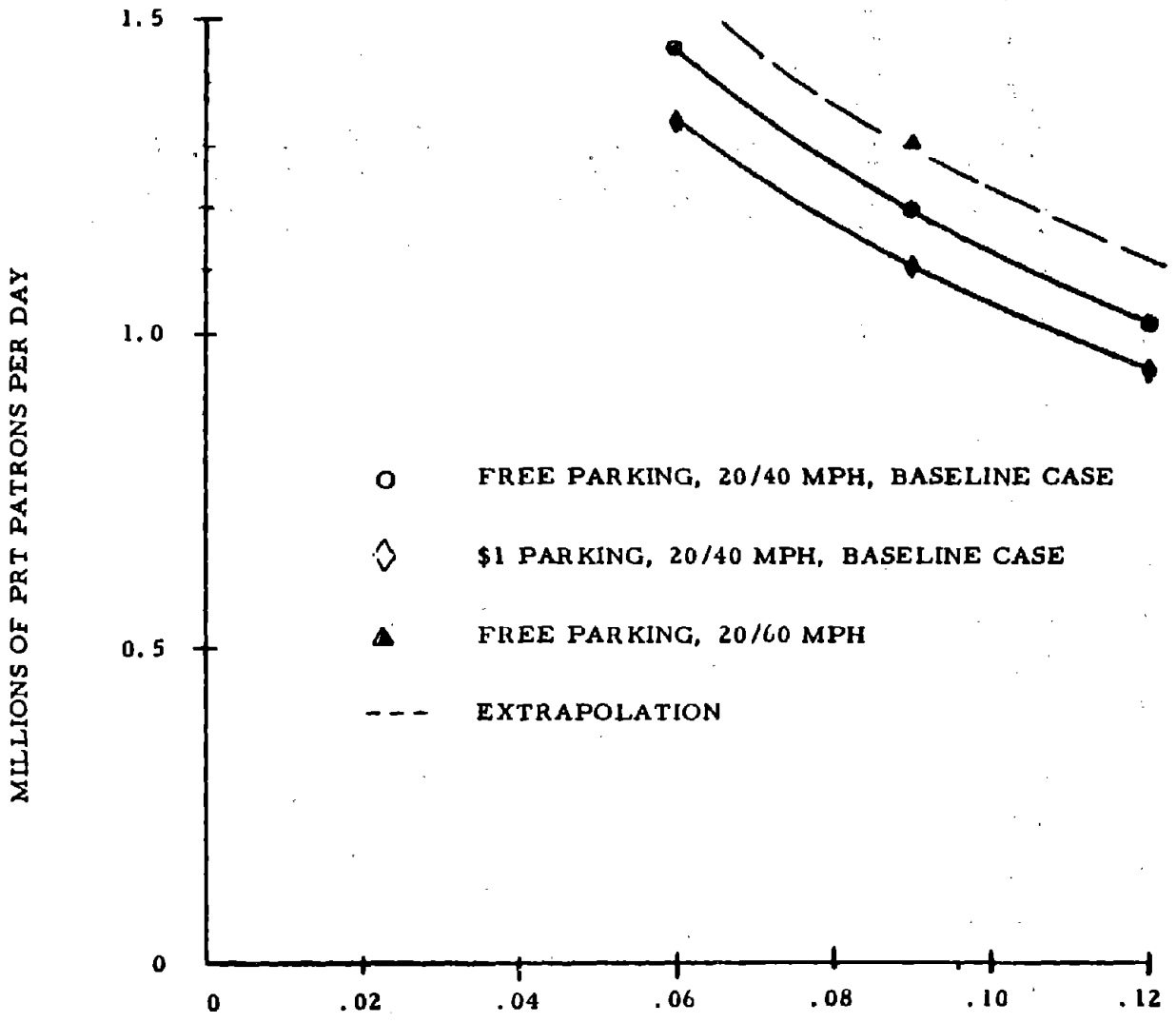


FIGURE 8. EFFECTS OF FARE RATE & RADIAL LINE SPEED ON PRT PATRONAGE

The effects of radial line speeds on annual revenue and O&M cost are shown in Figure 9. From the standpoint of considerations involved in planning a PRT system deployment, information of the type summarized in the figure furnishes great insight into the potential economic viability of the system in a given urban area.

The solid lines show the variation in annual revenue with average trip fare rate. It is evident that for average fare rates above about 9 cents per mile the decrease in patronage is greater than the increase in revenue, and the revenue is apparently maximized at about the twelve cent average fare rate.

It may be seen that the imposition of a ($1) parking charge at the radial station parking structures results in a small positive increment of total revenue even though the parking charge reduces system patronage by about nine percent. (The parking charge also cuts down on parking demand thus simplifying parking structure implementation.)

Of particular significance is the fact that the annual revenue derived from the cited forty mph radial line speed operation exceed the total annual operating and maintenance (O&M) costs for all fare rates greater than approximately five cents per occupied vehicle mile (OVM). It is noteworthy that this is the case even though no detailed optimization of guideway and station emplacements was accomplished through iteration of the simulations. A further indication of the flexibility afforded the PRT deployment planner is evident from the revenues shown with the square symbols at the 7.4 cent per mile fare rate, which were derived by simulating a fare structure of the $C_1 + C_2$ (L-3) form. The noted improvement in revenue over the fare structure ($C_1 + C_2$ L), upon which the solid lines are based, indicates that additional analysis and optimization of fare structure could be of considerable value.

Shown on the Figure 9, at the 9 cent per mile fare rate are two points representing revenue based on operation at sixty mph (as contrasted to the nominal forty mph) radial line speed. The attendant decrease in trip time appears to attract about an additional 9 percent of patronage, compared to the nominal forty mph radial speed, but the extrapolated dashed line shows that revenues would not be expected to break even with O&M cost for fare rates below 11 cents per OVM.

The relationship between revenues and total O&M costs in terms of radial line speeds in illustrated in Figure 10 for a specific fare structure of a nine cents per mile average rate. An excess of revenue over cost is predicated up to radial speeds of about 55 mph. A nominal radial line speed of about 45 mph would probably be selected in terms of good balance between service and discretionary revenue.

Section 4.2 of the report UMTA-CA-0071-76-1[1] contains a detailed discussion of design concepts for the attainment of PRT reliability levels from

[1]Personal Rapid Transit Research conducted at The Aerospace Corporation.

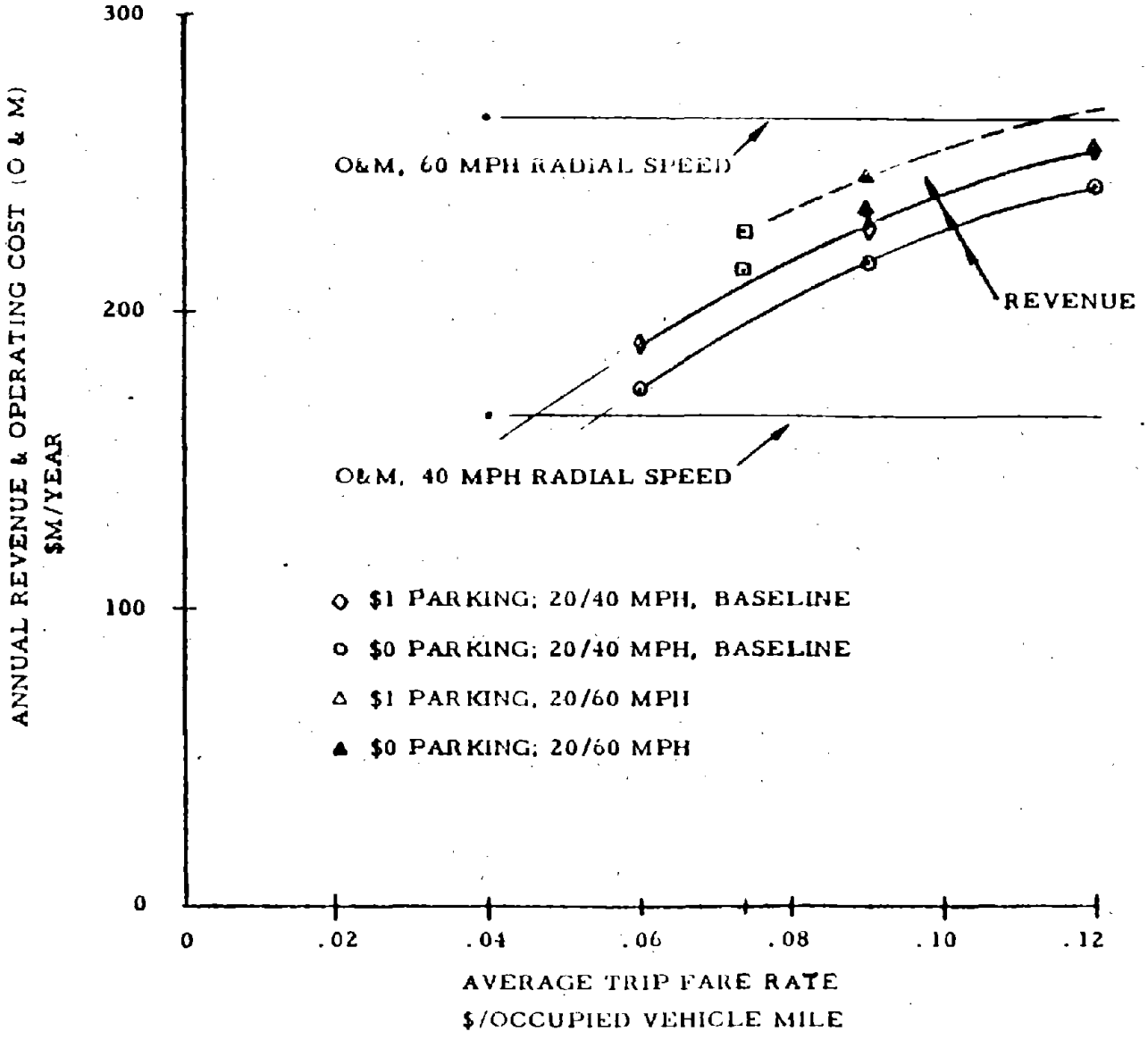


FIGURE 9. EFFECTS OF FARE RATES & RADIAL LINE SPEEDS ON ANNUAL REVENUE & OPERATING COST

MPH	REVENUE	O&M COST
40	229	165
55	-	234
60	245	278

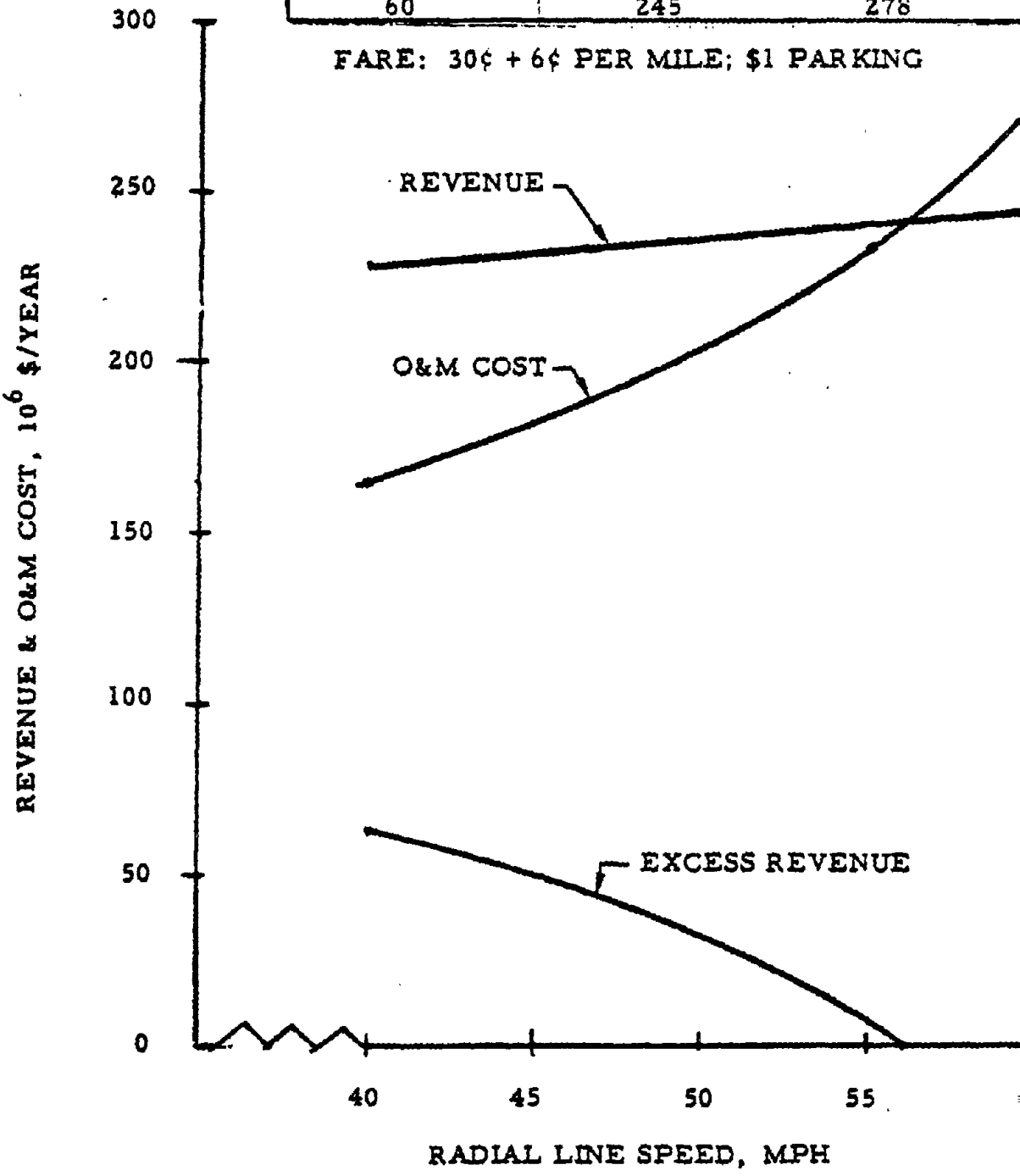


FIGURE 10. EFFECT OF RADIAL LINE SPEED ON REVENUE & O&M COST

one to two orders of magnitude greater than that of the contemporary automobile.

The reliability concepts are based on elimination of wear-out type failures through stringent preventive maintenance operations, on minimizing electronic component chance failures through use of functional and block redundancy in critical vehicle subsystems, and on suppression of failure rates through regular check-out of redundant components.

In the above reference this process is applied to a typical PRT longitudinal control system, and detailed analysis reveals that fewer than five losses of control per million operating hours can be readily achieved.

Most of the failures which do occur will result in free-rolling vehicles, and significant passenger delays can be nearly eliminated through adoption of an on-the-fly failed car pushing policy.

Table 6 and Figure 11 and 12 summarize the reliability concept and failure rate estimates.

Application of the longitudinal control failure rate estimates in Table 7 for a daily check-out operating plan is summarized for the fleet size associated with the Los Angeles PRT network studied in this task. It is concluded that about 360 longitudinal control failures would be anticipated per operating year, and that fewer than ten line-clearing incidents would be expected.

Whether such a high level of reliability would be required or whether lower reliability at less cost would suffice would be determined by detailed trade-off studies.

The data shown on Table 8 are required for the following energy and pollution estimates.

Total one-way occupied PRT vehicle trips per day or 10^6 if 1.3 people/vehicle (Reference Section 4.2.3.5).

PRT average speed = 34.5 mph
PRT average trip = 11.0 miles one way
DAP access distance = 4.18 miles one way
Door-door auto distance for PRT travelers = 13.77 miles

Reference simulation summary chart

miles one way

Door-door auto time for PRT Travelers = 24.85 minutes one way

Door-door auto speed for PRT travelers

$$\frac{13.77}{24.85} \times 60 = 33.3 \text{ mph}$$

44% of PRT travelers use DAP access mode for this case.

Auto gasoline mileage is computed based on the cold start factors and fuel inefficiencies shown in Table 8. This figure is based on the assumption

TABLE 6. DESIGN PHILOSOPHY FOR ATTAINMENT OF HCPRT RELIABILITY

- REDUCE WEAR-OUT FAILURES TO INSIGNIFICANT LEVEL THROUGH CAREFUL DESIGN AND A STRINGENT PREVENTIVE MAINTENANCE PROGRAM
- FOCUS ON MINIMIZING CHANCE FAILURES OF ELECTRONIC COMPONENTS (THE REMAINING SIGNIFICANT SOURCE OF SYSTEM FAILURES). USE
  - FUNCTIONAL AND BLOCK REDUNDANCY
  - "CONTROLLED" PARTS IN CRITICAL CIRCUITS
  - REGULAR CHECK-OUT OF REDUNDANT COMPONENTS

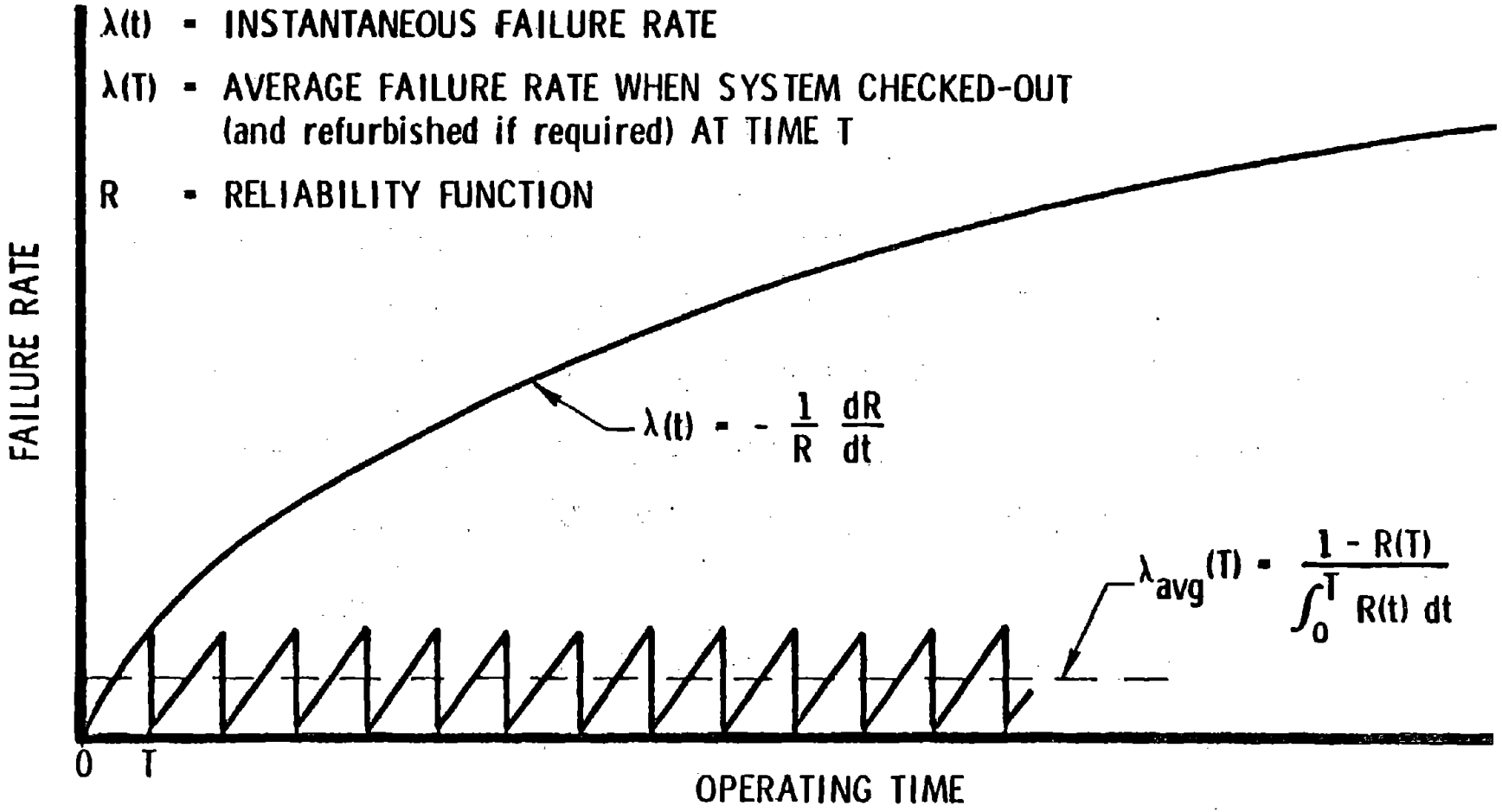


FIGURE 11. FAILURE RATE OF REDUNDANT SYSTEM WITH AND WITHOUT PREVENTIVE MAINTENANCE

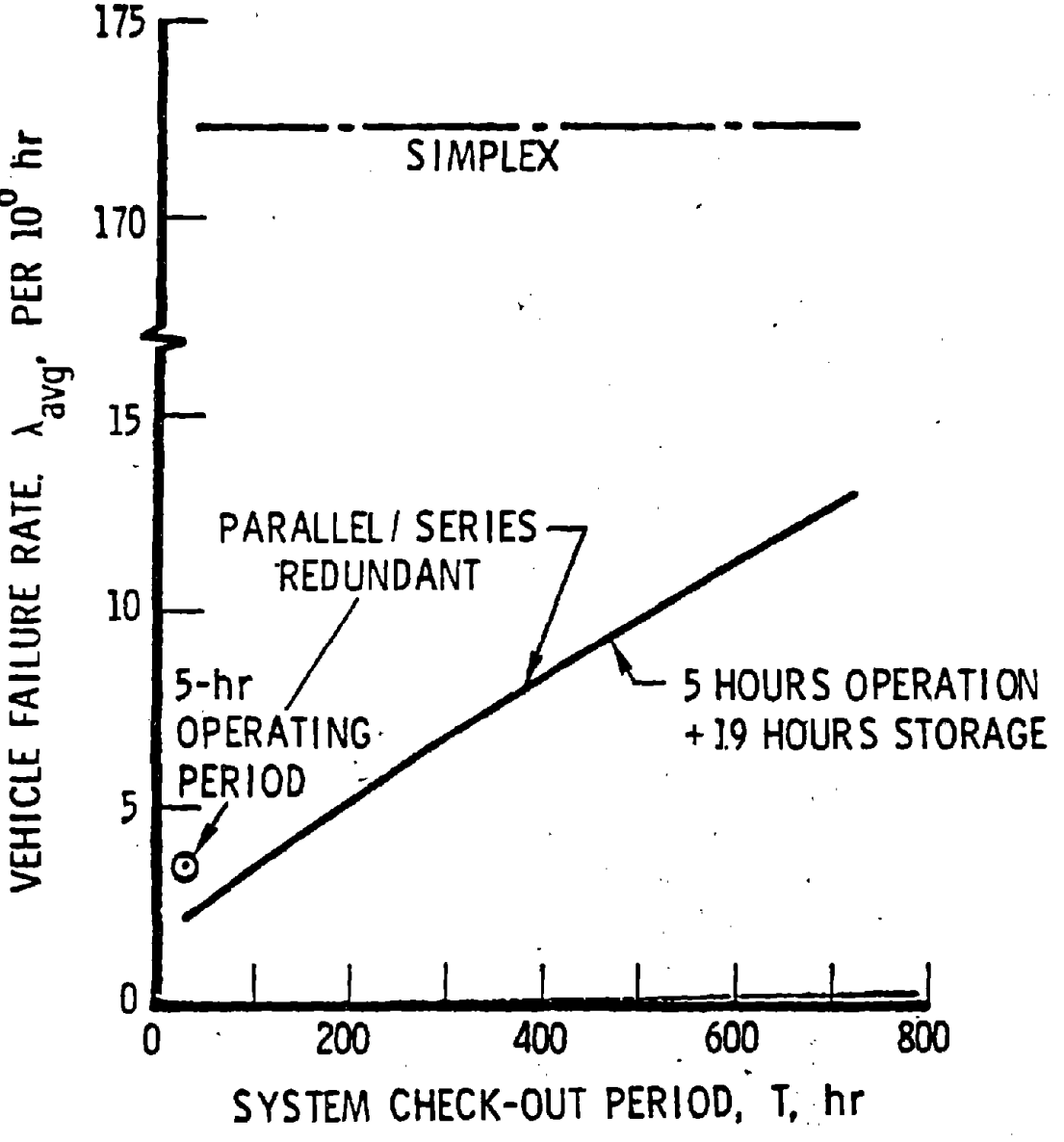


FIGURE 12. EFFECT OF CHECK-OUT PERIOD AND REDUNDANCE CONFIGURATION ON VEHICLE FAILURE RATE

TABLE 7. LOS ANGELES EXAMPLE NETWORK DEPENDABILITY CONSIDERATIONS

- System reliability between one and two orders of magnitude better than the automobile is clearly attainable

  The Los Angeles example fleet expected to experience ~

  $$3 \times 10^{-6} \frac{\text{failures/vehicle}}{\text{operating hour}} \times \frac{7 \text{ operating hours}}{\text{day}} \times \frac{300 \text{ operating days}}{\text{year}} \times 57{,}000 \frac{\text{vehicles}}{\text{fleet}} \cong$$

  360 losses of longitudinal control in the fleet per year.

- 1 or 2% of such failures expected to be "unpushable" (e.g. locked bearings), and resulting in line-clearing incidents.

  ∴ Predict fewer than ten line-clearing requirements per year.

TABLE 8. AUTOMOBILE GASOLINE MILEAGE

Auto gasoline mileage for Drive and Park trips

$$= \frac{1}{.034 \times 1.5} = 20 \text{ mph}$$

Auto gasoline mileage for Auto trips displaced by PRT

$$= \frac{1}{.030 \times 1.0} = 33 \text{ mph}$$

Auto gasoline gallons displaced by PRT =
(door-door auto trips displaced by PRT per day) x
(door-door auto distance displaced by PRT per trip) x
(PRT operating days per year) ÷ (mileage per gallon for displaced autos) =

$$\frac{10^6 \times 13.77 \times 300}{33} = 125.2 \times 10^6 \text{ gallons saved per year.}$$

Drive and Park auto gasoline used by PRT patrons =
(DAP fraction of PRT trip makers) x
(DAP trips per day) x (DAP distance per trip) x
(PRT operating days per year) ÷ (mileage per gallon for DAP autos) =

$$\frac{.44 \times 10^6 \times 4.18 \times 300}{20} = 27.6 \times 10^6 \text{ gallons used in DAP per year}$$

Net gasoline saved =
$(108.9-24.0) \times 10^6 = 97.6 \times 10^6$ gallons per year,
and, at 42 gallons per barrel,

Net barrels of gasoline saved per year by PRT =

$$\frac{84.9 \times 10^6}{42} = 2.32 \times 10^6 \text{ barrels per year.}$$

This is more than about 5% of the gasoline consumption predicted by SCAG for Los Angeles and Orange Counties in 1990.

The noted saving is based on the assumption that petroleum is not used to produce the electricity used by the PRT vehicles. The petroleum saving is much reduced if that were not the case.

that current statutory standards of 27.5 mph (1985) will be in effect in 1990. Auto emissions are based on current standards of 0.41 gm/mile HC, 3.4 gm/mile CO, and 0.4 gm/mile NO_x, all assumed to be independent of cold start effects.

Fare structure (.30 + .03 x L) dollars per trip of L miles.

CONCLUSION

The urban transportation planning process will initially define an overall areawide PRT network to be ultimately realized, and the potential economic viability of the predicated system will be verified through simulations. For a broadly populated region like the Los Angeles Basin, the long-range PRT goal may entail many hundreds of guideway miles and tens of thousands of vehicles. Considerations of both capital cost and implementation time will lead to definition of much more limited modular steps offering useful early applications. These modular network steps would logically furnish localized transportation for areas which are earmarked as activity centers in accepted regional master plans, and would be configured to conform with the long-term network goals. Thus, eventual areawide PRT service would be evolved from the activity center's subnetworks by a simple process of guideway connections at appropriate times.

This evolutionary process may be illustrated by reference to Figure 13, which depicts a potential major PRT network serving the Los Angeles Basin region. Initial subnetworks could be placed in the designated activity centers of the L.A. CBD, the Wilshire financial district, the Hollywood area, the Century City area, the Beverly Hills area, the Westwood area, and the Santa Monica beach area, somewhat as shown in Figure 13. Implementation of these modular network steps temporarily in parallel or in series would obviously depend upon possible financing arrangements, but it is evident that each represents a harmonious evolutionary element towards achievement of the overall network illustrated. The other designated district subnetworks shown on the layout could be developed in like manner, and eventually could be interconnected by the radial guideways shown in order to achieve a mature, areawide PRT system.

The subnetworks shown in Figure 13 could be operated at first with entrained PRT vehicles operated in essentially a scheduled GRT service mode. These entrained circulation systems, as shown in Figure 14, could be operated at perhaps ten second headways, which would permit utilization of currently available control technology. In this manner the basic vehicles, stations, and guideways would permit a smooth and totally compatible transition to individual, personal demand-activated service at fractional-second headways when close-headway control technology had achieved a satisfactory development status.

Thus a useable PRT Development Planning Methodology, favorable to the future application of the Method, has been demonstrated by the utilization of sophisticated computer programs, by establishing patronage, revenue and dependability criteria, and allowing for energy and pollution reductions, and capital and operating costs.

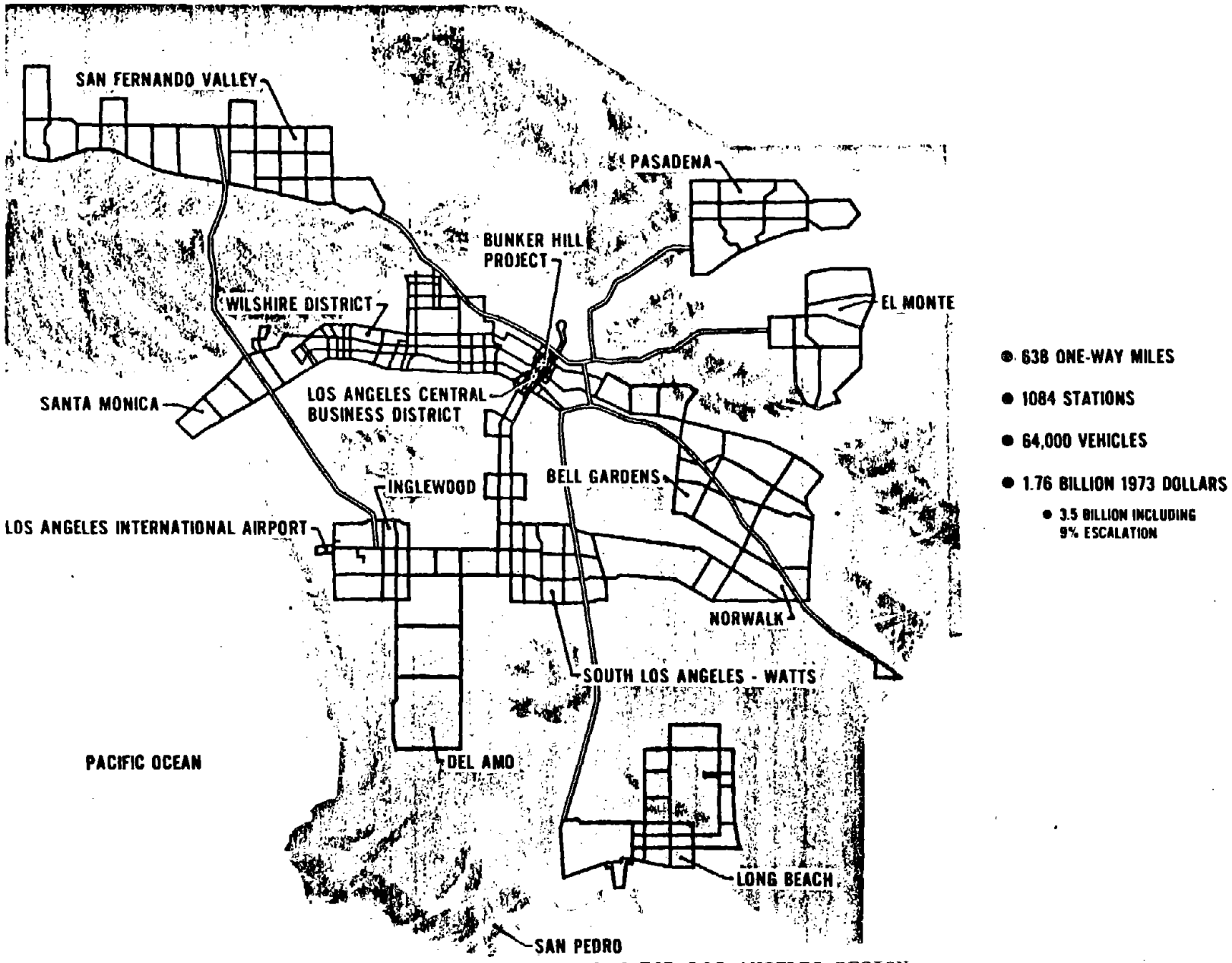
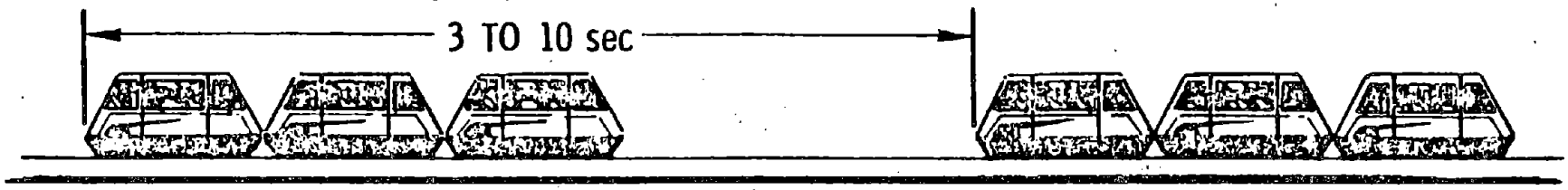


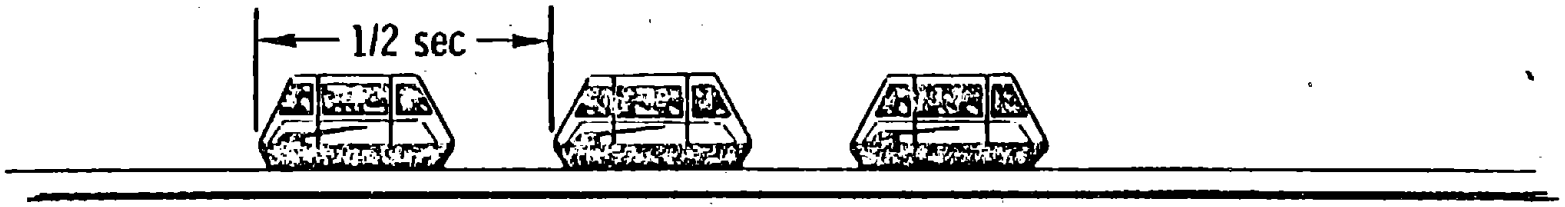
FIGURE 13. TYPICAL PRT NETWORK FOR LOS ANGELES REGION

- ENTRAINED PRT CIRCULATION SYSTEMS (eg LAX; Downtown; Century City-Beverly Hills-Westwood; Long Beach, etc)



  - ENTRAINED SMALL VEHICLES
  - CURRENT CONTROL TECHNOLOGY
  - SCHEDULED SHARED-VEHICLE SERVICE

- INITIAL CLOSE-HEADWAY PRT



  - INDIVIDUAL SMALL VEHICLES
  - CLOSE-HEADWAY CONTROL TECHNOLOGY
  - PERSONAL DEMAND-ACTIVATED SERVICE

FIGURE 14. PRT EVOLUTION

PAPER 8

Seattle-Tacoma International Airport Satellite Transit System Maintenance Program

Max Bitts
Port of Seattle

SEATTLE - TACOMA INTERNATIONAL AIRPORT
SATELLITE TRANSIT SYSTEM
MAINTENANCE PROGRAM

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ABSTRACT: The author, a registered electrical engineer in the states of Washington and Wisconsin, has been responsible for the acceptance of the subject AGT system and the development of a comprehensive maintenance program.

He assembled and trained the technical craft personnel, developed standard maintenance routines, established supporting spares inventory, and built a strong technical support team of transit specialists.

This program has created a measure of passenger service term "availability" with .998 performance maintained at a constant cost of under $600,000.00 annually for the last four years.

Productivity of craft labor has increased by improvement of methods, techniques and development of new tools. Mean time to restore service (MTTR) has been held down to .05 hr. resulting in the high availability. Configuration and quality control is maintained rigidly. That safety practices have been effective is proven by the fact of no harmful accidents occurring since initial start up.

SEA-TAC maintenance program's success has given the airlines and passengers a very high probability of "on time" departures with all aboard at a fixed ceiling of dollar cost during these years of inflation.

The total SEA-TAC Satellite Transit System (STS) story is detailed in UMTA's "Assessment of the Satellite Transit System at the Seattle-Tacoma International Airport", prepared by SRI International, December 1977, to be released shortly.

INITIATION & START-UP

The decision to enlarge the Seattle-Tacoma Airport, in its limited area, was made in 1966. The comprehensive plan included two new Satellite Terminals, one north and one south of the main terminal. This decision was based squarely on the designers confidence that a suitable passenger

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transportation system could be obtained. It is noteworthy that AGT systems at Houston and Tampa had been planned but had not yet been installed when this committment was made. Thus SEA-TAC was one of the bold pioneers in AGT exploration. (See P. 87, Paragraph 6.3 SRI.)

A search and study for passenger transportation finally ended in a contract award in June 1969. Westinghouse delivered hardware during 1972; the Port accepted the system in February 1973, and initiated a two year contract for operation and maintenance by Westinghouse. At this point the shakedown started; Westinghouse, with P.O.S. craftsmen, ran the system intensely and identified installation and latent design problems. W Transportation Division and the Port were very confident of the on-site team and the contractor reviewed locally developed fixes, approved and funded same. By opening day (26 June) passengers were carried to the north satellite and service to the south satellite opened in July. We firmly believe that the joint effort between W and the Port during this shakedown period is the key to our continuing success enjoyed at SEA-TAC. The development of the Port's contract relationship with Westinghouse is as follows:

a. Feb. 1973-1975, Westinghouse total system responsibility (except) Port furnished craft labor.

b. Feb. 1975-1977, Port total system responsibility w/ Westinghouse technical support - two engineers.

c. Feb. 1977-1979, Port total system responsibility w/ Westinghouse technical support - one engineer.*

MAINTENANCE STRATEGY

Management, Paper, Parts, People

On acceptance of the system the Port directed the development of a planned (preventive) maintenance program for the entire system (vehicles, wayside, central, power, communications, facilities and tools). The format requirements called for preventive maintenance instructions w/ accompanying records of accomplishment (PMI and PRR), w/ cook book or G.I. detail. Routines were estimated and scheduled in the Port computer to produce automatic due cards for performance. Experience to date has allowed stretching of schedules without sacrificing availability performance. (Example Vehicle PM 03 4000 miles 1974, 7500 miles 1976, 12000 miles 1978). These mileage increases were made possible with the advent of improved techniques and maintainability modifications. Parts inventory is now tested and verified from four years of experience.

*This level of manufacturer technical support is considered minimum for insurance of safety of the system and is planned to continue for the life of Revenue Service.

During this check out phase of the STS, the Westinghouse logistics people recommended a stock of spare hardware to support the original nine vehicles, roadway and stations, power centers, ATO and maintenance facilities. To date their recommendations have proved to be 90-95% effective not only to support the original fleet but also the three additional vehicles. The current value of this inventory maintained to the original provisioned level is approximately $330,000.00.

Consumable items such as tires, brake shoes, air filters and other short life items are in addition to the spare parts inventory and are procured during the year as specific use rates dictate. The cost of this inventory averages $31,000.00 per year.

Significant to our capability to rapidly restore a failed vehicle to service is the use of "working spare" ATO circuit boards or control modules to shorten fault isolation time and restore system availability. This is a part of the provisioned spare parts inventory.

The Satellite Transit generated the first requirement for Electronic Technicians at SEA-TAC. During the winter of 1972-73, we hired six electronic system technicians and trained them as "Duty Maintenance Representatives" (DMR). Four are now in their sixth year; three additional techs are in their fifth year. These highly trained specialists lead all other craftsmen (electricians, mechanical specialists, auto mechanics and miscellaneous totalling approximately three). The DMRs are constantly upgrading their skills by participating in STS improvement projects, i.e., VDAS, DYVEX (F.C.O.), and maintainability modifications. This latter opportunity area, I believe, is the reason we are successful in retaining these outstanding men, who otherwise would be long gone to greener, more challenging positions.

With the reduction of Westinghouse support, we have added one shop supervisor, one transit system specialist-electronic and one transit system specialist-electro/mechanical. With a fleet of twelve vehicles during a typical month, November 1977, we expended 8.6 man/months of craft and 4.8 man/months of supervision, technical and clerical support.

System performance of nearly .999 availability (P. 57, Table 4-11 SRI) is on a plateau which is not really practical to exceed; therefore, we are targeting to increase productivity by increasing maintainability with discrete modifications, so that increases in vehicle inventory and multiple car train operations will not increase manpower or dollar cost in a linear manner. To date the maintenance cost has not exceeded $600,000.00 a year (P. 78, Table 5.5 SRI) in an inflationary environment.

INCREASING VEHICLE INVENTORY

During the recent Christmas rush, we operated 20 days with eleven of twelve vehicles in passenger service. Availability for the month of December was .997 versus .999 in November. This record had to be related to a good schedule of maintenance just before Thanksgiving and luck. With only one spare, there was loads of luck. Presently, we are posturing for negotiations to procure six additional vehicles, bringing the inventory to eighteen. (6-

north loop, 1 - shuttle, 6 south loop, 3 ready spares and 2 in planned maintenance.)

PRODUCTIVITY INCREASE

In the maintenance strategy, I discussed the need to increase system maintainability and productivity. In this realm, we have recently added the DYVEX (FCO) to the shop tools which allows the DMRs to simulate loop operations in a fixed position in the shop. This device alone will allow testing of the vehicle(s) through the entire control cycle of its revenue sequence before entering passenger service. The only limitation is the lack of shake, rattle and roll effects. Time for this test is measured in minutes versus hours and days spent in the past when vehicle testing required the loops which were only available between 0130 and 0530 hours. (P. 45, Paragraph 4.3.2 SRI.)

The VDAS, currently in R&D assembly stage, will save untold hours of DMR time identifying illusive, intermittent failures. Final implementation of the VDAS with production models will probably occur within 24-30 months - just about coincident with the arrival of additional new vehicles, presently in the planning process.

You may have noticed the omission of reference to the all important subject of Safety. Actually, safety of passengers, employees and hardware, in that order, is our "cardinal" objective. Every time we touch the system each craftsman, specialist, parts man and clerk asks the question, "Have we considered all 'Safety' aspects in this procedure, parts and tests."

Second to safety, "configuration control" is paramount. Each vehicle, power center, wayside element, facility and tool is kept to drawing and specification. A formal change order control system is rigidly enforced. The shop supervisor is a trained quality and reliability control expert who exercises this background without question.

(P. 99, SRI) SEA-TAC's Satellite Transit effectiveness can best be summarized by the last paragraph in the SRI Report. "In reviewing the operational history of STS, one finds that a joint effort by system operator and system manufacturer produces an efficient maintenance program. The modus operandi is one to be considered for future AGT deployment."

DYNAMIC VEHICLE EXERCISER (DYVEX)

This system was conceived to minimize testing in the loop for intermittent problems and provide a standard for the fleet.

The basic design concept was to keep the design as simple as possible by using as many standard system PC board spares (to minimize design) yet test every vehicle subsystem up to the actual propulsion electrical system and mechanical brakes. Multiple car configuration was not considered as part of Phase 1 but provisions were provided for a later modification.

Safety was a prime consideration because actual speed codes were being transmitted with the vehicle reset and "ready to go". The DTE was used as a

reference for safety, plus mechanical and electrical layout constraints were imposed to insure safe operation.

A microprocessor was used to provide all loop simulated sequencing and monitor the subsystem for intermittent failures. In the event of a vehicle fault the sequence would be halted in a "freeze" mode and an alarm sounded. This allows the DMR an opportunity to isolate faults to the subsystem. When the VDAS is incorporated the fault isolation will be improved even more significantly.

All of this is an effort to minimize service interruptions, and passenger delays or maintenance, and further increase the reliability above what is already an industry standard.

VEHICLE DATA ACQUISITION SYSTEM (VDAS)

The SEA-TAC Satellite Transit System has logged over two million vehicle miles since start of operation in June 1973. During this period over 300 changes have been incorporated into the system. Eighty percent of these changes were reliability and maintainability oriented, which has resulted in a system that now achieves an average availability of 99.8%. An all time monthly high of 99.9% was reached in November. System MTTR has averaged less than three minutes over the past year.

It is recognized that these statistics cannot be maintained without significant increase in maintenance costs, once the more complex multicar train operations become the norm. Data indicated that 75% of problem correction efforts were being spent on trouble-shooting, with only 25% spent on actual repair. The largest single contributer to this trouble-shooting effort is the intermittent problem. Not only does the intermittent problem increase maintenance costs, but it affects operational integrity of the fleet.

Normally during the off peak periods of the year, half the twelve car fleet is required to provide service. Thus, if a vehicle has a known intermittent, the luxury exists of keeping that vehicle out of service until the problem is finally isolated. As airport passenger volume increases, this luxury will no longer exist. The impact of intermittents was very evident during the past Holiday Season. Eleven cars out of the twelve car fleet were in operation at one time to meet airline requirements. Resultant data indicated that intermittents accounted for 38% of all reported failures. This was over twice the average for previous months. Over two years ago it was realized that action had to be taken to reduce the effort being spent on trouble-shooting.

It was agreed that the most effective method to combat the intermittent problem would be to devise a recording system to assist technicians in their efforts. Such a system would have a memory of the sequence of events prior to the failure. As STS does not have operators, the technician had no one to ask, "What happened first?" With an equivalent to an aircraft "in flight" recorder, the technician would be able to obtain the key as to which parameter is at fault.

Obviously, the intermittents are an universal problem. With this in mind, it was suggested that the POS request federal funding to develop and build a prototype VDAS. Funds were provided by DOT in July 1977 to conduct a R&D program. The intent of the project is to determine if maintenance costs on AGT systems can be significantly reduced by incorporating monitoring devices into operational equipment. The second step of the program would be to determine if sufficient long term maintenance cost improvement can be realized to justify capital expenses of incorporating the monitoring device throughout the system.

Thirty test points were selected by maintenance personnel to be monitored. Fewer test points would suffice for fault isolation to the subsystem level. It was decided to have more test points to enhance precise analysis to conserve bench trouble-shooting efforts and also provide a more comprehensive coverage for failure types not anticipated. A minimum of twenty minutes storage time was also specified. This was done to assure that corrective action of restoring passenger service be accomplished prior to retrieving any data.

Engineering selected a PROLOG microprocessor to serve as the on-board scanner with 56K assigned to storage. Test points are to be scanned at 100 millisecond intervals. If a status change is detected from the previous scan, then all test point data will be stored along with a time code. Micro disks are to be used to retrieve recorded data from the vehicle. These disks will then be taken to central area for video viewing or printout as desired.

A technician will be able to do a coarse scan of the data and request a print-out of just that section of interest.

Schedule for Completion

3/1/78	Start installation into Vehicle #4
3/30/78	Safety review completed
4/1/78	Start dynamic testing
4/15/78	Start six month operational test
11/1/78	Final Report

CONCLUSION

We are all enthusiastic and very optimistic that this program will be successful in reducing corrective maintenance costs on a per vehicle basis. If the project succeeds as well as we think it will, the next step will be to install systems into the entire fleet. With the assistance of a VDAS system, we believe that we can maintain corrective maintenance costs on a plateau even with increased multi-car operations or increased fleet size and still provide excellent service to the passenger.

PAPER 9

Hydrostatic Drive Studies

George Adams
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HYDROSTATIC DRIVE STUDIES

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Abstract

Hydrostatic and Eddy Current Drives, and their possible future use as an integral and effective part of AGT systems, are covered in this paper. The various combinations of drive configurations, through the interchanging of the component parts of these Drives, demonstrate a flexibility which could be of great benefit to AGT technology. The question of hydrostatic noise--its causes, and the solutions being tested to eliminate such noise--are also included as part of this paper.

Introduction

This paper is about Eddy Current and Hydrostatic Drives. A Hydrostatic Drive is something that many of us are well acquainted with, and a brief review of that subject will aid in explaining how an Eddy Current Clutch and Eddy Current Drive can be of service to AGT systems. The graphics which are used to illustrate this presentation were taken from a report on such Drives, published some three years ago.

As illustrated in Figure 1, by using an AC Drive we can design an Eddy Current Clutch that can give us the characteristics of variable speed with extensive control. This is achieved by using a D.C. control source of less than 45 volts, which facilitates and simplifies the control of this type of drive.

In Figure 2 we see a Clutch Excitation Torque Curve demonstrating how clutch excitation can vary from zero to 100%. We see that at 100% excitation, the torque level generated is beyond 100%, which helps not only in acceleration, but also in negotiating grades or short terms. AGT vehicle systems--where appropriate to route design--are very much in need of the characteristics of this type of drive possessing an abundant capacity to generate torque.

The clutch and the brake are the two components of the Eddy Current Drive. These components give us the capability not only of driving, but also of reducing and controlling speed going downhill and braking for a station. All of this is accomplished with a very low control voltage and keeping the A.C. Drive running continually.

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In Figure 3 we see that by using a collector system with a wayside signal, we can devise a control system which will give the speeds desired but with a reduction in the volume of the control package on board the vehicle. By minimizing the volume of the control equipment, and the complicated components that might have to be installed on board a vehicle--especially a small vehicle of four, six or eight passengers--speed control can be easily implemented.

The Torque Control Block Diagram, as shown in Figure 4 contains an AC/DC converter, and as we might expect, the whole block is solid state which can easily be fabricated in a package no larger than six by twenty-eight inches.

The characteristics of the Drive, as seen in Figure 5, shows continuous duty always within the ratings of the system, for example a Drive on the order of 50 HP. Below the rated capacity we have continuous duty, and then an increased capacity almost double the intermittent and continuous duty shown as Clutch Continuous Duty/Motor Intermittent Duty. In other words, it's a combination of the motor and the clutch. This combination has been tested in dynamometers as well as in vehicle systems, and we will have more graphics showing the results of those tests.

In Figure 6 we see a cross section of the Drive that was used. It is a combination of an Eaton and variable speed drive with some changes in the brake system, and also a change in the control which was made to satisfy our requirements. It is evident that the motor, the clutch and the brake have been integrated into a close unit, illustrating one of the most important advantages that can be found in Eddy Current Drive, i.e., simplification of controls. Such a simplified control unit is easily changed, and uses an AC Drive which is more reliable and less costly to maintain than other drives.

A drive of this type was installed on a monorail style vehicle weighing about 9000 lbs. Instrumentation was installed on the vehicle to evaluate its performance in terms of ride quality and efficiency. We have recorded and analyzed a great deal of reported data from the vehicle which was obtained during operation in 1972 and 1973 at Pomona, California.

Figure 7 shows a Speed/Torque Curve made on the Pomona vehicle under continuous duty at 20 mph, with operation always within the rated torque. However, an attempt to increase vehicle speed caused a torque reduction. A 20 horsepower AC motor was also used, and its responses were comparable to those of the 15 horsepower AC motor.

Some of the results of testing are shown in Figure 8, where input power characteristics for cruising at 16'/sec. versus grade, respond to a power factor which goes over .8, almost to .9 and then declines. However the efficiency level of the application of power, and energy, is quite within the levels of other AC Drives with controls much larger, and though somewhat deficient, is within the scope of the expected requirement for energy consumption.

In Figure 9 we see virtually the same comparable results as in Figure 8 except this time we are using 21'/sec. versus grade. The power factor is

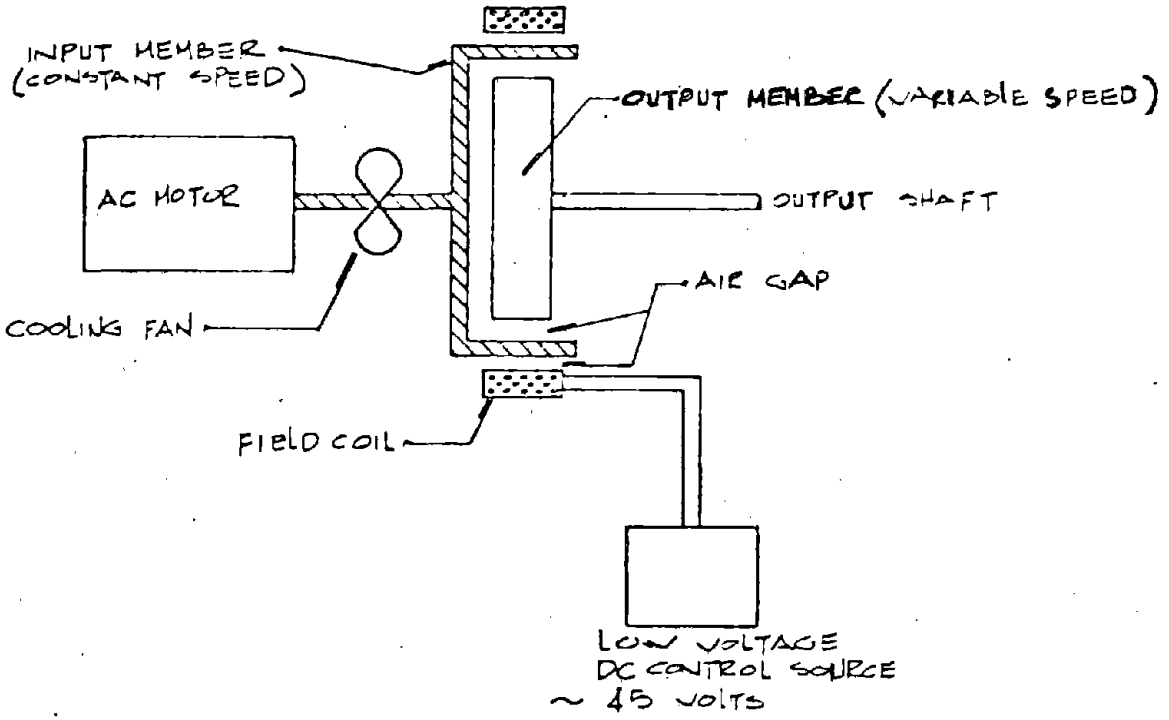


FIGURE 1. EDDY-CURRENT DRIVE COMPONENTS

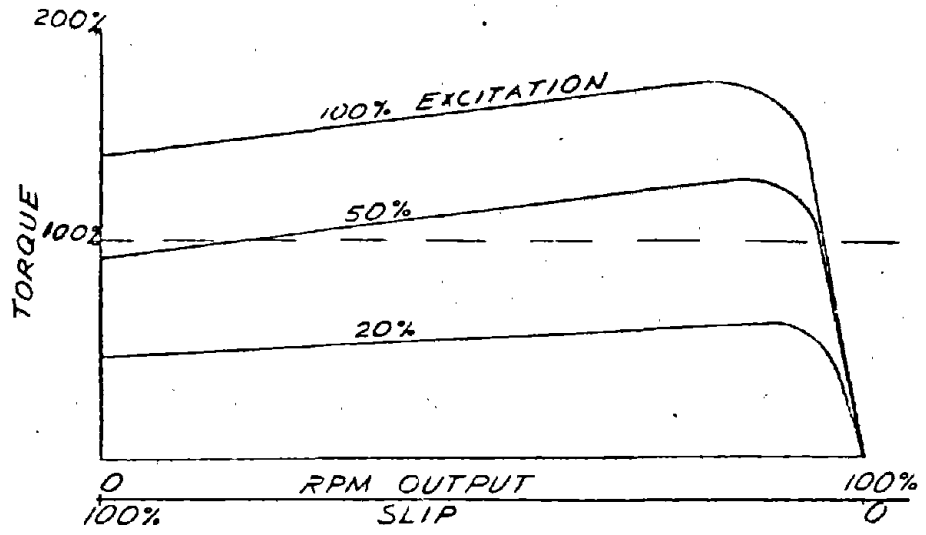


FIGURE 2. CLUTCH EXCITATION TORQUE CURVE

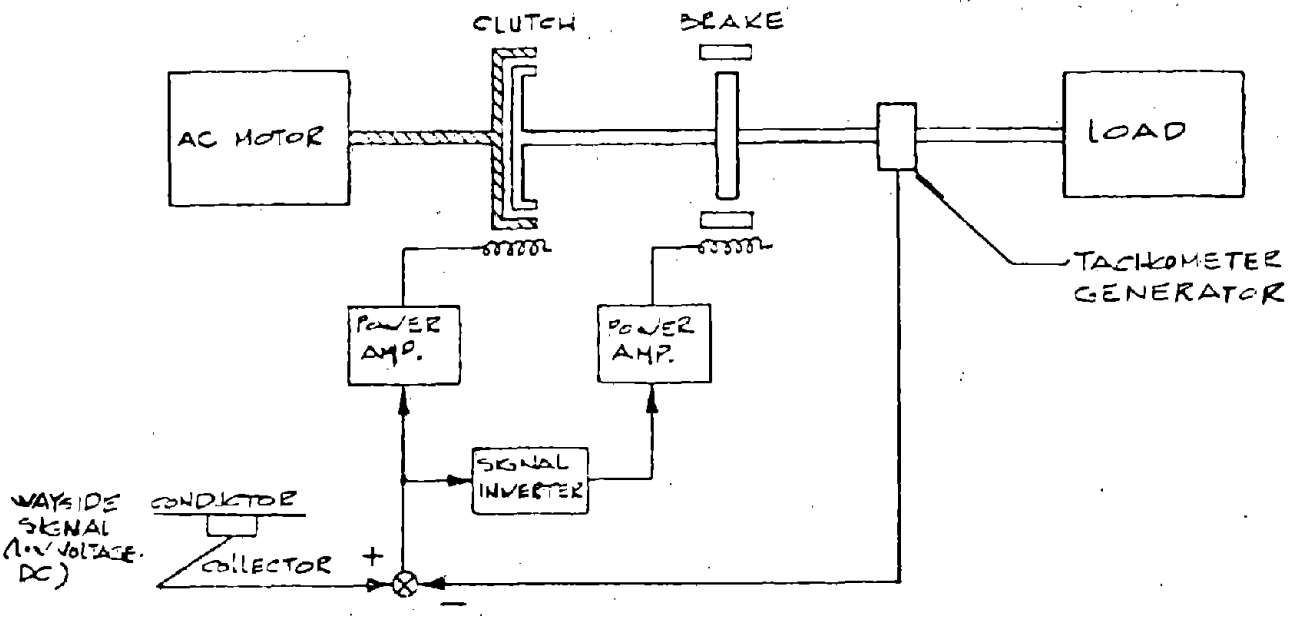


FIGURE 3. TYPICAL SPEED REGULATED EDDY-CURRENT CLUTCH/BRAKE DRIVE

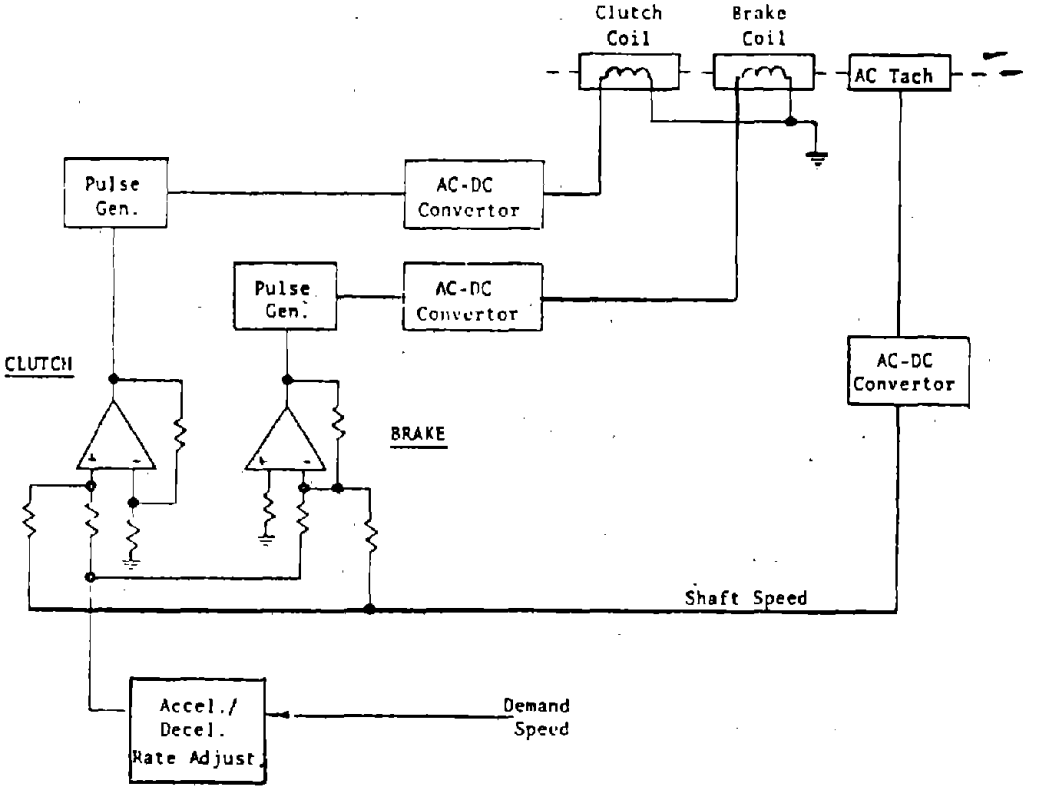


FIGURE 4. CONTROL BLOCK DIAGRAM

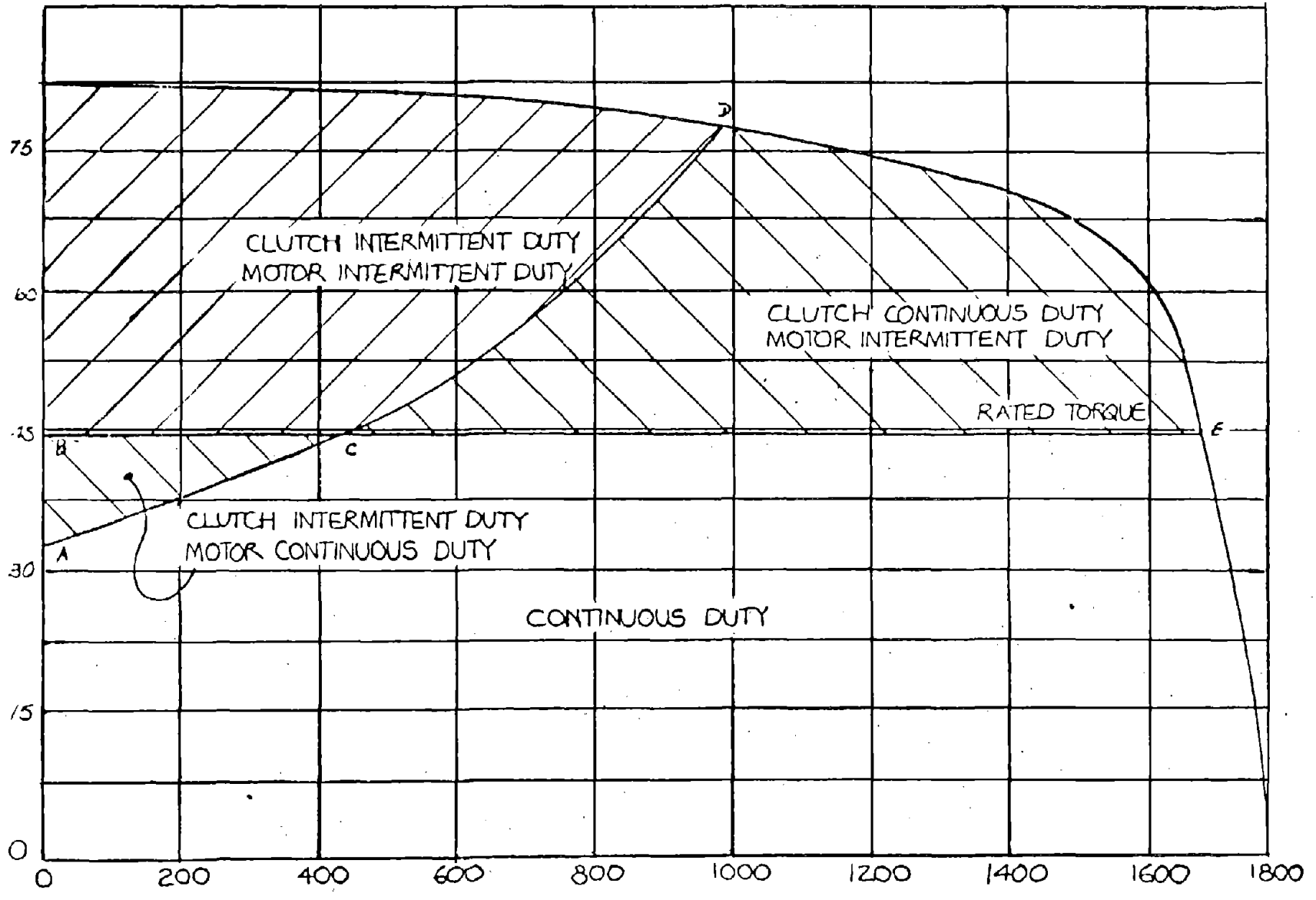
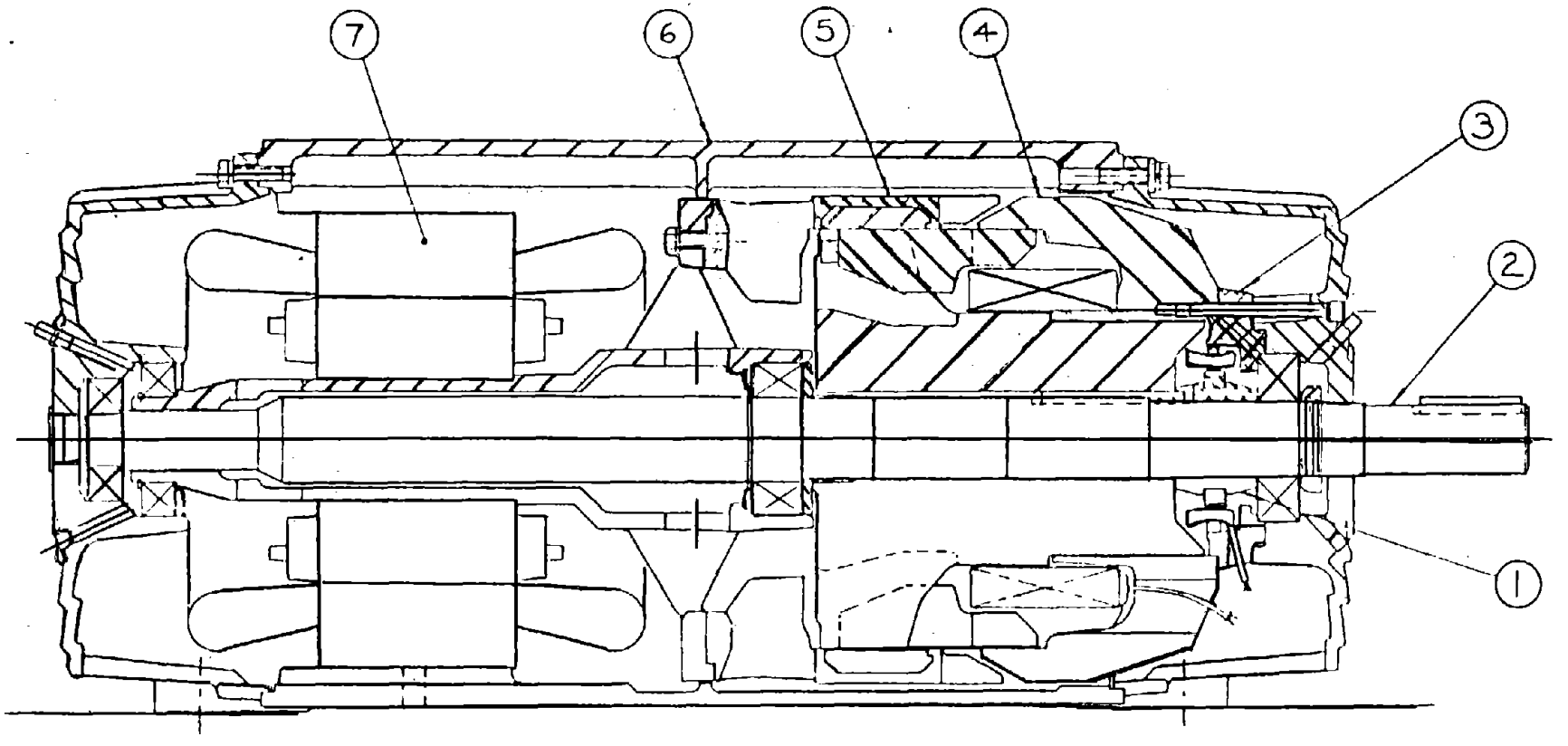


FIGURE 5. OUTPUT SPEED RPM



1 Generator Rotor
2 Shaft
3 Generator Field Assembly
4 Clutch Field Assembly
5 Rotor and Spindle Assembly
6 Housing
7 Stator

FIGURE 6. EDDY CURRENT DRIVE (CROSS SECTION)

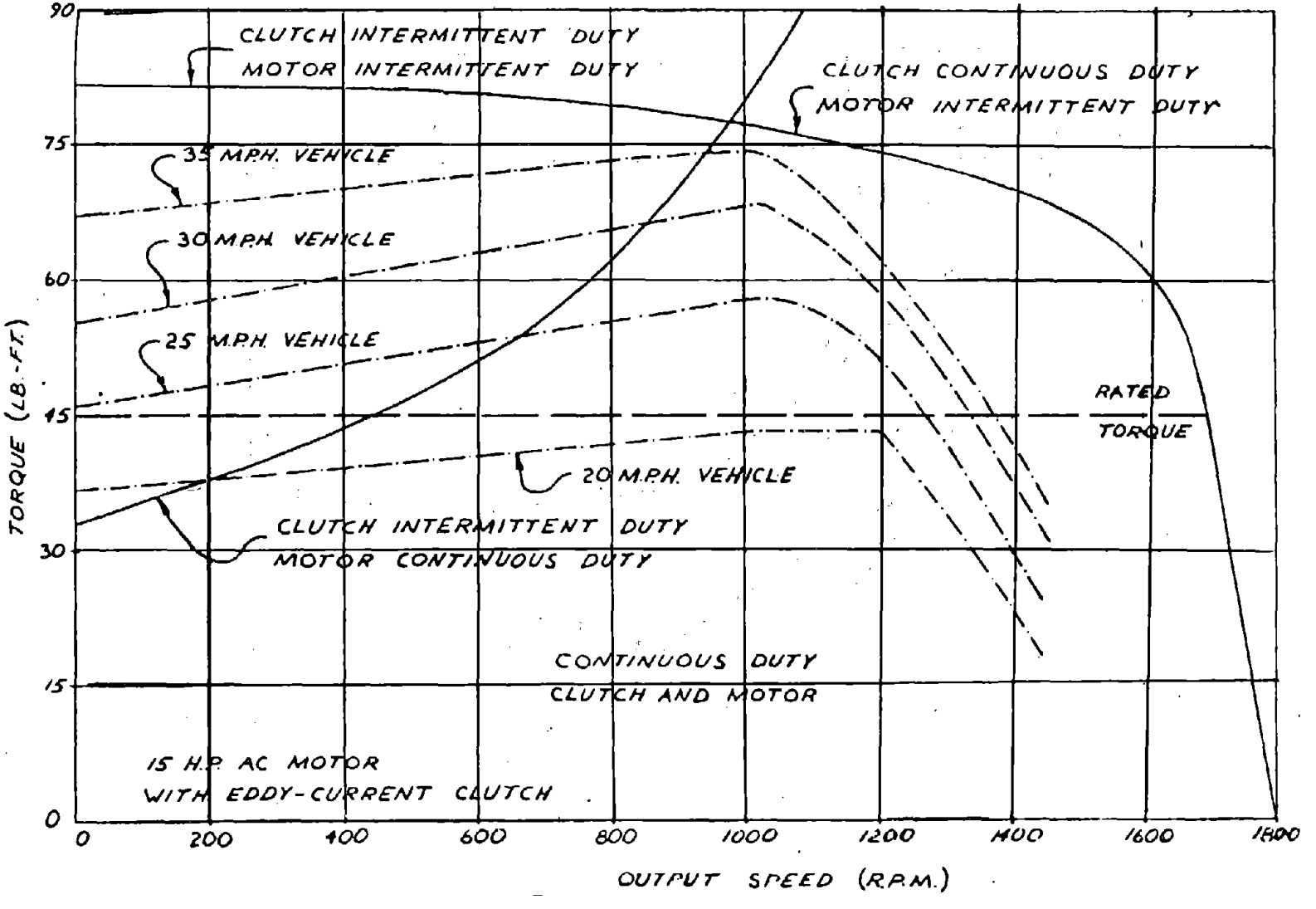


FIGURE 7. SPEED/TORQUE CURVES

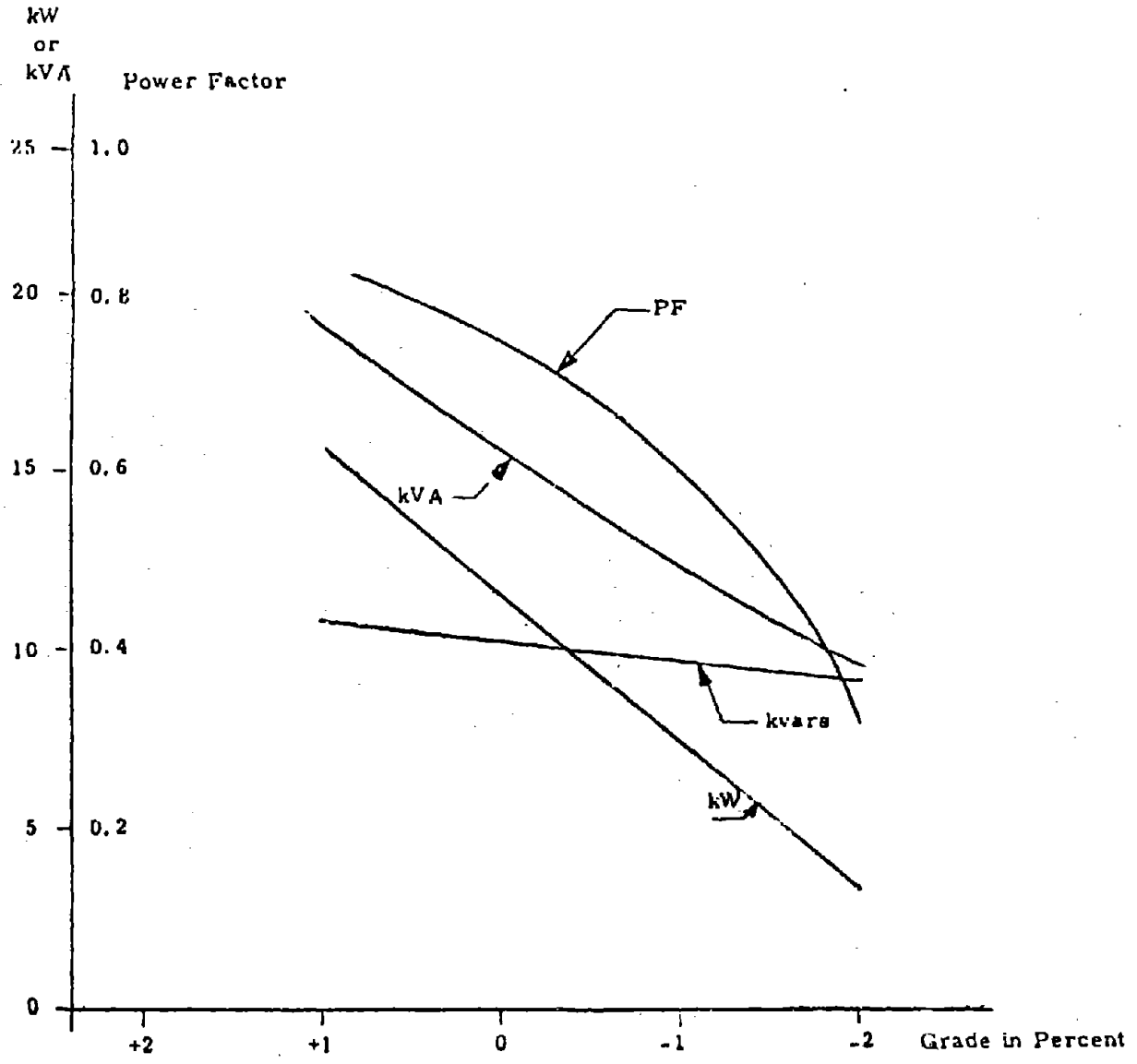


FIGURE 8. INPUT POWER CHARACTERISTICS FOR CRUISING AT 16 FEET/SECOND VS. GRADE

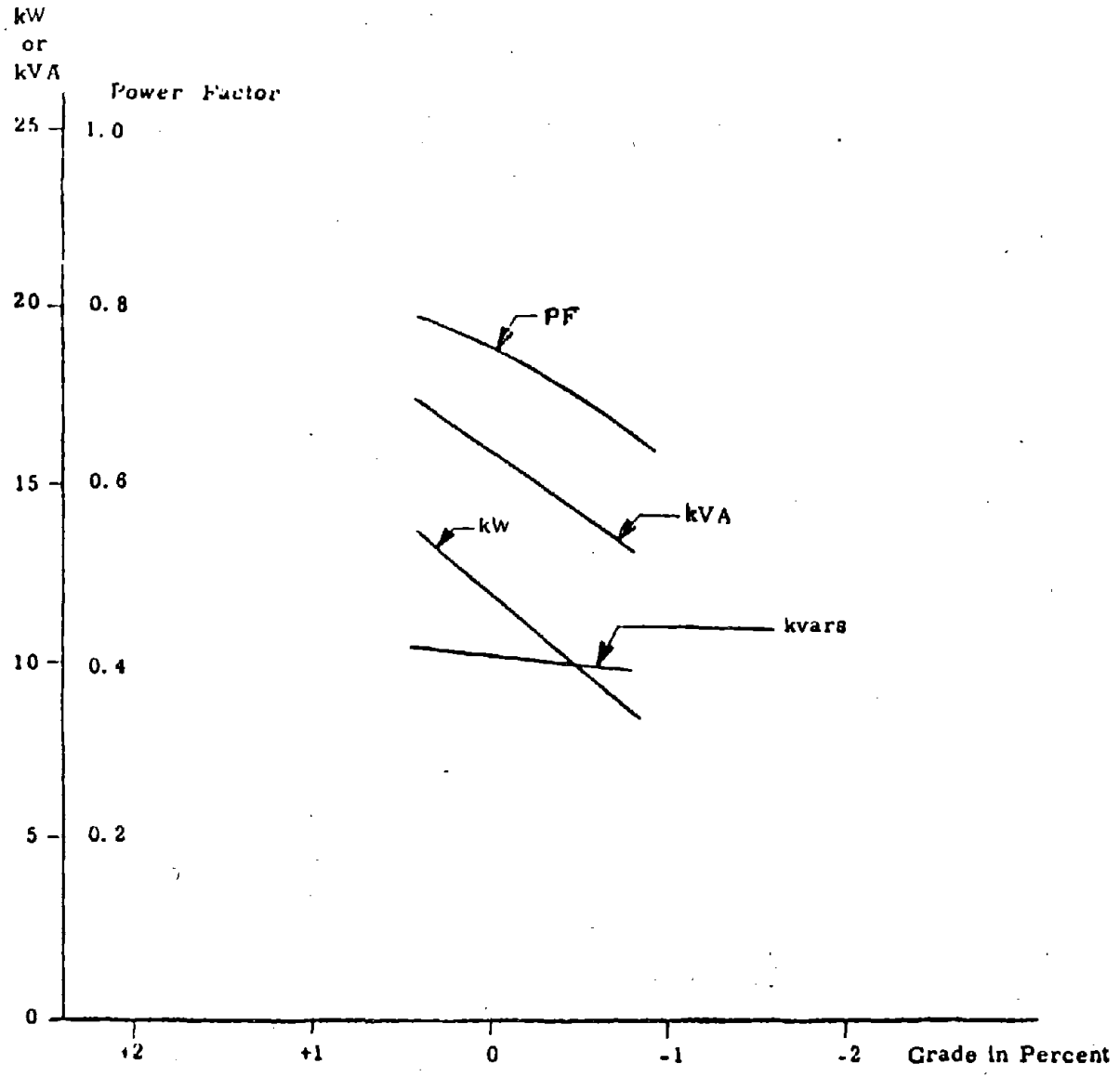


FIGURE 9. INPUT POWER CHARACTERISTICS FOR CRUISING AT 21 FEET/SECOND VS. GRADE

still about 0.8. The results of these tests were published in TSC reports referring to this project in 1972 and 1973.

In Figure 10 we see an analysis of the efficienty vs. vehicle speed. You will note that the efficiency of the system increases as speed increases, and efficiency decreases as speed decreases. Indications are that efficiency does not go much above 60%, but this analysis, demonstrating the drive in terms of total efficiency does not emphasize the aspects of Eddy Current Drive most beneficial to small AGT vehicles. The benefits derived are in other areas, such as: simplicity of controls and reliability of the drive unit--areas in which cost can really be important. You want to diminish operational cost, and energy is really not one of the largest component costs in operating the AGT vehicle system. Maintainability of the vehicle system is one of its most important cost considerations.

This program developed into another phase which looked at Hydrostatic Drives, in order to compare the two drive systems. Hydrostatic Drives and Eddy Current Drives have a lot of characteristics that are compatible. In fact, they are almost equal, especially the braking system, which would actually allow for a parking brake with the Dydrostatic Drive.

Consequently, we are currently studying Hydrostatic Drives, and to begin we will analyze the simplicity of a Hydrostatic Drive, viewed in Figure 11. It consists of a pump, hydraulic motor, and an AC motor. The AC motor drives the pump and the oil drives the hydraulic motor, which in turn drives the load. This is a very simple approach.

The only major problem with hydrostatic drives is the problem of noise. It is of note that when we began to study hydrostatic noise, we made a survey of related technology, not only on material in the English language, but also in other languages. We discovered that the phenomenon of hydraulic noise has not been explored sufficiently that anti-noise solutions have been developed as yet.

We have developed a concept that has been tested, and which appears to be a sensible concept. It is defined as a ratio of dp/dt, i.e., the variation of pressure during the rotation of the hydraulic motor.

First let us talk about piston pumps and piston motors. Figure 12 shows the pistons of a hydraulic pump. The Pump Port Plate continuously determines the flow of hydraulic oil from the vented cylinders, which are actuated by the pistons, to the pressurized section of the pump.

We found that if you were to run an 1800 RPM pump, which is 30 revolutions per second, there is a defined ratio of noise vibration to the frequency of rotation.

In this case using six cylinders, we found 180 hertz can be detected in the noise from the hydrostatic drive. Consequently, the dp/dt relation to the rotation of the drive. But what is the actual cause of the noise?

In Figure 13, we see that in the process of driving the pump, the line to the reservoir, which is open, is at a relatively low pressure, while the

line to the load, which is closed, has a relatively high pressure. Then, in the process of rotating, as seen in the middle picture, there is a moment in which both values are closed. When the piston begins to move back, the line connected to the load opens, and that pressure is high. When that happens the change of pressure produces the phenomenon that is referred to as hydraulic flow pressure, or the Port Valve Effect. The noise can be related to the Port Valve Effect, and thus when the drive runs at an even speed with a minimum amount of differences between the pump and the motor load, the noise is reduced. As soon as we began to increase the acceleration, the noise began to increase. Consequently, we have found a very definite correlation. In order to more effectively demonstrate the correlation, the size of the hydraulic motor was changed from 20 GPM to 29 GPM, and the resulting effects on rotation, and change of speed, demonstrated a pressure change which verified the correlation.

Consequently, we have come to the conclusion that the phenomenon is related to the change of pressure during the opening of the passage to the load motor, while the pressure in the pump is still low. Until the pressures even up, the expansion of the oil as well as the expansion of the components of the pump, transmitted through the hardware, will produce the noise that we hear on hydrostatic drives.

Now I would like to go on to the presentation of the characteristics of the combination of variable and fixed displacement pumps, with variable and fixed displacement motors. (see Figure 14). To produce a hydrostatic drive you can use various combinations of pumps and motors, e.g., the characteristics of a fixed pump and variable motor are displayed to the left, showing a maximum torque output at maximum speed. The pump horsepower is always the same, the efficiency is pretty good, especially for the piston type of hydraulic generator. The piston is better than the vane type of efficienty.

Next is the variable pump with fixed motor. This is the arrangment that we are using in our tests. It gives a maximum torque which is equal to or greater than 100%. The horse-power output varies, and the efficiency related to speed is also very good, changing from almost zero to something on the order of about 90 percent. The configurations illustrated in Figure 14 are all combinations of fixed and variable pumps and motors; through the use of different controls additional configurations can be achieved. We found the combination of variable pump and fixed motor to be the most economical, and most easily integrated for packaging.

In order to define and analyze the characteristics needed, we find the horsepower and torque required for a given route and duty cycle, as illustrated in Figure 15, and match this with the characteristics available from the unit, in this case, a 15 horsepower drive with a peak flow of 29 gallons/minute.

Figure 16 is a generalized drawing of the hydrostatic unit that we have been using in our tests. It is a Vickers unit. The electric motor, hydraulic pump and hydraulic motors can be installed in different ways to produce various drive configurations. These variations permit drives with remotely installed hydraulic motors that can be installed directly into the wheels. No other

gear sets are required between the drive and the wheel. They can go directly in and drive the wheel, which especially in a small vehicle system helps to reduce the weight and simplify the system.

A summary of the characteristics of hdyrostatic drives which makes them attractive for use on AGT is as follows:

-VARIABLE SPEED: Stepless, smooth changes can be made throughout the entire speed range.
-LOW SPEED: Continuous operation is possible at very low speeds.
-PRECISE SPEED: Extreme changes of load have negligible effect on output speed.
-REVERSIBILITY: Travel direction can be changed smoothly without gear change.
-STOP: At zero pump delivery, transmission will not creep.
-TORQUE-SPEED RATIO: Stepless range of 4 to 1 is possible with additional ranges available from multiple-motor combinations.
-OVERLOAD PROTECTION: Relief valve limits load on all mechanical members in power train.
-DYNAMIC BRAKING: Adequate braking is available for normal conditions.
-POWER LIMIT: Operating pressure and pump delivery can be controlled to prevent power drive overloading.
-RESPONSE: Hydrostatic transmissions can respond faster than any other type of power-transmitting system.
-EFFICIENCY: Efficiency is high over a wide range of operating conditions.
-GOOD TRACTION: Smooth application of torque and no tendency to spin provide excellent ground adhesion.

Conclusion

The flexible characteristics of Hydrostatic and Eddy Current Drives make these drives attractive for use in AGT applications. The problem of hydrostatic noise, once resolved, will eliminate the principal deficiency in the system, and should enable these drives to take their place as part of the AGT technology of the future.

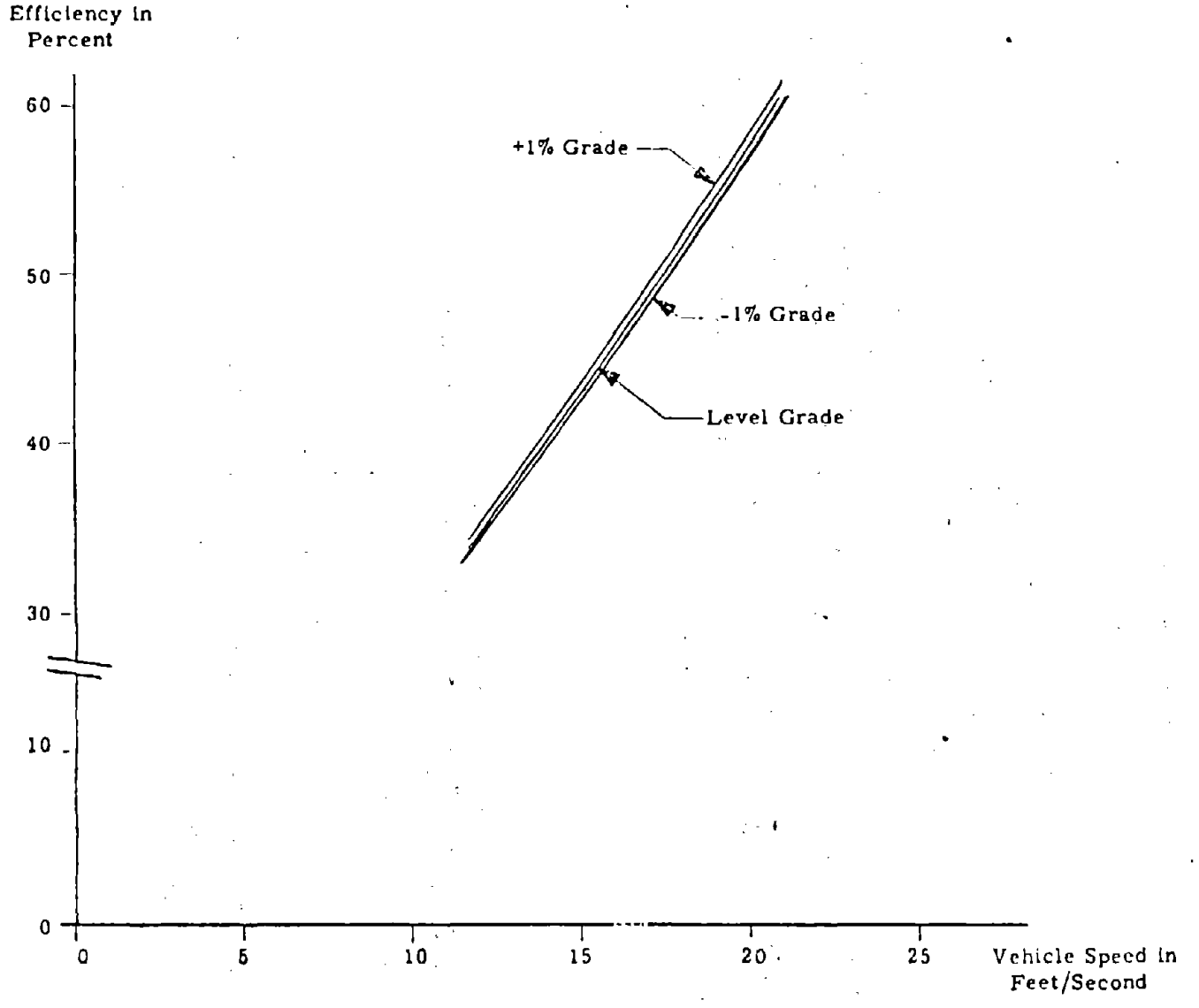
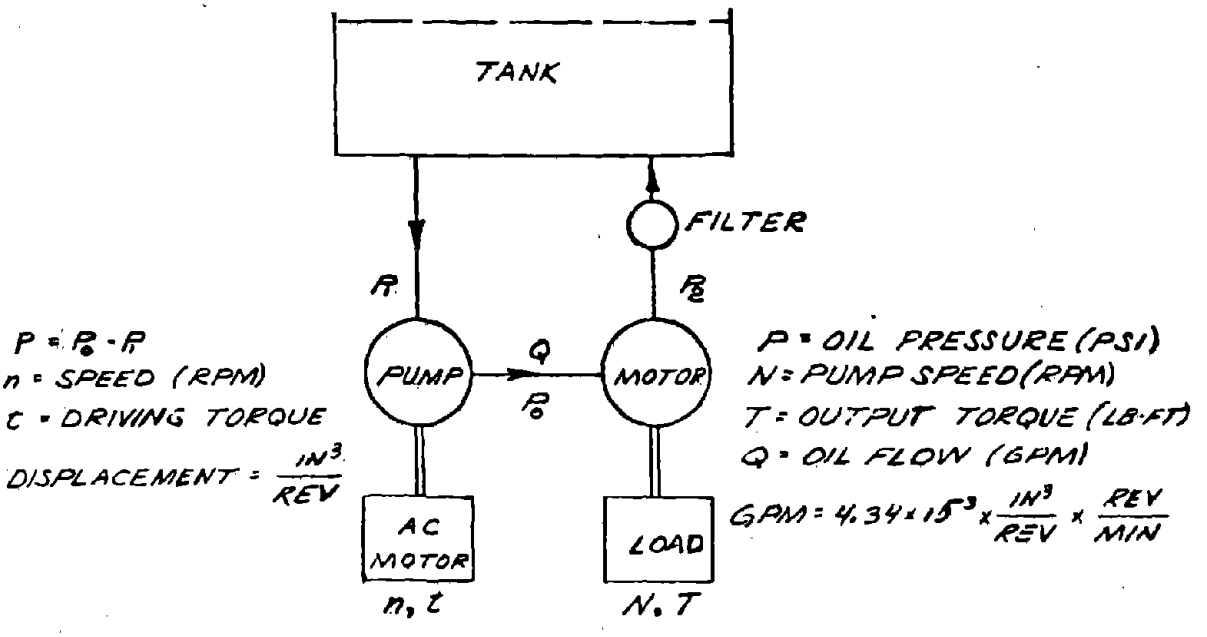


FIGURE 10. CRUISE EFFICIENCY VS. VEHICLE SPEED



Simple ideal circuit, gravity fed from header tank, an AC motor driven hydraulic pump supplying pressure fluid to a hydraulic motor connected to the load.

Power pumped into oil = $\frac{PQ}{1428}$ H.P.

Ideal power input = mechanical power output = $\frac{nT_1}{5252}$

Neglecting losses, power absorbed by motor = $\frac{(P_0 - P_2)Q}{1428}$ H.P.

Motor output = $\frac{NT_0}{5252}$ H.P.

FIGURE 11. IDEAL HYDROSTATIC DRIVE SYSTEM

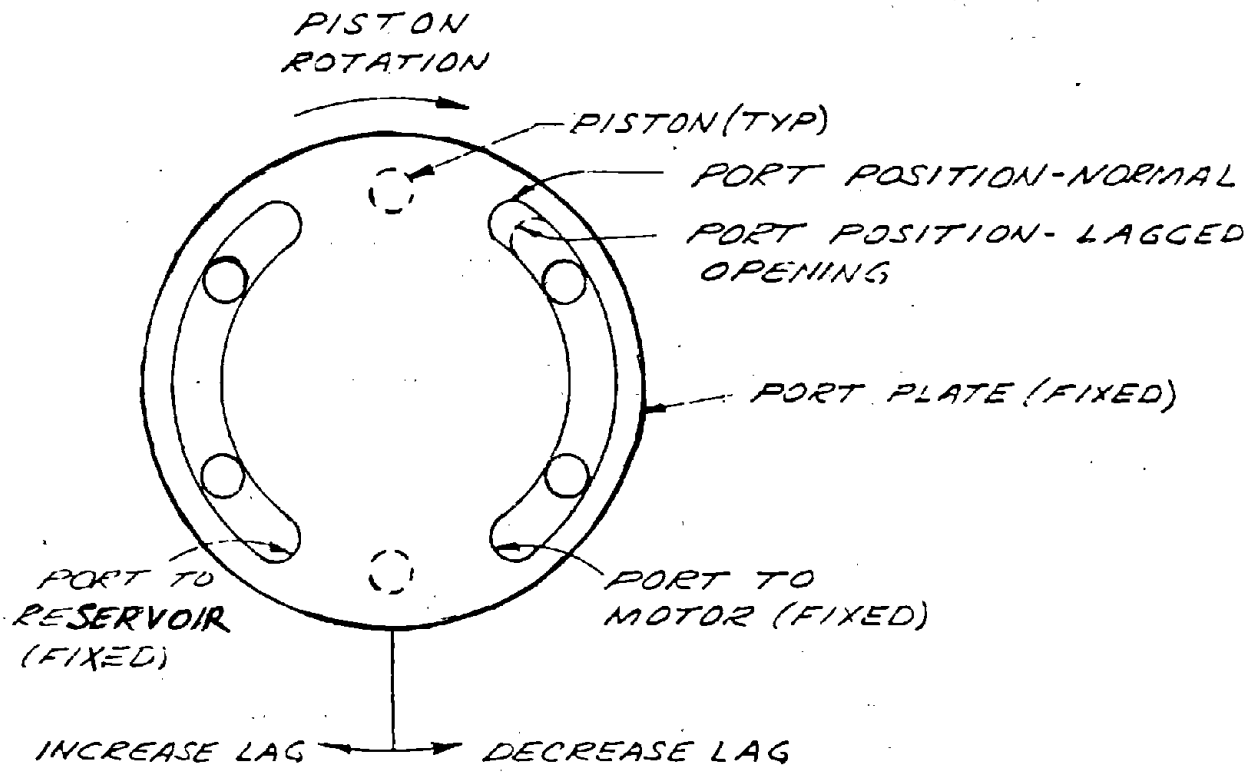


FIGURE 12. PUMP PORT PLATE

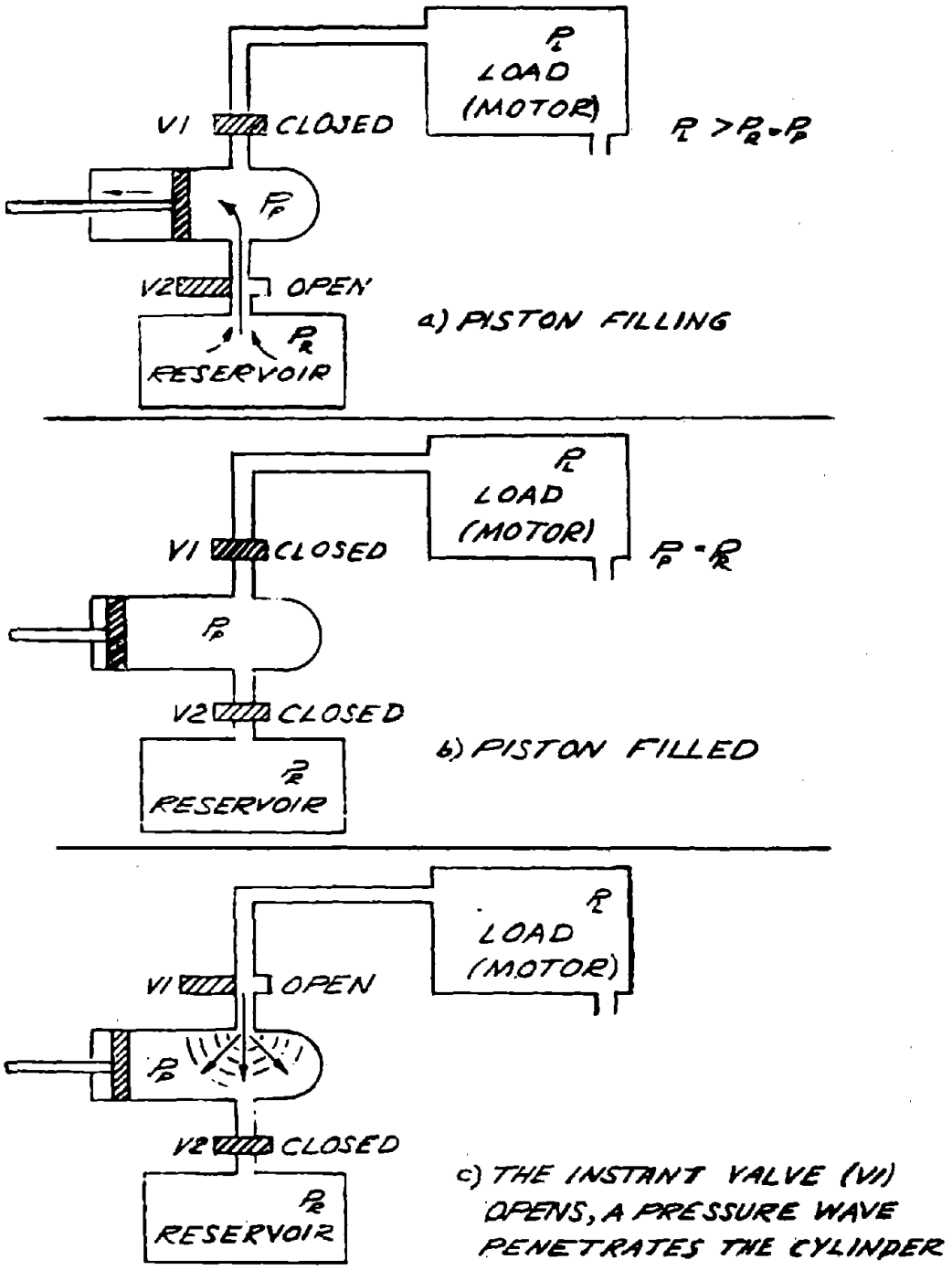


FIGURE 13. PORT VALVE OPENING AND PORT VALVE

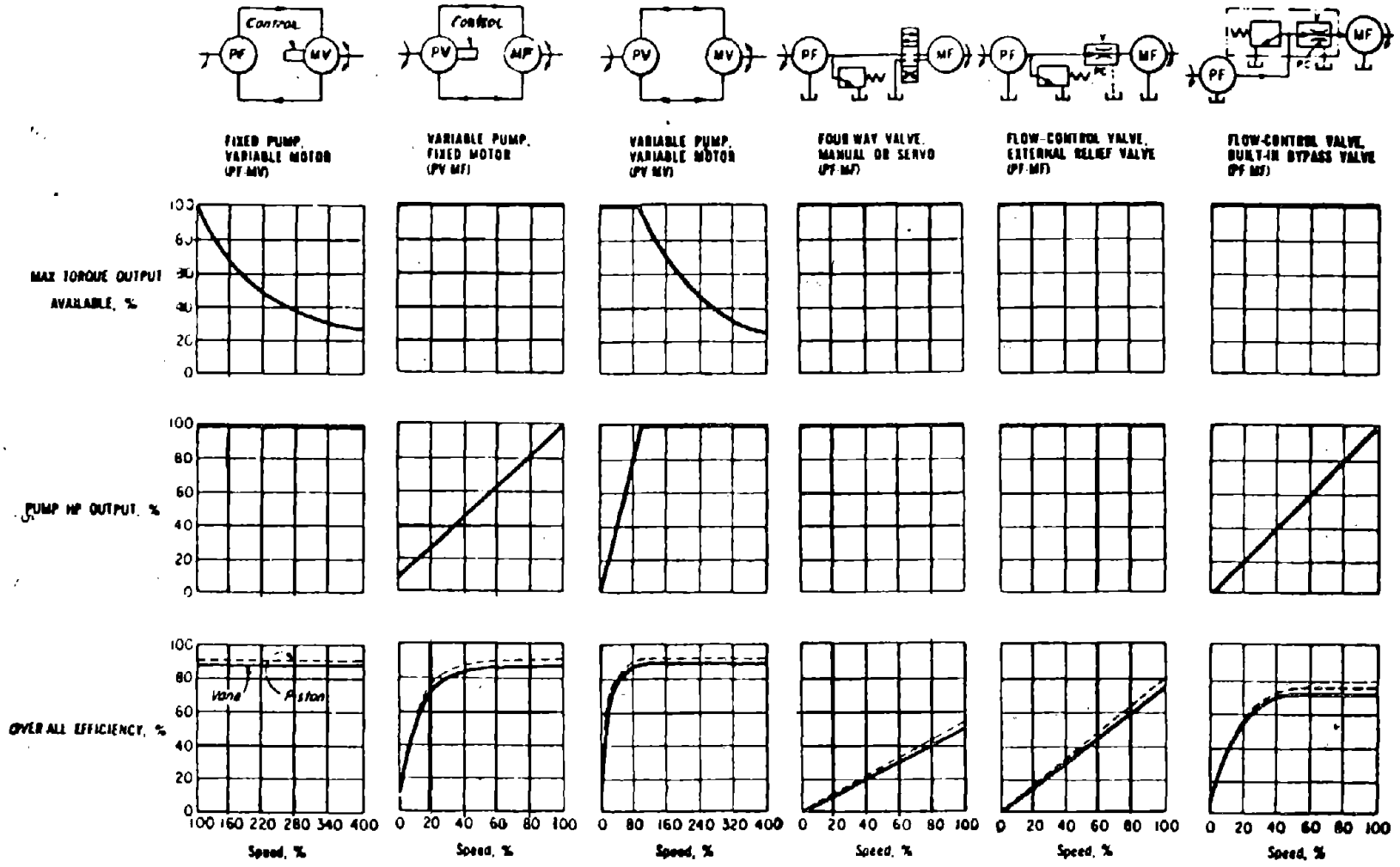


FIGURE 14. HYDROSTATIC DRIVE PERFORMANCE IN VARIOUS CONFIGURATIONS

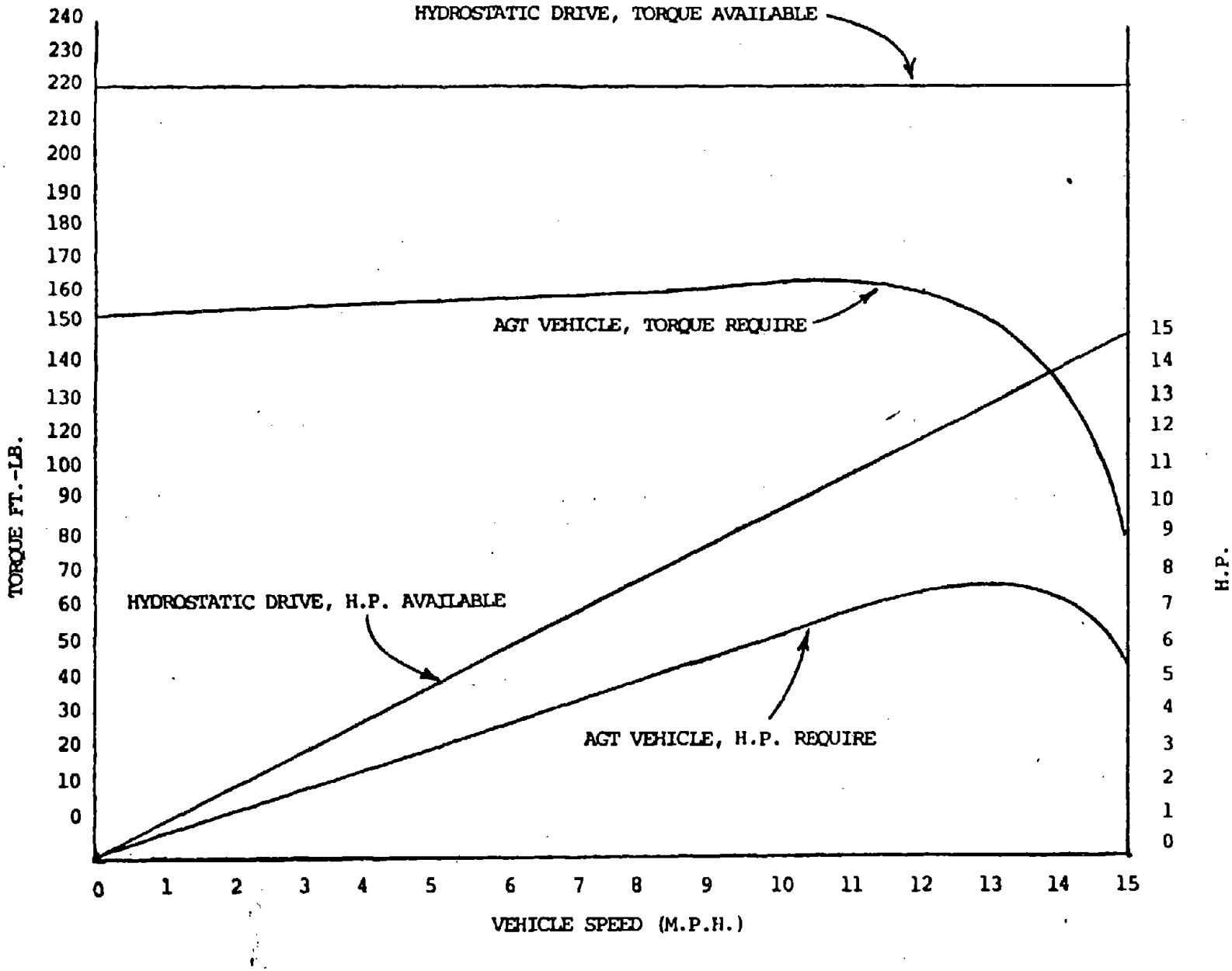


FIGURE 15. POWER REQUIREMENTS AND AVAILABLE H.P.

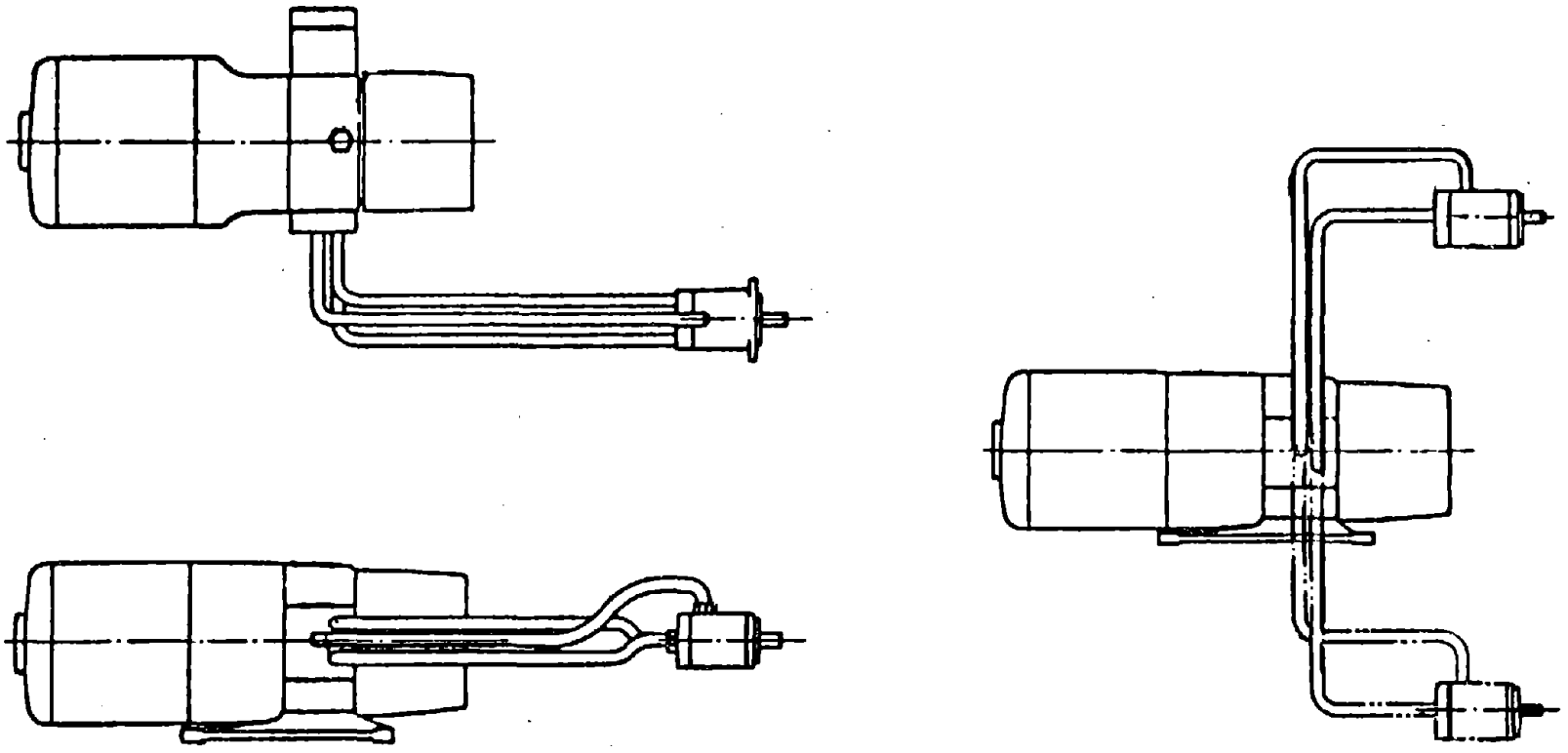


FIGURE 16. HYDROSTATIC DRIVE FOR WHEEL DRIVE CONFIGURATION (REMOTE MOTOR PLACEMENT)

PAPER 10

Overview of Automated Guideway Research at M.I.T.

Steven Shladover
Massachusetts Institute of Technology

OVERVIEW OF AUTOMATED GUIDEWAY RESEARCH AT M.I.T.

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ABSTRACT. This presentation serves as an overview of the automated guideway transit research conducted in the Department of Mechanical Engineering at M.I.T. in recent years. Our Vehicle Dynamics Laboratory group has pursued research topics in several areas directly and indirectly applicable to automated guideway systems:

- Vehicle-guideway dynamic interactions
- Automatic steering control
- Dynamic entrainment and platooning
- Related technologies:
  - air cushion suspensions
  - magnetic levitation and propulsion.

I will not be discussing the vehicle-guideway dynamics work at this time because Professor David Wormley will be talking about that later this afternoon. The air cushion and magnetic suspension work has been concentrated on applications for high-speed intercity ground transportation rather than automated guideways, but the technology is still applicable to AGT systems.

The two projects I will be discussing in more detail are the automatic steering control of guideway vehicles, an endeavor begun in 1972, and the dynamic entrainment and platooning of AGT vehicles, which was begun in 1975.

Automatic Steering Control

The work on automatic steering control (lateral guidance) for automated guideway vehicles has been specifically concerned with the dynamics of rubber-tired vehicles. Most of this work has been focused on the analysis of a vehicle having a single error sensor mounted at its front, with only the front wheels being steered. Separate analyses have been performed for operations on straight and curved guideways. Controller performance has been optimized for filtering of random roughness inputs from the guideway, and the optimal performance has been compared with that of simple, easily-

implementable controllers. Both steady-state performance in constant-radius curves and curve-entry transient response have also been studied.

More recent projects in automatic steering have been concerned with the potential benefits of sensing errors at both front and rear of the vehicle, and of steering both front and rear wheels.

The steering task is summarized in Fig. 1, which shows it to be fundamentally a regulation problem. Our work has been concentrated in the steering control block of Fig. 1. The reference steering signal may be corrupted by sensing errors or construction irregularities. The steering controller processes the information derived by the sensors from the reference and the state of the vehicle itself, to produce a command signal to the actuator, which then steers the front, and perhaps also the rear, wheels of the vehicle. The trajectory of the vehicle is determined by the steering angle(s) and the dynamic characteristics of the vehicle.

The basic vehicle dynamic model used for most of these studies is a standard two-degree-of-freedom model pictured in Fig. 2. The two degrees of freedom are the yaw angle, ψ, and the sideslip angle, β, which can also be expressed in terms of the lateral displacement, y. This model is quite adequate for normal, non-emergency guideway operations. A three-degree-of-freedom model, including a vehicle body roll mode, has also been used for the study of two-axle steering.

The first part of the steering controller development work has been the derivation of an optimal steering controller based on the performance index shown in Fig. 3. The optimal controller minimizes a weighted sum of the accelerations and tracking errors at any chosen location a distance ℓ ahead of the center of mass of the vehicle. Using standard methods of optimal control theory, the full-state-feedback control law shown in Fig. 3 was derived, and its performance used as a standard by which to evaluate the performance of the simple suboptimal control laws used on typical guideway vehicles.

The optimal controller's performance can be summarized by the plots and equations shown in Fig. 4. The r.m.s. accelerations and tracking errors of the optimally-steered vehicle following a statistically rough reference are seen to be functions of the natural frequency of the closed-loop controlled vehicle system. By combining the two curves in Fig. 4 and eliminating the frequency dependence, a single optimal tradeoff frontier, shown in Fig. 5, is derived. It is not (in general) possible to achieve a performance tradeoff which lies below that frontier. Fig. 5 shows the performance of some simple suboptimal steering controllers compared with the optimum.

For appropriate choices of controller gains, performance can be quite close to the optimum if the basic vehicle dynamics are suitable. Although the optimal frontier can be followed by any vehicle with a full-state-feedback controller, the ability to approach that frontier with simple controllers is vehicle-specific.

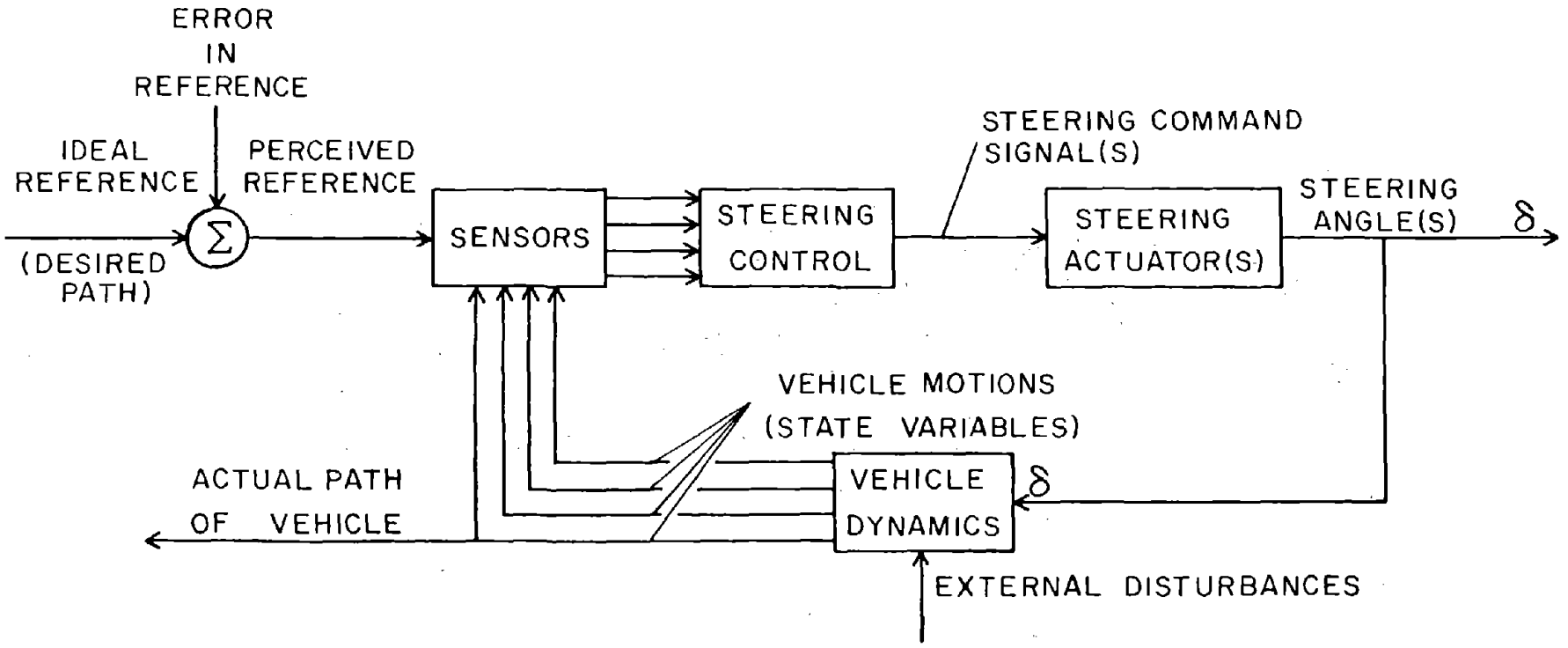


FIGURE 1 STEERING TASK

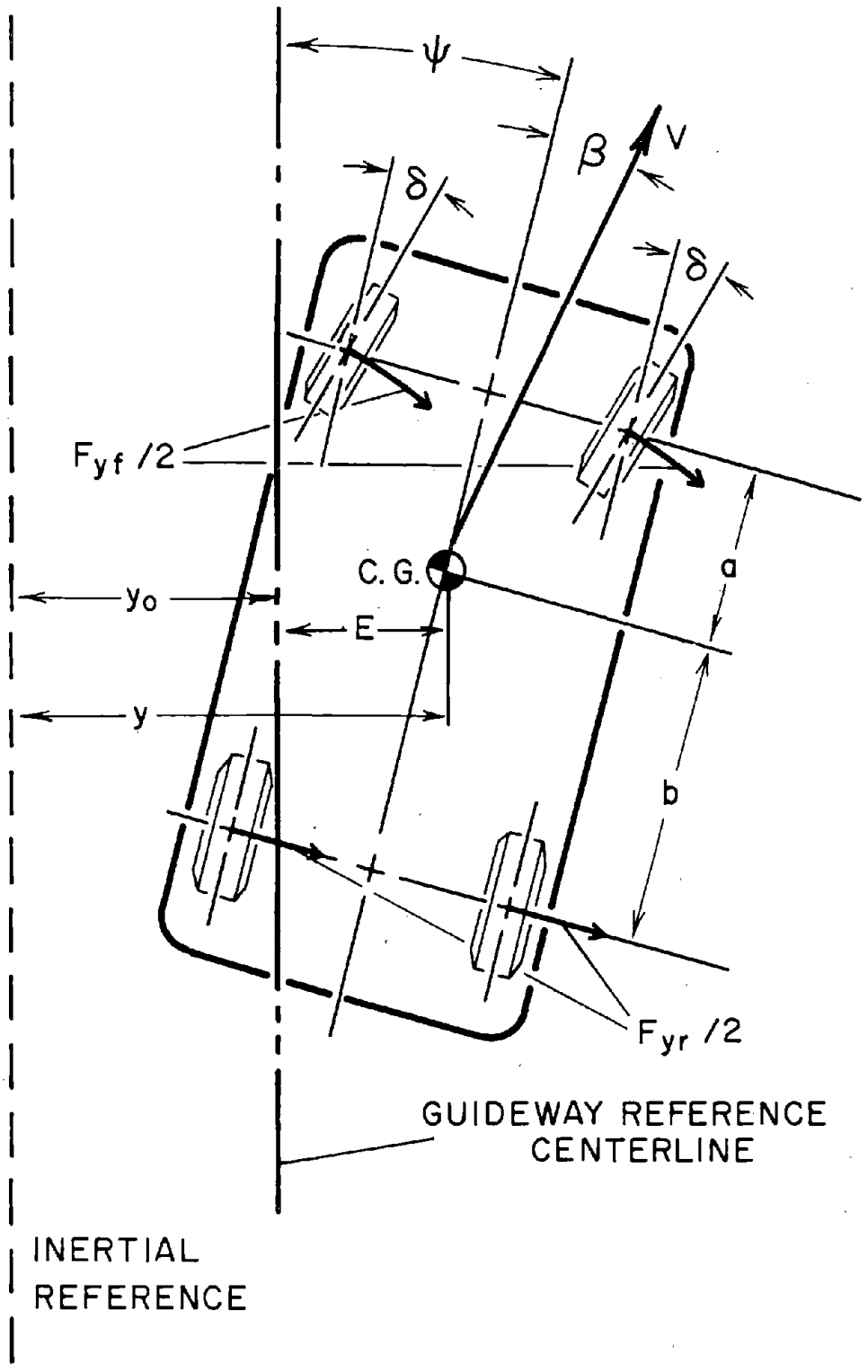


FIGURE 2 STANDARD TWO-DEGREE-OF-FREEDOM MODEL

OPTIMAL STEERING CONTROL

MINIMIZE PERFORMANCE INDEX :

$$J = \langle \ddot{y} + \ell\ddot{\psi} \rangle^2 + \rho^2 \langle y + \ell\psi - y_o \rangle^2$$

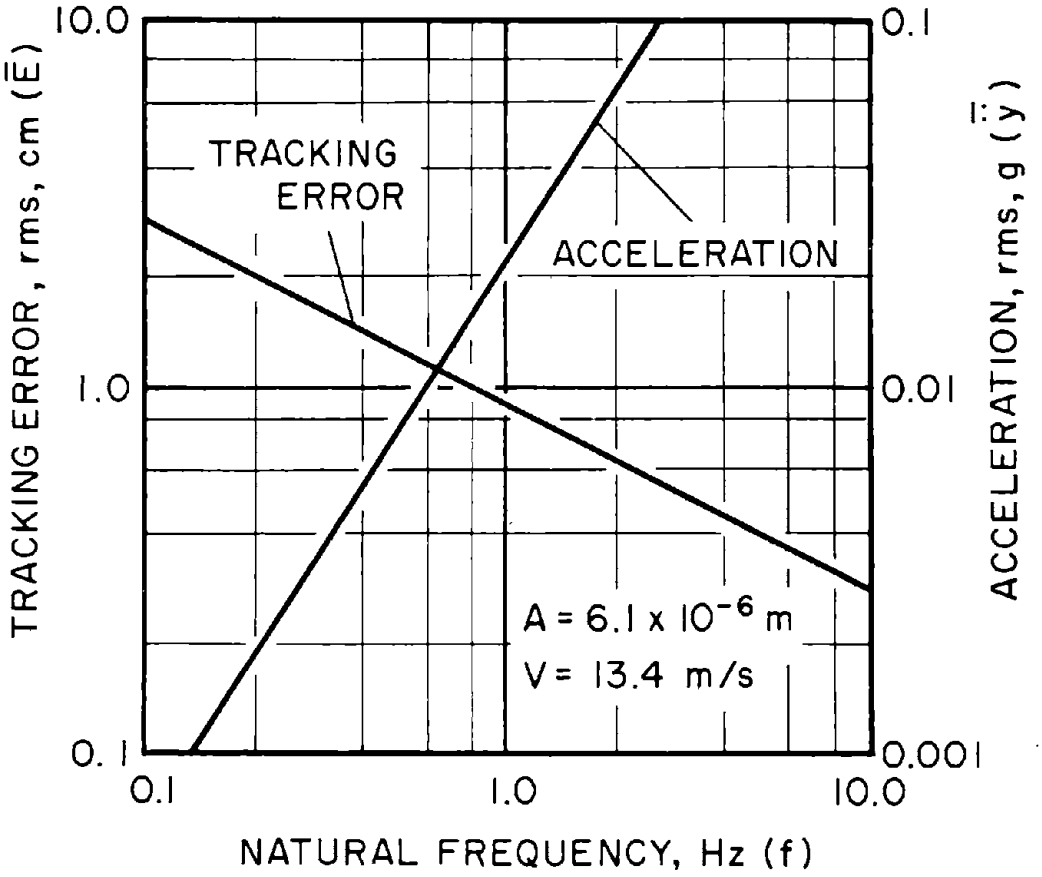
TO PRODUCE CONTROL LAW :

$$\delta = -K_y (y-y_o) - K_{\dot{y}}(\dot{y}-\dot{y}_o) - K_\psi(\psi-\psi_o) - K_{\dot{\psi}}(\dot{\psi}-\dot{\psi}_o) \ .$$

SUBOPTIMAL CONTROL IS :

$$\delta = - K_y (y-y_o) - K_\psi \psi$$

FIGURE 3 FULL STATE FEEDBACK CONTROL LAW



$$\bar{\ddot{y}} = \left(\frac{8\pi^4 AV}{\sqrt{2}}\right)^{1/2} f^{3/2}$$

$$\bar{E} = \left(\frac{3AV}{2\sqrt{2}}\right)^{1/2} f^{-1/2}$$

$$f = \omega_n / 2\pi$$

FIGURE 4 OPTIMAL CONTROLLER PERFORMANCE

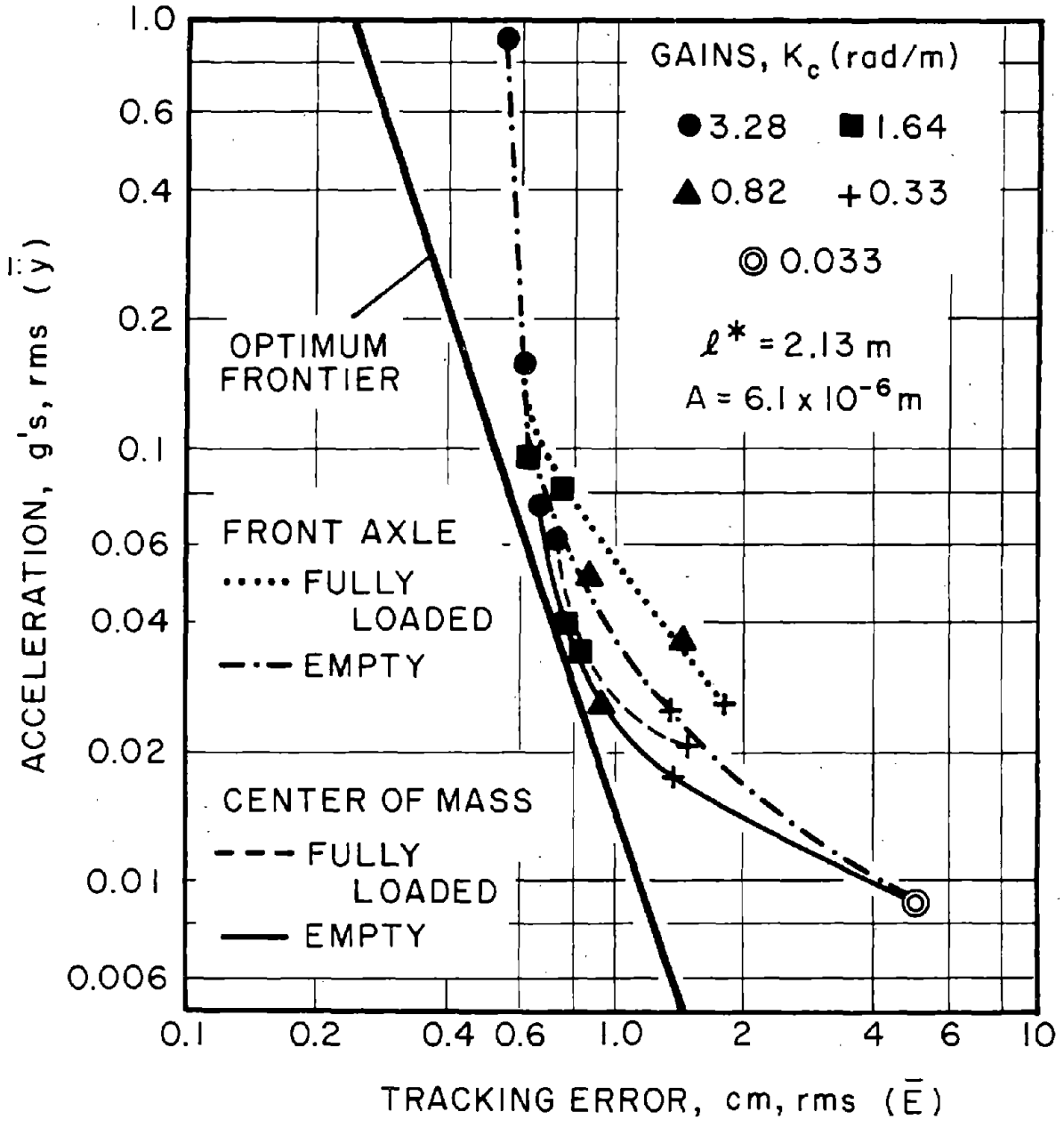


FIGURE 5 SINGLE OPTIMAL TRADEOFF FRONTIER

Performance can be significantly degraded if the steering actuator bandwidth is inadequate. Fig. 6 demonstrates how an increase in the dynamic lag introduced by the actuator (for example, a hydraulic power steering system) can destabilize the system, causing the closed-loop eigenvalues to move into the right half plane. The importance of actuator bandwidth has been verified independently by Daimler-Benz in West Germany, using both analytical and experimental methods.

Steady-state performance in curves is summarized in Fig. 7, which shows the tracking error at the center of mass as a function of forward speed for several different curve radii. Steady-state lateral acceleration is defined uniquely by the forward velocity and curve radius. The tracking errors are shown to be negligible close to the 13.4 m/s (30 mph) design speed, but even at off-nominal speeds these errors remain small.

Curve-entry transients are shown in Fig. 8, for the entry of a vehicle into a constant-radius curve without a transition spiral. The tracking errors can be seen to be very small, and the slight oscillations are expected to be reduced when a transition spiral is used.

Principal conclusions of this study of automatic steering are:

* The ride quality-tracking accuracy tradeoff can be clearly specified in general and used as a baseline for evaluating suboptimal controller performance.

* Good vehicle dynamic design (well damped, neutral steer, minimized roll-steer) permits a simple controller to provide near-optimal performance.

* Actuator dynamics can have a strong influence on performance, and high bandwidth actuators are needed for good steering control.

Work is continuing on the analysis of a steering controller which makes use of sensors at both front and rear of the vehicle to provide spatial filtering of disturbances. This permits performance to cross the optimal frontier of Fig. 5 under certain conditions, and by a relatively small amount. A control system permitting independent steering of front and rear wheels has also been studied and found to be effective in reducing tracking errors at the rear of the vehicle, permitting narrower guideway construction because of the more nearly tangent tracking of the reference.

Dynamic Entrainment and Platooning

The project I will concentrate on here is a multidisciplinary study of the dynamic entrainment and platooning of AGT vehicles. This study is divided into a system operations task and a vehicle control task. The former task includes a brief review of the potential urban implementations of an entrained AGT system, incorporating some consideration of its economics and an analysis of the competition between walking and AGT for activity center circulation. It also contains an analysis of the performance of merge junctions in an entrained AGT system, which is necessary

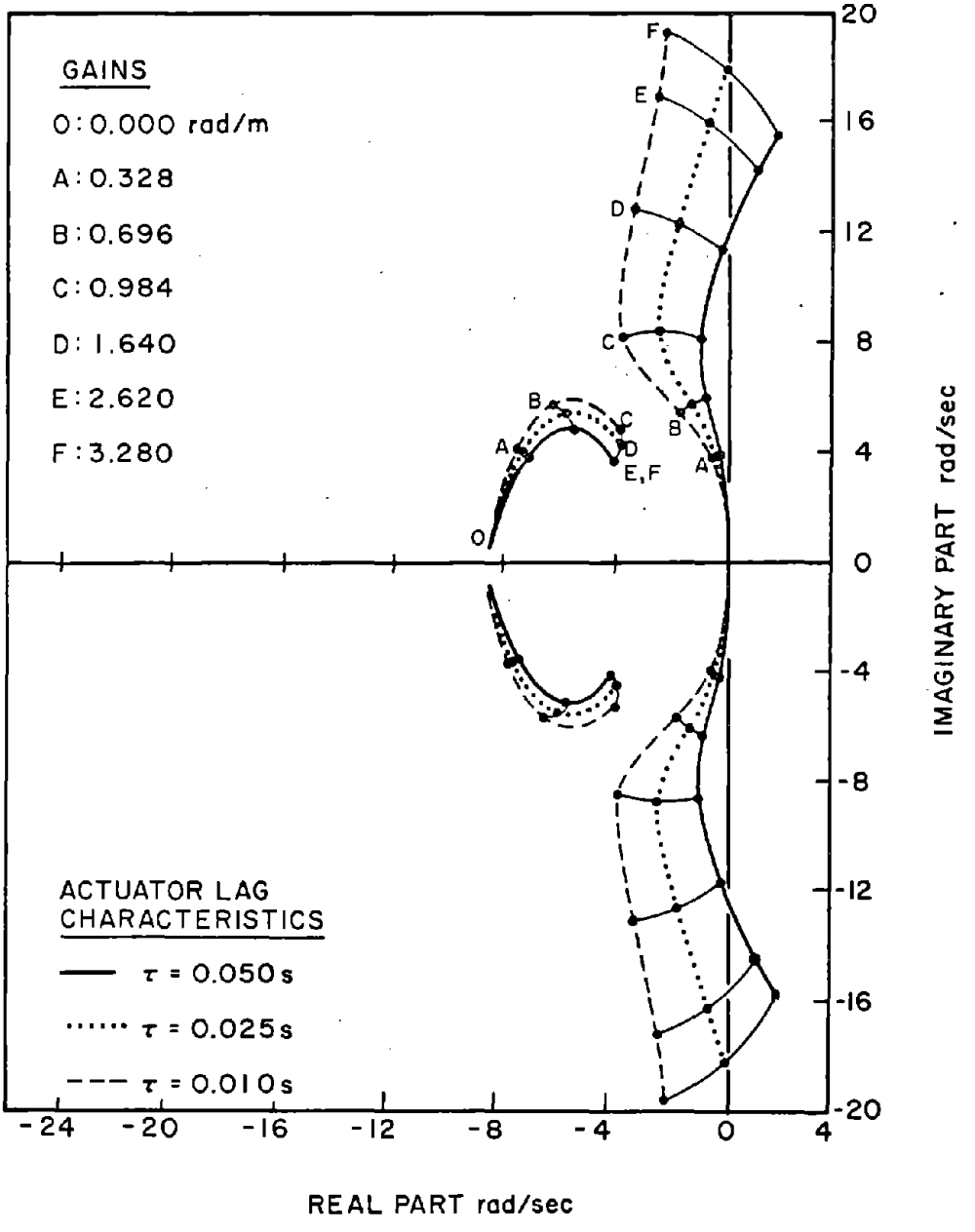


FIGURE 6 INCREASE IN DYNAMIC LAG

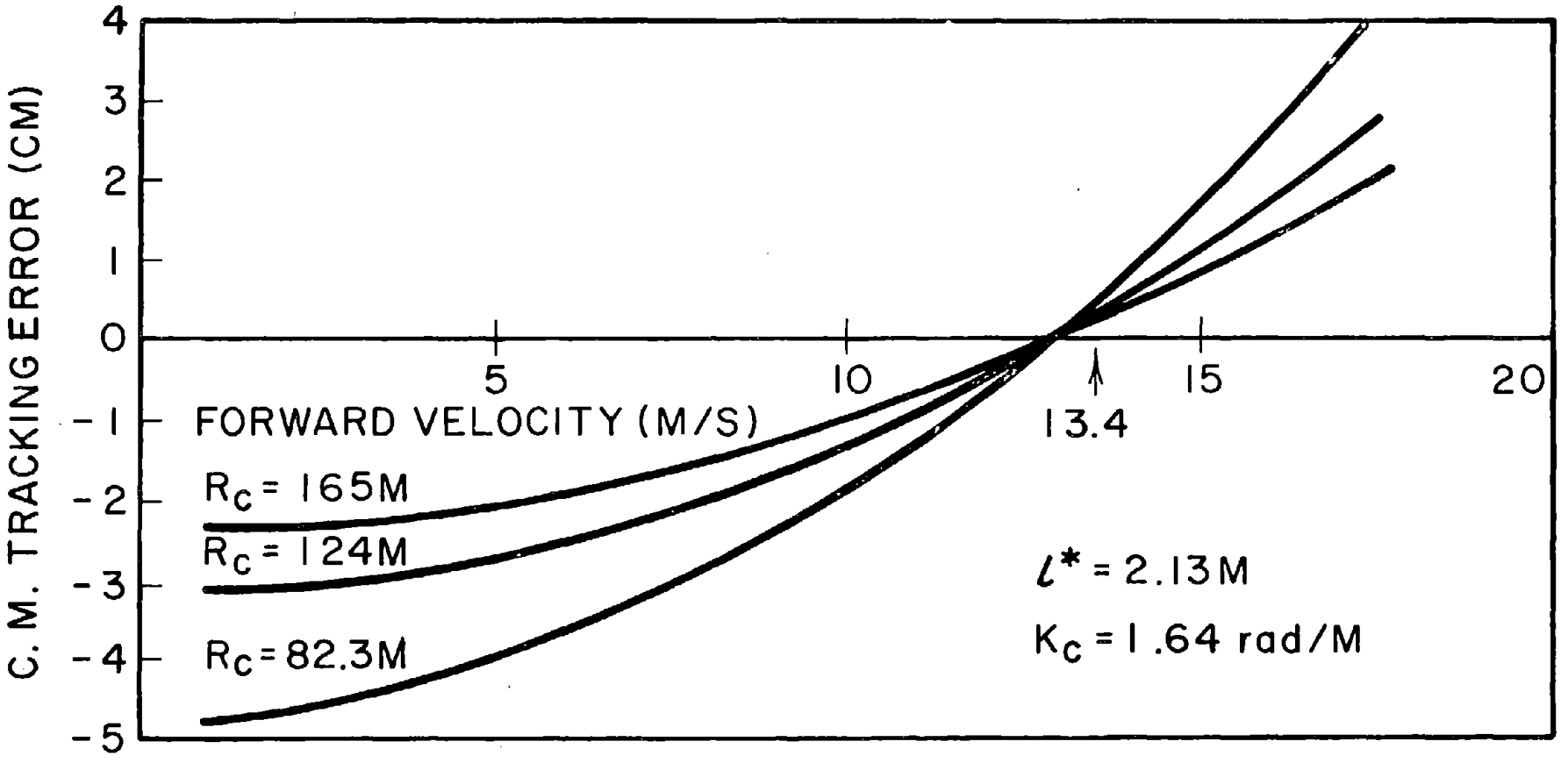


FIGURE 7 STEADY STATE PERFORMANCE

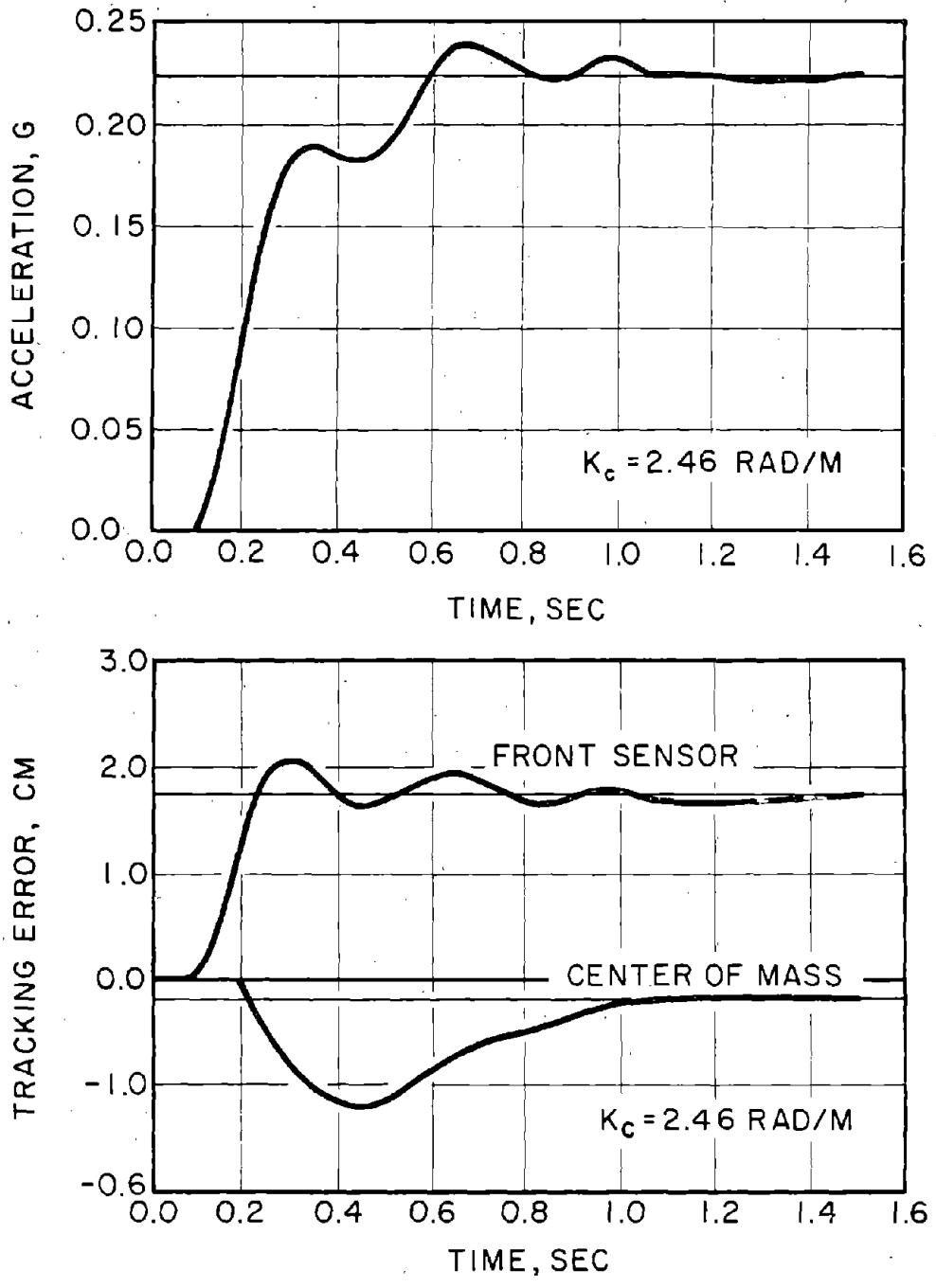


FIGURE 8 CURVE-ENTRY TRANSIENTS

to define its effective capacity. This is an important issue because the merge algorithms which should be used with trains are not necessarily the same as those which are used in single-vehicle systems.

The nonlinear, vehicle follower longitudinal controller which is needed to perform the entrainment and extrainment of vehicles "on the fly" has been designed and its performance simulated in detail. In addition, the controller characteristics needed for operation within platoons at inter-vehicle spacings of the order of 30 cm (one foot) have been determined. Jerk-limiting characteristics have been shown to be important influences on the in-platoon controller performance.

The motivation for entrainment (direct mechanical coupling) or platooning (functional coupling by control system) of AGT vehicles is increasing lane capacity at constant K-factor by grouping more vehicles together for each unit of safety-mandated open space. Dynamic entrainment and platooning refers to the ability of vehicles to entrain or extrain en route as needed at stations or merge junctions. This permits the use of small vehicles offering non-stop, single-party-occupancy service at an intermediate capacity level.

The use of smaller vehicles permits the construction of lighter, less-costly guideways and smaller tunnel cross-sections if it is necessary to tunnel. In comparison with single-vehicle systems using small vehicles, there are fewer entities to monitor and control on the guideway, simplifying the system-level control and communication function. The entrained system can be extremely flexible in adapting to both spatial and temporal shifts in travel demand. When a sudden surge of travelers appears in one section of the network, it can be accomodated by operating lengthened trains.

Simple entrainment by direct coupling (without the ability to dynamically reconfigure while traveling) can be used to facilitate the time-staged implementation of AGT systems. This makes it possible to make a reasonable start with a modestly-scaled system, but one which has a good growth potential and does not foreclose future options. It may be possible to provide the dynamic entrainment capability at minimal incremental cost in many cases because an equivalent ability to perform accurate close-range approaches and couplings may well be needed for rescuing failed vehicles along the guideway and for conducting operations within stations. Many of the linear station designs which have been proposed and studied have involved the assumption that the vehicles will operate in close-formation platoons at low speed.

An entrained system is tolerant of individual vehicle failures. If one vehicle in a platoon or train fails, the others can rescue it and remove it from the guideway so the lane is not blocked. There is also a possibility of energy savings from entrainment, as a consequence of the reduction of aerodynamic drag on the later vehicles in a train or platoon.

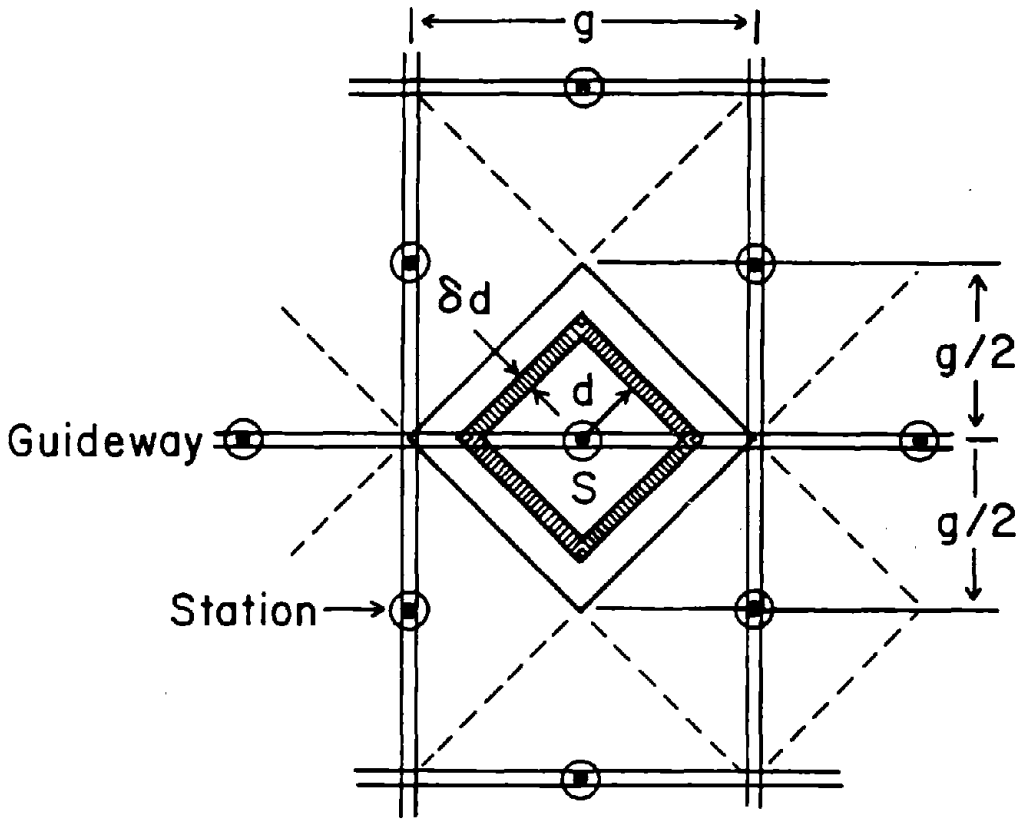
Several background analyses have been performed in order to better define the potential application characteristics of an entrained AGT system and determine the capacity which such a system should strive to achieve. The

travel times for AGT and walking in an activity center circulation application have been compared in order to determine a lower limit for service area size. The AGT system is assumed to be a square-grid guideway network with stations located at the midpoints of the grid sides, as shown in Fig. 9. Trip ends are assumed to be uniformly distributed throughout the service area, and people walk to and from the stations closest to their origins and destinations along a square grid street network. Fig. 10 shows a sample analytical result for operations with a 1/2-mile grid spacing in a one-mile-square activity center service area. The broadest distribution of trip times is for walking, and the intersection of the cumulative distribution of walk trip times with AGT times on a one-way guideway system is such that more than half of the trips are faster by walking all the way than by using the AGT system with walk access. Two-way service improves AGT performance considerably, but still leaves walking faster for 35% of the trips. The conclusion is that AGT is more suitable for service areas large enough that the distances cannot be comfortably walked.

In order to determine the lane capacity an AGT system should have in order to be able to operate at total passenger-km costs competitive with buses in activity centers, a simple economic analysis was performed. The parameters of this analysis are tabulated in Fig. 11, and a sample result, derived for an assumed interest rate of 8%, is shown in Figure 12. Following curves C (bus operating cost of $2.50/vehicle mile) and 3 (AGT capital cost of $5 million per mile) to their intersection, the costs are found to be comparable at a ridership of 25,000 passenger-km per route km per day. Using a simple assumption of 20% of the one-way daily flow being in the peak hour in the dominant direction, the hourly capacity needed is found to be 5000 passengers per lane per hour (or 10,000 passengers if the AGT system costs $ 10 million per mile).

The possible ways of achieving this level of lane capacity are summarized in Fig. 13. Using the performance assumptions at the top of the figure, it can be seen that very short headways and small K-factors would be required to achieve the desired capacity using the classical PRT paradigm. By going to shared-vehicle operations, with up to ten passengers per vehicle, the headways and K-factors become more nearly feasible. With entrained AGT vehicles, and maintaining a K-factor of unity between trains, it can be seen that the desired capacity of 5000 passengers per hour is achievable if the average train length is a little more than three vehicles, while double that capacity is possible with about eleven vehicles per train.

Capacity estimates such as those shown in Fig. 13 have been derived from a series of parametric kinematic capacity analyses. The baseline parameters for the capacity analyses are tabulated in Fig. 14, and a sample result of a typical parametric analysis is shown in Fig. 15. If the estimates of capacity in vehicles/hr in the lower frame of Fig. 15 are multiplied by 1.4 passengers per vehicle, the resulting passenger flows are below the desired level. Increasing train length permits higher capacity in passengers per hour, as shown in Fig. 16. This figure clearly demonstrates the capacity implications of entrained operation relative to single vehicles (curve 1).



c) Walk-access schematic

FIGURE 9 AN ASSUMED SQUARE GRID AGT NETWORK WITH STATIONS

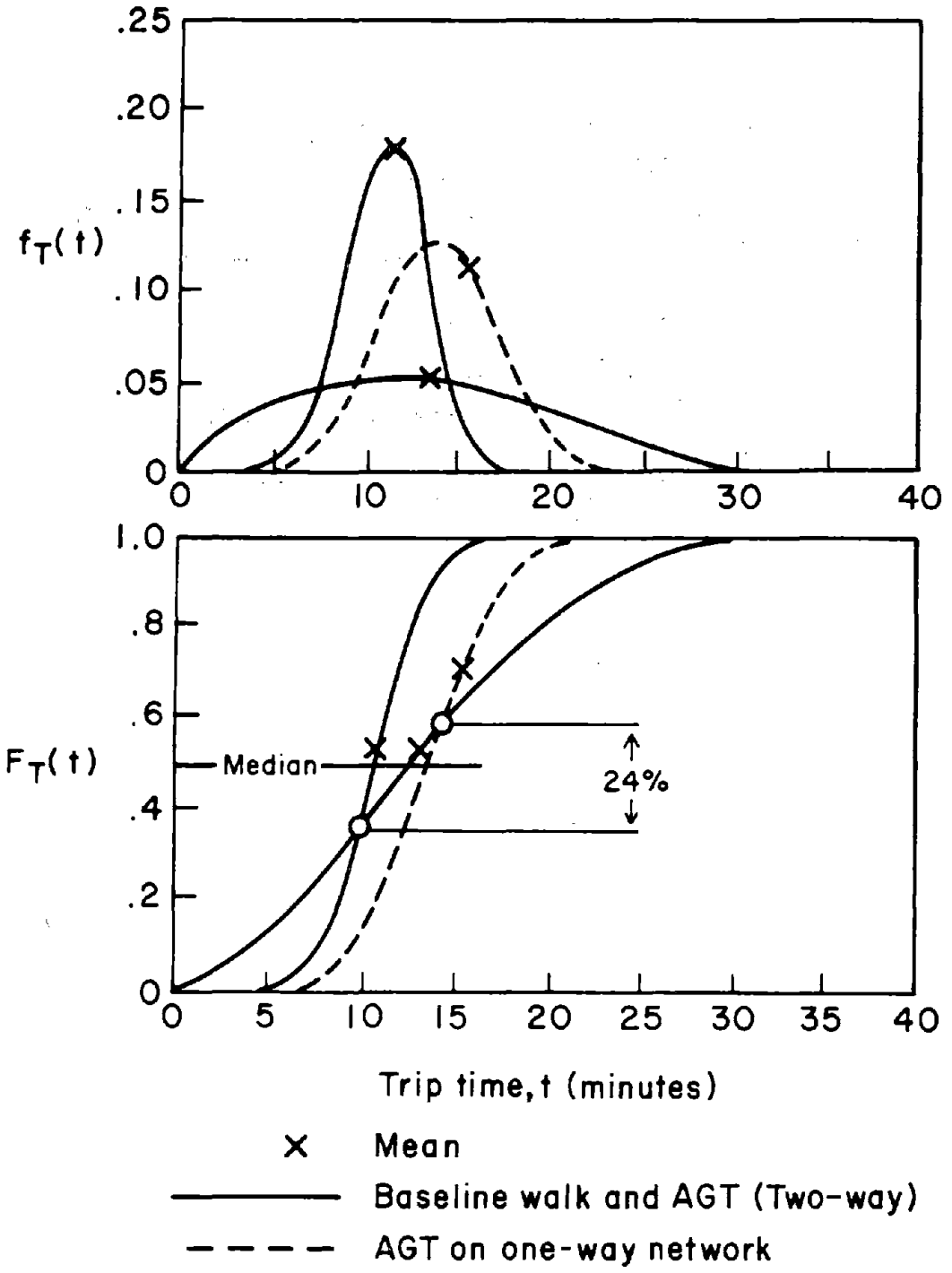


FIGURE 10 SQUARE GRID STREET NETWORK

AGT:	OPERATING COSTS	6¢ PER PASSENGER-MILE
	SYSTEM LIFE	40 YEARS
	CAPITAL COSTS	$1, 2, 5, 10, 20 MILLION/ 2-WAY MILE
BUS:	OPERATING COSTS	$1.50, 2.00, 2.50, 3.00 PER VEHICLE-MILE
	BUS LIFE	15 YEARS
	BUS UNIT COST	$60,000
	BUS CAPACITY	30 PASSENGERS (ALL SEATED)
	SPEED	9 MPH
BOTH:	INTEREST RATES	6%, 8%, 10%

FIGURE 11 PARAMETERS OF AGT-VS-BUS ECONOMIC ANALYSIS

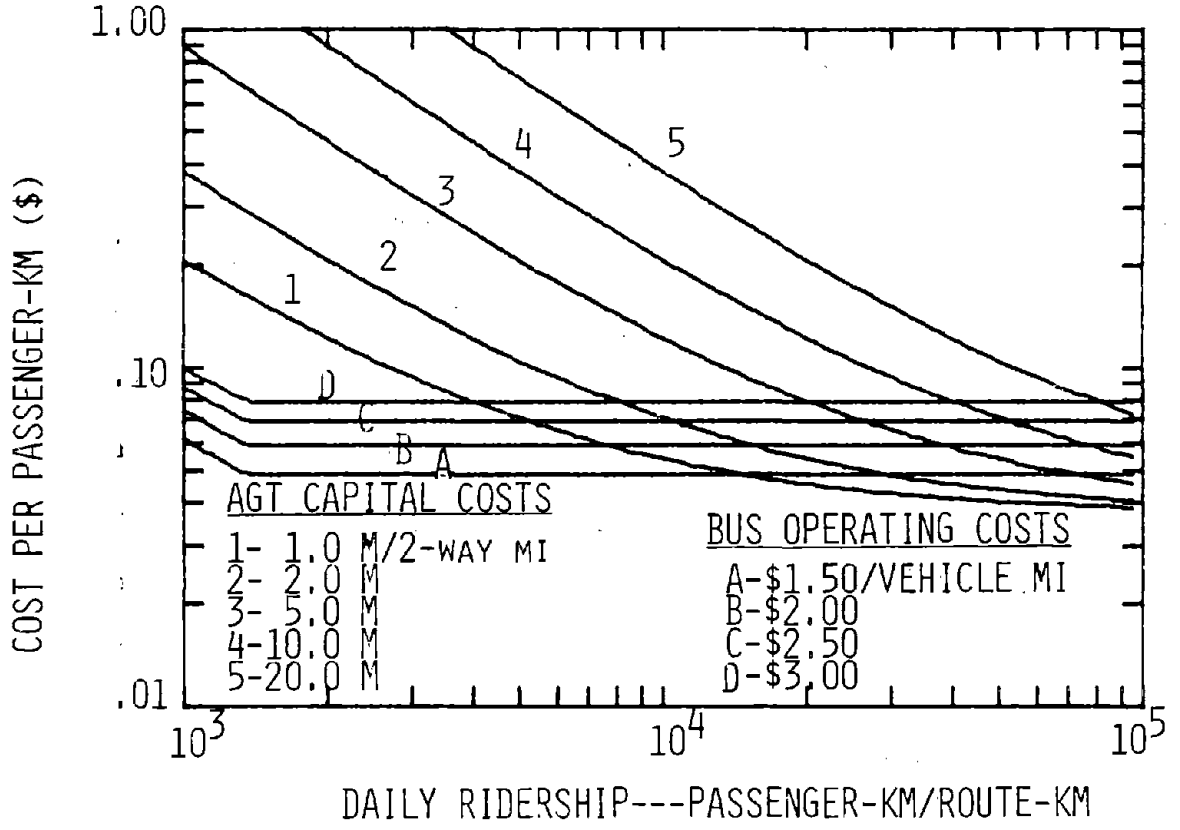


FIGURE 12 COMPARATIVE ECONOMICS OF AGT AND BUS CIRCULATORS

(5--10,000 PASSENGERS/HOUR)

PERFORMANCE ASSUMPTIONS: 30 MPH CRUISE
75% SLOT OCCUPANCY
10 FT. LONG VEHICLES
0.4 G EMERGENCY BRAKING

NONSTOP SINGLE-PARTY VEHICLES (OCCUPANCY 1.4)
AVERAGE HEADWAYS 0.378 - 0.756 SECONDS
(K FACTORS 0.195 - 0.391)

SHARED-VEHICLE OPERATIONS (UP TO 3 STOPS PER VEHICLE TRIP)
AVERAGE HEADWAYS 1.13 - 2.27 SECONDS
(K FACTORS 0.50 - 1.17)

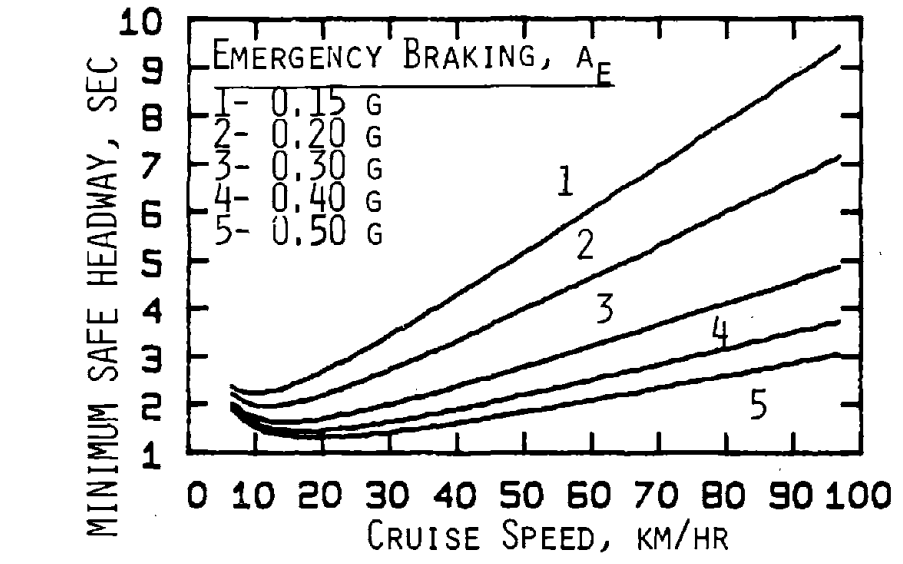
DYNAMICALLY-ENTRAINED AGT
REQUIRE K FACTOR = 1.0, OCCUPANCY 1.4

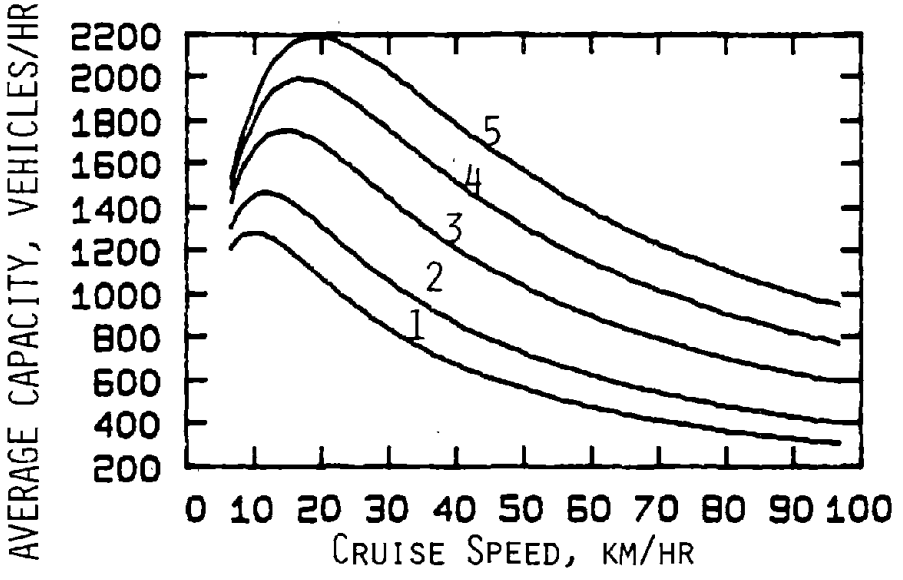
PASSENGERS/HOUR	AVERAGE HEADWAY (SEC)	AVERAGE TRAIN LENGTH
1,860	1.935	1.00 VEHICLES
5,000	0.756	3.23
10,000	0.378	11.34

FIGURE 13 TO ATTAIN REQUIRED LAND CAPACITY

K-FACTOR	1.0 (BETWEEN TRAINS)
VEHICLE LENGTH	10 FT
EMERGENCY BRAKING	0.3 G
SENSING-ACTUATION LAG	0.2 SECONDS
SPEED RANGE	4 TO 60 MPH
PASSENGER OCCUPANCY	1.4 PASSENGERS/VEHICLE
PERCENTAGE OF GUIDEWAY SLOTS USABLE	80%

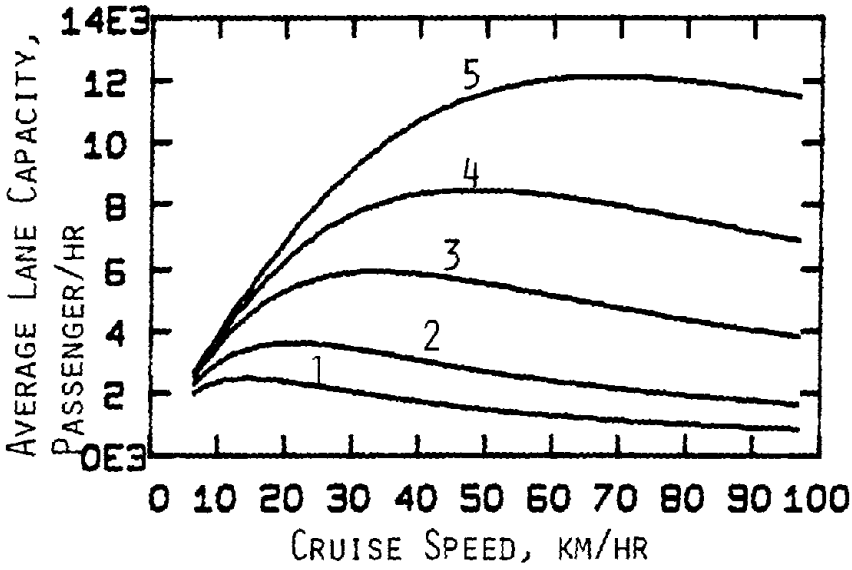
FIGURE 14 PARAMETERS OF KINEMATIC CAPACITY ANALYSIS





EFFECT OF EMERGENCY BRAKING RATE ON HEADWAY AND CAPACITY

FIGURE 15 TYPICAL BASELINE PARAMETRIC ANALYSIS



TRAIN LENGTHS

1- 1 VEHICLE

2- 2 VEHICLES

3- 5 VEHICLES

4- 10 VEHICLES

5- 20 VEHICLES

FIGURE 16 HIGHER PASSENGER CAPACITY/HR THROUGH INCREASED TRAIN LENGTHS

If vehicle safety is evaluated on the basis of the maximum collision impact velocity in the event of a failure, it can be shown that vehicles are safest when they are either very far apart or very close together. Entrainment requires operation under both of those conditions, with the transition between them being effected as quickly as possible. Collision impact speed as a function of initial spacing between vehicles (at the time the first vehicle undergoes a rapid deceleration) is shown in Fig. 17, which is similar to results which have been derived by others in the past. To the left of the peak in each curve, the collision occurs while the first vehicle is still moving, so that the relative collision velocity remains small. To the right of the peak the collision velocity remains small. To the right of the peak the collision occurs after the first vehicle has stopped, and far enough to the right there is no collision because the second vehicle is able to stop before it reaches the first.

A typical entrainment maneuver, using the nonlinear vehicle follower controller developed as part of this project, is shown in Fig. 18. The transition between following at long range (K factor greater than unity) and very short range is best visualized in the error phase plane on the lower right side of the figure. The vehicle closes its initial safe spacing of about 45 m to a nominal zero error (about 30 cm spacing) in 18 seconds, remaining inside the kinematic boundary which has been established. The acceleration and jerk remain within acceptable limits, the latter because of active jerk limiting.

The control of platoons of numerous vehicles is fundamentally different from the control of a pair of vehicles in a vehicle-follower system because of the need to guarantee asymptotic stability. An example of a nine-vehicle platoon effecting a commanded speed change with its leader in a velocity-regulator control mode is shown in Fig. 19. The velocity differences between consecutive vehicles can be seen to be quite small, and the spacing errors do not exceed 25 cm. Significantly, the errors decrease with distance from the front of the platoon, indicating asymptotic stability. The bounding of the spacing errors within 25 cm indicates the potential feasibility of operating platoons with intervehicle spacings of perhaps 30 cm, without risking contact between vehicles during maneuvers such as the speed change shown in Fig. 19.

Conclusion

This preliminary study of entrainment and platooning has demonstrated some of the advantages which these types of AGT operations can offer, and has also indicated some promising methods for providing the control capabilities needed to make dynamic entrainment and platooning feasible.

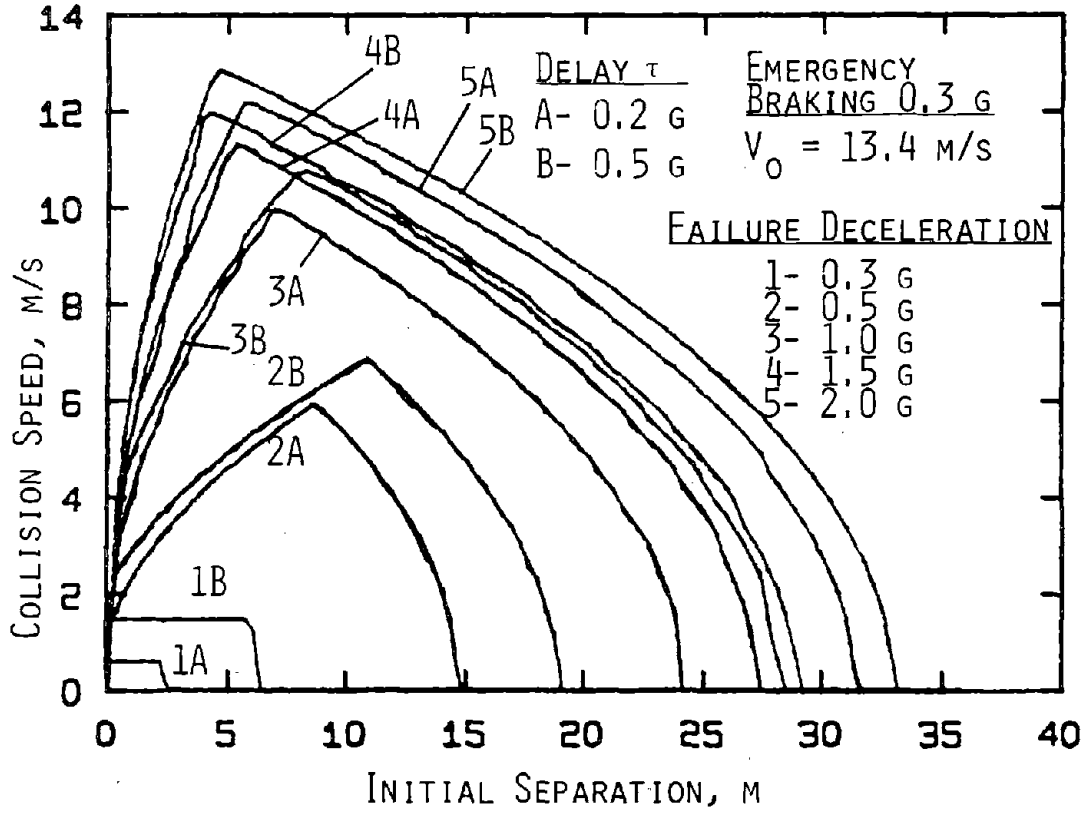


FIGURE 17 COLLISION IMPACT SPEED OF INITIAL SPACING BETWEEN VEHICLES

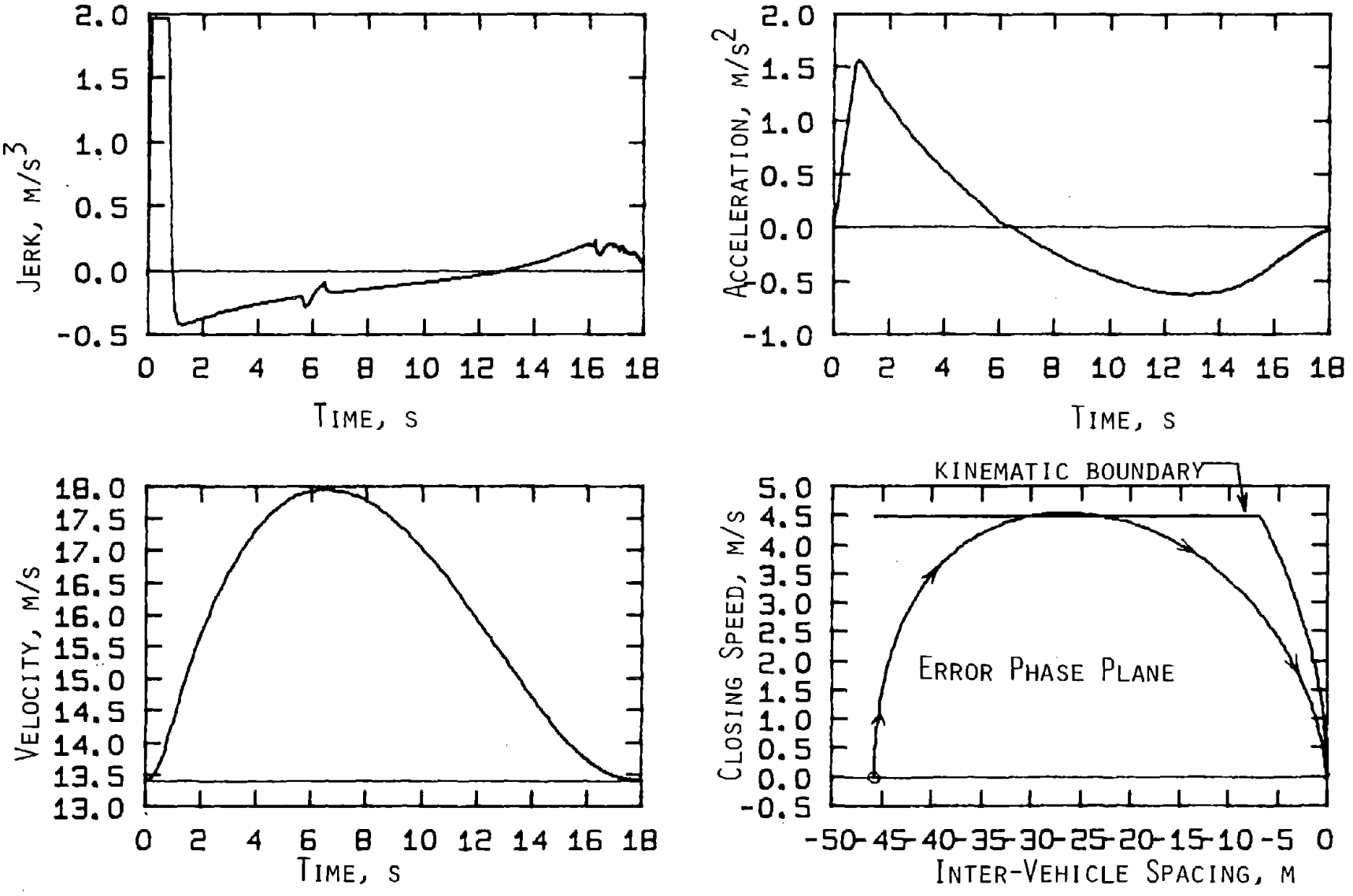


FIGURE 18 NOMINAL ENTRAINMENT MANEUVER

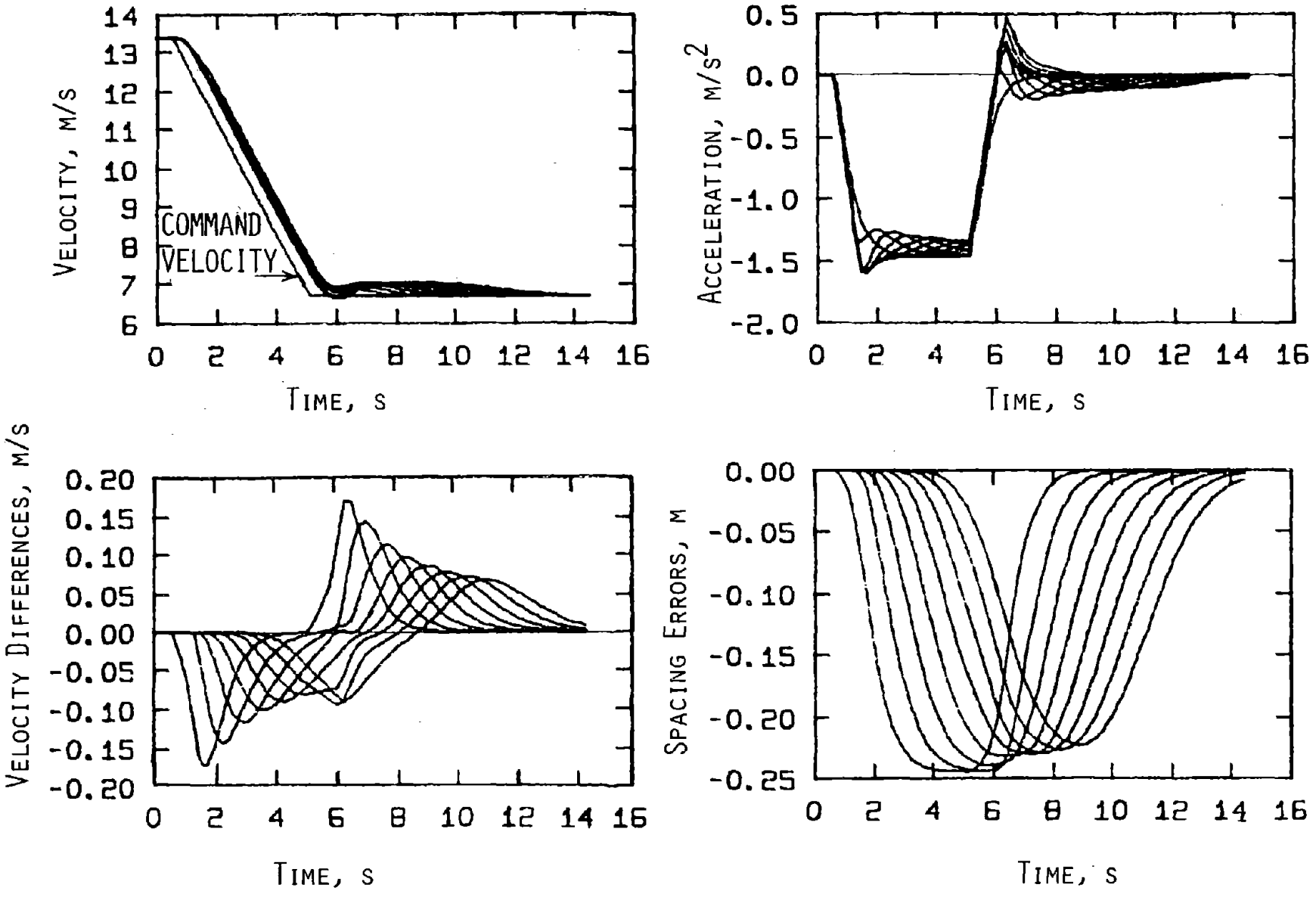


FIGURE 19 SPEED REDUCTION OF NINE-VEHICLE PLATOON UNDER VELOCITY REGULATOR CONTROL

PAPER 11

Vehicle-Follower Control Approach for Short Headway AGT Systems

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A VEHICLE FOLLOWER CONTROL APPROACH FOR SHORT HEADWAY AUTOMATED GUIDEWAY TRANSIT SYSTEMS

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ABSTRACT. Vehicle following in an automated transit system is a longitudinal control scheme where the state of a given vehicle is determined by the behavior of the preceding vehicle. At short time headways (0.5 to 3.0 sec) a kinematic constraint on vehicle operation arises as a consequence of the velocity, acceleration, and jerk limits imposed to assure passenger comfort. This constraint requires a trailing vehicle to maintain a spacing such that it may react to nominal (non-emergency) preceding vehicle maneuvers without collision and without exceeding service jerk and acceleration limits. The large initial conditions which may result preclude the use of linear time-invariant feedback. Thus, a nonlinear feedback controller is designed which forces the vehicle to follow the kinematically required spacing until the desired headway is attained. The design is based upon a technique which uses an approximately optimal feedback control with state constraints. In addition, several suboptimal controls with reduced informational requirements are presented, thus producing an easily instrumentable controller which properly responds to all possible nominal maneuvers of a preceding vehicle.

INTRODUCTION

Two basic approaches have been employed for the longitudinal control of vehicles in automated guideway transit systems. The approach, termed "vehicle following," considered in this paper allows communication between successive vehicles so that the motion of a given vehicle is controlled in accordance with the motion of its neighbors. This approach contrasts with "point-following" which assigns a vehicle to a cell (or slot); the cells being propagated along the guideway network at predetermined velocities and spacings. In this latter case, propulsion commands are generated to maintain the vehicles' location within the assigned cells.

Several investigators have studied the feasibility of the vehicle following approach by using a linear, time-invariant regulator to control perturbations from a nominal operating condition. Levine and Athans [1] use the linear optimal regulator to design a system where each vehicle generates propulsion commands based on information from all other vehicles in a string. In [2], Athans et al. reduce the complexity of this technique by applying the optimization procedure to smaller overlapping strings. Finally, Cunningham and Hinman [3] reduce the scheme to one in which vehicle control is based

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only on vehicle state and the state of the immediately preceding vehicle. This strategy is pursued by Brown in [4] while Fenton [5] deals with the design and testing of hardware systems.

Recently, Stupp et al. [6] have shown that at time headways (i.e., the time between successive vehicles passing a fixed point on the guideway) of less than 3 seconds the large initial conditions which may be present in a real system are incompatible with a linear time-invariant design. The analysis in [6] was formulated in terms of a control that uses an open loop velocity command at large headways and a closed loop control for regulation at shorter headways. For given acceleration and jerk limits it was recognized that a fundamental kinematic constraint arises which creates bounds on vehicle motion. This constraint dictates a minimum allowable spacing between vehicles which is a function of trailing vehicle state, preceding vehicle state, and the future maneuver capability of each vehicle. This constraint is of greatest significance at short headways, particularly in the case of an overtake situation. It is then shown in [6] that the kinematic constraint determines the point at which a vehicle must switch from a velocity command mode to the closed loop regulation mode of operation. As a result, the bandwidth requirement for the closed loop regulator at short headways was inconsistent with the large initial values of vehicle motion, i.e., the system response to these initial conditions typically led to violation of comfort criteria and the kinematically required spacing.

The state-constrained approach presented in this paper explicitly incorporates the kinematic constraint function (an inequality constraint on the state variables) into the control law. The procedure taken combines the kinematic constraint (our performance criterion for transient phenomena, principally the overtake situation) and a quadratic performance index (the criterion for steady state perturbational phenomena) into an optimal control problem. The solution to such a problem, however, is complex and requires a large amount of computation. Consequently, a less complex approximate solution is sought that may prove easier to implement. This approximate solution is based upon a procedure derived by Saridis [7]. The application of this technique to the vehicle following problem assumes that when the states of the trailing and preceding vehicle are such that violation of the kinematic constraint is not imminent, the well known solution to the optimal control problem with quadratic performance index (a constant gain linear regulator which ignores the kinematic constraint) can be used. When conditions change such that the kinematic constraint may be violated a control is implemented which causes the vehicle to precisely follow the kinematically required spacing until it is determined that regulator control would again satisfy the constraint. A further simplification is presented whereby the linear regulator portion of the controller is eliminated. This simplification of the controller requires some modification of the kinematic constraint but has little impact on performance. However, even with this simplification the informational requirements for precisely maintaining the kinematically required spacing include preceding vehicle velocity, acceleration, and jerk. To overcome this drawback, several suboptimal controllers are derived with the intent of simplifying the kinematic constraint such that the resulting control will satisfy the actual kinematic constraint but will require less computation and information. The final result is an easily instrumentable controller requiring preceding vehicle information in the form of spacing and its derivatives (i.e., relative velocity and acceleration).

The kinematic constraint is derived in Section 2 for two possible vehicle maneuvers which yield the minimum allowable spacing as a function of vehicle state. Section 3 describes the design problem by explicitly considering the jerk, acceleration, and kinematic constraints. An approximately optimal regulator is then introduced. The simplification of the kinematic constraint and three suboptimal control laws which result from this simplification are examined in Section 4. Finally, the results of simulated test cases are presented in Section 5.

KINEMATIC BOUNDARY CONSTRAINT

The kinematic constraint is the result of a fundamental characteristic of vehicle-following, that is, future maneuvers of a preceding vehicle are unknown by a trailing vehicle. Thus, safety considerations require that the trailing vehicle controller anticipate a non-emergency minimum time deceleration to minimum line speed by the preceding vehicle at any time. The minimum time deceleration is determined by the velocity, acceleration, and jerk limits imposed on the system in order to assure passenger safety and comfort. Consequently, the maneuver capability of a given vehicle as defined by these limits yields a time and distance required for a vehicle to decelerate to a given speed. In view of this fact, a trailing vehicle traveling at a higher velocity than a preceding vehicle (i.e., an overtake situation) will require a greater distance than the preceding vehicle to decelerate to minimum line speed. As a result, the trailing vehicle must maintain a spacing such that if the preceding vehicle should perform a minimum-time deceleration maneuver, the trailing vehicle may react with its full service braking capability and avoid collision. It is important to note that an underlying assumption in this augument is that the trailing vehicle adheres to its service limits. Obviously, if the preceding vehicle brakes at service limits the trailing vehicle may avoid collision by applying emergency braking. However, it is desirable to avoid the use of emergency limits in non-emergency situations and therefore, the kinematic constraint described above is constructed.

To develop a mathematical description of the kinematic constraint, we first examine the maneuver capability of a given vehicle. The limits assumed for this study are:

Service Acceleration Limit, $A_s = 2.6 m/sec^2$

Service Jerk Limit, $J_s = 2.6 m/sec^3$

Maximum Guideway Speed, $V_{max} = 25 m/sec$

Minimum Guideway Speed, $V_{min} = 10 m/sec$

Since both acceleration and jerk limits have been specified there are two possible minimum time maneuver profiles which may occur when a vehicle decelerates to a lower speed. They are characterized by the various minimum time trajectories indicated by dashed lines in Figure 1. Suppose, for example, a vehicle has acceleration and velocity given by point 1 in the figure. In order to decelerate to V_{min} in minimum time the vehicle is immediately placed on the negative jerk limit and subsequently follows the parabolic trajectory shown. When the vehicle reaches the lower boundary of the acceptable region

the jerk is switched to zero and the vehicle thus follows the negative acceleration limit until the lower left boundary of the acceptable region is reached. At this point the positive jerk limit is applied until the vehicle reaches minimum line speed. Alternatively, if the vehicle has an acceleration and velocity given by point 2 in the figure then the minimum time trajectory does not include the switching curve corresponding to zero jerk. Trajectories which include the switching curve, $J = 0$, will be designated as Maneuver 1 and those only including the switching curve, $J = J_s$, as Maneuver 2.

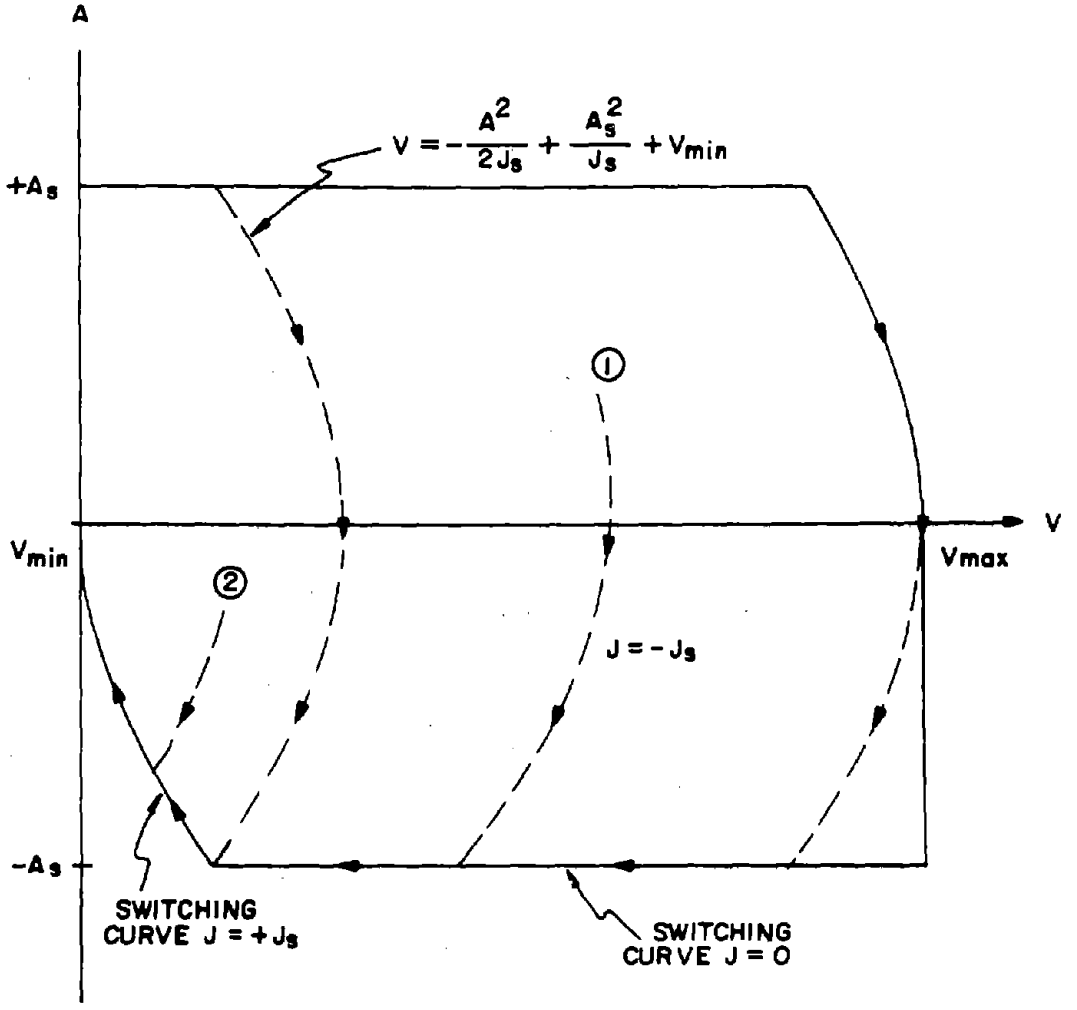


FIGURE 1. MINIMUM TIME PHASE TRAJECTORIES

In order to functionally describe the kinematic requirement it is necessary to determine the time and distance in which a vehicle performs a minimum time deceleration to minimum line speed as a function of current velocity and acceleration. A repeated integration of the trajectories shown in Figure 1 will result in two sets of expressions for required time and distance, each set corresponding to one of the two possible maneuvers. These expressions are easily determined and may be found in [8].

Figure 2 illustrates the kinematic requirements as the spacing required to prevent collision in the event of a minimum time deceleration by the preceding vehicle. As shown in Figure 2 this spacing is given in terms of the distance required for each vehicle to complete a maneuver to minimum line speed and the time in which each vehicle accomplishes the maneuver. Consequently, the minimum required spacing is given by

$$S_{min} = X_P - X_T$$

$$= d_r^T - d_r^P - V_{min}\,(t_r^T - t_r^P) + hV_{min} \qquad (1)$$

where $X_T(X_P)$ = trailing (preceding) vehicle position, d_r^T (d_r^P) = distance required for trailing (preceding) vehicle to decelerate to minimum line speed t_r^T (t_r^P) = time required for trailing (preceding) vehicle to decelerate to minimum line speed, and h = desired headway (headway is defined as separation in time assuming constant velocity).

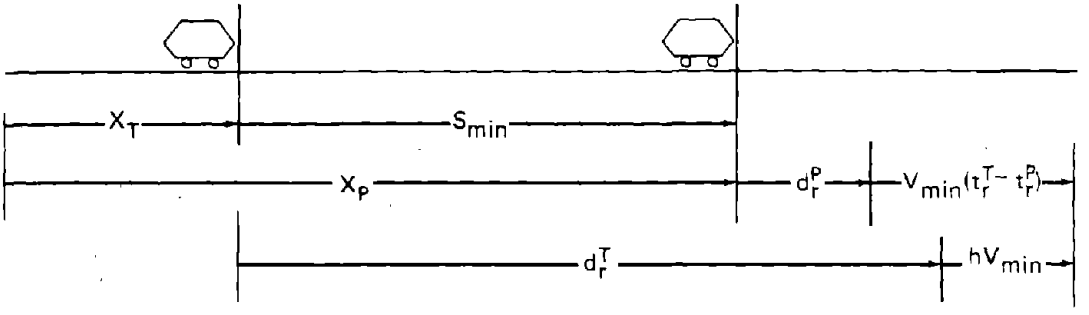


FIGURE 2. MINIMUM SPACING REQUIRED BY KINEMATICS

In the overtake situation the preceding vehicle is at a lower velocity than the trailing vehicle and will complete its maneuver to minimum line speed before the trailing vehicle reaches V_{min}. Thus, the term, $V_{min}\,(t_r^T - t_r^P)$, represents the distance traveled by the preceding vehicle at minimum line speed while the trailing vehicle is still in the process of accomplishing its deceleration maneuver. If, on the other hand, the trailing vehicle should be at a lower velocity this term will subtract from the overall required spacing.

The term, hV_{min}, represents the desired spacing when both vehicles are at V_{min} with zero acceleration. Hence, it constitutes a residual term which specifies the desired spacing when the kinematically required spacing is zero. As a result, any suitable factor may be used and not necessarily hV_{min}. In

fact, it will be shown in Section 3 that using hV_T rather than hV_{min} simplifies the control problem. Moreover, other vehicle following strategies may be employed through inclusion of the appropriate term in the constraint function.

Consequently, the kinematic constraint may be formulated in terms of vehicle spacing, S, as follows:

$$S_{min} - S \leq 0 \tag{2}$$

where S_{min} is given by (1). The presence of this constraint is only significant at short headways because the nominal spacing, hV_T, is typically less than the required spacing, S_{min}.

In summary, for a given set of vehicle states and assuming that vehicles are constrained to operate within service jerk and acceleration limits there exists a safe spacing between the trailing and preceding vehicle. If the spacing between vehicles is less than this spacing the kinematic constraint is violated and the possibility of collision is present. That is, if the preceding vehicle should perform a minimum time maneuver to minimum line speed the trailing vehicle cannot attain the desired headway using service limits. Clearly, a controller must be designed to regulate to the desired headway but at same time it must maintain the proper spacing between vehicles when velocity errors become significant. The development in the following sections will demonstrate how the kinematic constraint may be explicitly incorporated into the control law and thus satisfy this objective.

APPROXIMATELY OPTIMAL REGULATOR WITH STATE CONSTRAINTS

The vehicle following problem may be formulated [6] into the optimal regulator with linear plant and an infinite time integral quadratic performance index. That is, a plant of the form

$$\dot{\underline{x}} = A\underline{x} + bu \tag{3}$$

is assumed where $\underline{x}$ is the n-dimensional state vector, u the scalar control, A a constant n x n matrix, and b a constant n-dimensional vector. The performance index is of the standard form

$$I = \int_0^\infty (\underline{x}^T Q \underline{x} + \tfrac{1}{2} u^2)\, dt \tag{4}$$

where Q is a constant positive semidefinite n x n matrix. The resulting regulator is a feedback controller designed to maintain the system within an acceptable deviation from a nominal condition using acceptable amounts of control. This has been shown [6] to produce satisfactory results for small initial conditions. However, in the mode transition (e.g., overtaking) problem where large initial condition errors are present the resulting controller produces a response which exceeds the desired jerk, acceleration,

and kinematic limits. This is due to the high bandwidth requirements for short headway operation [6].

Consequently, in designing a controller for the mode transition problem, the jerk and acceleration limits and in particular, the kinematic constraint should be explicitly considered. Hence, the design problem may be described in terms of (3), (4), and a constraint vector given by

$$\begin{bmatrix} c(x) \\ |A| \\ |J| \end{bmatrix} \leq \begin{bmatrix} 0 \\ A_s \\ J_s \end{bmatrix} \tag{5}$$

where $c(\underline{x}) = S_{min} - S$ (see (1), (2)), A is vehicle acceleration, and J is vehicle jerk. However, recall that d_r^T and t_r^T as well as d_r^P and t_r^P are determined from one of two possible maneuvers as shown in Figure 1. Thus the function, $c(x)$, comprises four distinct forms since each vehicle may have an acceleration and velocity which dictate any one of the two maneuver profiles, although only one form is applicable for a given set of vehicle states.

The minimization of (4) subject to (3) and (5) necessitates computational complexity which would likely become prohibitive in terms of an onboard controller. Consequently, an alternative solution which produces a near optimal controller is used.

Saridis [7] presents an approximate solution based on observations of the geometric features of the optimal constrained trajectories. A dual-mode controller is developed which follows the optimal unconstrained trajectories as determined by the steady state Ricatti equation when the presence of the constraint has little effect upon the solution. When the unconstrained solution tends to violate the constraint a nonlinear mode is introduced which keeps the solution on the boundary of the constraint region. This technique will be adopted to the present problem with some modification.

An ideal vehicle plant will be assumed with state equation given by

$$\dot{\underline{x}} = A\underline{x} + bJ_T + gJ_P$$

where $\underline{x} = [S \; V_T \; A_T \; V_P \; A_P]'$;

$$A = \begin{bmatrix} 0 & -1 & 0 & 1 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

and

$$b = [0 \quad 0 \quad 1 \quad 0 \quad 0]' ,$$

$$g = [0 \quad 0 \quad 0 \quad 0 \quad 1]' .$$

In the above, A_P is the preceding vehicle acceleration, V_P is the preceding vehicle velocity, and J_P is the preceding vehicle jerk. The prime ($'$) denotes transpose. The control input to the trailing vehicle is a jerk command, J_T. If the initial states are such that the kinematic constraint, $c(\underline{x}) = 0$, then a necessary and sufficient condition that $c(\underline{x})$ remain zero is that its time derivative be zero or

$$J_T = - (\nabla c' b)^{-1} \nabla c' [A\underline{x} + gJ_P] \tag{6}$$

This constitutes the nonlinear mode of the dual-mode controller proposed by Saridis where the del operator (∇) denotes the gradient. The gradient vector is determined from one of four possible functions depending upon the values of A_T, V_T, A_P, and V_P. Rather than solving for the linear gains in the unconstrained problem, however, an on-limits jerk command will be used at a specified distance from the kinematic boundary. The controller structure then takes the form shown in Figure 3.

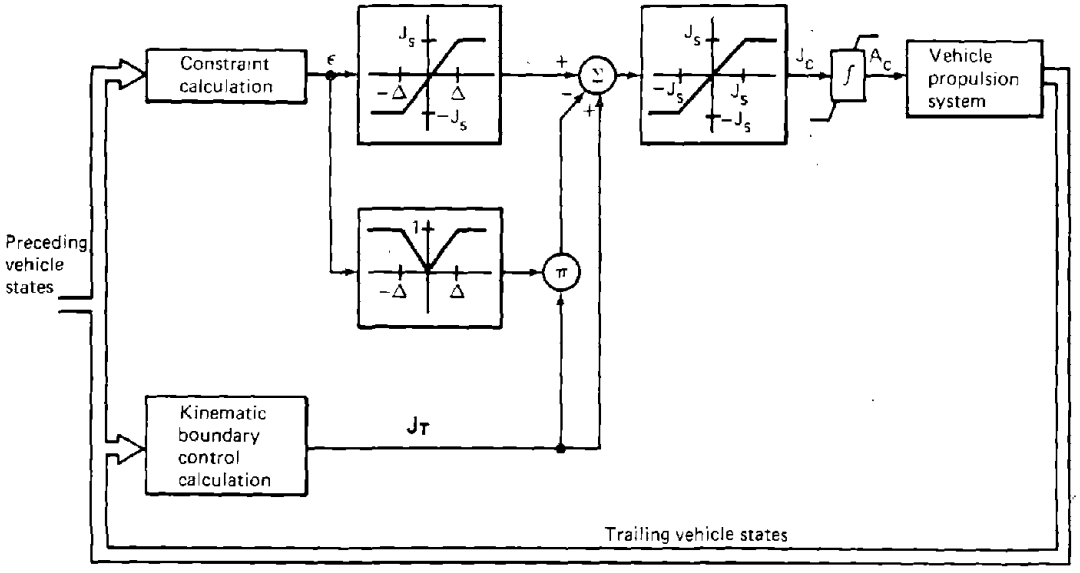


FIGURE 3. CONTROLLER STRUCTURE

The error calculation consists of determining the difference ($\varepsilon = -c(\underline{x})$) between actual vehicle spacing and the kinematically required spacing. When this error is zero the kinematic boundary control given by (6) is implemented ($J_c = J_T$). When $\varepsilon < 0$ the vehicle is violating the constraint (i.e., vehicle

is too close) and the negative jerk limit is gradually applied until at $\epsilon = -\Delta$ the on-limit negative jerk command becomes the input to the system ($J_c = -J_s$). Similarly, when $\epsilon > 0$ the vehicle is safely satisfying the kinematic constraint and a positive jerk may be applied ($J_c = J_s$). The parameter Δ, effectively a gain in the system, is selected through consideration of closed loop stability using a describing function analysis [8]. This analysis shows for a headway of 0.5 seconds a value $\Delta = 1$ yields adequate stability and in addition, simulation studies have also demonstrated satisfactory performance for this value.

Inspection of (1) reveals that when the trailing and preceding vehicles are at the same constant velocity (i.e., $d_r^T = d_r^P$ and $t_r^T = t_r^P$) then the required spacing is hV_{min}. Hence, it would be desirable to modify the kinematic constraint such that the kinematic boundary will coincide with the nominal operating headway. This is easily accomplished by replacing hV_{min} with hV_T in (1) so we now have

$$c(\underline{x}) = d_r^T - d_r^P - V_{min}(t_r^T - t_r^P) + hV_T - S \qquad (7)$$

This is acceptable since $hV_T \geq hV_{min}$, and therefore, the spacing when $c(\underline{x}) = 0$ is greater than the spacing as required by our original constraint. Furthermore, the regulator will act to maintain the desired headway for any $V_P > V_{min}$.

The performance of this controller has been evaluated with the use of computer simulation in a variety of circumstances [8]. It is found to properly react to any nominal maneuver of a preceding vehicle during both an overtake situation and at the desired headway while precisely maintaining the kinematically required spacing. As seen from (6), however, the informational requirement consists of the complete state vector, $\underline{x}$, and the preceding vehicle jerk, J_P. Thus, in an attempt to relax this requirement several suboptimal controls are derived.

SUBOPTIMAL VEHICLE CONTROL

All of the suboptimal controllers to be presented are derived with the intent of simplifying the kinematic constraint such that the resulting control will satisfy the actual constraint (2) while requiring less computation and information.

Suboptimal Control I

The first simplification of the kinematic constraint assumes the preceding vehicle will always decelerate to the negative acceleration limit even if the vehicle is traveling at minimum line speed. As a result, although the actual minimum line speed remains the same, for purposes of control calculation we adopt a new minimum line speed less than the actual. Consequently, we need only consider Maneuver 1 in the constraint vector,

$$\begin{bmatrix} c(\underline{x}) \\ |A_T| \\ |J_T| \end{bmatrix} \leq \begin{bmatrix} 0 \\ A_s \\ J_s \end{bmatrix}$$

where $c(\underline{x})$ is given by (7).

If we assume a vehicle traveling at 10 m/sec will decelerate at the jerk limit to a -2.6 m/sec^2 acceleration the largest final velocity it can have is 7.4 m/sec. As a result, consistent with our assumption for Maneuver 1 we may set $V_{min} = 7.4$ m/sec in the constraint equation although our minimum line speed is still 10 m/sec.

The computational requirements are considerably less than for the optimal but will still require measurements of all vehicle states (i.e., V_T, A_T, V_P, A_P, J_P, S).

Suboptimal Control II

The remaining suboptimal strategies are obtained from simplification of the kinematic constraint for suboptimal I with the aim of only requiring error states, that is, spacing and its derivatives. First, the kinematic constraint for Maneuver 1 in terms of vehicle states is given by:

$$\begin{aligned} c(\underline{x}) = {} & .007(A_T^4 - A_P^4) + .05(A_T^3 - A_P^3) + .1(A_T^2 - A_P^2) \\ & + .074(A_T^2 V_T^2 - A_P^2 V_P) + .38(A_T V_T - A_P V_P) + .5(V_T - V_P) \\ & + .19(V_T^2 - V_P^2) - 10(.38(A_T - A_P P + .07(A_T^2 - A_P^2) \\ & + .38(V_T - V_P)) + hV_T - S \end{aligned} \tag{8}$$

where we have used $A_s = 2.6$ m/sec^2, $J_s = 2.6$ m/sec^3 and $V_{min} = 10$ m/sec.

If all acceleration terms in the above constraint are dropped the kinematic constraint becomes

$$c(\underline{x}) = -3.3(V_T - V_P) + .19(V_T^2 - V_P^2) + hV_T - S \tag{9}$$

There is no guarantee that (9) satisfies the kinematic constraint. However, due to the additional simplifications shown below, numerical comparison with the original constraint and verification by simulation justify its use [8].

The second term in (9) may be factored to yield

$$c(\underline{x}) = -3.3(V_T - V_P) + .19(V_T - V_P)(V_T + V_P) + hV_T - S$$

Since we are interested in error states the sum term, $V_T + V_P$, may be eliminated by substituting $V_T + V_{max}$ to obtain

$$c(\underline{x}) = 1.4(V_T - V_P) + .19\ V_T(V_T - V_P) + hV_T - S$$

This is permissible since $V_T \leq V_{max}$ and the new required spacing is greater than what is required by (9). In order to formulate a jerk command input from the above constraint it is necessary that $\dot{c}(\underline{x})$ contain a trailing vehicle jerk term or equivalently that $c(\underline{x})$ include an acceleration term. Thus, we simply add a constant times A_T to yield

$$c(\underline{x}) = 1.4(V_T - V_P) + .19\ V_T(V_T - V_P) + kA_T + hV_T - S \tag{10}$$

where k will be determined below on the basis of string stability (i.e., disturbances do not propagate through a string of vehicles with increasing magnitude).

The corresponding control which keeps $c(\underline{x}) = 0$ is then given by

$$J_T = -\frac{1}{k}\left[-1.4\,A_E - .19(V_E A_T + A_E V_T) + hA_T - V_E\right]$$

where

$$A_E = A_P - A_T$$

$$V_E = V_P - V_T$$

Suboptimal Control III

Equation (10) may be further simplified by substituting V_{max} for V_T in the second term. Again, this is valid since $V_T \leq V_{max}$ and therefore our new minimum spacing is greater than what is required by (10). As a result, we have

$$c(\underline{x}) = 6\ (V_T - V_P) + kA_T + hV_T - S \tag{11}$$

and the corresponding control is given by

$$J_T = \frac{1}{k}\left[-6\,A_E + hA_T - V_E\right] \tag{12}$$

Consequently, the control (12) which keeps the vehicle on the kinematic boundary defined by (11) becomes a linear time-invariant feedback controller (assuming the vehicle is within jerk and acceleration limits). The transfer function of this system for small $c(\underline{x})$ becomes

$$G(s) = \frac{X_T(s)}{X_P(s)} = \frac{6s + 1}{ks^2 + (6+h)\,s + 1} \tag{13}$$

We may now calculate k based on the string stability requirement that the magnitude of the above transfer function be less than one. The magnitude of the transfer is given by

$$|G(j\omega)| = \left|\frac{6j\omega + 1}{(1 - k\omega^2) + j(6+h)\omega}\right| \tag{14}$$

From (14) the magnitude of the transfer will always be less than one if

$$k^2\omega^4 - (2k - 12h - h^2)\omega^2 \geq 0$$

which reduces to the requirement that

$$k \leq 6h + \frac{h^2}{2} \tag{15}$$

It is desirable to have k as large as possible to reduce bandwidth and decrease the time in which a transition will occur. For a headway of 0.5 seconds a value of k = 2.0 has been selected for both suboptimal controls II and III. For a desired headway equal to 3 seconds the same logic as above may be followed to select a value for k. From (15) the string stability requirement will be met at h = 3 seconds for any $k \leq 22.5$.

SIMULATION RESULTS

A number of test cases have been simulated to demonstrate the performance of the approximately optimal and the various suboptimal controls discussed in previous sections.

The first example presents a comparison of performance between the approximately optimal and the suboptimal controls. The case shown here involves a simple transition where a trailing vehicle traveling at 20 m/sec encounters a preceding vehicle 100 meters ahead with a speed of 10 m/sec. Closed loop control is switched on at the appropriate time (when spacing approaches the kinematically required spacing for each control law) and the resulting headway profiles are shown in Figure 4 where the desired headway is 0.5 seconds. As expected it takes progressively longer to complete the transition as the control law becomes simpler. These results, in conjunction with other test cases which have been simulated [8], indicate that suboptimal control II is a good choice among the control laws which have been considered. The only information requirements are trailing vehicle states and relative states while suboptimal I requires measurements of all states. In addition, comparison of (10) and (11) shows computational complexity is slightly greater than III, but II provides better performance as demonstrated in Figure 4.

The next two examples illustrate the performance of suboptimal control II in a five vehicle string. In Figure 5 a lead vehicle is initially traveling at 15 m/sec and spaced 100 meters from the second vehicle in the string. The remaining four vehicles are traveling at 25 m/sec and are spaced at 50 meters. Consequently, we have an overtake situation between the lead vehicle and the remaining four vehicles. At 20 seconds into the transition the lead vehicle decelerates on jerk and acceleration limits to the minimum line speed of 10 m/sec. Each of the following vehicles successfully maneuver to the

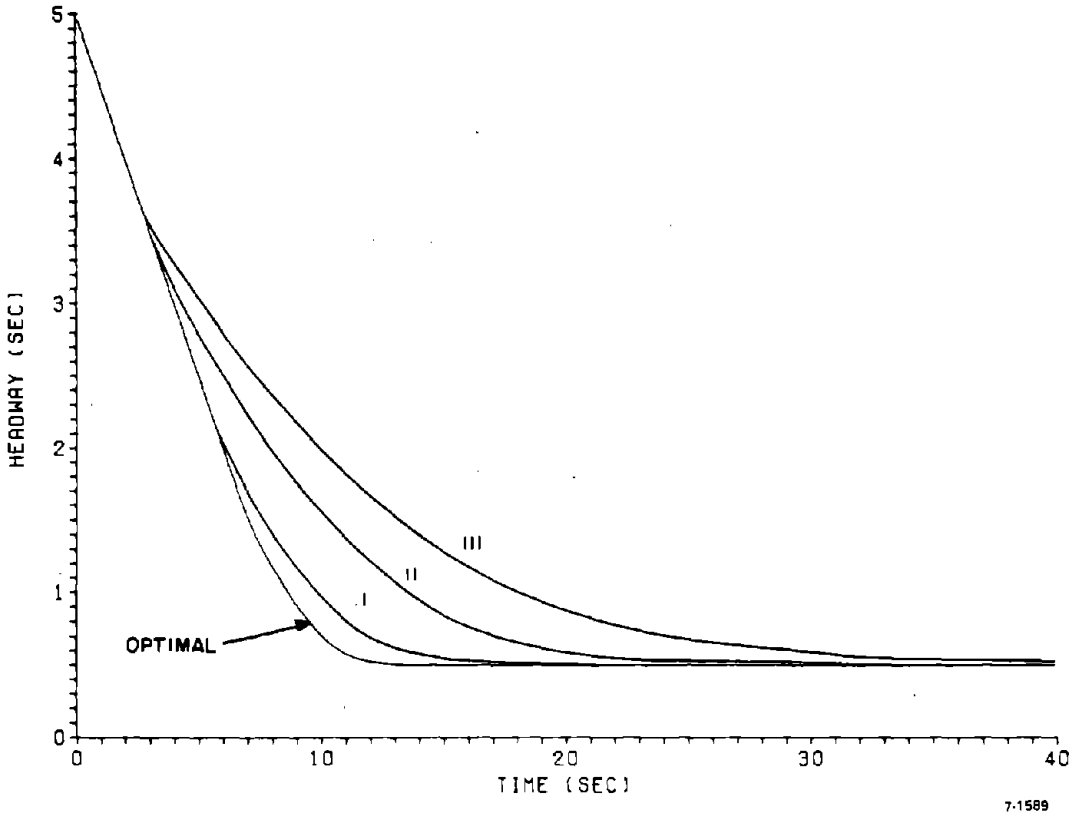


FIGURE 4. HEADWAY COMPARISON BETWEEN CONTROL LAWS

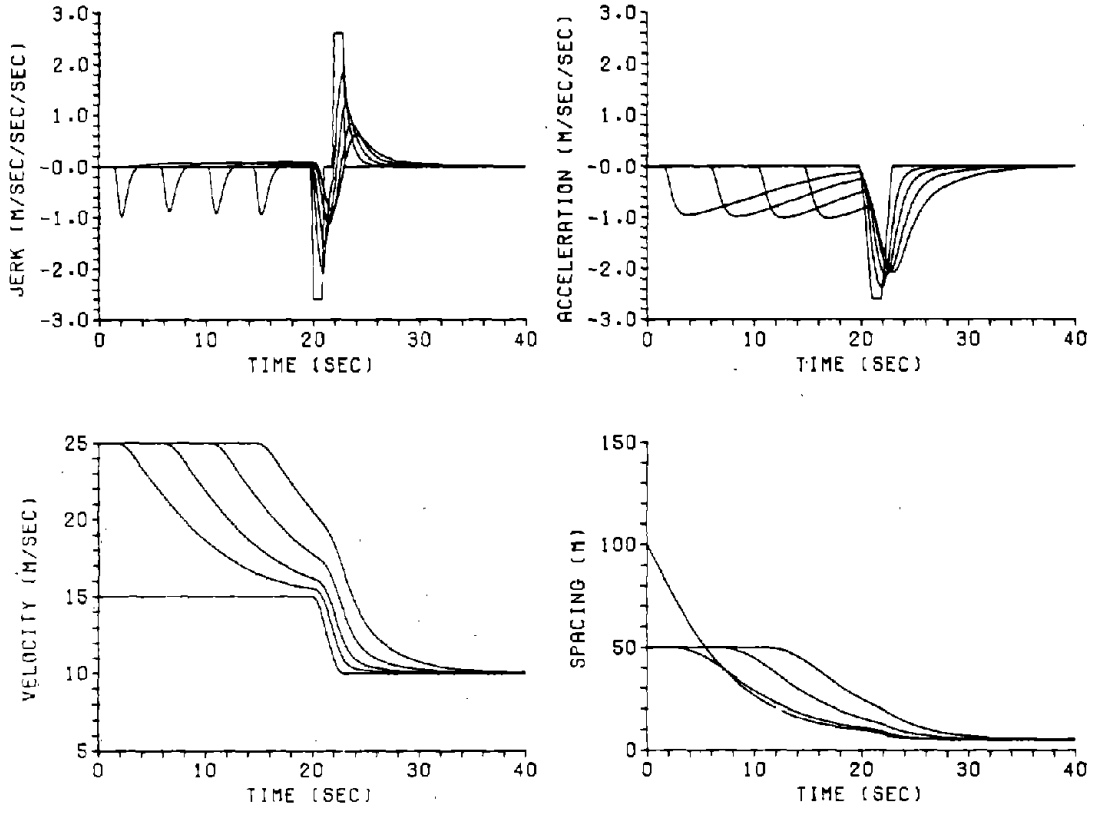


FIGURE 5. FIVE VEHICLE STRING RESPONSE WITH H = 0.5 SEC.

desired headway of 0.5 seconds. In Figure 6 the fire vehicles are initially traveling at a desired headway of 3 seconds with a velocity of 20 m/sec. The lead vehicle performs several speed-up and slow-down maneuvers as shown with each of the trailing vehicles regulating to the desired headway. These simulation studies have also served to illustrate that disturbances are propagated with decreasing magnitude through the vehicle string. The developed control may thus be seen to be robust in its ability to track preceding vehicle maneuvers over a wide range of operating conditions.

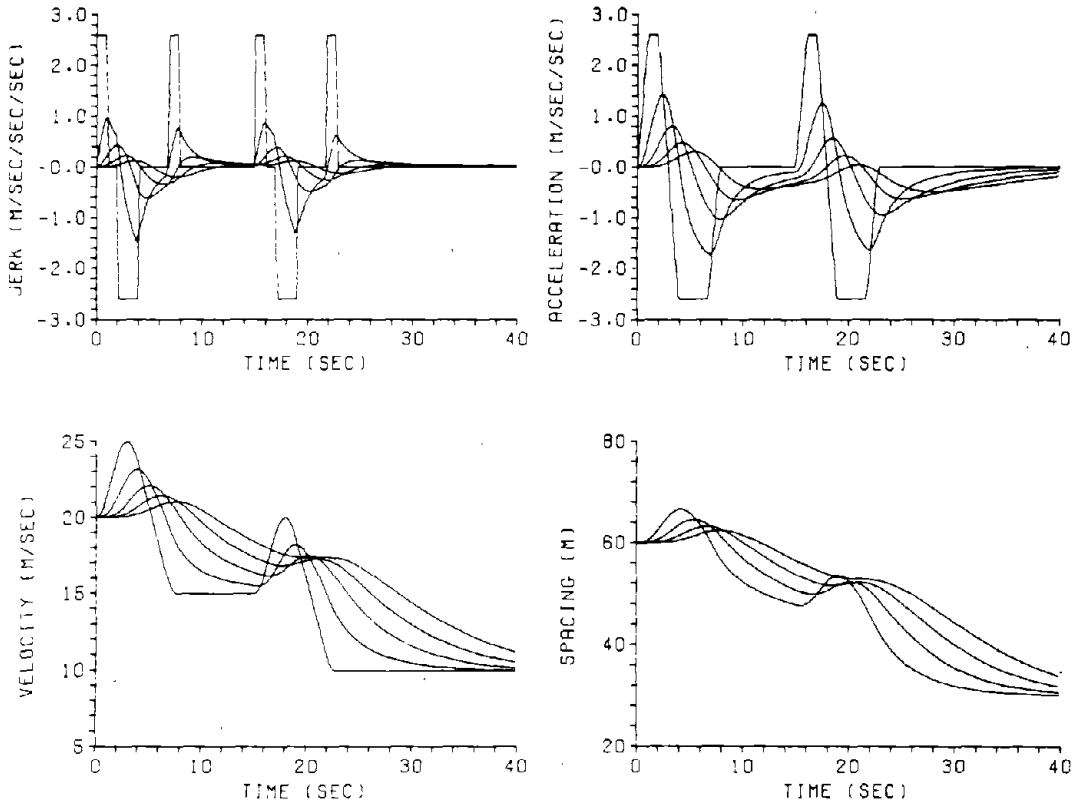


FIGURE 6. FIVE VEHICLE STRING RESPONSE WITH H = 3 SEC.

CONCLUSIONS

A vehicle following control law has been designed which explicitly considers the state constraints that define the capabilities of each vehicle. The imposed jerk and acceleration limits which assure passenger safety and comfort dictate these constraints and lead to an approximately optimal nonlinear controller design which may satisfactorily control transient events such as overtaking a slow moving vehicle at short headways.

Although the approximately optimal control law could be implementable in terms of the on-line computational requirements, several suboptimal controls were derived with the aim of reducing the informational requirements. That is, the optimal control requires preceding vehicle velocity, acceleration, and jerk while suboptimal controls II and III only need spacing, relative velocity, and relative acceleration in addition to trailing vehicle velocity

and acceleration. Furthermore, suboptimal II provides better performance than III with a small increase in computation and therefore seems to be the most attractive in terms of complexity and performance.

The principal accomplishments of this work may now be summarized as follows:

(1) For the first time the state-constraints inherent in a vehicle-following strategy are expressed as part of the control scheme. The resulting control is a non-linear function of states which constitutes a natural way to conduct the transition between the modes of operation normally designed into a vehicle following system. Thus, it affords a general formulation and systematic approach which designers may adapt for future work in this area.

(2) Near optimal performance may be obtained in that the spacing between vehicles is the minimum which allows safe and comfortable operation for all possible nominal maneuvers of a preceding vehicle.

(3) An easily instrumentable controller is designed through simplification of the kinematic constraint. A particular control law is selected based on the trade-off between vehicle performance and controller complexity.

(4) Simulation studies verify the effectiveness of the controllers in a variety of situations.

Current work includes application of this technique to other situations such as merging, injection of vehicles on to the guideway, emergency operation, and determination of appropriate data rates and accuracies. In addition, the application of a Kalman filter approach shows promise in reducing the data requirements to only the spacing between vehicles.

The major advantage of the state-constrained approach would then be to provide uniformity in control for a variety of situations such as merging, emergency operation, and overtaking a preceding vehicle. Consequently, this suggests a simplified controller as opposed to a collection of ad hoc procedures to handle these various conditions.

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PAPER 12

Automated Mixed Traffic Vehicle Status

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AUTOMATED MIXED TRAFFIC VEHICLE STATUS*

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ABSTRACT. This paper reviews work that has been directed toward development and analysis of an automated mixed traffic vehicle (AMTV). Completed work is described in some detail and on-going work is discussed insofar as is possible. Illustrations and discussion of possible applications are also included.

INTRODUCTION

The AMTV concept has grown out of recognition of the major problem faced by public transit today, i.e., cost. Total costs cannot be borne by revenue from the fare box alone. This problem is due to escalating capital cost and debt service for exclusive guideway systems and to increasing labor rates for conventional bus systems.

To understand some alternative concepts, a study[1] was performed by the Jet Propulsion Laboratory (JPL) for the Department of Transportation during 1972. That task analyzed various forms of dual-mode transport, selected one system design as a baseline, and compared its annualized costs to other common forms of transport. The particular system chosen in that report was made up of two essential parts: (1) a fleet of pallets that carried private autos during the guideway portion of the trip, and (2) small public buses for use (a) on the high-speed guideway and (b) in an automated low-speed distribution mode on conventional surface streets. It was seen that the low-speed automated mode, if developed, might be useful for other

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*This paper presents the results of one phase of research carried out at the Jet Propulsion Laboratory, California Institute of Technology, under Contract NAS7-100, jointly sponsored by the National Aeronautics and Space Administration and the Department of Transportation.

[1]"Technical and Cost Considerations for Urban Application of Dual-Mode Transportation," Jet Propulsion Laboratory, Pasadena, Calif., 1200-33, prepared for Department of Transportation, TST-2, Report Task #111.1.3, May 23, 1972.

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types of service and that total costs in that mode of operation could potentially be extremely low -- given that the necessary developments were successful.

This low-speed automated mode of travel has recently come closer to reality through new developments in low-cost sensors, microprocessors, and control systems. Capitalizing on these developments, an initial experiment has been conducted at JPL with a modified six-passenger electric tram. The modifications allow the vehicle to function on existing streets at JPL in an automatic mode. The results of this experiment have been reported in the literature,[2] and an UMTA-funded control and scheduling study has also been completed. Work presently underway is a technology and safety study being done by JPL and a market survey being done at SRI.

COMPLETED WORK

Initial Experiment and Vehicle Description

Vehicle: The present vehicle is based on a commercial six-passenger electric tram to which sensing and control components have been added to permit automated operation following a buried sense cable in the roadway. A speed of 7 mph, about 3 times normal walking speed, is used on the straight sections of the route. Lower speeds are used at intersection crossings and in turns. Established techniques for following a buried sense cable were used to guide the vehicle.

The control system's important elements are a set of headway sensors to detect obstacles in the path of the vehicle, the wire-following system for steering, and an electronic controller to adjust vehicle speed in response to various inputs. A functional block diagram of the AMTV control system is shown in Fig. 1.

The steering sensor is a multiple-coil phase-sensitive device similar to sensors already described in the literature[3,4]; it is not described further here. The most important element of the AMTV control system is the headway sensing capability, which provides a means to detect obstacles in the path of the vehicle and thus prevent collision with them.

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[2]G. W. Meisenholder and A. R. Johnston, "Control Techniques for an Automated Mixed Traffic Vehicle," In: PROCEEDINGS OF THE JOINT AUTOMATIC CONTROLS CONFERENCE, San Francisco, Calif., June 21-24, 1977, p. 421.

[3]K. W. Olson, "Reference System for Vehicular Lateral Guidance," Proc. IEEE 61, 1764 (1973).

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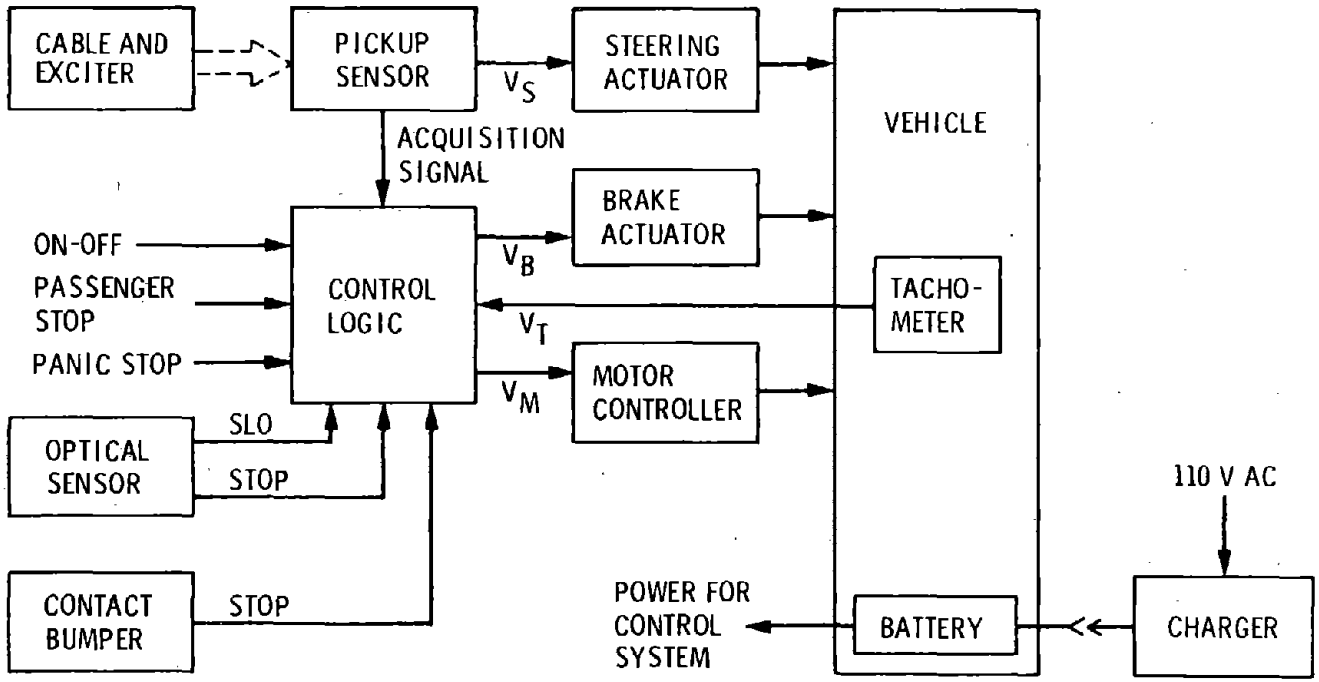


FIGURE 1. AUTOMATED MIXED TRAFFIC VEHICLE BLOCK DIAGRAM

The headway sensors detect pedestrians or vehicles in the path of the AMTV to a distance of at least 25 ft, causing the AMTV to slow. A second and independent optical sensor detects objects to a distance of approximately 10 ft, commanding a stop.

Figure 2 illustrates the operating principle of the headway sensors. The light source is a gallium arsenide LED emitting at a wavelength of 0.94 μ. A silicon solid-state detector is used to sense any light reflected back by an object in the carefully defined light beam. Only objects in the overlapping volume of the transmitted light beam and the detector field of view will be detected. Both pulsed LED with electronic phase detection and an appropriate narrow-band optical filter are used to discriminate against sunlight and other unwanted background light.

The desired overall beam profile is shown in Fig. 3. Two beam profiles are shown in the figure, a 25-ft primary beam, and a 5-ft secondary beam. The profile indicates the boundary of the region within which a minimum-area target will be detected. The sensitive region corresponds to the shaded overlap of the two beams in Fig. 2. In the fan-beam configuration, the cylindrical lens spreads the beam horizontally, perpendicular to the plane shown in Fig. 2.

The control logic is a very simple on-off scheme. It appears to be adequate for a 7-mph operation, for which a comfortable stopping distance is 15 ft, but would need to be more sophisticated at 15 mph or higher speeds. Referring to the block diagram (Fig. 1), there are four discrete commands: run, slow, stop, and emergency stop. Run is initiated by an operator key switch and requires in addition an acquisition signal indicating the steering sensor is picking up a signal from the sense wire.

Slow, a 2-1/2 mph speed, is commanded by the primary (25-ft range) optical sensor, or by a sufficiently large steering angle on the front wheels, such as occurs during the short-radius U-turns at each end of the route loop. All changes in speed are acceleration- and jerk rate-limited by a program internal to the control logic. The emergency ("panic") stop applies full brake without regard to acceleration. Conspicuous buttons accessible to passengers are the source of this command. A flexible "whisker pole" bumper also contains microswitches which command the emergency stop if the bumper is touched.

Operating Mode: The vehicle operates continuously, faithfully following the guide cable and making brief stops for passengers. Since the desired speed of 7 mph is too fast for a sharp turn, the vehicle is programmed to stop before entering each U-turn and to move through the turn at a walking pace.

Riders were instructed to wait at one of several designated points for the vehicle to approach. Each curve entry is one of these points, but others were also provided. After stopping, the vehicle waits 4 seconds and then moves on. If one or more passengers board, the vehicle can be inhibited from moving by pressure-sensitive passenger stop switches located on the canopy supports. When the passenger is seated in the vehicle, he releases his grip,

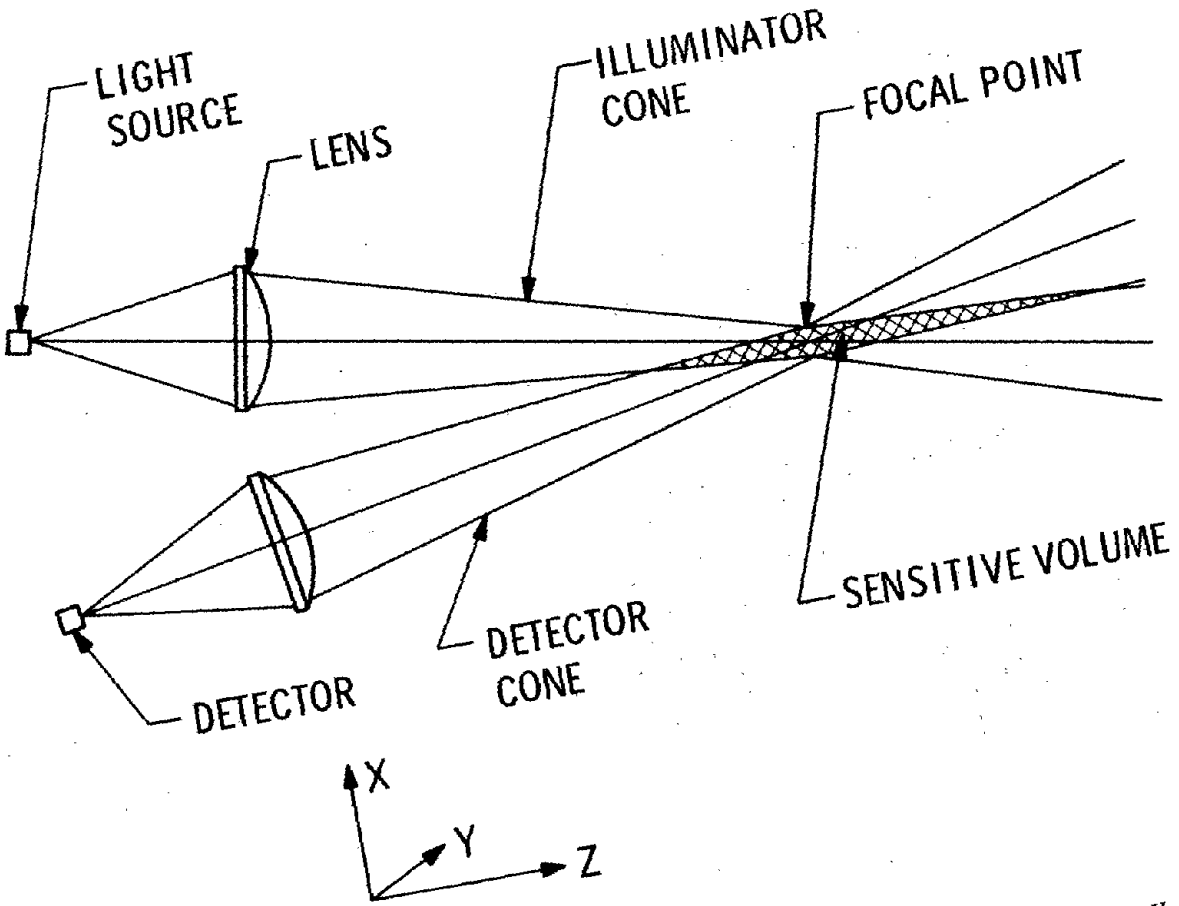


FIGURE 2. SKETCH SHOWING PRINCIPLE OF OPERATION OF OPTICAL HEADWAY SENSORS

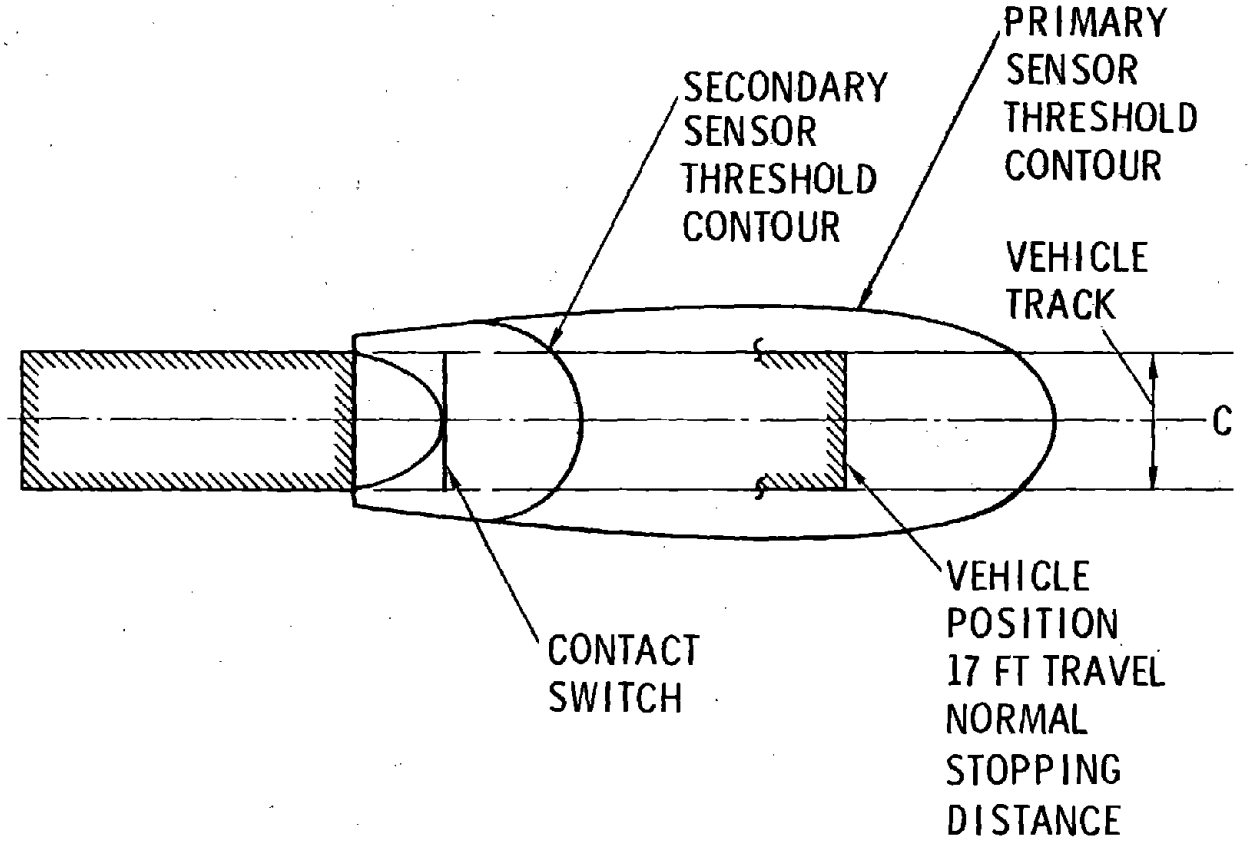


FIGURE 3. SENSOR THRESHOLD CONTOUR

allowing the vehicle to move off. The same pressure switches will command the vehicle to stop at any time (not just at the programmed stop) so that the passengers can get off at will.

Route: The present route at JPL is a single loop of 2000 ft total length as shown in Fig. 4. The U-turns at each end are executed at intersections which are protected by stop signs. The intermediate intersection is also a 4-way stop. The guide wire is a No. 12 copper wire buried in a 1-in.-deep groove sawed in the road surface and back-filled with an appropriate compound. The wire is in the form of a continuous loop excited at 10 kHz by a low-power oscillator placed near the roadside. The ends of the guidance wire are brought to the side of the road in an intersecting slot cut transverse to the roadway. This feed wire pair must be held close together to avoid a small steering perturbation of the feed point. The dc resistance of the loop is 3.2 Ω, and the drive current was 175 mA rms. A mile of wire could be driven with about 2 watts of power at 10 kHz.

Performance Simulations

The mixed traffic mode causes average speeds to be reduced, depending on the location and frequency of interference by other traffic. To ascertain more generally the character of this speed performance degradation, a study was done by Peng and Chon[5] at JPL.

Simulated encounters (pedestrians crossing pathway) were modelled for three classes of pedestrians: (1) aggressive, wherein the pedestrian takes advantage of his foreknowledge that the vehicle will slow down for him and walks into its path, (2) nonaggressive, wherein he proceeds across the pathway only if he believes that he can cross and that the vehicle need not slow down, and (3) a 50-50 mix of both aggressive and nonaggressive types. The encounter distance between vehicle and pedestrian is assumed probabilistic (higher probabilities at the far end of the sensor range), and time to cross was assumed random (between 1 and 3 seconds).

Results are shown in Fig. 5. Pedestrian crossings at an average rate less than once per 15 seconds resulted in minimal speed reduction (for all classes of pedestrians). However, crossings greater than one every 2 seconds resulted in speed slowing of about 50% for the aggressive pedestrian case. For the nonaggressive pedestrian, crossings of one every 2 seconds reduced average speed by only 1.6 mph. This indicates that rules inhibiting path crossing by pedestrians in crowded areas will greatly improve service levels, even if they are not 100% obeyed. The JPL experiment also supports the thesis that after a reasonably short period of time (~1 month), the public becomes more aware of how to interface with the vehicle, thus causing less interference.

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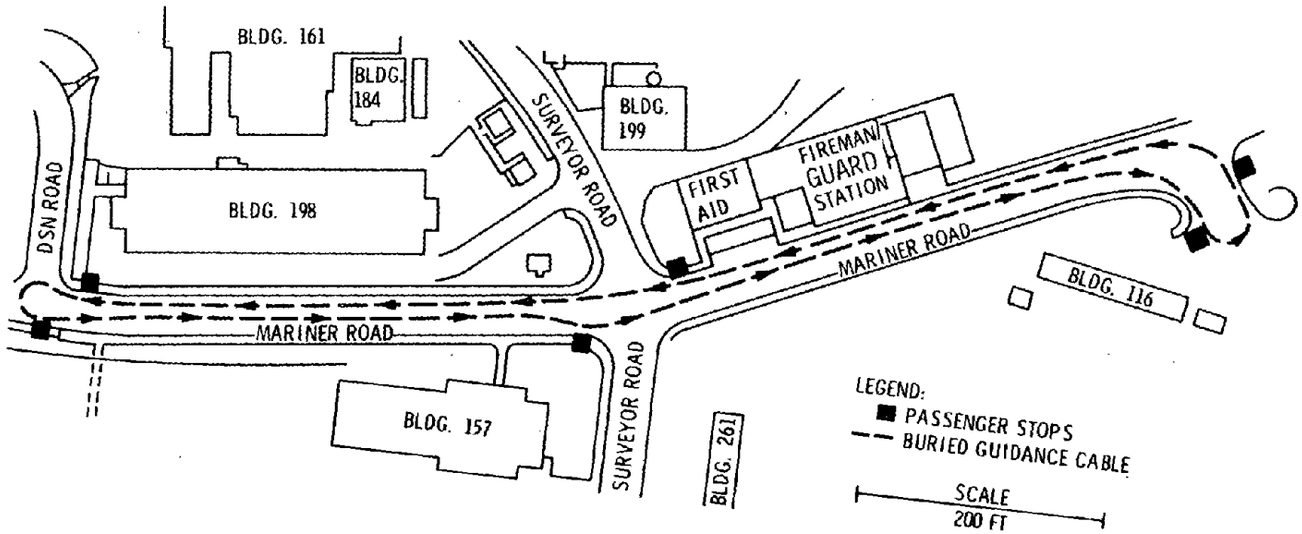


FIGURE 4. MAP OF PRESENT JPL LOOP ROUTE

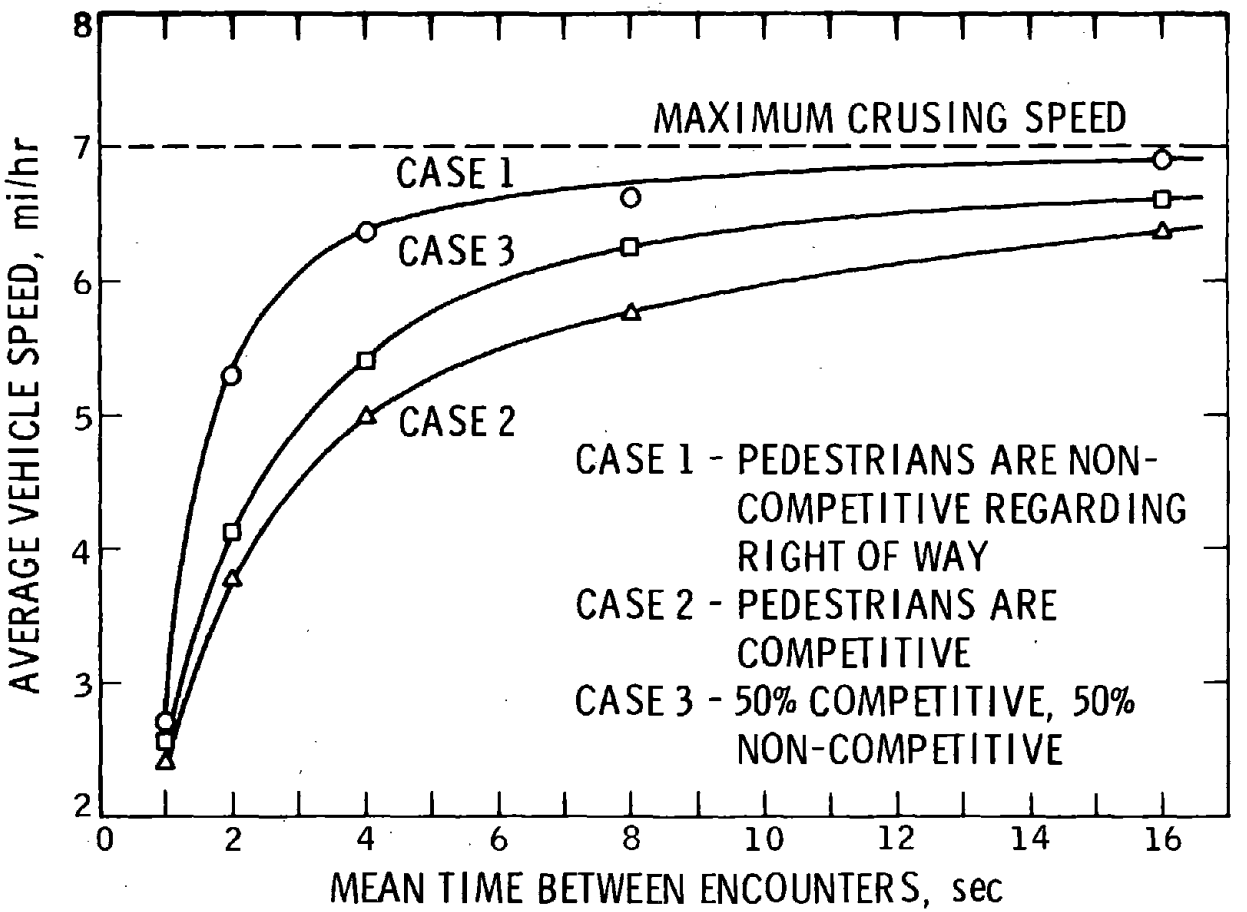


FIGURE 5. AVERAGE SPEED OF AMTV UNDER PEDESTRIAN DISTURBANCES

ON-GOING WORK

Technology and Safety Study

A technology and safety study is currently underway at JPL. The purpose of this work is first to analyze failure modes and hazards that can be anticipated in transit operations and to suggest methods for prevention, and, secondly, to identify needed developments. The results are intended to guide further efforts in system design and technology development.

This study will examine an expanded speed range including 1-1/2 mph, 7 mph and a 7- to 20-mph hybrid. In order to facilitate the safety analysis, a specific application model was developed. This is illustrated in Figs. 6 and 7.

The specific application model selected as a development goal provides shuttle service between two large shopping centers separated by a distance of about one mile. Low-speed operation is then provided within each shopping area. The route passes through parking lots where pedestrian and low-speed vehicle traffic is encountered. Three- to four-second stops are made routinely and on demand to permit passengers to enter or leave the vehicle. Intersections are controlled by signals or stop signs.

Between the two shopping centers, the vehicle moves at 20-mph peak speed in a path specifically reserved for it (except at intersections where the vehicle travels at 7 mph maximum and must obey conventional signals). Auxiliary sensors at the intersections may be required to anticipate violations of the intersection signals by crossing autos. Designated locations for passenger stops are incorporated at approximately one-block intervals.

Market Survey

A market survey is now underway at SRI. The work will provide some insight into the "market" for such a new vehicle type. A new type of area tentatively called transit pedestrian zones has been observed by SRI to spontaneously grow on their own and forms the basis for the SRI study.

A phased program involving development of a number of scenarios for AMTV demonstration system development is factored into the study, where in the early stages the sensor and logic technology is not greatly advanced from that incorporated in the present JPL vehicle. Later, it is expected that with the rapidly evolving sensor and microprocessor technologies a much more sophisticated vehicle will be possible.

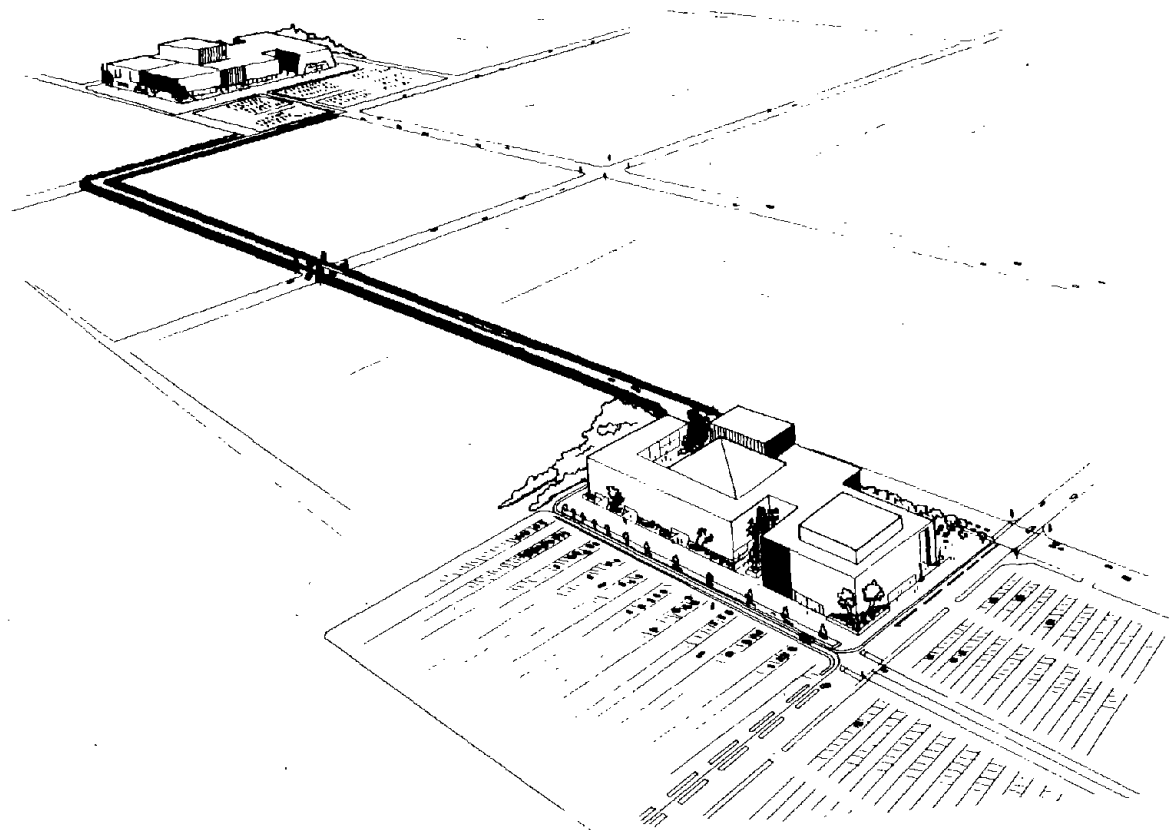


FIGURE 6. SHOPPING CENTER INTERCONNECT

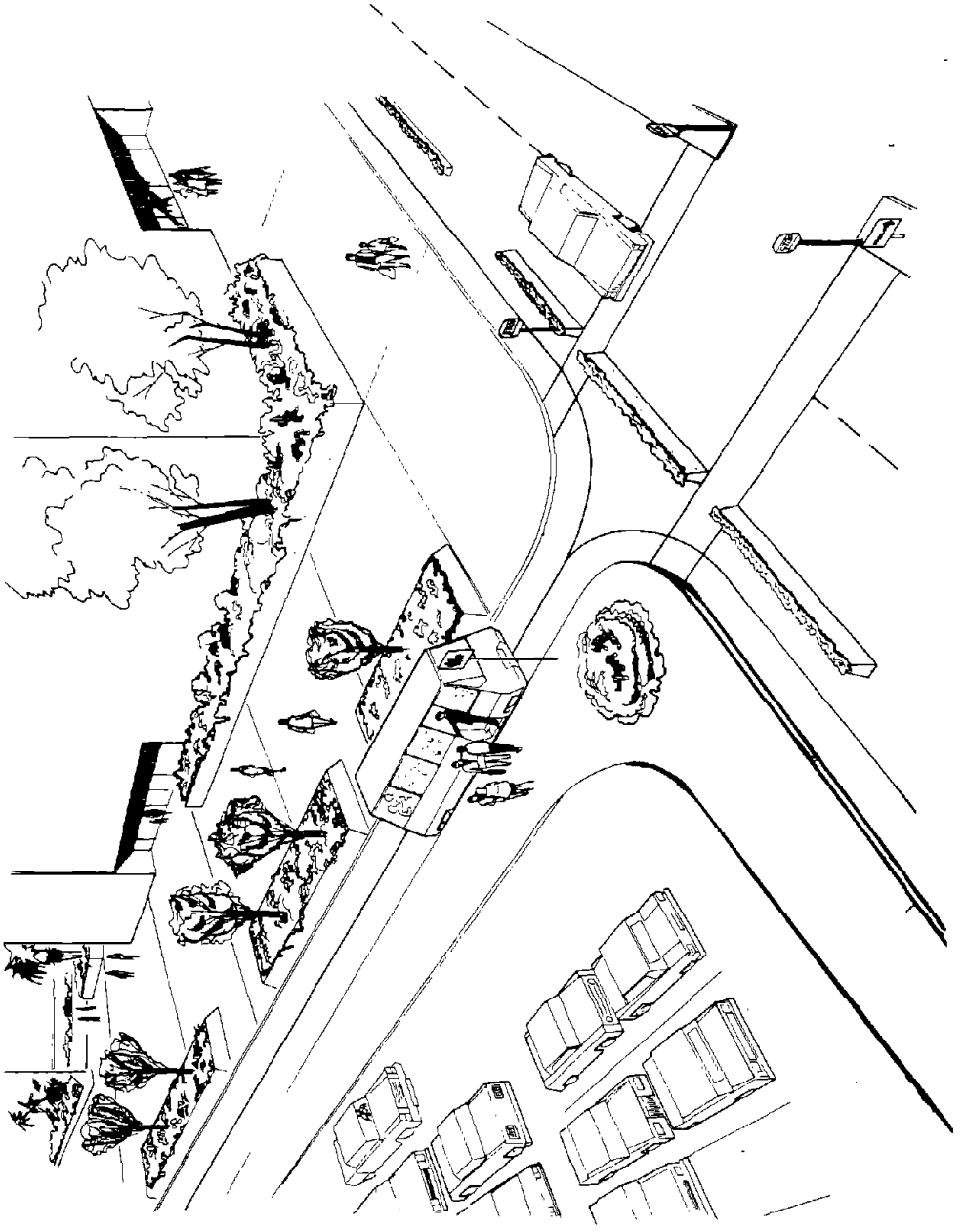


FIGURE 7. LOW SPEED TRAFFIC MODE

PAPER13

Life-Cycle Costs and Application Analyses for New Systems

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LIFE CYCLE COSTS AND APPLICATION ANALYSES FOR NEW SYSTEMS

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ABSTRACT: Estimated life cycle costs of two promising feeder and local circulation systems are examined in this paper. Cost functions for the accelerating walkway and the automated mixed traffic vehicle system are described; their sensitivity to some of the design, operating and cost parameters is examined. The two systems are then placed in the context of hypothetical applications to identify typical user costs.

INTRODUCTION

Short trips are the most frequent in an urban setting; the pedestrian mode predominates at this end of the trip spectrum. Even if there is a desire to avoid walking, it is frequently impossible or impractical to do so for short trips. Typical situations include heavy traffic, the lack of parking space or the high cost of parking that make the use of the automobile impractical; transit service that does not carry passengers to their exact destination; short trips in controlled areas where the use of personal vehicles is not permitted, and parking facilities that are distant from the parker's destination. Airports and other transportation terminals, central business districts, urban universities, and hospital are examples of locations where such conditions occur frequently, even though large numbers of pedestrians would prefer more convenient means of transportation.

The accelerating walkway (AW) and the automated mixed traffic vehicle system (AMTV) are currently under development and investigation to provide services for these needs. An AW is similar to a conventional moving belt type passenger conveyor. By accelerating passengers after entry and decelerating prior to exit the speed of an AW may be increased by a factor of four to five times increasing the range and usefulness of these devices. Compared to a moving belt, which is limited in speed by entrance and exit speed requirements to about half of that of normal walking speed, the practical applicability of AW systems is increased from 100 meters (305 feet) or less to 1 or 2 km (1 or 1½ miles).

The AMTV system can be compared to existing robot electric cars used in warehouses to provide driverless transportation along routes defined by buried guidance cables. The AMTV vehicle is a small, driverless, electric bus, operating on a similar principle and equipped with obstacle detectors that bring the vehicle to a halt if an obstacle appears in front of it. These vehicles will be used under controlled conditions at a slow speed (up to

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12 km/hr. or 7 mph), in areas where they can mingle with pedestrians, and at a higher speed (32 km/hr. or 20 mph) on grade-separated, guideway-like route segments. Combining these characteristics, AMTV could provide collection, distribution, and local transportation services for trips up to 5 or 7 km (3 or 4 miles) long.

ACCELERATING WALKWAY LIFE CYCLE COSTS

This paper is concerned only with the life cycle cost characteristics of these two systems. Considering first the accelerating walkway, a "sample" AW system was chosen to illustrate design and cost characteristics of these systems:[1]

- One-directional, reversible
- Elevated, enclosed
- Two full lanes, 1.2m (48") tread width
- Adjacent sidewalk, 2.1m (7 ft) total width
- Length: 305m (1000 ft)
- Capacity: 7200 pass./hr.
- Operation:
  - -peak direction
  - -16 hrs/day total
  - 300 days/year

The one-directional reversible characteristic of the sample system indicates application at a location with commuter traffic, such as a transit station or a large parking structure in the CBD. Considering the peaked nature of this type of traffic, the 7200 pass./hr. capacity might imply that 15,000 travelers per day use the facility in each direction on weekdays, almost as many but more evenly distributed on Saturday, and very few on Sunday.

The framework prescribed by OMB Circular #A-94[2] has been adopted for the life cycle costing procedure. This sets the interest rate (10%), the longest period to be considered (25 years), and requires that all costs during this period be treated in constant terms, though permitting changes in the relative levels of cost items. Cost information developed for urban transit systems was then adopted as the basis of determining relative changes in cost items. This information is based on treating all recent cost changes in relation to an overall annual inflation rate of 7%. Thus a +1% relative inflation rate for an item implies that the cost of the item increases (1.01 x 1.07) times every year.

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[1] Much of the cost data are based on a draft version of a report, currently under preparation: Fruin, J., Marshall, R., Perilla, O.: "Accelerating Moving Walkway System - Market, Attributes, Applications and Benefits."

[2] "Discount Rates to be Used in Evaluating Time Distributed Costs and Benefits," 27 March 1972.

Table 1 relates the cost elements of the AW system to the general cost categories of Reference 3, giving also the pertinent relative inflation rates. Using standard engineering economics to calculate present value costs for all spending during the 25-year period, including replacement of capital equipment as well as credit for its salvage value (assuming linear rates of depreciation) the information in Table 1 is sufficient to calculate the present value of all costs for the entire period. This result has then been converted into an annual rate of spending by applying a capital recovery factor over the 25-year period.

TABLE 1. COST ELEMENT RELATIONSHIP MATRIX

AW Cost Elements	General Cost Categories					
	Guideway	Station	Machinery & Equipment	Maintenance Labor	Power	General & Administ.
Furnishings & Installation						
AMWS Device Installation			66.7%	33.3%		
Structural Preparation						
Structure	30%					
Enclosure		70%				
Maintenance						
Mechanic				62.5%		
Administrative						12.5%
Contingencies						12.5%
Parts			12.5%			
Power					100%	
Insurance						100%
Relative Inflation Rate, %	+0.34	+1.0	−1.15	+0.06	+2.6	+2.01

(3) Graver, C. Jenkins-Stark, J.: "Life Cycle Cost Model for Comparing AGT and Conventional Transit Alternatives," Gen. Research Corp., Feb. 1976.

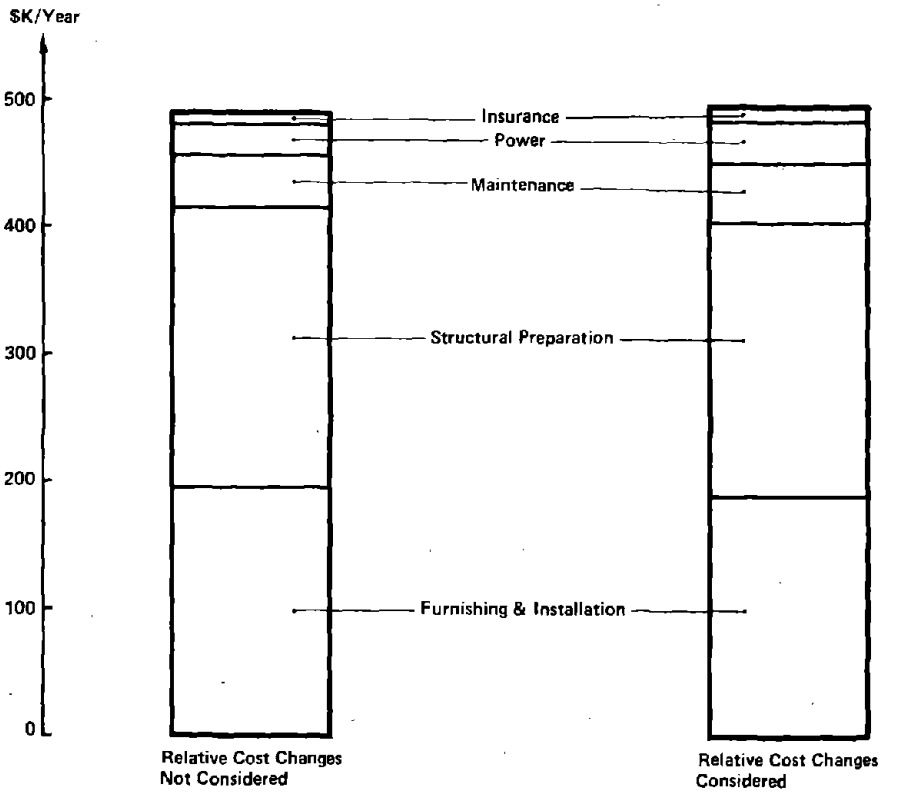


FIGURE 1. SAMPLE ACCELERATING WALKWAY SYSTEM LIFE CYCLE

Figure 1 shows the result in bar graph form. Also shown is a bar graph that simply applied the appropriate capital recovery factors to the capital items to obtain their equivalent annual cost. For this result, shown on the left in Figure 1, the effect of relative changes of cost is therefore not accounted for. The difference is slight, primarily because the three operating cost items that are growing faster than the general cost index only make up a small fraction of the total cost function. Dividing the annual 497 $K cost into the 300 assumed days of usage and the 2 times 15000 trips made per day, the estimated cost per trip is about 5.5¢. The figure shows that the cost of the system is completely dominated by the two capital items, split about evenly between the cost of building and installing the machine itself, and the cost of building the structure that supports and encloses the walkway. The former cost is fixed and nearly independent of application; whereas, the latter cost is highly application and site dependent.

Table 2 compares the cost of the sample system, which assumed an elevated installation, to equivalent systems located underground, at grade and inside a building, where there is no need to construct an enclosure. The range of annual life cycle costs for the four identical systems is seen to be highly location dependent, varying almost by a factor of two to one from the highest (underground location) to the lowest (inside a building), with a corresponding range of 6.6 to 3.9¢ per trip, for the same assumed traffic.

TABLE 2. IMPACT OF LOCATION ON SAMPLE AWS COSTS

	Elevated (Reference Case)	Tunnel	At Grade	Inside Building
• Structural Preparation:				
– Initial cost, $M	2.0	3.0	1.3	0.7
– Annual life cycle cost, $K/yr	220.3	330.4	143.2	77.1
• Total system:				
– Initial cost, $M	3.5	4.5	2.8	2.2
– Annual life cycle cost, $K/yr	497.0	607.1	419.9	353.8
– Annual life cycle, % of Ref. Case	100	122.2	84.5	71.2

The assumed operating schedule of 16 hours per day results in long periods of time when little use is made of the AW service. Curtailing usage during such slack periods may reduce costs. To test how much costs could change, due to a changed usage pattern, the three assumptions listed in Table 3 were made.

TABLE 3. POSSIBLE IMPACT OF USAGE ON SAMPLE AWS COSTS

Assumptions: years of service proportional to hours/year
maintenance costs proportional to hours/year
power costs proportional to hours/year

Hours/day in service	16	24	8	3
Days/year in service	300	365	250	250
Equipment service life, years	15	8	36	96
Equipment life cycle cost, $K/yr	186.6	270.4	161.5	156.3
Maintenance cost, $K/year	46.7	85.3	19.5	7.3
Power cost, $K/year	30.4	55.5	12.7	4.7
Total system cost, $K/year	497.0	644.5	427.1	401.6
Total system cost, % of reference case	100	129.7	85.9	80.8
Cost per capacity, ¢/moving space	1.438	1.022	2.966	7.437

It can be observed that the third assumption is realistic but that the other two will tend to exaggerate the impact of usage on annual total system costs. The next to the last line in Table 3 therefore shows that, compared to the reference case, increasing usage from 16 daily hours for 300 days to continuous 24 hours/day operation would increase total system costs by less than 29.7%. Curtailing usage to a minimal schedule of 3 daily hours on work-days only, on the other hand, would save less than 19.2% of total system cost, when compared to the reference case. Consideration of these extreme cases, therefore, indicates that even large changes in the hours of operation will have only minor impact on total costs. The last line of Table 3 expresses these total costs on the basis of the space provided for travel by potential users (analogous to cost per seat mile for transit vehicles). The large differences clearly indicate the sensitivity of user costs to the actual number of passengers. Applications with substantial daily traffic have a user cost advantage almost in direct proportion to the number of users. An example of such an application is a connection between an urban university and a rapid transit station; the following parameters selected illustrate such an application.

- o Connect urban university campus with rapid transit station 610 meters away
- o 305 meter long passageway from tracks to street entrance already exists
- o remaining 305 meters will be elevated and enclosed
- o bi-directional, one-lane-each, design
- o small sidewalk provided: total width same as sample system
- o 16 hours/day, 300 days/year

The cost function for this illustrative example has been estimated by comparison with the sample AW system, and is shown in Table 4. Assuming a 0.2 load factor for the 16 hour daily period indicates that a total of 23,000 daily trips are served, resulting in a cost of 17.2¢ per trip. The increase in trip unit cost, when compared to the 5.5¢ quoted previously for the sample system, is primarily due to the doubled length of the application example system, as well as the increased complexity (continuous service in both directions) and somewhat lower load factor. For similar systems the principal costs will increase almost linearly with the length of the application.

TABLE 4. ACCELERATING WALKWAY COST FUNCTION FOR EXAMPLE APPLICATION

Item	Annual Cost, $K/year: Application Example	Sample System	Ratio
Furnishing and Installation	581	187	3.0
Structural Preparation	207	220	1.3
Maintenance	186	47	4.0
Power	91	30	3.0
Insurance	26	13	2.0
Total	1161	497	2.3

1/5 Load Factor for Application Results in:
17.2 ¢/trip, for
23,000 trips/day, 300 days/year

AUTOMATED MIXED TRAFFIC VEHICLE LIFE CYCLE COSTS

The life cycle costs of AMTV systems will now be examined in an analogous manner, by selecting an "example" system and examining the impact of varying its characteristics on system costs. The principal characteristics of the AMTV example system are summarized below:

Vehicle:

- o 20 passenger bus
- o Battery-electric propulsion

Controls:

- o Automated steering following buried cable signal
- o Speed control in discrete steps
- o Position stop and automated door control at stations
- o Onboard obstacle detector for collision safety

Operation:

- o Separated by barriers from vehicular traffic
- o Slow speeds in pedestrian areas
- o High speeds (32 km/hr. max.) in completely separated lanes

Because of the uncertainties of the interface between AMTV and vehicular traffic it was decided to keep the operation of the example system completely separated from road vehicles, with mixed traffic occurring only in areas common to AMTV and pedestrians. Establishing a link between the CBD and parking available outside the CBD would be a typical application of such an AMTV system. Corresponding cost characteristics of the principal components were estimated as follows:

Wayside:		
o Guide cable	25 $K/km	(20 years life)
o Parking lot barriers	25 $K/km	(25 years life)
o Two-lane connecting link	160 $K/km	(25 years life)
o One-lane connecting link	100 $K/km	(25 years life)
o Underpasses	100 $K/km	(25 years life)
Vehicle & Operation		
o Vehicle	80 $K each	(15 years life)
o Vehicle operation	40¢/veh.km	

Parking lot barriers are low barriers that do not permit the movement of cars searching for a parking place but are low enough for pedestrians to step across. Warning signs, recommended in Reference 4, will minimize interference of crossing pedestrians with the movement of AMTV vehicles at such locations.

"Connecting links" represent high speed segments of the route, in contrast with the low speed operation on the parking lot itself or in other areas where the vehicles mingle with pedestrians. Costs of vehicles and vehicle operation were estimated; the latter includes charging and replacing the batteries during the 15 year lifetime of the vehicle.

Figure 2 shows a sketch of such an AMTV application. The "before" and "after" conditions shown indicate that both the parking facility and the right-of-way for the connecting links were available prior to establishing the AMTV service. Two configurations are shown simultaneously, in one the vehicles traverse a complete loop during their collection/distribution service on the parking lot. In the other configuration, the parking lot is traversed in one direction only, the other half of the loop is laid out as a continuation of the high speed connecting link; an underpass permits cars to pass in and out of the enclosed parking area. This latter configuration, though somewhat less effective in its service characteristics, decreases the vehicles' turn-around

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(4) Meisenholder, G.W., Johnston, A.R.: "Control Techniques for an Automated Mixed Traffic Vehicle," in: Proceedings of the Joint Automatic Controls Conference, San Francisco, June 21-24, 1977, p. 421.

time, and will therefore decrease the cost of the service. A schematic representation of these two configurations is shown as "A" and "B" in Figure 3.

A CBD destination immediately adjacent to the parking lot will result in yet another cost pattern; the corresponding two alternatives are shown as "C" and "D" in Figure 3. By considering high and low speeds during the vehicle's motion in its mixed mode of travel on the parking lot (6.4 and 12.0 km/hr, or 4.0 and 7.5 mph respectively) eight different cases for estimating the total costs can be identified.

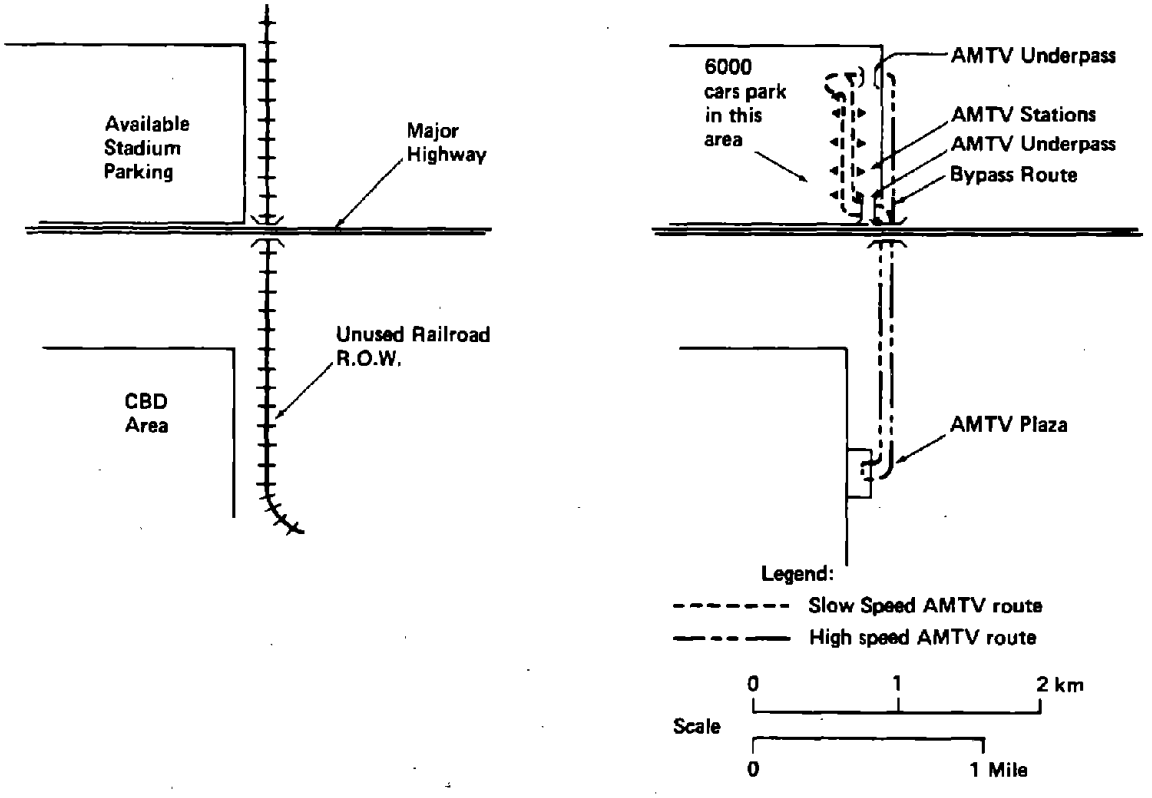


FIGURE 2. SKETCH OF AMTV APPLICATION TO CBD PARKING

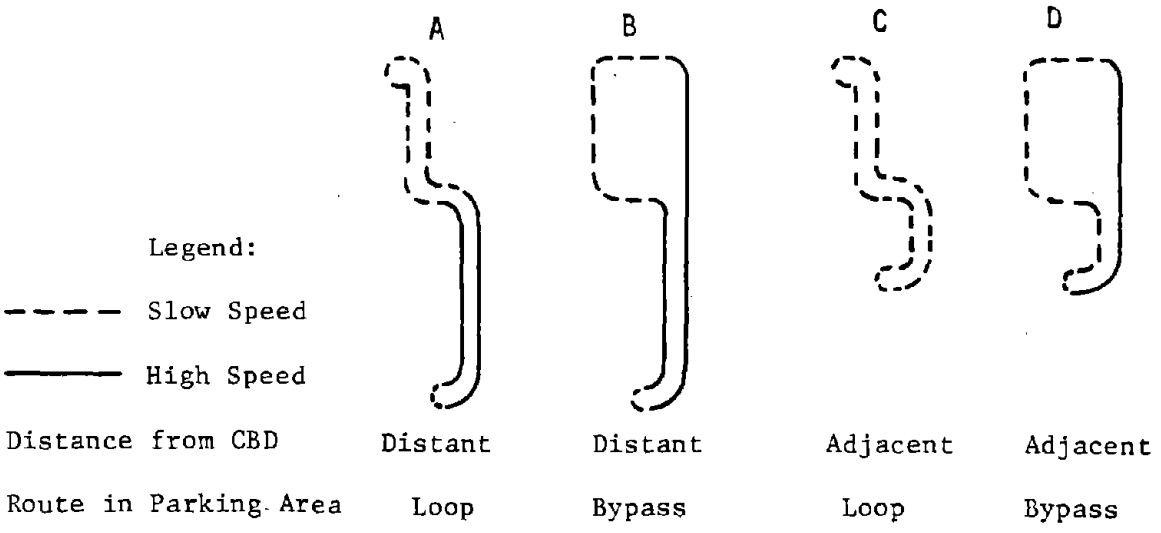


FIGURE 3. SCHEMATIC REPRESENTATION OF AMTV SYSTEM CONFIGURATIONS

To develop user costs typical demand and service characteristics were assumed as follows:

Peak period:

- o Two 3-hour peak periods per day
- o 3000 cars with 4200 passengers in peak direction during each period
- o Maximum flow rate is double of average peak rate (2800 pass./hr.)
- o Peak period AMTV headway: 40 sec.
- o Peak period passenger loads: 16 average, 32 maximum per bus

Off-peak period:

- o 10 hours of off-peak service per day
- o Off-peak demand: ½ of average peak period demand (700 pass.hr.)
- o Off-peak (maximum) headway: 90 sec.

With the above characteristics, assuming that 20 seconds were lost at every stop on the parking lot and 60 seconds at the CBD stop, and assuming also 300 days of operation per year, estimated life cycle costs were developed for all 8 cases under consideration by applying the cost data shown earlier. (Changes in relative price levels were not considered in this simplified approach.) The principal parameters and user costs for the 8 cases are shown in Table 5; life cycle costs are shown in bar graph form in Figure 4. User costs were calculated by assuming that average peak period traffic in

TABLE 5. PARAMETERS AND USER COSTS FOR AMTV PARING LOT APPLICATION

Distance from CBD	Distant	Distant	Distant	Distant	Adjacent	Adjacent	Adjacent	Adjacent
Route in Parking Area	loop	loop	bypass	bypass	loop	loop	bypass	bypass
Speed on Parking Area, km/hr	6.4	12	6.4	12	6.4	12	6.4	12
Total Route Length, km	6	6	6	6	2.8	2.8	2.8	2.8
High Speed Segment Length, km	3.6	3.6	4.8	4.8	0.4	0.4	1.6	1.6
Stops on Parking Area	9	9	5	5	9	9	5	5
Fleetsize	55	38	38	29	45	28	28	20
¢/Veh.-km	78	67	69	63	120	93	97	84
¢/Trip	25	21.7	22.1	20.3	15.4	12	12.5	10.9

the off-peak direction is half of the average off-peak period traffic (i.e. 350 pass./hr.) resulting in a total annual traffic of 5.25×10^6 trips per year. Vehicle fleet sizes include a spare vehicle for every 10 vehicles needed during peak periods.

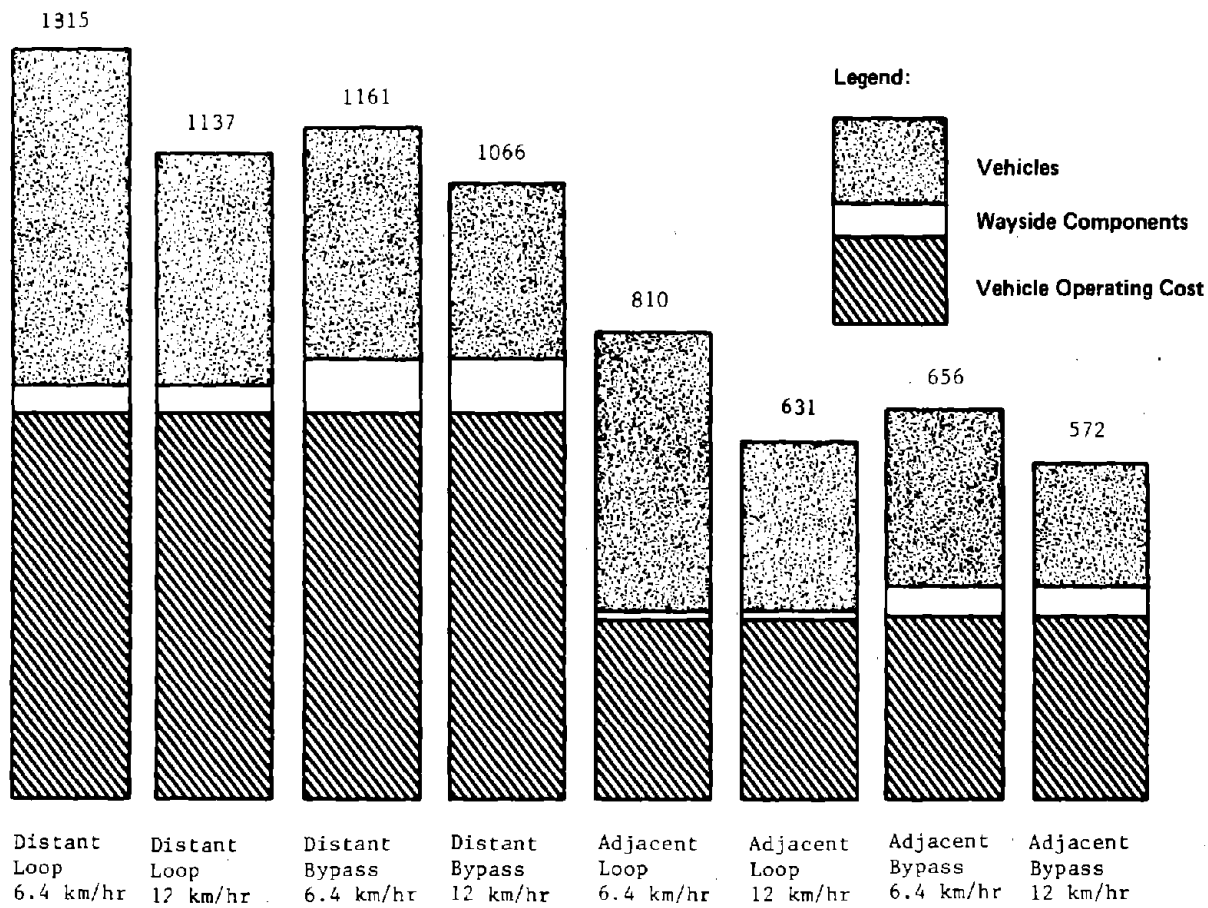


FIGURE 4. AMTV SYSTEM ANNUAL LIFE CYCLE COSTS, K/YEAR

DISCUSSION

Both the accelerating walkway and the automated mixed traffic vehicle system provide service for short urban trips, though their cost as well as their performance characteristics are considerably different. The accelerating walkway provides service between two end points; its costs are dominated by the cost of building the system. Economic success therefore is dependent on a large and continuing flow of users between two particular locations. Indoor, or partially indoor applications are particularly promising because of lower cost. Transportation terminals or connecting busy locations separated by natural or manmade barriers appear to be cost effective applications, with unit user costs of one or two cents per trip per 100 meter distance at suitable locations.

The AMTV system is designed to provide multi-station collection and distribution services for applications where complete grade separation is not possible or desirable. Its cost characteristics are dominated by the vehicle capital and operating costs. The latter are vehicle-mile dependent; the system operator therefore can economize by decreasing dispatch rates during off-peak hours at the expense of degraded service characteristics during these times.

Vehicles, the other cost component, are largely determined by the peak hour requirement. These costs can be significantly reduced by the judicious use of high speed grade separated route segments. For the vehicle size that was selected for the example, user costs can vary from 2 to 5¢ per passenger-km for properly selected applications, a value that compares favorably with the use of automobiles at vehicle occupancies typical for urban trips. For short trips in busy areas, where the use of automobiles is not practical or even possible, the advantage of AMTV over automobiles is that much more obvious.

PAPER 14

Accelerating Walkway Systems

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ACCELERATING WALKWAY SYSTEMS

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ABSTRACT. The Urban Mass Transportation Administration, in conjunction with the Tri-State Regional Planning Commission and the Port Authority of New York and New Jersey is sponsoring a phased program leading to a public demonstration of an Accelerating Walkway System. Variable speed accelerating walkways resemble conventional moving walkway systems but have the capability to accelerate pedestrians 4 to 5 times the speed of the conventional systems and to decelerate for discharge. Time savings resulting from these systems would make deployments over longer distances more feasible than with conventional walkways. Potential applications include a wide spectrum of possible short range passenger movement situations, including feeders to transit, airport movement systems, in vehicle free zones, and as a possible substitute for AGT, bus, or rail transit. Prospective benefits include improved pedestrian convenience and safety, reduced energy use and atmospheric pollution. Five accelerating walkway systems are currently in various stages of hardware development and testing. These systems vary in configuration and site adaptability, affecting their applicability. User safety, including acceptability by the elderly and handicapped, is a significant development factor.

Introduction

The Urban Mass Transportation Administration, in conjunction with the Tri-State Regional Planning Commission and the Port Authority of New York and New Jersey, is sponsoring a program to determine the practicality, reliability, and safety of accelerating walkway systems (AWSs). The AWS Project involves a phased program consisting of an initial feasibility study, technology development and testing, system selection, and public demonstration, and product improvement. This paper provides an overview of the available technology developed as part of feasibility studies conducted by the Port Authority. Accelerating walkways resemble conventional moving walkway systems but have the capability of attaining speeds 4 to 5 times the speed of the conventional systems, or about double the normal pedestrian walking speed. A wide variety of short range transportation applications in transit systems, at airports, and urban core areas are envisioned for an economic, site adaptable and user acceptable variable speed accelerating walkway.

Accelerating Walkway Development Objectives

Transportation technology development has concentrated largely on the

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longer distance transportation demand segments with relatively little attention being given to the largest segment, the pedestrian trip. Pedestrian mobility is a significant factor in determining the effective service area, convenience and utility of public transit systems, and the configuration of most airports and activity centers. Walking has many positive attributes as a transportation mode. It is continuously available, travel times are predictable, routes ubiquitous and easily maintainable, service reliable, free, non-polluting, and non-fossil energy consuming. The constraints on increased utility and wider use of walking as an urban transportation mode are related to the limits of human energy and time expenditure.

Conventional moving walkways have been introduced in transit systems, airports, and urban activity centers as a supplement to the walking mode to improve its utility. The intention of these walkways was to provide a reliable, lower operating cost, continuous service transportation mode offering human energy savings and trip time advantages for those walking on the system. However, it has been found in United States practice that pedestrians will stand on the mechanical walkway, effectively blocking those seeking the walking time advantage. Since the common mechanical walkway speed of 120 fpm (37 mpm) is actually less than half of the normal walking speed of 270 fpm (83 mpm), use of the walk actually results in a loss of time for most users over the equivalent walking distance.

Higher speed mechanical walkway systems are considered to have much greater potential for urban applications because of the attractiveness of the increased speed, and the concomitant prospects of greater deployment length. A five minute ride on a 120 fpm system equals the generally accepted 600 foot length limit for conventional walkways. A five minute ride on an accelerating walkway operating at 500-600 fpm (150-180 mpm) expands the range of a pedestrian conveyor to 2500-3000 feet (.8-1 km), thus opening up a realm of many more applications, and even competing with vehicular systems.

The development objectives for accelerating walkways include user acceptability and safety characteristics equivalent to or better than conventional escalators and moving walkways, continuously available passenger service at high levels of reliability, line haul operating speeds approximately double that of walking, relatively low system installation and operating costs, maximal site adaptability, and minimal environmental impact.

Accelerating Walkway System Descriptions

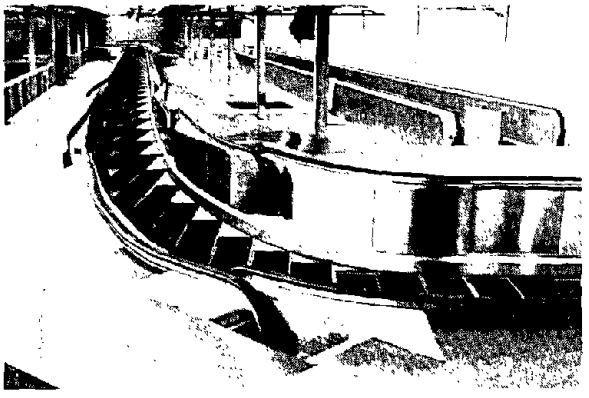
A review of the available variable speed accelerating walkway system (AWS) technology indicates that there are currently five potential AWS developers at, or near, the hardware prototype stage of development and testing. These five systems, in the approximate order of their present development are: (1) the Speedaway system by Dunlop, (2) the TRAX system by the Regie Autonome de Transports Parisiens (RATP - Paris Transit Authority), (3) the Applied Physics Laboratory (APL) system by Johns Hopkins University, (4) the Boeing system by the Boeing Corporation, and (5) the Dean system by the Dean Research Corporation.

The Dunlop Speedaway is a one-directional design resembling an escalator but with a much wider entrance. The treadway is comprised of rectangular

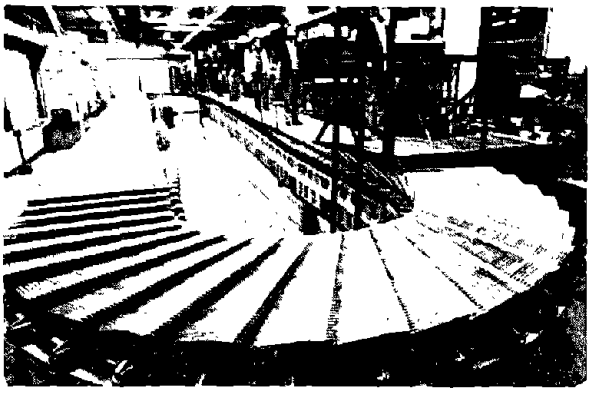
platforms fed at escalator speed at entry and then accelerated laterally in the primary direction of travel to five times the boarding speed. This combination of transverse and longitudinal speeds produces an 'S'-shaped trajectory or path for the roller mounted platforms, which are guided by tracks. The continuous treadway is propelled by friction drive supplied by variable speed electric motors. Conventional combplates are provided at the entry and exit. The speed ratio and acceleration/deceleration rate determines the geometric shape of the platforms, the width of guideway tracks and the dimensions of the entry and exit sections of the system. The 'Speedaway' handrail is designed in seven constant speed sections so that the handrail speed matches the walk speed for the high speed section, and in the accelerating/decelerating sections operates at a speed averaged to that of each adjacent walk section (see Figure 1, upper left). The Dunlop system is the only AWS utilizing a non-changing tread like an escalator, although the direction of the tread changes. Other AWS's rely on expansion and contraction of the treadway surface in some manner, or variable speed rollers, to produce acceleration and deceleration of the walkway. The Speedaway system has undergone considerable engineering testing and demonstration in a laboratory environment.

The RATP-TRAX system is a variable speed conveyor configured in a two-directional loop with a continuous treadway formed of intermeshing grooved sliding plates combing each other and combed at entry and exit. The relative longitudinal sliding motion of grooved plates is obtained by interconnecting the underside of each of two successive plates by a moveable chain linkage. The movement of the chain (and plates) is controlled by sprockets and a telescoping tube assembly which runs in variable gauge tracks flanking the undersides of the treadway. The spacing or gauge of these rails determines the configuration of the combination of telescoping tubes, connecting sprockets and chain, and the treadway. The rails are spread wider and plates meshed closer together in the slow speed section, and conversely, the rails are closer and plates spread further apart in the high speed section. Electric motors driving cleated chains power the system (see Figure 1, upper right). The TRAX handrail consists of individual handgrips, and between these a continuous articulated band forming a less comfortable handhold. At the boarding and discharge zones, the spacing of the individual handgrips would correspond to the minimum desirable distance between passengers. The TRAX system has undergone considerable engineering testing in a laboratory environment.

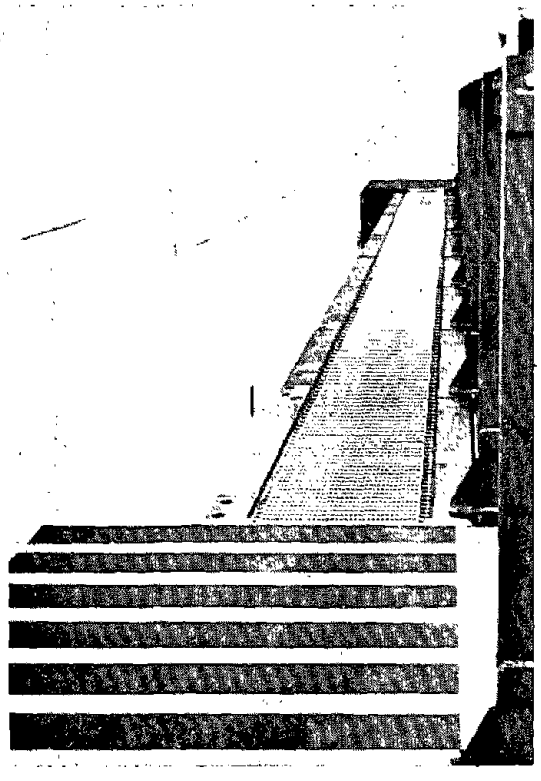
The Applied Physics Laboratory (APL) Johns Hopkins University variable speed walkway is a linear, one-directional design using a treadway comprised of overlapping, intermeshing leaves combing each other and combed at entry and exit. The leaves are linked together and supported by a track to form an endless chain. Acceleration and deceleration is accomplished by a variable pitch screw beneath the treadway which changes the leaf angle to expand or contract the treadway surface. Each of the individual leaves forming the treadway is curved so that the composite surface remains practically level during changes of the leaf angle. The system is electrically driven. The handrail concept is a covered coil spring slaved in mean speed to match the leaved walkway speed. A 31 foot (9.5 m) long prototype of the APL Variable Speed Walkway has undergone engineering testing and demonstration in a laboratory environment (see Figure 1, lower left).



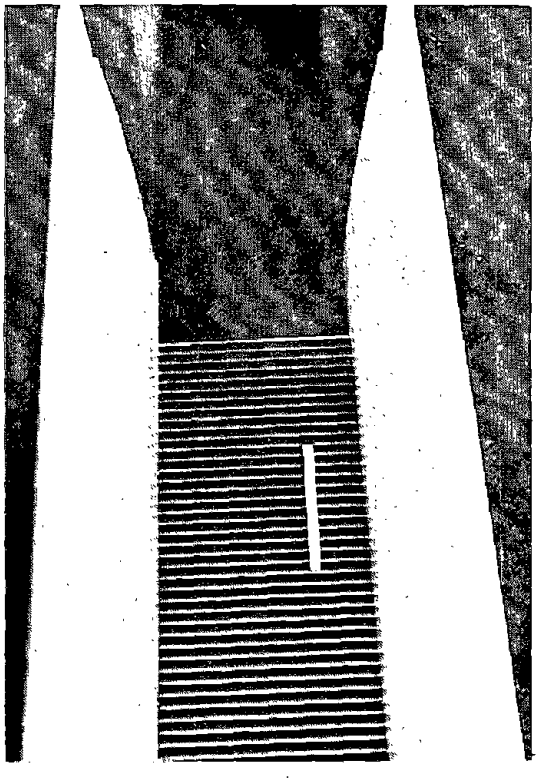
DUNLOP



TRAX



APPLIED PHYSICS LABORATORY



DEAN

FIGURE 1. VARIOUS AWS SYSTEMS UNDER DEVELOPMENT

The Boeing Walkway proposal is a two-directional loop system with a continuous treadway comprised of overlapping, intermeshing, sliding pallets combing each other and combed at entry and exit, similar to the TRAX system. The sliding pallets would be mounted on rollers running in flanking tracks. Propulsion would be supplied by a linear induction motor. The spread of the pallets and length of the treadway would be increased in the acceleration section and decreased in the deceleration section. A matching speed handrail is proposed employing overlapping sections to form a telescoping variable speed handrail for the acceleration/deceleration areas. Some component development work is in progress.

The Dean Research walkway prototype is a linear one-directional system utilizing a treadway surface comprised of a series of abutting steel rollers. The steel rollers in acceleration and deceleration sections are programmed to produce gradually increasing or decreasing speeds. User tests have been performed on a very short length prototype, reportedly without incident. An operational handrail has not yet been developed (see Figure 1, lower right).

Safety and Human Factors

Accelerating Walkway Systems are recognizable as an extension of conventional escalator and moving walkway technology, which has enjoyed wide public acceptability and use for more than 80 years. However, accelerating walkways will introduce several new operating characteristics which may influence accident experience. Depending on the system, treadway surfaces will expand and contract as compared to present systems where the treadway surface is a constant configuration. The expansion and subsequent contraction of the treadway surface may produce dense crowding as pedestrians close ranks in decelerating sections of the system. Instead of a continuous moving handrail of constant speed and configuration, multiple handrails moving at different speeds, or expanding and contracting handrails will be encountered. Additionally, there is the question of the adaptability of different elements of the user population to the acceleration, deceleration and higher constant speeds of the new systems. A primary consideration will be the acceptability of these new operating characteristics to the elderly and handicapped.

Six potential accident risk categories have been identified as being associated with the operation and use of accelerating walkways. These risk categories are briefly described as follows:

- The inertial hazard refers to the movement forces placed on the user by acceleration, deceleration, and the rates of change of these factors.

- The entrapment hazard is common to all moving machinery and involves the catching and possible ingestion into the equipment of clothing, footwear, or human extremities.

- Divergence and discontinuities are defined respectively as a displacement or differential in treadway or handrail speed or direction, and interruptions in treadway or handrail surfaces.

- Bunching may be defined as the crowding of pedestrians to such an extent that their free movement is restricted. Bunching is considered to be a

potential hazard on Accelerating Walkways because of the treadway contraction and reduction of surface area in the deceleration section of these systems.

- The post problem can be described as the presence of any stationary object or design feature along the system or at its outlet which protrudes into the walkway plane from the sides, or from above, situated in such a way that it could come in contact with moving passengers.

- Mechanical failure risks occur where components of a system fail in a manner hazardous to passengers.

An additional potential risk would be individual physiological or psychological responses to the equipment movement, possibly in combination with characteristics of the environment, equipment finishes, and lighting, motion and stroboscopic illusions, or other similar disorienting effects.

On the basis of limited passenger tests of existing prototype accelerating walkways, and a review of available equipment characteristics, the probable safety experience with the new systems may fall somewhere between that of existing moving walks and the escalator, which generally has a higher rate of accidents than the level walk. However, the final determination of the actual safety and acceptability of the new systems can only be made in the context of an operational demonstration and use by the general public.

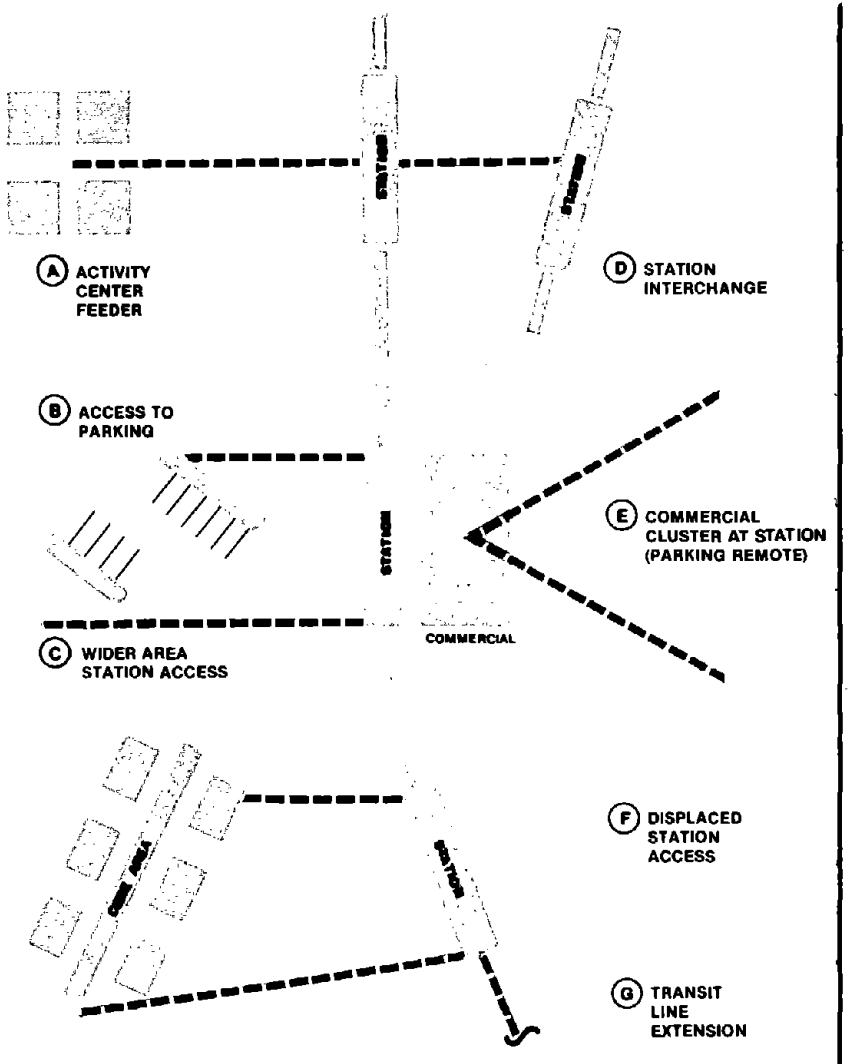
Accelerating Walkway Applications

Potentially there are a wide range of possible applications for a short range small scale horizontal movement system such as an AWS. Many opportunities exist in cities, airports and activity centers, where the installation of such systems would substantially improve pedestrian mobility and convenience. The constraints on installation, including system cost, site adaptability, public acceptability and other similar factors will determine the degree of actual future use in these applications. Five generic classifications of AWS use have been identified and are discussed briefly.

Transit uses for an AWS include utilization as a transfer element between transportation terminals and adjacent transit stations, as a feeder and distributor for transit lines, and as a connector to peripheral parking or nearby activity centers. Perhaps one of the most intriguing applications under this category is the development of potentially lower cost alternative alignment options for new mass transit systems (see Figure 2).

Airport applications for an AWS include use as a landside connector between individual terminals, as an intra-terminal movement system within a main terminal building, or connecting to airside satellite lounges or as an on-airport connector to landside transportation elements such as a nearby transit or bus system, centralized parking or other auxiliary passenger processing sub-systems (see Figure 2).

Urban Development uses include connections with land uses adjacent to the urban core now separated by natural topographic or man-made barriers, integrating lower valued land with favorable land uses to enhance development



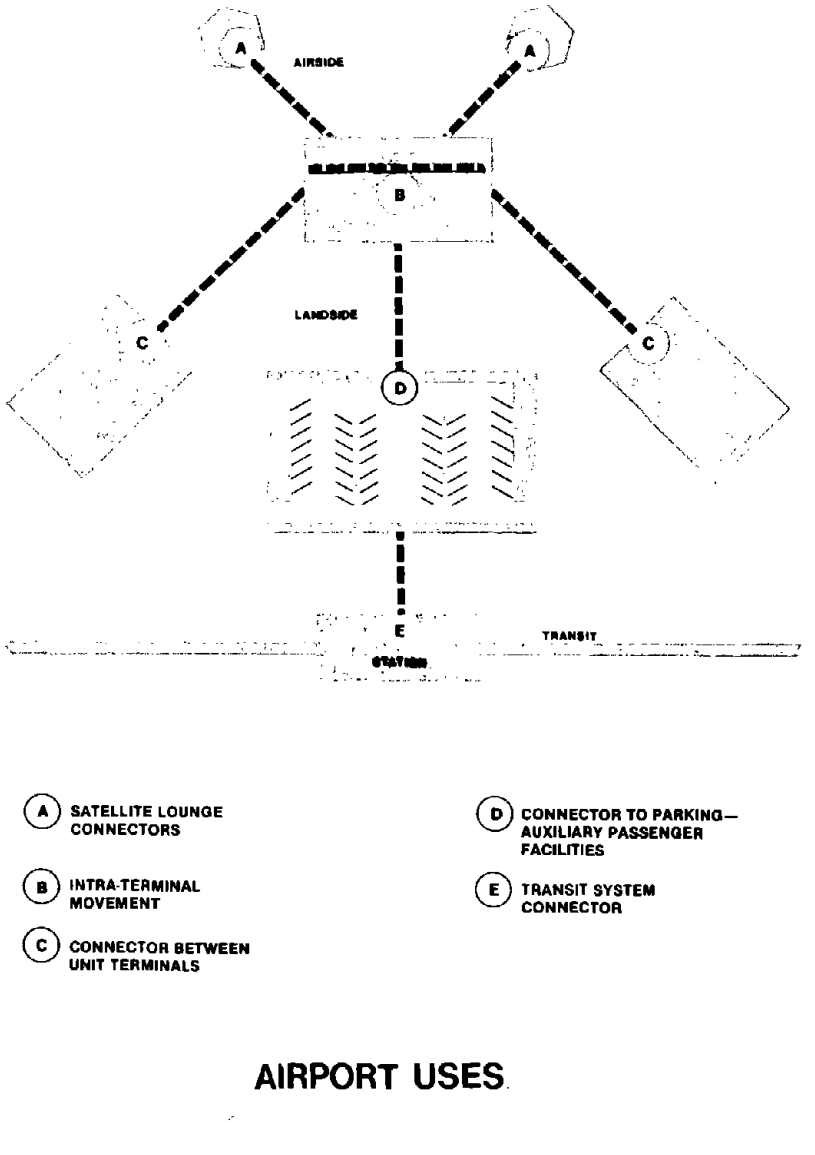


FIGURE 2. ACCELERATING WALKWAY APPLICATIONS

potential and relocating of parking now occupying high value land space within the core, releasing land for other types of use.

Vehicle Free Zones could utilize accelerating walkways to expand the size of pedestrian precincts, allow more alternative VFZ configurations, connections to remote parking and transit stations, and as a possible radial service alternative to a peripheral downtown shuttle loop transit system.

As an Alternative Mode, a short range, continuous service transport system such as the accelerating walkway presents many opportunities for considering it as an alternative to taxis, bus, automated guideway transit, light rail transit, or in some cases even heavy rail transit. As compared to these vehicular systems, an AWS would provide continuous, rather than intermittent batch service, would require less manpower to operate, and because of scale would be relatively simpler to deploy. It would not require exotic control systems, or a fleet of vehicles to be maintained, and would be simpler to operate. Environmental impacts would be considerably less than vehicular systems, and there would be lower energy consumption per passenger.

Costs and Benefits

Cost/benefit analysis may be described as a procedure by which the range of benefits resulting from a prospective course of action are identified, translated in dollar terms and quantified where possible, and measured against the costs or other penalties associated with the action. If the benefits developed from such an analysis exceed the costs, the action can be considered a favorable one from the standpoint of the decision maker establishing the benefit/cost parameters. The larger the ratio of benefits to costs, the more favorable the action may be considered by the decision maker. This basic description of cost/benefit analysis is a reasonable model of how many decisions are made, including such simple things as everyday personal purchases.

The most accurate and effective uses of cost/benefit analysis occur when it is used as a management decision procedure involving such things as the purchase of new equipment with easily identifiable productivity improvement capabilities. Although cost/benefit analysis has been applied to public transportation decision processes, it has been the subject of debate because of the inability to completely identify the benefits (and disbenefits) associated with transportation improvements. In particular, difficulties have been experienced in valuing passenger time and convenience, since passengers themselves may vary in their perception of this value under differing circumstances.

Benefits that have been identified for a potential accelerating walkway deployment include: trip time and human energy savings, expansion of the pedestrian trip range, improved pedestrian convenience, safety and security, and reduced air pollution and resource energy use. For the purpose of cost/benefits analysis, four different ways of viewing an accelerating walkway deployment are possible, including: (1) the users' Time Energy Value or the worth of human time/energy saving associated with the walkway use; (2) Least Cost Alternative, a comparison of the cost of a walkway as an alternative to use of another transportation mode; (3) Value Transfer, the use of an AWS in a context in which increases in property values, rentals or other

equities will result, and, (4) Developmental Advantage, where an AWS allows a potentially lower cost development plan, or one with superior advantages.

Total system costs, including the furnishing and installation of the unit (generally included in the manufacturer's quoted price), the cost of structural and architectural site preparation by the owner, insurance, operation and maintenance expense and property acquisition costs where necessary, will affect the decision to deploy an AWS. Conventional moving walkways currently cost about $1000-1200 per lineal foot ($305-366/m) for furnishing and installation of the unit. This cost is based on established manufacturing and installation procedures. It is expected that a first generation production unit AWS will cost from 50% to 100% more for furnishing and installation than conventional systems depending on system complexity, manufacturing plant set-up requirements and manufacturer experience and capabilities. Variations in preparation costs can occur depending on the system dimensional envelope, whether the system is installed in existing or new structures, and whether it is to be installed at-grade, elevated on a pedestrian bridge or in a tunnel. Operation and maintenance costs will depend on power rates, the length, width and passenger utilization of the system, and the maintenance experience.

Because of the many variables, system cost, daily user volume and the perceived system value (or potential fare), it is difficult to establish a definitive cost/benefits ratio for an accelerating walkway, unless these data for a specific site are determined in detail. However, the range of these parameters can be developed in such a manner as to establish the region of AWS economic feasibility in terms of system cost, use and perceived value (or fare) and cost. Figure 3 is a nomograph developed on this basis. The horizontal plot on this nomograph is the value placed on either the avoidance of walking or savings in time. The left side vertical plot is daily use in thousands of trips. The curved lines on the nomograph are the resulting product of use and value in increments of $5000 daily revenue and/or system cost. Also illustrated as a curved line on this nomograph is the approximate $1500 daily cost of a theoretical baseline system.

The baseline system assumed for the cost/benefit analysis consists of a 1000 ft. (305 m) long linear one-directional system, elevated on a pedestrian bridge section, weather protected, plus heating and air conditioning, with an installed power of 200 hp, operating in a reversible "tidal flow" commuter demand situation, 16 hrs. per day, 300 days per year. The assumed furnishing and installation cost of the system is $1500 per lineal foot ($4920/m) or $1.5 million, and the structural preparation or bridge cost, $2240 per foot ($518/m) or $2.24 million. The capital write-off for the baseline system would be based on a 25-year life cycle for structure and 15-year life cycle for equipment, at 7% interest (capital recovery factors 0.086, 0.11 annually). No site acquisition cost has been assumed on the basis that the system is installed on public right-of-way, over sidewalks and streets. Annual operating cost for the baseline system would include an estimated insurance cost of $10,000. Power cost with an installed capacity of 200 hp, power draw averaging 50% of capacity, 80% electrical efficiency, a power cost of $.05 kilowatt hour, is $4.70 per operating hour. Heating, ventilating and air conditioning costs, which would depend on location, have been assumed at $10,000 annually. Maintenance costs for the baseline AWS would be based on system location and such factors as maintenance experience and costs of replacement parts. Where

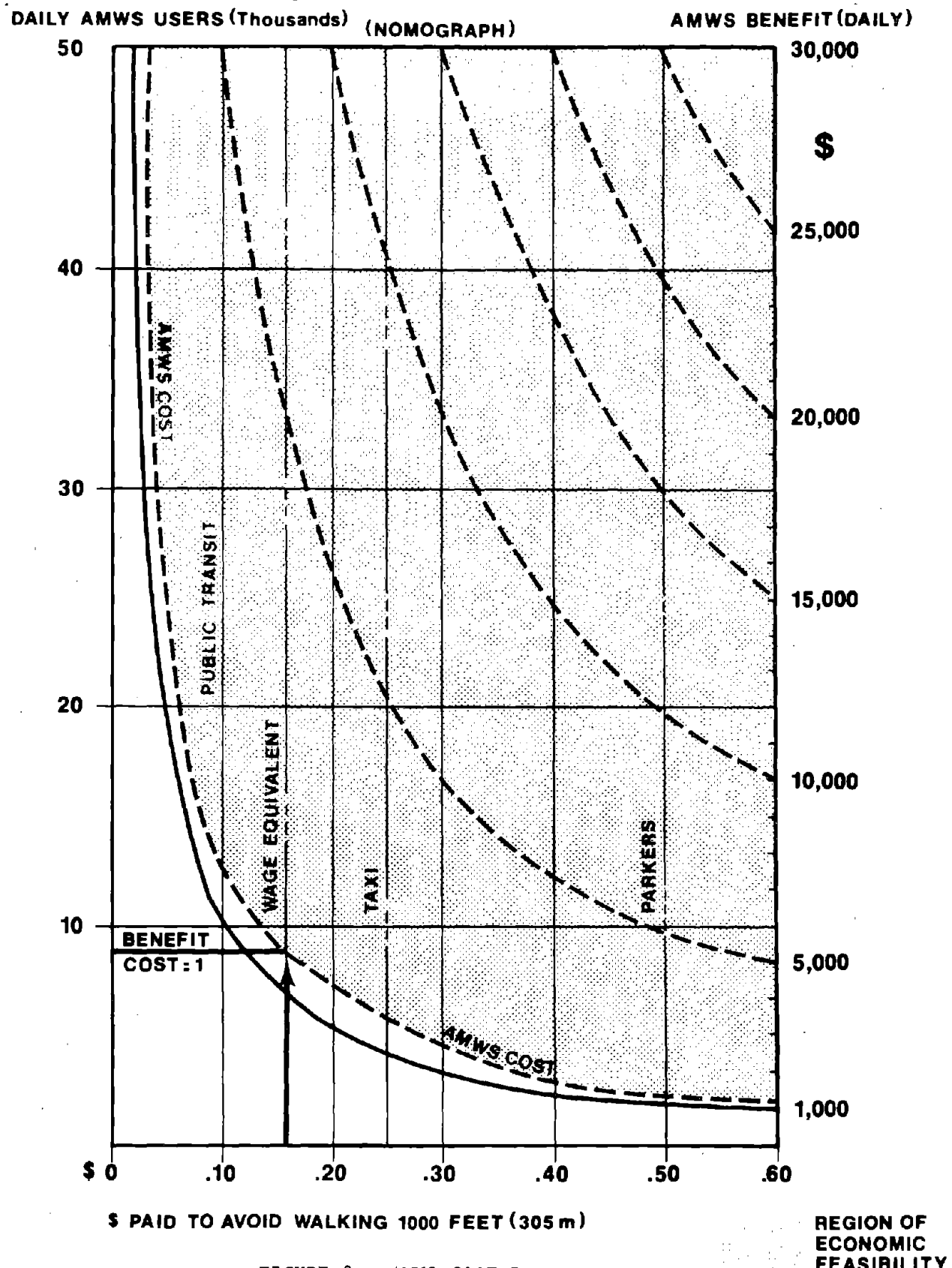


FIGURE 3. AMWS COST BENEFIT

the AWS would be part of a larger system of moving way units, such as with a transit property or airport, operation and maintenance would be significantly less than a single installation. An annual cost of $20,000 or roughly about one mechanic man-year, has been assumed. An additional $20,000 would be added for overheads, contingencies and supplies.

The nomograph may be entered in various ways depending on available data, or the assumptions of the user. For example, the total daily cost of about $1500 for the baseline system at a wage equivalent time savings based on an annual wage of $10,000 (equating to $0.16 per trip), requires about 9,000 daily users to offset costs, or the cost/benefit value of one. Either doubling system use or doubling the users' perceived time energy value is required to bring the cost benefits ratio up to two. Based on pedestrian safety research, an added accident avoidance value of $8 per 1000 users could be assumed for each pedestrian grade crossing eliminated by the system. A baseline system eliminating 5 such grade crossings would add 25% to the wage equivalent value developed above, raising the cost benefits ratio to 1.25 with 9,000 daily users.

The potential value that pedestrians may place on time savings and the avoidance of walking varies considerably. A study by the New York Regional Plan Association (RPA) comparing the prices paid for long term parking versus distance to destination, found a one-directional walking avoidance cost for parkers in Manhattan of $0.65 per 1000 ft. (305 m) in 1969 prices. RPA reported the results of a similar study for Los Angeles indicating walking avoidance values ranging between $0.36 and $0.48. The RPA study found walking avoidance values for transit users in Manhattan varying between $0.03 to $0.50 per 1000 ft. (305 m), with a value of $0.11 to $0.13 being representative of the typical cross-town transit bus trip in Midtown Manhattan. This latter value is reasonably close to the assumed wage rate value of time savings of $0.16, shown in Figure 3.

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PAPER 15

Socio-Economic Research on Automated Guideway Transit

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SOCIO-ECONOMIC RESEARCH ON AUTOMATED GUIDEWAY TRANSIT

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ABSTRACT

This article describes an ongoing Urban Mass Transportation Administration (UMTA) program: The Automated Guideway Transit Socio-Economic Research Program which was designed to examine the appropriateness of this new transit technology as a means of satisfying presently unmet or ineffectively met urban transportation requirements.

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INTRODUCTION

Over the past few decades, American cities have changed significantly in form, shape, population distribution, and concentration of activities. Central cities have been losing much of the manufacturing and other goods-handling activities which, in the past, were concentrated in cities. During the 1960's, significant population increases occurred within metropolitan areas, [1] and about 68 percent of this increase was in the suburbs. However, during the first three years of the 1970's, the largest increase in population was in nonmetropolitan areas, accompanied only by a 37 percent population growth in metropolitan areas. It is worth noting that this 37 percent population growth consists of a 60 percent decline in the population of central cities and a 98 percent increase in suburban population. Accompanying this growth in suburban population, employment in the central cities of the United States declined during the same period, favoring suburban growth. This suburbanization had tended to scatter activity centers, thus prompting increased intra-urban travel demand. In fact, during the 1960's, urban travel increased by about 65 percent to about 740 billion passenger-miles a year. Most of this urban travel increase was satisfied by the automobile, while during this period transit patronage declined about 35 percent.

The decline in transit patronage in U.S. metropolitan areas can be attributed in part to suburbanization, to a high proportion of intrasuburban trips, and to a decline in the level of transit service. But the most important factor is the individual's distinct preference for the automobile, offering convenience, comfort, privacy, flexibility, and low perceived cost of use. As a result, mass transit has been burdened with severe financial deficits resulting from rising capital, operating and maintenance costs, and reduced revenues.

To improve this situation, federal, state, and local programs have been established to aid public transit including capital assistance, operating subsidies, demonstrations, and research and development.

The largest expenditures for these programs to date have gone to the conventional transit technologies (bus and rail). More recently, funding of paratransit services has also become significant. Nonetheless, the full range of urban transportation needs is often difficult or impossible to satisfy economically or effectively with these forms of transit.[2]

This article describes an ongoing Urban Mass Transportation Administration (UMTA) program: the Automated Guideway Transit Socio-Economic Research Program.

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WHAT ARE AUTOMATED GUIDEWAY TRANSIT SYSTEMS?

Several definitions have been used in describing automated transit systems. During the past two years, however, a standard definition was formulated by the Office of Technology Assessment (OTA) of the United States Congress.[3] This definition is based on operating characteristics.

Definitions

Automated Guideway Transit (AGT) is defined as a type of transportation system in which automatically-controlled vehicles operate on fixed guideways along exclusive rights-of-way. These include shuttle loop transit, group rapid transit, and personal rapid transit which are defined as follows:

- Shuttle Loop Transit (SLT). A class of AGT in which vehicles move along fixed paths with few or no switches. In a shuttle system, vehicles move back and forth on a single guideway; in a loop system, vehicles move around a closed path, stopping at any number of stations. Vehicles may vary considerably in size and may travel singly or coupled together in trains with headways generally of 60 seconds or greater.

- Group Rapid Transit (GRT). A class of AGT which is designed to serve groups of people with similar origins and destinations. Vehicle capacity ranges from 10 to 50 passengers and vehicle headways range from 3 to 60 seconds. GRT systems generally have more switching than SLT systems to shorten en route travel times.

- Personal Rapid Transit (PRT). A class of AGT systems with fleets of small vehicles (two to six passenger capacity) that travel automatically on guideways with off-line stations providing nonstop origin-to-destination demand-responsive service. Vehicle headways are generally three seconds or less.

Description of AGT System Characteristics

There are presently 17 AGT systems in the United States supplied by six manufacturers. These systems are also being developed and tested in Europe (Germany and France), as well as in Japan. Examples of each class of AGT are listed in Table I.

TABLE I–EXAMPLES OF AGT SYSTEMS

AGT Class	*Location*	*Function*
SLT	Tampa Airport, Florida	System connects main satellite terminals in a shuttle mode.
GRT	Dallas/Fort Worth Airport, Texas	System connects stations over 13 miles of guideway with switching and multi-route network.
PRT	Hagen, Germany	System operational in a test site, including high-speed switching, bidirectional flow, and stations of on-line, and off-line types.

One of the major problems facing transportation planners considering alternative urban transportation facilities is the lack of reliable information on AGT systems. For illustrative purposes, Table II summarizes some available system characteristics of the AGT classes listed in Table I. Some of the cost figures in Table II include research, development, and testing which are difficult to separate from the actual operations costs. It is also important to note that the operating and maintenance costs of a new technology often decline considerably during the first years of operational service.

TABLE II—DESCRIPTION OF AGT SYSTEM CHARACTERISTICS

System Characteristics	*Tampa Florida* [b]	*Dallas/ Fort Worth Texas*	*Hagen Germany* [o]
Sizing			
Guideway length (single lane in miles)	1.4	13	0.7 [l]
Number of stations	8 (on line)	53 [c] (8 on line)	3 (1 on line)
Number of vehicles	8	68 [d]	12 [m]
Performance			
Passengers carried per year (millions)	13	5.6 [e]	[a]
Vehicle mileage	400,000/year	6,472,000 [e]	[a]
Maximum capacity in passengers/lane/hour	7,340	14,400 [f]	7,500 [n]
Average trip time on vehicle (seconds)	40	660	80
Minimum vehicle headways (seconds)	not applicable	18	1.4
Maximum speeds (miles per hour)	30	17	23
Labor-force to vehicle ratio	0.75	1.5 [g]	[a]
Costs			
Initial capital cost (millions of dollars)	8.25	64 [h]	[a]
Operating and maintenance costs per vehicle-mile (dollars)	1.2	0.57 [k]	[a]
Operating and maintenance costs per passenger (dollars)	0.04	0.42 [k]	[a]

[a] n.a.—data not available.
[b] "The Tampa and Seattle-Tacoma Airport Transit Systems" by Gillespie, Society of Automotive Engineers, Air Transportation Meeting, Hartford, Connecticut, May 1975.
[c] 28 stations for passengers and employees and 25 utility stations.
[d] 51 for passenger and 17 for freight.
[e] As of September 1976.
[f] Based on 80 passengers per train at 20-second headways.
[g] Based on 100 maintenance employees and 68 vehicles.
[h] "Assessment of Operational Automated Guideway Systems—AIRTRANS (Phase I)." U.S. Department of Transportation, September 1976.
[k] During period April through November 1976.
[l] Bidirectional length. There is also 0.3 mile underslung.
[m] 10 (3-passenger) vehicles, 1 (12-passenger) vehicle, 1 service vehicle.
[n] With (3-passenger) vehicles at 12-second headways.
[o] "Nahverkehrsforschung," Federal Ministry of Research and Technology, West Germany, 1975.

Note: The data in this table are presented for illustrative purposes and should not be used for comparing systems.

BASIS FOR THE AGT SOCIO-ECONOMIC RESEARCH PROGRAM

The 1966 Reuss-Tyding Amendments to the Urban Mass Transportation Act of 1964 called for federal study and development of programs of research, development, and demonstration of new systems of urban transportation. Since the passage of these amendments, many metropolitan areas have investigated the potential of AGT systems to meet their specific urban public transportation needs. Moreover, a number of AGT research, development, and demonstration programs have also been undertaken.

In September, 1974, the U.S. Senate Transportation Appropriations Subcommittee, Committee on Appropriations, recognizing the increased interest in new types of fixed guideway systems by local communities, requested the OTA to investigate the value of PRT systems--the transit system terminology then in use to broadly refer to the AGT technology. In May, 1975, OTA responded to this request with a report on the current developments of AGT systems in the United States and abroad, their social acceptability and economic considerations, and their operations and technology.[4]

During the Senate fiscal year (FY) 1975 UMTA Appropriations Hearings, a new program area was then recommended entitled "Social Economic Research in AGT" with a recommended funding level of $2 million for FY 1976.[5] The recommended program was based in part on the OTA report. The Senate made reference to that report by stating that social and economic research is needed on AGT systems and added that:

> The Committee recommends providing $2 million for such research to be used to study the comparative advantages of AGT systems over other forms of mass transportation, evaluation of performance and cost experience of existing AGT systems, assessment of market potential for urban application of AGT, and simulation and experimentation with existing AGT systems to determine what can be learned about the human response to them.

At the subsequent Senate Appropriations Hearings, UMTA agreed that a significant increase in social, economic, and environmental research would be necessary before AGT systems can become fully accepted as a form of urban transportation. UMTA estimated that it would take several years of concerted effort to complete such a program and that "the entire program could be definitized and started during FY 1976." The Joint House/Senate Report on UMTA FY 1976 appropriations subsequently recommended $1 million for the research during FY 1976.

The need for this research program was also expressed by several state and local governments. In fact, the OTA committee identified a number of localities that have shown an interest in AGT in 1975. More recently in 1976, 39 U.S. cities submitted proposals to UMTA for financing the AGT system serving as a downtown people mover. The information obtained through the conduct of the AGT Socio-Economic Research Program will be valuable to local governments in undertaking their local "alternatives analysis process," a current UMTA requirement to qualify for federal capital assistance for major public transportation investments.[6]

This research program addresses many of the following types of basic questions regarding automated guideway transit systems: (1) Where and under what conditions will AGT service characteristics satisfy the travel needs and socio-economic requirements of U.S. urban areas in a manner competitive with or superior to other transportation alternatives? (2) What is the role of AGT in providing a balanced total transportation service, and how does it integrate with existing services? (3) What are the costs of development, construction, and operation of AGT systems, and how do these costs compare with those of other transportation alternatives? (4) Where and under what conditions will the public accept automated over conventional transportation systems? (5) Will American cities accept the intrusion of AGT guideways? (6) Is there a potential market for transportation technology with the characteristics of AGT systems?

DESCRIPTION OF THE AGT SOCIO-ECONOMIC RESEARCH PROGRAM

In content, the program is structured as five major activities (see Figure 1:

1. The Generic Alternatives Analyses Activity examines the question of how AGT compares with other forms of urban transportation.

2. The Assessments Activity examines the question of how well the existing AGT systems work.

3. The Costs Activity examines how much AGT systems cost.

4. The Markets Activity examines the question of how many places want and can use AGT.

5. The Communications Activity aims at disseminating information about AGT to all interested audiences and receiving local expressions of views regarding AGT.

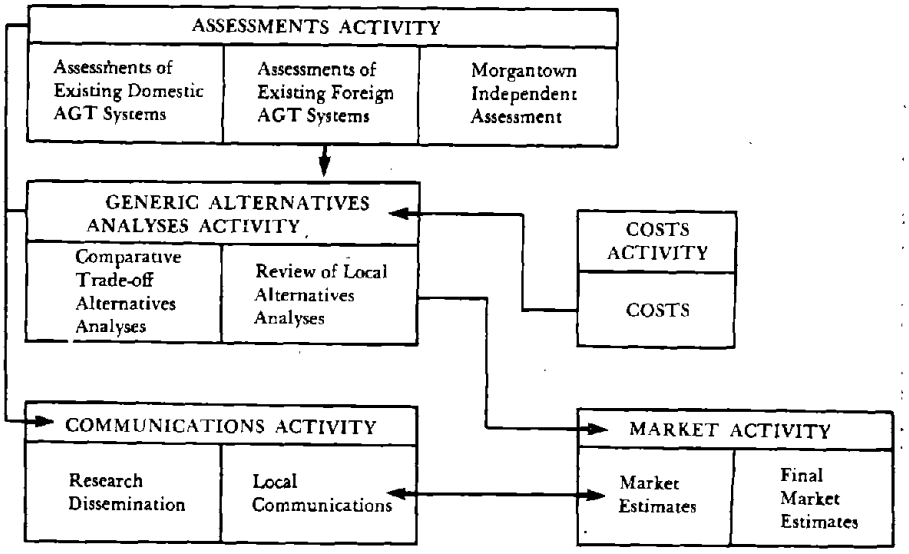


Figure 1. AGT Socio-Economic Research Program activities

These five activities are interrelated and are generally parallel in nature. The following describes briefly each of these activities and their relationships.[7]

The Generic Alternatives Analyses Activity

This aspect of the program will evaluate alternative modes of transportation (bus, rail, paratransit, AGT, and the private automobile) in hypothetical applications,[8] including examination of social, economic, environmental, and performance considerations associated with each transportation mode.

It will identify the transportation alternatives that are most appropriate for each hypothetical application. The results will show where, and under what conditions, AGT service characteristics satisfy the travel needs and socio-economic requirements of U.S. urban areas and how they compare with or complement other transportation alternatives. During this comparative process, an inventory of current information on transit socio-economic and performance characteristics will be compiled through direct interface with the Assessments Activity and the Costs Activity (see Figure 1).

The Generic Alternatives Analyses activity consists of two major parts: (1) comparative trade-off alternatives analyses and (2) review of local alternatives analyses of AGT case studies.

1. Comparative Trade-Off Alternatives Analyses. These analyses will identify the present and future urban transportation needs which are created by representative urban forms. They will determine the ability of the alternative transportation modes to satisfy economic and environmental considerations as well as the operational characteristics associated with each mode. Table III summarizes the type of issue and assessment measures that will be investigated. The analyses will consist of: (1) preparation of a comparative inventory of data on AGT and other transportation systems; and (2) a trade-off analysis performed for each hypothetical application by making comparisons of the measures of transportation performance, economics, environment, and demand.

   Specifically considered will be issues that appear to have critical significance to AGT systems in the urban environment; three of these are:

   - Social Barriers. Social barriers to AGT will include those issues that may constrain community implementation of AGT or affect its usage by various groups. Significant user characteristics and the effect on ridership of AGT operations and variations in its level of service will be established. The requirements of elderly and handicapped persons regarding level of service and design features will be identified. In addition, consideration will be given to issues such as community resistance to family or business relocation, construction activity; AGT system potential for vandalism and crime; and minimal trip information requirements for various user groups.

   - Policy Issues. The current and expected political and institutional

conditions at all levels of government that may affect urban transportation decision-making and related land-use planning for AGT systems deployment will be examined. Emphasis will be placed on assessing the broad policy implications for the AGT industry and national market. Laws or policies that presently affect AGT implementation as well as those issues that may require new or revised legislation or transportation policy will be identified. Also, of importance is the identification and evaluation of issues related to jurisdictional differences (particularly at the local level) concerning the implementation and operation of transportation systems and methods employed to overcome these differences. In addition, an examination will be made of existing and innovative methods of public and private financing of AGT systems in a variety of applications. This analysis will include transportation projects of all government levels. Particular attention will be given to capital grants funding criteria as well as funding practices at the state and local levels. Marginal capital, operating, and maintenance costs currently used in system selection and their impact on AGT development will be identified.

- Visual Intrusion. Visual intrusion of the various transportation systems in residential, commercial, and parkland applications will be identified. Human response to the visual impact of elevated, at-grade, or sub-grade facilities will be addressed. Consideration will be given to: guideway width and height for a variety of applications, as well as conflicts with physical appearance of existing structures; invasion of privacy in homes, offices, and buildings; changes in microclimate (natural lighting, temperature, wind, noise levels) near elevated and at-grade facilities; the feasibility of multiple purpose systems (such as joint-use station design); and identification of construction activity impacts.

2. Review of Alternatives Analyses. The objective of this review is to determine the near-term demand for AGT systems based on actual transportation planning studies conducted at the local level. This aspect of the program will be used to test and validate the findings resulting from the investigation of assessment measures listed in Table III. Useful input to this activity will be the knowledge gained through the UMTA critiques of case studies made at local levels (local alternatives analyses) to qualify for federal capital assistance.

   The variations in forms of AGT (SLT, GRT, PRT) in these case studies will be identified and categorized, and the methodologies of comparing them in individual studies will be described. The degree to which the choice of methodology and/or transportation alternatives reflect the local perception of the role for AGT will be evaluated by direct investigation of local transportation studies and of pertinent public hearings conducted in such cities as Denver, Colorado, and the Twin Cities (Minneapolis and Saint Paul, Minnesota).

TABLE III—ISSUES AND ASSESSMENT MEASURES

Performance Measures

- Service
  - Travel and dwell time
  - Accessibility
  - Flexibility
  - Convenience
  - Ride quality
  - Availability
  - Reliability
  - Passenger information systems
- Performance
  - Speed
  - Headway
  - Acceleration and deceleration
  - Jerk
  - Capacity
  - Braking

Social Measures

- Impacts of transportation systems
  - Human activity patterns (tripmaking behavior, employment and shopping opportunities)
  - Land-use density
  - Changes in property value
  - Community disruption
  - Housing choices for the poor
  - Regional versus local
  - Short- and long-term impacts on relocated business/families

Social Measures (Continued)

- Economic costs
- Barriers to social acceptance of transportation systems
  - Patron reluctance to use transit versus automobile
  - Patron reluctance to use unmanned systems
  - Vandalism
  - Security
  - Crime
  - Travel information requirements
  - Requirements for the elderly and handicapped (dwell times, safety, access and egress to stations and vehicles, and design features such as elevators, ramps, door width)
  - Human behavior (large- versus small-capacity vehicles)
  - Elevated, at-grade, and subgrade systems
  - Station accessibility
  - Privacy
  - Usage by various incident groups and identification of significant user characteristics (socioeconomic status, distance from system, existing travel behavior, existence of alternatives.)
  - Other

Economic Measures

- Capital costs (right of way, stations, guideways, maintenance yards, vehicles)
- Operating costs

TABLE III *(Continued)*

Economic Measures (Continued)

- Maintenance costs (parts, labor, administrative)
- Life-cycle costs
- Manned versus automated systems
- Social, safety, and environmental requirements costs (such as elevators, closed-circuit television)
- Other

Institutional Measures

- Institutional environment
- Pertinent existing legislation
- Jurisdictional differences
- Transportation land-use planning activities
- Citizen participation
- Planning organization and relationship with other agencies
- Labor and transit management relationships/policies
- Automatic effects
- Policy options and institutional constraints
- Influence of political considerations, regulatory measures, federal and state laws, and policies on local planning process
- Other

Financial Measures

- Procurement practices
  - Capital grants funding criteria
  - Capital, operating and maintenance costs
- Particular financial requirements of individual urban transportation modes (such as marginal costs of capital and/or operational and maintenance)
- Methods of public and/or private financing
  - Impacts on different incident groups and financing of other societal programs
  - Short- and long-range effects on local tax base
- High-risk capital-intensive programs
- Other

Financial Measures (Continued)

Urban Development Measures

- Impacts on urban and regional development (short- and long-term, such as property values, density, and form of adjacent neighborhoods, effect on the central business district)
- Land-use goals (such as preservation of existing institutions, businesses)
- Land-use controls (such as different categories of zoning)
- Reduction of land (consumed for transportation purposes, community facilities, and public utility purposes)

System Measures

- Stations
- Guideway
- Vehicles
- Suspension
- Propulsion
- Switching
- Power consumption

The results of these direct investigations will be analyzed to determine the commonalities and differences in perception among community groups. Typical aspects to be examined for case studies that include AGT as a transportation development alternative are: transportation cost (capital, operating, operating deficit), transit usage and quality (transit person-trips, modal splits), community objectives (land-use objectives, noise, safety, traffic impact), and national objectives (air quality, petroleum dependency).

This review of transportation alternatives will serve as input to the Markets Activity (see Figure 1).

The Assessments Activity

Information concerning the social, economic, financial, and performance characteristics of the existing AGT systems in the United States and abroad will be acquired, analyzed, and evaluated. This information will serve as direct input to the other activities of the program and to a central repository on AGT systems. The Assessments Activity deals with surveys of existing domestic AGT systems, foreign AGT systems, and the Morgantown, West Virginia, people mover system. Each AGT system installation will be analyzed and evaluated. For selected installations an historical documentation of major decisions influencing system development will be compiled.

A typical investigation of the AGT systems will include studies of:

1. System and subsystem performance. This relates to system and subsystem effectiveness, reliability, and safety measures. Subsystems include vehicular command and control, steering, monitoring, propulsion, power distribution, and fixed guideway.

2. System economics. Capital costs (in total and by subsystem elements), operating and maintenance costs for each major system, energy costs, the total labor requirements for system operation, and life-cycle costs will be considered.

3. Environmental and aesthetic impacts. This includes the adverse effect caused by air/noise pollution in addition to visual intrusion factors of the guideway.

4. Public response and acceptance. This applies to human factors interaction including the information system (usefulness to the rider and ease of interpretation) and the requirements of elderly and handicapped persons.

The developmental process for AGT systems will be reviewed including consideration of the institutional, contractual, and legal arrangements among the system sponsor, organized public groups, the developer, and the manufacturer. Also the relationship between the funding authorities (local and federal) and the developmental process will be reviewed.

For the foreign assessments, a program of information exchange on urban

transportation research related to the socio-economic implications of new transportation systems has been initiated with France, Germany, and the Organization for Economic Cooperation and Development.

The Costs Activity

Capital, operating, maintenance, and life-cycle cost ranges for the modal classes of AGT will be identified for various hypothetical applications. Information gained in this study will serve as input to the comparative trade-off alternatives analyses. Capital costs will include right-of-way acquisition, construction of facilities (stations, guideways, maintenance yards), command and control, vehicles and vehicle subsystems. Operating and maintenance costs will include such items as parts, labor, and administrative costs. Cost data will be collected from existing sources to estimate likely future AGT industry cost reduction potential as the technology matures. Life-cycle cost analyses will be undertaken of alternative transportation modes to examine the comparative economic potential of AGT under various ranges of possible future interest and inflation rates. This study will also determine those peripheral aspects of AGT systems which might be more economically operated by automation (such as fare collection and surveillance).

The Markets Activity

The capability of AGT to meet the present and future demands for transportation service and the socio-economic requirements of individual U.S. urban areas will be ascertained through: (1) an identification of these areas' urban transportation needs and requirements, and (2) analysis of transportation mode alternatives at specific sites.

Thus the nature and magnitude of the potential market for AGT systems and the locations for specific transit projects (such as for the downtown people mover systems in which 39 urban areas have already indicated interest) will be determined.

The analysis of the transportation needs and requirements of the urban areas will be based on the wealth of existing information that can be obtained from local technical studies, public hearings, studies related to federal grants application, and the like. The findings from the local communications activity of the program (see Figure 1) will be used in determining and assessing travel needs and socio-economic requirements, community goals and objectives, and institutional considerations.

A sample of urban applications will be chosen for undertaking the analysis of transportation alternatives for specific sites. The findings of the Generic Alternatives Analyses Activity will be applied to corresponding applications in each sample city to validate on a site-specific basis where AGT might be an appropriate transportation alternative. Existing transportation planning techniques such as the Urban Mass Transportation Administration Planning System may be used in undertaking parts of the site-specific analyses.

The Communications Activity

This activity consists of two efforts: (1) research dissemination and (2) local communications. The first effort will continue throughout the AGT Socio-Economic Research Program to disseminate the research findings of the various activities. Also, an inventory of transportation systems will be compiled to include data on performance, socio-economic, and engineering parameters of various transportation systems. This inventory will serve as a central repository of information on these new transit systems.

The local communications aspect of this effort will obtain input from a study to determine public attitudes and concerns of local public officials, citizens, planners, and other interest groups toward AGT and other transportation alternatives. This information will be used to develop a better understanding of the travel needs and social acceptance of new transportation technologies in the various U.S. urban areas. The interest groups will include public transportation users (commuters, the elderly, the handicapped); general public (nonusers, landowners, neighborhoods, businesses); transit operations (public and private); labor; industry (system manufacturers and related industries); government (all levels); and planning commissions.

Since AGT systems technology is generally little known or understood at the local level, various communication techniques (including displays, movies, literature, and meetings) will be developed and tested to transfer basic system information to various local groups. In addition, surveys and observation methods will be developed and used to determine public attitudes. Two survey approaches are planned to isolate the local response to AGT. One establishes local public attitudes toward public transportation from samples selected to represent various interest groups. The other gathers comparative information from sample respondents after they have been acquainted with AGT operation, characteristics, and performance.

CONCLUSION AND SUMMARY

This article has described UMTA's AGT Socio-Economic Research Program, which addresses the role and social acceptability of this transit technology. Factors of a social, economic, institutional, performance and land-use nature will be analyzed under five major program activities. For a brief summary: the Assessment and Costs Activities will collect and evaluate information on existing AGT systems; the Generic Alternative Analyses Activity will perform comparative trade-off analyses of AGT and other transportation modes; the Markets Activity will apply the findings of the comparative analyses to site-specific U.S. urban areas; and the Communications Activity will disseminate the findings of the various activities.

LIST OF FOOTNOTES

1. U.S. Bureau of Census, Current Population Reports: Special Studies, Series P-25, No. 537, July 1974.

2. Melvin Webber, "The BART Experience, What Have We Learned?" Public Interest (Fall 1976).

3. U.S. Congress, Office of Technology Assessment, "Automated Guideway Transit: An Assessment of PRT and Other New Systems," June 1975.

4. Ibid.

5. U.S. Congress, Senate Hearings Before the Committee on Appropriations, Department of Transportation and Related Agencies Appropriations, Part 2, Fiscal Year 1976.

6. Federal Register, "Major Urban Mass Transportation Investments," Volume 41, No. 185, September 1976.

7. U.S. Department of Transportation, Urban Mass Transportation Administration, "AGT Socio-Economic Research Program Plan," URD Document Control No. 76-61, September 1976.

8. An application is defined as a major transportation function within a geographic location. Two major classes of applications consist of: (1) defined area and (2) corridor travel service. Defined area applications include airports, shopping centers, downtowns, universities, new towns, and industrial parks. A corridor application is the major link between any two defined areas.

PAPER 16

Assessments of Six Domestic AGT Systems

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ASSESSMENT OF SIX DOMESTIC AUTOMATED GUIDEWAY TRANSIT SYSTEMS

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ABSTRACT. This paper summarizes the results of the assessments of automated guideway transit (AGT) systems at Houston Intercontinental Airport, Tampa International Airport, Seattle-Tacoma International Airport, Fairlane Town Center, WALT DISNEY WORLD, and King's Dominion Amusement Park. Technology-related data, system economics and performance, and public response and acceptance were examined. The results of the assessments provide useful guidelines for planning future AGT systems.

INTRODUCTION AND BACKGROUND

The 1966 Reuss-Tyding Amendments to the Urban Mass Transportation Act of 1964 called for federal study and development of programs of research, development, and demonstration of new systems of urban transportation. Since the passage of these amendments, many metropolitan areas have investigated the potential of AGT systems to meet their specific urban public transportation needs. Moreover, a number of AGT research, development, and demonstration programs have also been undertaken.

In September 1974 the U.S. Senate Transportation Appropriations Subcommittee, Committee on Appropriations, recognizing the increased interest in new types of fixed-guideway systems by local communities, requested the Office of Technology Assessment (OTA) to investigate the value of personal rapid transit (PRT) systems--the transit system terminology then in use to refer broadly to AGT technology. In May 1975, OTA responded to this request with a report on the current developments of AGT systems in the United States and abroad, their social acceptability and economic considerations, and their operations and technology.[1]

During the Senate fiscal year (FY) 1975 UMTA Appropriations Hearings, a new program area was recommended entitled "Social and Economic Research in AGT," with a recommended funding level of $2 million for FY 1975.[2] The program was based in part on the OTA report. Several state and local governments also expressed a need for an AGT research program. In fact, the OTA committee identified a number of localities that showed an interest in AGT in 1975. More recently, in 1976, 39 U.S. cities submitted proposals to UMTA for financing an AGT system serving as a downtown people mover. The kinds of information

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that could be obtained through an AGT research program were viewed as valuable to local governments in undertaking their local "alternatives analysis process," a current UMTA requirement to qualify for federal capital assistance for a major public transportation investment.

Consequently, the AGT Socio-Economic Research Program was established to address many basic questions about the technological maturity, service, reliability, maintainability, costs, and public acceptance of AGT systems that transportation planners considering AGT as a candidate mode alternative have cited. In short, there exists a scarcity of data to establish the state of the art for AGT technology. The Urban Mass Transportation Administration has begun to satisfy the need for such data by conducting assessments in Morgantown, West Virginia; on AIRTRANS at the Dallas-Fort Worth Airport; on Jetrail at Love Field; and on foreign AGT developments including the Cabintaxi and Cabinlift systems in Germany.

In addition, SRI International recently completed a series of assessments of six domestic automated guideway transit (AGT) systems as part of the Socio-Economic Research Program. The AGT systems at Houston Intercontinental Airport, Seattle-Tacoma International Airport (Sea-Tac), Fairlane Town Center, Tampa International Airport, WALT DISNEY WORLD, and King's Dominion Amusement Park were assessed.

The objective of the assessments was to provide UMTA with an in-depth understanding of the performance, capabilities, and limitations of each system and its major component subsystems. To accomplish this objective, a program of research was carried out to obtain and analyze the following data:

- Actual engineering and operational data and specifications.
- System performance and system economics data and user perceptions of performance.
- Descriptive information on the design, development, procurement, and implementation processes of each system.

The findings of the assessment are intended to establish the state of the art of AGT systems for ultimate use in planning, evaluating, producing, and deploying future AGT systems.

Reports describing the results of each assessment have been published.[3-9] This paper provides a summary of findings in a comparative framework.

BASIC FACTS ABOUT THE SIX AGT SYSTEMS

The six AGT systems studied represent solutions to specific passenger transit needs at each site. These needs affected the design requirements and subsequent operations of each system. A short summary of some basic facts describing each system and its purpose is provided in Table 1. The geometric layouts of the systems are shown in Figure 1.

TABLE 1. BASIC FACTS ABOUT SYSTEMS ASSESSED BY SRI INTERNATIONAL

System Name and Location	Purpose of the System	Total Guideway Length and Type (ft)	Vehicle Capacity (passengers/vehicle)	Approximate System Capacity* (passengers/hour)	Approximate Installation Period	System Manufacturer
Tunnel train system (TTS) at Houston Intercontinental Airport (Texas)	Provides service between two terminals, to a parking lot and to a hotel.	6,080 (underground)	12	640	1969-1972	Rohr
Passenger Shuttle System (PSS) at Tampa International Airport (Florida)	Provides service between main terminal and four passenger terminals.	7,132 (elevated)	100	20,000	1968-1971	Westinghouse
Satellite Transit System (STS) at Seattle-Tacoma International Airport (Washington)	Provides service between main terminal and two satellite passenger terminals.	9,007 (underground)	102	20,000	1970-1973	Westinghouse
Automatically Controlled Transportation System (ACT) at Fairlane Town Center (Michigan)	Provides transportation between a shopping mall and a hotel. Also served as a prototype for Ford's AGT design concept.	2,600 (elevated)	24	625	1973-1976	Ford
WEDWay People Mover System at WALT DISNEY WORLD (Florida)	The system is an attraction of the theme park in WALT DISNEY WORLD.	4,590 (elevated)	4	3,500	1973-1975	WED Enterprises
Type II Tourister AGT System at King's Dominion (Virginia)	Provides a recreation ride through the animal park in the King's Dominion Amusement Park.	10,899 (at grade with an elevated section of 550 feet)	12	1,800	1974-1975	Universal Mobility

*Sum of line capacities of different sections of the system; e.g., for Sea-Tac, the system capacity was calculated by adding the operating capacities of north and south loop as well as the shuttle portion.

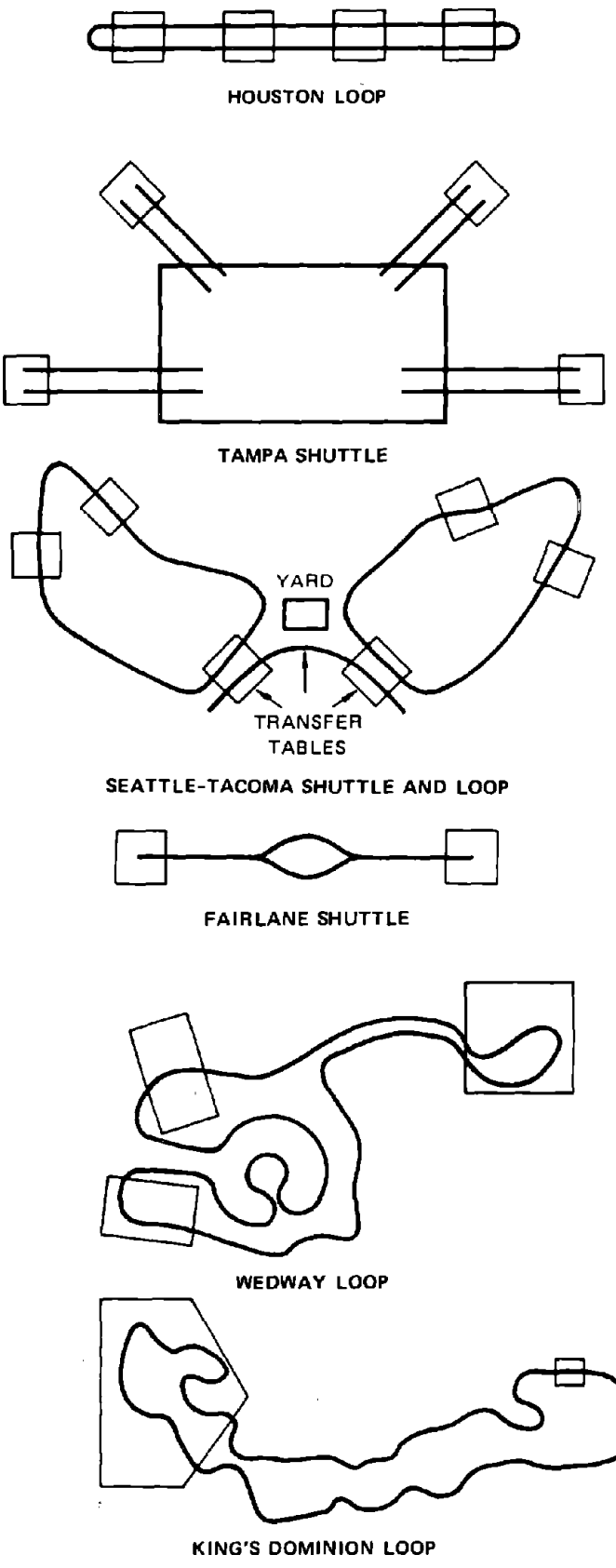


FIGURE 1. GEOMETRIC LAYOUTS OF THE SIX AGT SYSTEMS

DEVELOPMENT PROCESS AND OVERALL EXPERIENCE OF THE SIX AGT SYSTEMS

Houston Intercontinental Airport

The installation of the AGT system at Houston Intercontinental Airport has been carried out in stages. In the initial stage, two unit terminals were constructed and linked by an AGT system. In the second stage, a hotel complex was added. Planning is in progress for a third terminal. The master plan provides for a fourth terminal and reserves land for two additional units. Walking is always an available alternative to the AGT system at the Houston Airport.

As the pioneer in exploiting AGT systems in airports, the Houston Intercontinental Airport suffers from some unfortunate design decisions that would not be repeated in current designs. The guideway geometry includes short-radius curves, a narrow pathway, and a very small vertical space to accommodate running gear. The first installation used hardware that was evidently not adequately developed for passenger service. Few hardware choices were available as replacement, and the system chosen has experienced considerable difficulty, including rapid wear of major components.

Tampa International Airport

The present construction of Tampa International Airport consists of a landside building, four airside buildings, and four dual-guideway AGT shuttle systems. Provisions exist for growth. Walking is an available alternative only on rare occasions when the AGT system is out of service.

Tampa had the good fortune to choose a simple, elegant system concept and suitable hardware. Difficulties were encountered initially because passenger service was provided during the shakedown period. These problems were cleared during the first ten months of operation.

Seattle-Tacoma International Airport

The conditions facing the designers at Sea-Tac were quite difficult. The problem was to achieve a major expansion of capacity at a site with an active airport and terminal complex and where land was in short supply and costly to acquire and exploit. The present design was adopted after considering several alternatives.

Each of the three terminal building has provisions for expansion, and the AGT system initially installed has a growth potential of 200% on the loops and 100% on the shuttle.

Walking is always an available alternative within the main terminal but is not ordinarily permitted to and from the satellites.

The Sea-Tac system represents an excellent solution to the difficult problem of planning and designing an AGT system for the expansion of a terminal in active operation. The designers made intelligent use of the experience of suppliers and design specialists, and the procurement was accomplished under conventional competitive rules. The shakedown period was completed before passenger service began. Availability of service was good from the start.

Fairlane Town Center

The AGT system at Fairlane Town Center evidently was viewed as having two roles--to serve as both a prototype and a demonstration piece for Ford's new AGT system extending to other buildings on Ford property. Ford has withdrawn from the AGT business, and neither of the roles has particular relevance to the current situation.

Acquisition of the system was within the Ford corporate complex and has not been publicized. Although the system does not provide an essential service, its presence and operation are highly visible. The system opened for passenger service without an adequate shakedown. Service was interrupted on numerous occasions, and large expenditures of time and effort were made, over a period of several months, to achieve satisfactory operation.

WALT DISNEY WORLD

The WEDway system at WALT DISNEY WORLD was developed by a Disney subsidiary, and its main role is to provide entertainment and recreation for visitors. Secondary roles are to provide an overview of a portion of the park and to transport riders past a series of commercial and educational displays. The system is the third in a series of related systems developed by Disney but represents a major advance in technical sophistication in propulsion, braking, and control.

The system was developed, fabricated, installed, and operated by Disney companies. Testing and debugging were largely completed at a test track in California before the full installation was made in Florida. Evidently, few problems were encountered other than those associated with technical details.

King's Dominion

The AGT system at King's Dominion transports visitors through an extensive park in which animals roam freely. A tour guide slows or stops the vehicle as viewing opportunities are found and comments on the animals over a public address system. Buses or other manually controlled road vehicles could be employed for this trip, but they were considered less satisfactory than the AGT system.

Procurement was by competitive bidding. The supplier had made numerous successful installations in other places. Some technical problems have been experienced, such as insufficient power to start on grades, but the system is regarded as highly successful.

TECHNOLOGY-RELATED ASPECTS OF THE SIX AGT SYSTEMS

Vehicle Size

The dimensions of the AGT vehicles assessed varied widely (see Figure 2). Vehicle sizes at various sites were selected on the basis of projected needs, site-specific constraints, and the general design philosophy of a manufacturer.

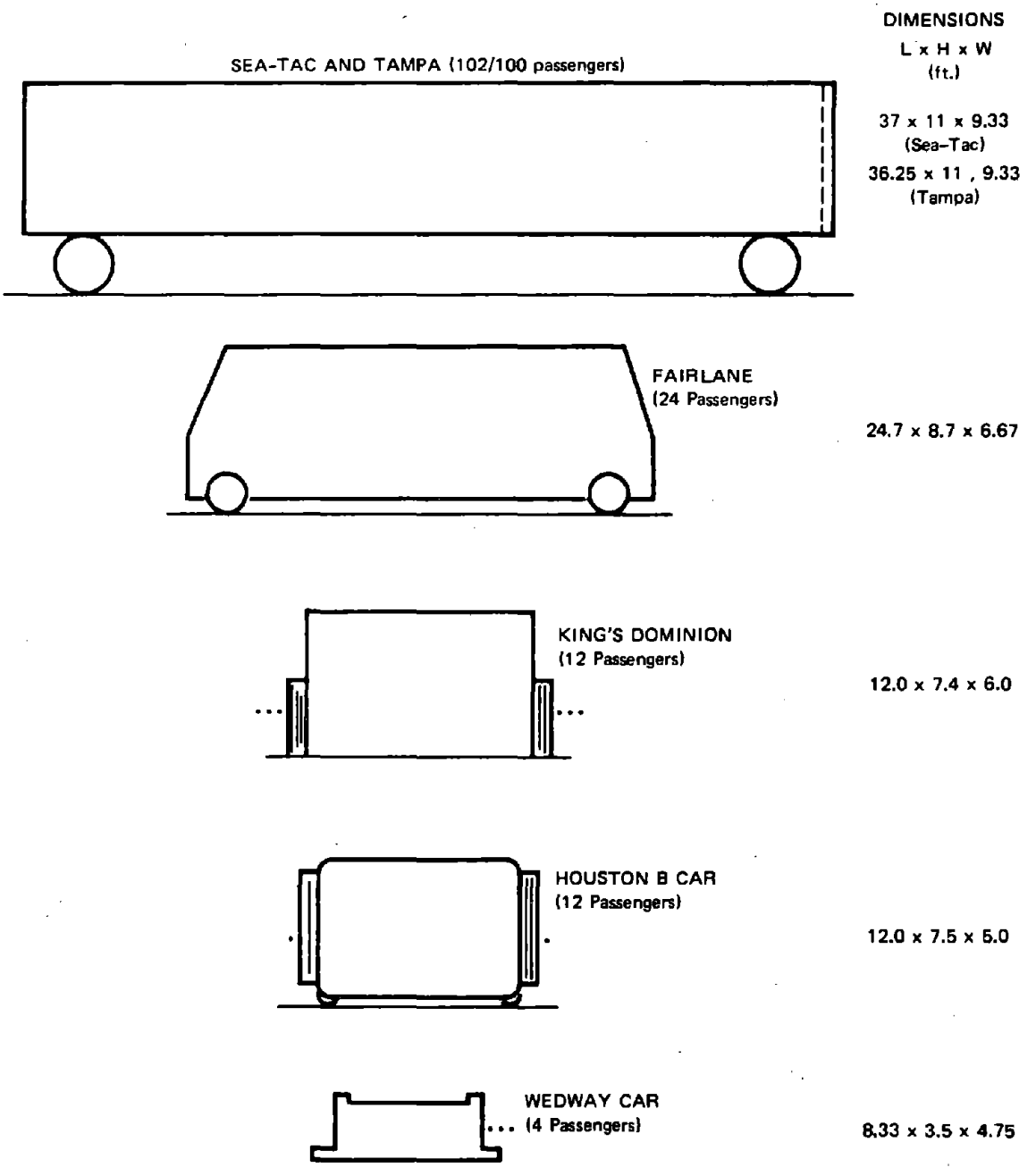


FIGURE 2. RELATIVE SIZES AND CAPACITIES OF AGT VEHICLES AT THE SIX AGT SYSTEMS.

Switching, Steering, Suspension, and Braking Subsystems

The network geometry of all six AGT systems is basically quite simple--either single line elements or simple loops. As such, the switches or transfer tables are used to add or extract cars for changing the number of operating vehicles on the guideway in response to the level of demand and to extract cars for maintenance. At Fairlane, however, switching is used for normal operations as well. The system uses a single guideway, with a bypass section in the middle. Two vehicles traveling in opposite directions pass each other at the bypass section, and onboard switching is used for this purpose.

Steering of vehicles in all six AGT systems is accomplished by using a vertical guiding surface in the guideway and a set of horizontal guidewheels on the vehicle. The guiding surface is provided either by a special guidebeam (Houston, Tampa, Sea-Tac) or by the vertical side of the channel-shaped guideway (Fairlane, WEDway and King's Dominion). Figure 3 shows the steering and running gear configurations used at the different sites.

The suspension and braking systems of the six AGT systems assessed are constructed of components that are commercially available. The vehicles in all six AGT systems use tires. The designs of the suspension and braking systems are based on standard and well-understood procedures.

Command, Control, and Communications Subsystems

The six AGT systems assessed perform simple shuttle-loop types of operation using elementary networks and a small number of vehicles. Therefore, sophisticated control subsystems based on the concepts of synchronous, quasisynchronous, point-follower, or vehicle-follower controls are neither needed nor used. The vehicle control functions, such as acceleration, deceleration, programmed stops, and emergency stops, in all six AGT systems are performed through prespecified control signals under the restriction of the conventional block protection system.

Table 2 summarizes vehicle protection and operational controls and their associated major hardware subsystems. The amount of control hardware and software installed on both the guideway and the vehicle is determined by the level of responsibility placed on both the guideway and the vehicle for controlling the movement of vehicles. At one extreme, the responsibility for performing the bulk of control functions can be placed on the vehicle itself--the so-called intelligent vehicle approach. At the other extreme, the responsibility can be placed on the guideway--the so-called dumb vehicle, or intelligent guideway, approach. The AGT system at Fairlane corresponds closely to the intelligent vehicle design approach; the AGT system at WEDway uses the intelligent guideway approach. Other AGT systems distribute various levels of control responsibility between the vehicle and the guideway.

The Ford vehicle at Fairlane has an onboard computer (PDP 8) and is capable of choosing simple routes (through onboard switching) and modifying such operating parameters as speed, acceleration, braking, and station stops. In a shuttle system such as that at Fairlane, however, the operating capabilities of an intelligent vehicle cannot fully be demonstrated or tested.

In the WEDway system, primary linear induction motors (LIMs) are installed

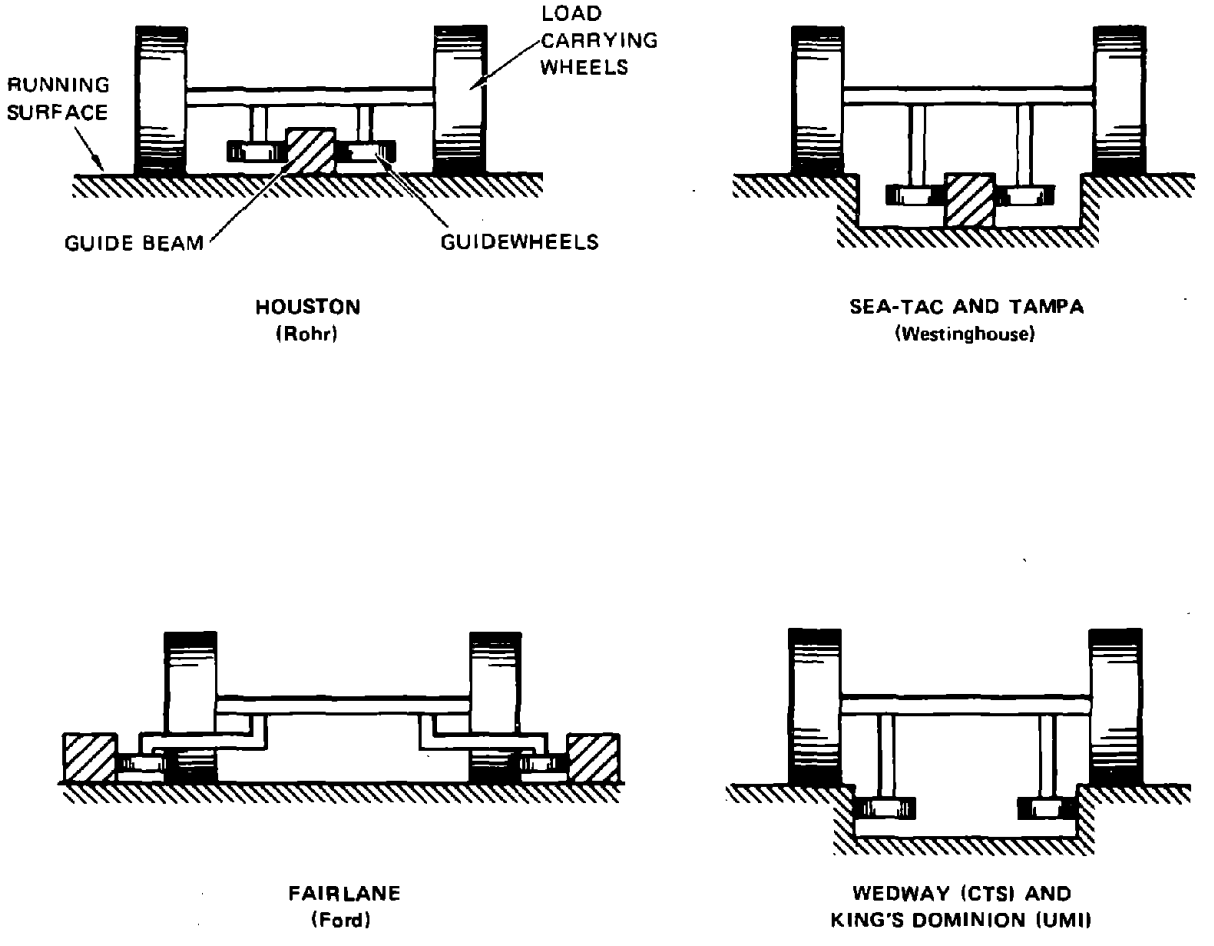


FIGURE 3. GEOMETRIC CONFIGURATIONS OF STEERING AND RUNNING GEAR AT THE SIX AGT SYSTEMS

TABLE 2. VEHICLE CONTROL APPROACHES AND ASSOCIATED HARDWARE AT THE SIX AGT SYSTEMS

AGT System at	Protection Control	Operational Control	Operation Control	
			Zone Size	Computer
Houston	8 fixed sector blocks with wayside vital relay for overspeed protections	On-board SCR controller wayside control voltage	1 zone 8 stations 1.14 miles	1 central monitor console (not a computer)
Tampa	1 fixed block per leg with overspeed and overshoot protection	On-board logic/minicomputer and wayside spatial antenna special station-antenna communication	4 zones (4 shuttles) (8 stations) 1.35 miles	1 central Westinghouse 32 KBYTS computer
Sea-Tac	11.9 and 3 blocks on N-, S-loop, and shuttle (122-950 ft) with wayside vital relays for overspeed protections	Same as Tampa; plus overshoot control	3 zones (2 loops) (1 shuttle) 1.71 miles	1 central Westinghouse 32 KBYTS computer
Fairlane	14 fixed blocks (3-406 ft) with on-board and wayside vital relays for overspeed protection	On-board computer PDP-8 and V/W communication tones	2 zones, stations and 1 bypass	1 central 1 PDP-8 on each vehicle
WEDWay	Activation or deactivation of LIM	Level and durations of wayside LIM thrust	6 zones 1 station 0.85 miles	6 wayside 1 central Data General NOVA 2 computers
King's Dominion	Variable block determined by on-board autopilot and guideway diodes	On-board autopilot and wayside diode units	1 zone	None

on the guideway and spaced according to the designated speed zones. Vehicles with aluminum plates acting as the secondary to the LIMs are propelled by the guideway primaries when they are excited. There is no onboard command and control equipment or power. The vehicle is completely passive except for its mechanical running gears. Such a configuration eliminates the need for block control for vehicle protection; however, it requires that speed, acceleration, and deceleration profiles at various guideway sections be permanently imbedded in the guideway control system, making it a rather inflexible system.

Designing command, control and communications subsystems for AGT systems is a complex task. More research and testing is still needed in this area, particularly for those applications where the networks to be served are more complex and the number of vehicles larger than those of the six AGT systems assessed.

Guideway Designs

Various guideway designs were observed during the AGT systems assessment. The types of guideway include a two-way tunnel with a walkway in the middle (Houston); a two-way elevated structure with a walkway in the middle (Tampa); a one-way tunnel with a catwalk (Sea-Tac); and a one-way, at-grade track with a short elevated section (King's Dominion). The material used for the guideways and the methods of construction vary from site to site. The running surface of the Houston AGT system is a concrete floor. Both the Tampa and Sea-Tac AGT systems have I-beams with a concrete finish surface. The running surface of the Fairlane AGT system is a concrete floor. The WEDway system uses box-shaped steel rail, and the King's dominion system uses I-beams.

OPERATIONAL AND PERFORMANCE CHARACTERISTICS OF THE SIX AGT SYSTEMS

Performance Characteristics Related to Capacities, Speeds, and Headways

Performance characteristics related to the capacities, speeds, and headways of the six AGT systems are shown in Table 3.

The maximum operating speeds of the systems range from 6.5 mph to 30 mph. Two of the systems (King's Dominion and WEDway) are located in theme, or amusement, parks where high speed is neither necessary nor desirable. The systems are designed to provide an enjoyable ride during which the passengers can observe park exhibits (WEDway) and a wild animal park (King's Dominion). The speed of the AGT system at Houston is restricted by its installation in a narrow tunnel with many curves. At Fairlane and Sea-Tac, the speed of the vehicles is restricted by considerations of passenger comfort on curves. At Tampa, the shuttle paths, although straight, are so short that the vehicles reach a speed of only 30 mph before starting to slow down.

The train capacities of the six systems also cover a wide range. Each WEDway car carries 4 seated passengers and is permanently coupled into five-car trains. Each Houston car carries 6 seated passengers and 6 standees and is permanently coupled into three-car trains. The King's Dominion car carries 12 seated passengers and is permanently coupled into eight-car trains behind a lead car that carries no passengers. At Fairlane the vehicles are large enough to hold 12 seated passengers and 12 standees, but there is no

TABLE 3. PERFORMANCE CHARACTERISTICS RELATED TO CAPACITIES, SPEEDS, AND HEADWAYS

ACT System at	Passenger Capacity/ Vehicle	Vehicles per Train	Passenger Capacity per Train	Typical Number of Operating Trains	Speed			Headway (min)	Line Capacity Passengers/ Hour
					Designed Maximum	Operating Maximum	Average Operational		
Houston	12	3	36	3	12	8	3.7	4.5	430
Tampa	100	1	100	8	60	30	8.8	0.58	5,140*
Sea-Tac	102	1†	102	6	60	26	9.2	1.68	7,260‡
Fairlane	24	1	24	2	30	20	9.8	2.9	500
WEDWay	4	5	20	30	13.6	6.8	5.2	0.33	3,500
King's Dominion	12	8	96	6	18	6.5	6.2	3.75	1,730

*Two-way capacity.

†Two-car trains are occasionally used.

‡North loop operating capacity.

provision for coupling. The Westinghouse vehicles at Sea-Tac and Tampa are considerably larger. The Sea-Tac cars provide seats for 12 people and space for 90 standees. The Tampa cars have no seats and can hold 100 standees. At Sea-Tac the cars can be coupled into trains as desired; at present, the maximum train size is two vehicles. The stations can be enlarged to accommodate four-car trains.

The headways in the loop systems range from 20 sec at WEDway to 4.5 min at Houston. The short headway at WEDway reflects a characteristic of the LIM control, which approximates a moving block train protection system. The present maximum speed at WEDway is 13.6 mph. At Sea-Tac the loops were not designed for more than three trains. Hence, automatic train protection uses relatively long blocks. Closer spacing of trains and shorter headways would probably require shorter blocks. At King's Dominion the system could be operated with up to 18 trains at 1-min headways, assuming that station dwell time is reduced. At Houston, the simple train protection system with long blocks would begin to cause delays if more than five trains were operating. Therefore, a reduction in the loop headway at Houston could only be accomplished by modifying the train protection system.

The shuttle systems at Tampa and Fairlane operate under different constraints. The Tampa system has parallel guideways, and the Fairlane system has a central bypass to allow the vehicles to pass each other. The AGT system at Tampa achieves a higher shuttle capacity than the Fairlane system by using a larger vehicle and a higher departure frequency.

Performance Data Related to System Patronage, Usage, and Degree of Automation

Values of several performance measures related to the patronage, usage, and degree of automation of each AGT system are shown in Table 4.

The employee-to-unit (EMP:TU) ratio provides the number of personnel used to operate and maintain all of the transportation units in the system. The values range from a low of 0.48 for WEDway to a high of 5 for King's Dominion. This ratio, however, is directly related to the operational policy of the system. For example, King's Dominion uses a relatively large number of attendants to assist passengers in boarding. This, of course, results in a high EMP:TU value. The EMP:TU ratio is also proportional to the number of transportation units in a system. Thus the AGT system at Fairlane, which has only two vehicles, also shows a high EMP:TU value.

The ratio of annual place miles of travel to annual system man-hours (CMT:SM) is also affected by operational policy. In addition this ratio is sensitive to the operational characteristics of line capacity, trip time and headway, and system operational time. Both Tampa and Sea-Tac, which show high CMT:SM values, are large systems and operate 24 hours per day.

Operational Data Related to System Reliability, Maintainability, and Availability

A summary of historical system reliability, maintainability, and availability data for 1976 associated with each of the six AGT systems is given in Table 5. Mean time between failure (MTBF), mean time to repair (MTTR), and system availability are the values for the overall system calculated on the basis of

TABLE 4.. PERFORMANCE DATA RELATED TO PARTONAGE, USAGE, AND DEGREE OF AUTOMATION (1976)

AGT System at	Annual Patronage (millions)	Annual Unit* Mile Travel	Annual Passenger Miles Travel (millions)	Annual Place Mile Travel (millions)	Load Factor	Employee Unit* Ratio	Number of Units*		Annual Place Miles to System Man-Hours
							Vehicle	Train	
Houston	1.3	366,000	0.325	3.82	0.085	1.8	3	3	244
Tampa	14.5	405,000	2.47	40.5	0.061	0.825	8	--	3,068
Sea-Tac	10.1	710,600	3.6	41.06	0.087	1.58	12	6	1,102
Fairlane	2.43	6,239	1.15	1.79	0.64	5	2	--	390.1
WEDWay	4.66	712,000	4.05	16.2	0.28	0.48	5	30	508.5
King's Dominion	0.87	228,000	1.8	21.8	0.66	5	8	6	120

*Unit is the discrete moving unit, either a vehicle or a train of vehicles.

TABLE 5. SYSTEM RELIABILITY, MAINTAINABILITY, AND AVAILABILITY DATA. (BASED ON SYSTEM OPERATIONS IN 1976)

AGT System at	System Length (ft)	Maintenance Strategy	System* MTBF (hr)	System* MTTR (min)	System* Availability	Typical Subsystems or Components Which Failed	Comments on MTBF, MTTR, and Availability
Houston	6,080	Mainly C.M.	63	120	0.97	Braking system, guide wheel, and vehicle door	Maintenance personnel's recollection of failure occurrences.
Tampa	779 Leg B 1,002 Leg C 1,002 Leg D 783 Leg E	P.M. and C.M.	19.5 15.7 21.6 26.3	6 6.4 5.3 6.3	0.995 0.993 0.996 0.996	Command, communication, and control system and vehicle door	Calculated by SRI based on the information from Hillsborough County Aviation Authority Communications Center PSS Failure Log. The figures represent one vehicle failures.
Sea-Tac	4,089 North Loop 3,718 South Loop 1,200 Shuttle	Intensive P.M. and Intensive C.M.	25 73 61	2.8 2.25 5	0.998 0.999 0.998	Command, communication, and control system and vehicle door	Calculated by SRI based on the information from Monthly STS Operations and Maintenance Report, Port of Seattle.
Fairlane	2,600	Intensive C.M. P.M.	n.a.	n.a.	0.937	n.a.	Calculated by SRI based on the Ford Failure Record. It should be noted the system was still in the modification process when the data was taken.
WEDWay	4,590	Mainly P.M.	198	24	0.998	Linear induction motors and electronic components	Supplied by WALT DISNEY WORLD.
King's Dominion	10,899	Mainly P.M.	96.5	48	0.993	Mechanical subsystems	Supplied by King's Dominion Operations Department.

Notes: P.M. = Preventive Maintenance
C.M. = Corrective Maintenance.

*Average for 1 year of operation.

subsystem and component failures and repair records. System availability is defined as the ratio of the system uptime and the sum of system uptime and system downtime. System availability was calculated by appropriately adding subsystem and component uptimes and downtimes. The details of various failures, failure recovery techniques, data recording, and maintenance programs are discussed in the respective site reports.[3-8]

All six AGT systems have a high level of system availability. However, different systems use slightly different maintenance strategies to accomplish the desired level of availability. Factors affecting the maintenance strategies include system geometry, criticality of service availability, and reliability characteristics of subsystems and components. These factors are briefly discussed below.

The Houston tunnel train system provides a convenient but a nonessential service since passengers can use the walkway parallel to the guideway in case the AGT system is out of service. Therefore, there is no critical need for an intensive preventive maintenance program or very short MTTRs. System operators use a "repair-when-failed" philosophy, that is, a corrective maintenance strategy. At Tampa and Sea-Tac, the AGT system is the only means by which people can travel from the main terminal to the boarding stations. Furthermore, at Sea-Tac, the main portions of the guideway are loop shaped and the guideway is totally underground. A prolonged failure on any portion of a loop causes substantial disruption in service. Therefore, Sea-Tac has intensive preventive and corrective maintenance programs and short MTTRs. At Tampa, the shuttle legs consist of two independent guideways. A failure on one guideway does not disrupt the service critically since the other leg can still provide a reasonable level of service. Therefore, the maintenance strategies used at Tampa are not as intensive as those at Sea-Tac, but they are adequate. Mean times to repair at Tampa are longer than those at Sea-Tac but short enough to provide high availability.

Intensive corrective maintenance was used for the AGT system at Fairlane during the initial stages of debugging and early operations. Eventually a moderate preventive and corrective maintenance program should be adequate.

The AGT systems at WEDway and King's Dominion were built for the purpose of providing rides through an amusement park and a wild animal park. The operators wish to keep the systems in good operating condition to attract patrons. Both systems have long off-line times during some week days and off-season periods. A complete preventive maintenance program is therefore conveniently carried out during these periods.

COSTS AND ECONOMICS OF THE SIX AGT SYSTEMS

Several practical and theoretical difficulties were encountered in conducting the cost and economics studies for the six AGT systems:

- Complete and detailed cost data frequently were not available.
- Many AGT subsystems were constructed as parts of another facility or as a joint facility so that the costs associated with the AGT parts alone were simply not available.

- Various subsystems and components were constructed or purchased at different times. Therefore the associated costs could not be readily added or easily compared without translating the costs to a common basis.

The approach taken by the assessment team to overcome the above difficulties is discussed in detail in the site reports.[3-8] Briefly, the approach consisted of the following techniques:

- Data gaps were filled by making suitable engineering estimates and calculations. For example, when costs associated with a station or a tunnel were not available, these were calculated based on the dimensions of the station or tunnel and using an estimated unit cost of construction from available data.

- Costs associated with the AGT system of a joint facility were estimated by one of the following three approaches:
  - Duplicate cost approach. System costs were estimated by assuming free-standing duplicate facility with appropriate dimensions.
  - Allocation cost approach. System costs were estimated by allocating a suitable fraction of the total cost to the AGT system.
  - Marginal cost approach. System costs were estimated as the additional cost that must have been incurred because of the inclusion of the AGT system.

- All costs were translated to represent costs in 1976 dollars. Suitable escalation factors were used for different components.

The capital, operations, and equivalent annual costs associated with various systems are presented in Tables 6 through 8, respectively. The reader is advised that the cost data presented in these tables are based on specific assumptions and techniques. Any attempts to extrapolate the data for a new system without carefully considering site-specific characteristics and problems will be misleading. The planners and designers of any new AGT system should use the data presented here only as a general guide for planners.

The capital costs of the six AGT systems are summarized in Table 6. Capital costs are presented in actual year and 1976 dollars.

Table 7 shows the operations and maintenance costs of the six sites. This table also presents the unit cost of service for operations and maintenance per various system performance measures. The operations and maintenance costs include operations and maintenance labor cost, energy cost, maintenance material cost, and administration cost.

The largest share of the operations and maintenance cost is associated with the labor cost. This labor cost is not a linear function of the system size. For example, at Tampa seven maintenance staff and two operations staff are engaged in the systems operation of eight 100-passenger vehicles while at Fairlane a maintenance and operations staff of ten operates a system of two 24-passenger vehicles. Although the size of the two systems differs, the difference is not reflected in the labor requirements. This is due to the fact that at both sites

TABLE 6. SUMMARY OF THE CAPITAL COSTS ALONG WITH BASIC DESIGN DATA FOR THE SIX AGT SYSTEMS

AGT System at	Total One-Way Guideway Length (ft) and Type	Total System Capacity Passengers/Hour (approximate)	Capital Cost (Actual Year Dollars) (millions)*			Capital Cost (1976 Dollars) (millions)*			Comments on Cost Data
			Construction	Hardware	Total	Construction	Hardware	Total	
Houston	6,080 (underground)	640	$ 2.98 (1969)	$0.93 (1972)	$ 3.91 (1969-1972)	$ 5.5	$ 1.31	$ 6.81	Construction: Estimated by SRI based on duplicate cost principle Hardware: Houston Intercontinental Airport
Tampa	7,132 (elevated)	20,000	3.66 (1969-1970)	5.11 (1969-1970)	8.77 (1969-1970)	6.46	7.81	14.27	Construction: Estimated by SRI based on allocation principle Hardware: Contract document
Sea-Tac	9,007 (underground)	20,000	13.85 (1970-1971)	8.85 (1972-1976)	22.7 (1970-1976)	22.87	11.76	34.63	Construction: Estimated by SRI based on duplicate cost principle Hardware: Port of Seattle accounting record
Fairlane	2,600 (elevated)	625	2.53 (1974)	2.59 (1974)	5.12 (1974)	2.99	3.12	6.11	Construction: Estimated by SRI based on allocation principle Hardware: Estimated by SRI based on Ford supplied data
WEDWay	4,590 (elevated)	3,500	3.81 (1974)	6.81 (1974-1975)	10.62 (1974-1975)	4.49	7.76	12.25	Construction: Supplied by Community Transportation Services Hardware: Supplied by Community Transportation Services
King's Dominion	10,899 (at-grade with elevated section of 550 ft)	1,800	2.06 (1974)	2.54 (1974)	4.6 (1974)	2.42	3.07	5.49	Construction: King's Dominion accounting records Hardware: King's Dominion accounting records

*Third digit after decimal rounded off.

Table 7

TABLE 7. ANNUAL OPERATIONS AND MAINTENANCE COSTS AND UNIT COSTS OF SERVICE. (IN 1976 DOLLARS)

AGT System at	Annual Operations and Maintenance Cost (dollars)	Unit Cost of Service for Operations and Maintenance (dollars)			
		Per VMT*	Per PMT†	Per Pass.‡	Per CMT§
Houston	$328,930	$2.70**	$1.01	$0.25	$0.07
Tampa	478,480	1.18	0.19	0.03	0.01
Sea-Tac	751,200	1.83	0.21	0.07	0.02
Fairlane	395,000	6.55	0.34	0.16	0.27
WEDWay	349,000	0.49**	0.09	0.07	0.02
King's Dominion	156,500	6.18**	0.09	0.18	0.06

*VMT = vehicles miles of travel.

†PMT = passenger miles of travel.

‡Pass. = passenger.

§CMT = unit capacity miles of travel or place miles of travel.

**Train miles of travel instead of vehicle miles of travel was used.

TABLE 8. EQUIVALENT ANNUAL COSTS AND UNIT COSTS OF SERVICE FOR THE SIX AGT SYSTEMS (IN 1976 DOLLARS)

AGT System at	Equivalent Annual Cost of Capital (dollars)	Annual Operations and Maintenance Cost (dollars)	Total Equivalent Annual Cost (dollars)	Unit Cost of Service for Total System Cost (dollars)			
				Per VMT*	Per PMT†	Per Pass.‡	Per CMT§
Houston	$ 742,200	$328,930	$1,071,130	$ 8.78**	$3.30	$0.82	$0.24
Tampa	1,696,200	478,480	2,174,680	5.37	0.88	0.15	0.05
Sea-Tac	3,918,000	751,200	4,669,200	11.37	1.29	0.46	0.11
Fairlane	719,800	395,000	1,114,800	18.50	0.97	0.46	0.77
WEDWay	1,485,400	349,000	1,834,000	2.58**	0.45	0.39	0.13
King's Dominion	654,400	156,500	810,900	32.01**	0.45	0.93	0.33

*VMT = vehicle mile of travel.

†PMT = passenger mile of travel.

‡Pass. = passenger.

§CMT = unit capacity mile of travel or place mile of travel.

**Train miles of travel instead of vehicle miles of travel was used.

the number of employees engaged in operations and maintenance of the system is determined from the minimum crew requirement because both systems are small enough to be operated by the minimum size crew.

The total equivalent annual cost includes the annual operations and maintenance cost and the equivalent annual cost of capital. The equivalent annual cost of capital was calculated for each AGT system based on the assumption that the service lives of all systems are identical (35 years for construction and 15 years for hardware); the subsystems are replaced at the end of their service lives at the same prices as the initial installation; and the annual discount rate of each system is 10%. The equivalent annual cost of capital, annual operations and maintenance cost, total equivalent annual cost, and unit cost of service are given in Table 8.

RESULTS OF HUMAN INTERFACE STUDIES

The assessment team was not apprised of any significant complaints about such human factor considerations as wait times, travel speeds, ride comfort, or information displays at any of the six AGT systems. To obtain some preliminary information about the public acceptance of AGT systems in urban environments, a survey of over 400 individuals was conducted at the Fairlane Town Center AGT, the only system among the six systems assessed that is located in an urban setting. Both AGT riders and nonriders were interviewed at the shopping center and hotel within the Center. The basic objectives of the survey were to:

- Determine the reasons for and necessity of using or not using AGT.
- Assess the rider's perception of comfort, ride quality, convenience, safety and security, appearance, and information factors, and their relative importance to the rider.
- Determine preferences about guideway elevation, vehicle size, seating direction.
- Identify attitude-dependent socioeconomic classifications based on age, sex, income, and transit use.

Results of the survey are presented below.

Reasons for Using or Not Using AGT

Most nonriders merely did not use the AGT system because they had no reason to travel between the hotel and shopping center. Those who preferred to walk or drive stated that they felt that they might have to wait too long to ride the AGT. Of the AGT riders surveyed, almost one half used the system for sightseeing or simply to try out the system rather than to travel between the hotel and shopping center for a specific purpose. Nonsightseers indicated a greater willingness than sightseers to pay a hypothetical 25¢ fare.

Riders' Perception of System Features

When asked about the relative importance of the various features of the system, riders rated them in the following order:

- Convenience (most important)
- Safety and security
- Comfort
- Ride quality
- Appearance (least important).

The relative acceptability of these features was rated as follows:

- Ride quality (most acceptable)
- Appearance
- Safety and security
- Convenience
- Comfort
- Information (least acceptable).

The ratings were quite good for all system features even the least acceptable. Information was 75% acceptable. Ride quality and appearance ratings were especially good. Some special problems cited by a few people, for features that were less acceptable were:

- Safety and security--Dissatisfaction with the system because riders, especially women, feel that police or attendants are needed on board.
- Convenience--Wait time is long and speed is slow for public transit users.
- Comfort--Stations are crowded.
- Information--Inadequate for some users.

Preferences about AGT System Features

Those who had ridden the Fairlane Town Center AGT had a greater preference for elevated guideways than had nonriders; the preference was strongest among the more satisfied riders. More than one half of the individuals surveyed felt that the Fairlane vehicle was too small. More than one half of those surveyed had no preference at all about seating direction; of those with a preference, a forward direction was preferred.

Attitude-Dependent Socioeconomic Classifications

Income levels for the survey sample were higher than average, but income had little effect on attitudes about AGT. The only attitude differences based on sex were in the area of safety and security. System ratings and some special attitudes were related to age and previous experience on public transit. Individuals over 50 years of age gave the system the highest rating; individuals under 20 years of age gave the lowest rating, particularly with respect to appearance. Those individuals who use both a car and public transit gave the system the highest ratings; those who do not use a car gave the lowest rating.

In summary, attitudes about AGT at the Fairlane Town Center were generally quite good. Although the system has only two arrival and departure points

(the shopping center and the hotel), the problems encountered, such as crowds, security, obtrusiveness, and lack of instructions, are not unique to the Center. The AGT is well known in the area. The majority of individuals surveyed had formed opinions about the system, and therefore their opinions have merit.

CONCLUSIONS AND RECOMMENDATIONS

Summary of Conclusions

1. All six AGT systems satisfactorily provide the specific services for which they were installed.

2. There is adequate expertise and experience among AGT system planners, designers, and manufacturers to develop, manufacture, install, and operate AGT systems under diverse conditions and requirements.

3. The technical feasibility of automatically implementing such vehicle control functions as acceleration, deceleration, speed regulation, simple switching operations, and stopping accurately at single station platforms has been satisfactorily demonstrated in the six AGT systems. However, automatic implementation of more complicated functions, such as merging, multiple switching operations, and stopping accurately at multiberth stations, has not been and cannot be demonstrated at the six AGT sites because of the simplicity of the network geometry and the small number of vehicles.

4. The overall system availability of the six AGT systems is quite high and is expected to improve further as the systems become more mature. This high availability results in part from good subsystems design and efficient maintenance programs, and in part because all the six systems operate in controlled environments, have simple network geometry, and use a small number of vehicles. To achieve comparable availability in urban applications where the environments will be much less controllable, the networks more complex, and the number of vehicles higher, the reliability and maintainability requirements of AGT subsystems, particularly those of vehicles and command and control subsystems, will have to be correspondingly more stringent.

5. The total capital costs of AGT systems are typically $10 to $14 million per mile (in 1976 dollars) for elevated guideway systems and $6 to $20 million per mile for underground guideway systems, depending on tunnel size, location, and soil conditions. The unit cost of service per passenger, once the system is installed, ranges from $0.03 to $0.25. If the capital cost is annualized over the life of the system (e.g., 35 years for construction, 15 years for hardware), the unit cost of service per passenger, averaged over the life of the system, ranges from $0.15 to $0.93. These values suggest that, under the assumed conditions, the equivalent annual costs of the assessed AGT systems are not excessive. However, each application of an AGT system requires consideration of several site-specific constraints and operating needs, which have a substantial effect on both capital and operating costs. Therefore, extreme care must be exercised in using the above figures for estimating the costs of other AGT systems.

6. The following operational features of a transportation system, listed in order of priority, are important for public acceptance of the system, assuming the costs are attractive:

- Convenience (i.e., easy access, short wait times, and short trip times)
- Safety and security
- Ride comfort.

These results should be useful in planning and designing future AGT systems.

Recommendations

On the basis of the results of the AGT assessment, several recommendations for further study of AGT systems are presented below.

1. Similar assessments of other AGT systems and competing systems (e.g., bus and light rail) should be conducted to establish a larger and more meaningful data base. An assessment of AGT systems means assessing the service, cost, and reliability performance of these systems in relation to alternative systems. Therefore, it would be of value to assess other systems in a manner similar to that used in the SRI assessment of the six domestic AGT systems.

2. System operators should be requested to keep the full records of data associated with costs, operations, failures, and maintenance of the system. The assessment team found many gaps in the availability of important data on AGT systems.

3. A standard list of normalized performance measures and a set of standard operation environments should be established so that performance of competing systems can be compared on a common basis.

4. Systems that have been assessed once should be reassessed after a few years to study the improvements or deteriorations that take place in the course of time. Most of the systems assessed by SRI International have had an operating experience of only one or two years and therefore have not experienced the full benefits of a mature system.

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PAPER 17

Morgantown Assessment

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MORGANTOWN ASSESSMENT

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ABSTRACT

The Morgantown system is the most ambitious research and development program undertaken thus far in the United States in the field of Automated Guideway Transit (AGT). An independent assessment has been conducted by N. D. Lea & Associates, Inc., under contract to UMTA. This paper presents highlights of this assessment of Phase I of the Morgantown system.

1.0 INTRODUCTION

This assessment of the Morgantown AGT System has been accomplished as part of the Urban Mass Transportation Administration's AGT Socio-Economic Research Program. The purpose is to relate the characteristics of Automated Guideway Transit technology to the needs for improved forms of urban transportation and to determine the social, economic, environmental and performance factors which affect the usefulness of AGT systems.

The objectives of this assessment of the Morgantown AGT System are threefold:

- To provide information on the system installation, including engineering and operating data; descriptive information on system performance, economics and public response; experience with system design, development and implementation. In short, to summarize the current state of the art for Automated Guideway Transit.
- To evaluate the information in order to assess system and subsystem technical performance, system economics, and overall system performance in meeting transportation requirements.
- To report results of the assessment in ways useful for guiding R & D on key problem areas, for planning AGT installations, and for making product improvements in AGT systems.

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The assessment was accomplished in four steps:

(1) Organization of the project team involved the assignment of responsibilities for tasks, reporting and coordination.

(2) Available data from extensive documentation in UMTA, with the supplier and at Morgantown was assembled and analyzed.

(3) Field visits were made to interview key project personnel and to make on-site measurements of certain performance measures.

(4) Reports documented the evaluation of the system and assessment findings.

This assessment is expected to be useful to local planners and decision makers in their consideration of AGT installations. It will also be useful in suggesting areas in which government policies and procedures may need revision to foster the adoption of AGT systems.

Only the initial experience of the Phase I system have been assessed. Basically these experiences occurred during the first and second operational years; however, the majority of the data that was available covered the period September 15, 1975 through June 30, 1977. The results derived by this study are interim judgements which yield insight into how an AGT might evolve in an urban installation which is built in stages. A complete and final assessment cannot be made at this time for two reasons.

1. The system is not yet completed and has not matured. As with any new system development, as well as new conventional rail transit systems, a period of time is required during which changes and improvements are made.
2. Phase II, which is presently underway will make a number of changes and improvements to the system. It will also extend the system providing accessibility to a larger area of the University.

2.2 SYSTEM DESCRIPTION

The Morgantown People Mover System , as it is referred to locally, is the world's most sophisticated Automated Guideway Transit System in regular passenger service. Its essential features are summarized below. More comprehensive technical information concerning system design and function are contained in the detailed final assessment report to be published shortly.

2.2.1 System Layout and Operational Concept

The Morgantown People Mover connects the Main (Downtown) Campus of West Virginia University with both the Morgantown central business district and the newer Evansdale Campus on the northern edge of the city. There are three

stations connected by a double lane guideway system somewhat over two miles in length. The route from downtown Morgantown northward parallels the railroad tracks along the Monongahela River. The maintenance shop, vehicle test facility and the control center are located about halfway between the Beechurst Station at the Main Campus and the Engineering Station at the Evansdale Campus.

An extension to the system is now being built under Phase II of the project that will add new stations at the Towers Dormitory complex and the Medical Center as well as a new car-wash and minor maintenance facility. The Engineering station will also be doubled in size and all three existing stations upgraded, including installation of elevators for the mobility handicapped. The complete system will include three off-line stations and two terminal stations.

A total of 45 operational vehicles were provided in Phase I and 28 additional vehicles will be delivered under Phase II. Current operational requirements can be satisfied with 22 vehicles in service, with seven in reserve as spares. Each vehicle is capable of carrying a total of 8 seated and 13 standing passengers.

An essential feature of the Morgantown design is its ability to automatically operate driverless vehicles along the main-line guideway at 15-second intervals. During acceptance testing in August 1975, a total of 21 vehicles were launched consecutively from the Beechurst Station for Engineering at 15-second intervals. This served to demonstrate the effectiveness of the control system in achieving the specified 15-second operational headways.

Unlike all other AGT systems in service in the U.S., Morgantown provides nonstop service from origin to destination on either a scheduled or on-demand mode. Scheduled service is used during periods of heavy travel with on-demand service available at other times.

2.2.2 Vehicles

The Morgantown vehicles are completely automated and travel from origin to destination under computer surveillance. They are relatively small, 15.5 feet long and 6.7 feet wide. Each has seats for eight passengers and space for 13 standees. They travel along the guideway system at speeds up to 30 miles per hour.

The vehicles have doors on both sides. They draw electric power for propulsion, heating and air conditioning, lighting and other purposes from power rails along the edges of the guideway. Lateral guidance is accomplished by a sensing wheel which maintains itself in contact with a steel guiderail by controlling an automotive-type steering mechanism. Since tight turns must be negotiated in station areas, both front and rear wheels are steered. Steel guiderails are located on both sides of the guideway in those locations where the route branches. Vehicles are switched by a simple command from central control instructing the sensing wheel to maintain contact with the guidance rail on the side of the track which corresponds to the direction the vehicle is to turn. The cars run on rubber tires which provide traction to negotiate grades up to 10 percent required by the rugged Morgantown terrain.

2.2.3 Guideways

The main-line double-lane guideway system is 2.1 miles in length. Over two-thirds of it is elevated well above street level and the rest is built at grade. Including station ramps and the vehicle testing and storage loops in the maintenance area a total of 5.5 miles of single lane guideway have been built at Morgantown.

The running surface is reinforced concrete. It is supported in elevated sections by a steel super structure mounted on sturdy concrete piers. As will be noted, the at-grade guideways blend in well with the existing terrain and are relatively unobtrusive. This is not the case with the elevated structures which appear massive. Fortunately, most elevated sections are located in an industrial area along a railroad right-of-way, so that the visual impact is not objectionable.

Operations during severe winter weather require that the guideway be heated by circulating a hot water and ethylene glycol solution through pipes imbedded in the concrete running surface. Ten natural gas fired boilers in three sub-stations provide the heat required to keep the guideway free of ice and snow. The entire heating system is remotely operated from the control center and may be activated by the system operator whenever weather conditions so dictate.

The guideway heating system was well tested during the extremely severe winters of 1976-1977 and 1977-1978. No serious problems were encountered in keeping the guideway in operation.

2.2.4 Stations

Of the three existing stations at Morgantown, Beechurst, which serves the downtown campus, is the largest and the most complex. This station has the following unique features.

- There are two separate island platforms, each of which is served by two guideway ramps or channels.
- Each station channel has four vehicle berths (except the through channels at the Beechurst station have only three berths),one of which is used for loading while the other three are only for discharging passengers.
- Three of the channels serve only passengers bound to and from the Engineering Station and points north. The fourth serves traffic from Walnut Station in downtown Morgantown.
- The main line guideway passes under the station platforms, permitting through traffic to by-pass Beechurst without stopping.
- Through vehicles may also make intermediate stops at Beechurst, using three berths on either end of the larger of the two island platforms.

The Walnut Station which serves the Morgantown Central Business District has one island platform served by two turn-around channels. The Engineering Station presently has the same configuration but will be expanded during Phase II to include a second island platform which will make it equivalent to Beechurst in passenger handling capability. The new Towers Station will be a similar configuration.

All of the platforms are island structures, which are presently reached by stairways. However, Phase II improvements will provide elevators for the use of the elderly and handicapped. Existing stations were provided with elevator shafts. Upon reaching the platform level, passengers pass through fare-card turnstiles and are then directed to the proper loading gate by lighted signs.

2.2.5 Control and Communication

There are four principal components of the Control and Communication System; their functions are summarized briefly as follows:

Central Control and Communication. Dual computers and peripheral equipment monitor and control all system operations. In the control room there are display consoles, a closed circuit television system and voice and data communications circuits. The central computer is programmed to manage the dispatching and destination assignments of all vehicles in the system for either scheduled service or on-demand operation.

Station and Guideway Control and Communication Sub-System. The station computers have the responsibility for movement of the vehicles on the guideway. Dual computers control local vehicle operations such as speed commands, switching, safe tone, stopping, door operations, and station graphics. Transmission of information between vehicles and station computers is by means of vehicle-borne antennae which communicate with wire loops embedded in the guideway.

Vehicle Control and Communication Sub-System. This control equipment is carried on board the vehicles. It receives and executes commands received from the guideway wire loops. In addition it operates propulsion and braking controls in order to regulate speed and guideway position. Once a vehicle is dispatched, control of vehicle speed and position is the sole responsibility of vehicle-borne equipment. Station and central computers monitor its performance but are unable to issue any commands to correct the vehicle trajectory other than to stop an offending vehicle.

Collision Avoidance System. A redundant and failsafe technique assures that safe spacing of vehicles is maintained along the main guideway, in switch areas, and at ramps leading into stations. The system is independent of all other control in that separate software is backed up by separate hardwired logic. The guideway is divided into segments or blocks. Vehicle-borne magnets actuate detector relays in the guideway segment which automatically turns off a "safe tone" signal in the segment of guideway behind the vehicle. If a vehicle intrudes into this segment, the lack of "safe tone" signal will automatically apply emergency brakes.

Vehicle management is based upon the concept of a series of imaginary moving points, separated by 15-second time intervals, circulating continuously around the guideway. Vehicles are dispatched to merge with one of these moving points. The position of each of these points as it circulates through the system is stored in the station computers and is compared with actual vehicle progress through the system. Should the vehicle drift too far out of synchronism with its assigned moving point, where it might encroach upon the space occupied by another vehicle, it is necessary to shut all or a portion of the system down.

2.2.6 Power Supply and Electrification

Electric power for vehicles is supplied to the guideway power rail system at three propulsion sub-stations spaced about evenly along the route. Three-phase, 575-volt, 60-Hz power is fed into the power rails and thereafter picked up by the vehicles through specially designed power collectors. The AC Power is rectified on board the vehicle to supply a 70-HP DC traction motor.

Housekeeping power for the stations and support facilities is supplied by separate sub-stations located at the maintenance facility and at each of the three stations.

2.3 OPERATIONAL EVALUATION

2.3.1 Public Acceptance

An attitude survey of both riders and non-riders was conducted during April and May 1977, one and one-half years after public service started, the results of which are summarized as follows:

- Both riders and non-riders consider the system to be generally satisfactory. The most frequently cited reason for not riding the system was that it does not take non-riders where they want to go.
- Neither safety nor personal security appeared to be of concern to passengers.
- Most of the riders considered the appearance of the guideways and stations to be acceptable, but a sizeable minority did not.
- There were no serious objections to vehicle comfort, but many respondents objected to the wet and cold station platforms.
- The most frequent criticism related to system reliability. Many of the riders had been inconvenienced by frequent system failure, but much of the criticism related to problems encountered during the first operational year.
- Most respondents considered the 25¢ fare and the $15.00 charge for a semester pass acceptable, but there were some objections to the University's policy of requiring all students to purchase a semester pass as part of their fees.

Ride comfort measurements made by the Assessment Team confirmed the opinion expressed by about three out of five of the passengers surveyed that the ride is somewhat bumpy. This was caused by guideway roughness only in certain localized areas. There were also lateral vibrations measured due to a few instances of misalignment of the lateral guiderail, which results in oscillations in the power steering drive. Slightly over 50 percent of riders surveyed said that the vehicles sway too much from side to side.

2.2.3 Cost

The capital cost of the Morgantown System has been the subject of detailed investigations by the General Accounting Office and other government agencies. Rather than duplicate these efforts, the Assessment Team has reviewed the record of expenditures to determine what it would cost in 1976 dollars to duplicate the Morgantown facilities and equipment under normal conditions and a realistic implementation schedule. Since much of the money spent on this project was for non-recurring research and development, adjustments were made to eliminate the estimated cost of this R & D effort. Similarly, estimates were made of amounts spent to meet the exceptionally short time schedule established for the project, as well as amounts wasted as a result of the undue haste which characterized the project. These adjustments, together with the application of separate escalation rates for construction, hardware, and personal services resulted in an estimated replacement cost of $57.9 million for the Phase I system. This amount is equivalent to a total cost of $11.0 million per lane mile.

Operating and maintenance costs during the first year were high at $3.36 per vehicle-mile or $2.13 per passenger carried. Significant reductions have occurred during the second year where the average for the first three quarters was $2.25 per vehicle-mile or $0.68 per passenger carried. Continued reduction appears to be the trend with Boeing predicting the steady state after Phase II to be $1.20 per vehicle-mile.

2.3.3 Energy Consumption

Excluding the energy consumed for guideway heating, the entire system used somewhat less than 5 kilowatt hours per vehicle-mile travelled during the nine-month period, October 1976 - June 1977. This consumption includes the power supplied to the vehicles for propulsion, lighting, climate control, and the housekeeping power used at the stations and maintenance facility. This is roughly the energy equivalent of a third of a gallon of petroleum fuel per vehicle-mile, roughly the same as the consumption of a typical city bus. It is important to note that since the system runs on electrical energy, it need not depend on any petroleum based fuels.

In contrast to the vehicle fleet, the guideway heating system is quite energy intensive. During the first year of operation, the consumption of natural gas by the guideway heating system was about equivalent in energy usage to the electrical energy required by the rest of the system. In the second year, which included the unusually severe winter of 1976-1977, guideway heating accounted for almost twice as much energy as did the vehicles and housekeeping demands. This situation prompted the examination of various techniques for conserving energy which should be reflected in lower usage in the third operational year.

2.3.4 System Performance

As of the end of October 1977, after two years of operation, the system had carried about 3.25 million passengers and had accumulated 1.25 million vehicle-miles in passenger service.

Since the vast majority of the system users are students, travel demands closely parallel activities at the University. Thus the pattern of travel differs significantly from a typical urban application, in that there are several peaks of relatively short duration during the average day. Another interesting feature of the current operation is the transfer of numerous students to and from the University's campus bus system at the Engineering Station.

The operational procedure used at Morgantown involves a vehicle discharging passengers at the most forward available of three unloading berths in a station channel. It then moves forward to the loading berth and awaits there until it receives a dispatch command which will launch it onto the main guideway at the precise time necessary to match up with the imaginary moving point (open slot) assigned to it by the central computer. During periods of light travel, empty vehicles are customarily stored in the station channels or in the maintenance "ready storage" area where they are available for dispatch in response to passenger demand or a scheduled rate of dispatch determined by the central control.

During peak periods of operation, vehicles are dispatched sequentially from different channels. Beechurst, which has three channels "facing" the Engineering Station, could launch vehicles continuously at 15 second intervals, filling all of the available main guideway "slots". Walnut and Engineering, however, have only two station channels and are limited to dispatch rates of 2.67 vehicles per minute, or filling two out of three available "slots." With expansion of the Engineering Station in Phase II the system will be able to utilize the full capability designed into the Beechurst Station as well as the new Towers Station.

Due to the limited capacity of the Engineering Station which is only half completed, the system is unable to sustain its maximum line capacity of 5040 passengers per hour (4 vehicles per minute each with 21 passengers). In actual practice much lower dispatch rates are used. For example, during peak periods Engineering dispatches one vehicle to Beechurst every minute and one to Walnut every 5 minutes. This would permit a single direction passenger flow rate of 1512 per hour, assuming each vehicle were loaded to its design capacity.

In the scheduled mode, the average vehicle requires a minimum of 1.1 minutes from the time it first stops in the station to disembark passengers until it has moved successively forward through the station channel and dispatched. This delay results in an appreciable amount of vehicle idle time (average of 2.3 minutes) in the stations, currently averaging about 39 percent of total vehicle time. The delay is presently used as a means of actively storing vehicles in the station channels during off-peak periods when the scheduled dispatch rate is reduced.

2.3.5 System Dependability

As might be expected, the dependability of the Morgantown System has improved steadily since passenger service was initiated in October 1975. The detailed records maintained by Boeing during the first operational year as well as the University's operating logs for the second year indicate the following pattern:

SYSTEM DEPENDABILITY

	First Year	Second Year
	10/75-9/76	10/76-9/77
Winter Months*	69.8%	89.3%
Other 8 Months	89.5%	95.5%

The System Dependability percentages cited previously are a composite of:

a) The overall system availability, that is the percentage of time the system was actually operating as contrasted with periods when it was shut down due to vehicle or other malfunction, and

b) The probability that a vehicle dispatched on a trip will complete it within certain prescribed limits.

A goal of 98.1% has been set for the Phase I system and it appears likely that this target will be achieved during the third operating year.

Similar improvements have been made in the times required to restore service after a failure occurs. Initially it took an average of about 35 minutes to get the system operating again. In the second year this average was reduced to about 15 minutes.

Among the problems which have been encountered in maintaining continuity of operations were the following:

- Moisture from melting snow has condensed on vehicle steering mechanisms and power rails causing a variety of malfunctions. This problem has prompted extensive sub-system modifications which will be implemented in Phase II.

- The vehicle hydraulic system has been the cause of considerable failures and has been redesigned and tested for implementation in Phase II.

*November through February

2.3.6 Safety and Security

There have been no serious operation related injuries or fatalities since operations began over two years ago. Similarly there have been no serious security problems or examples of criminal behavior. There have been a few incidents with pranksters. Invariably they have been successfully handled through the use of the closed circuit TV, reports by passengers over the emergency telephone and the rerouting of the vehicle to stations or the maintenance area where the campus police were able to apprehend the offenders.

Other than occasional bumping together of vehicles moving at very slow speeds (nominally 4 feet per second) in station channels, there have been no collisions between vehicles. There have, however, been a few incidents where vehicles have lost steering control and made contact with the protective guardrails along the edge of the guideway.

Because there is no mechanical entrapment of vehicles during switching, positive traction for both front and rear wheels is essential to insure safe operation. The guideway heating system will melt the accumulation of ice and snow, but tire and pavement surface conditions must be carefully monitored to assure that adequate traction is available at all times.

PAPER 18

Summary of Joint U.S./German Development/Deployment Investigation of Cabintaxi/Cabinlift System

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SUMMARY OF A JOINT U.S./GERMAN DEVELOPMENT/DEPLOYMENT INVESTIGATION OF CABINTAXI/CABINLIFT SYSTEM

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ABSTRACT. This paper presents an overview of the results of an investigation of the Cabintaxi/Cabinlift automated guideway transit (AGT) systems** under development in The Federal Republic of Germany. The study was conducted under a bilateral agreement between the U.S. Department of Transportation (DOT) and the Germany Federal Ministry of Research and Technology (MORT). It was carried out jointly by DOT's Transportation Systems Center (TSC) and the Studiengesellschaft Nahverkehr mbH (SNV). The Cabintaxi/Cabinlift investigation is sponsored in Germany by MORT and in the United States by DOT's Urban Mass Transportation Administration (UMTA). In the United States, this is one of several assessments of AGT systems, both domestic and foreign, being conducted by the Office of Socio-Economic and Special Projects of UMTA's Office of Technology Development and Deployment. The purposes of these assessments are to:

1. Gather and exchange information on Automated Guideway Technology to better understand the state of technological advancement and to obtain synergistic improvements for future development.

**Vivian J. Hobbs, Wolfgang Heckelmann, Neil G. Patt, J. Harry Hill, "Development/Deployment Investigation of Cabintaxi/Cabinlift System," U.S. Department of Transportation, Transportation Systems Center, Cambridge, MA, SNV Studiengesellschaft Nahverkehr mbH, Hamburg 20, Germany, December 1977, Report No. UMTA-MA-06-0067-77-02.

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2. Review problems and solutions encountered during the design, development, implementation, and operation of AGT systems in order to improve the process based on experience.

3. Obtain information on engineering, economics, operational performance, and public response which can be used in planning future AGT systems.

4. Provide urban planners with information which will enable them to determine the applicability of AGT systems to their specific transportation problems.

INTRODUCTION

The Cabintaxi/Cabinlift systems (see Figure 1) differ from the other AGT systems currently being studied under UMTA's Assessment Program in two significant ways:

1. These systems have not been conceived and designed for a particular transportation need at a specific site. The Cabintaxi/Cabinlift concept is one of modularity: a set of components and operational modes which are being developed as building blocks to suit a variety of applications.

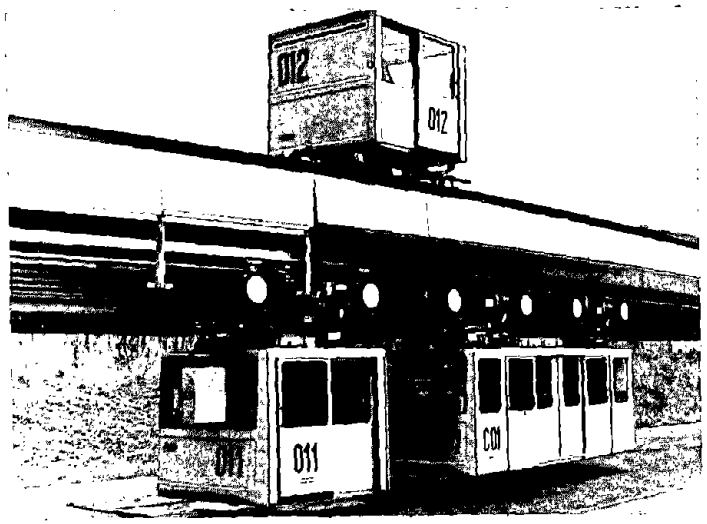
2. The systems are still evolving; most of the individual components have reached a high level of maturity, which the technical development of others is just beginning. A Cabintaxi/Cabinlift system has not yet been deployed for use by the general public except for a simple, single-vehicle shuttle system in Ziegenhain, Germany.

The latter point reflects the German approach to fielding of new systems, which is characterized by an extensive and lengthy development period to refine the design of individual components in order to reduce the risks associated with implementation. The present Cabintaxi/Cabinlift technology is the result of an iterative design process which began in 1969 and has been greatly aided by the use of a large and sophisticated test facility in Hagen since 1973.

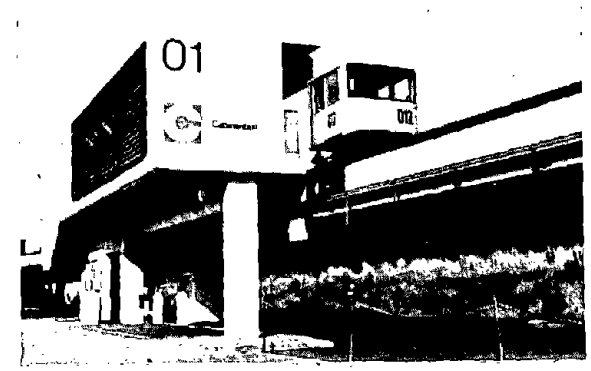
This report focuses on a description of the technological concept; the status of the systems (and major subsystems) relative to deployment; experience gained in design refinement and reliability through realistic testing; theoretical analyses; and feasibility studies. UMTA's other assessment reports focus, in addition, on "lessons learned" during system deployment, performance experience in carrying passengers, and public response; these types of information relative to Cabintaxi/Cabinlift must await future deployments such as those currently under consideration for Hamburg, Marl, and other cities.

SYSTEM DESCRIPTION

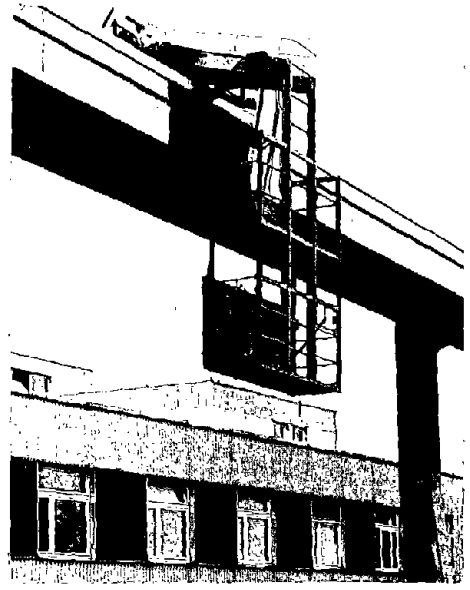
The system presently boasts three types of vehicles: a three-passenger vehicle (KK3), a twelve passenger vehicle (KK12), both accommodating seated passengers only, and a Cabinlift vehicle, which is a slightly larger cargo or



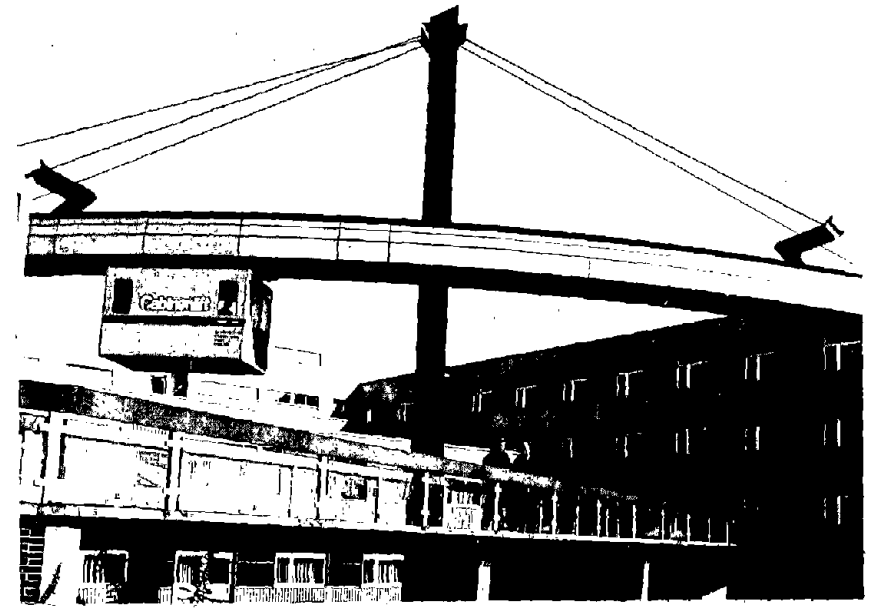
GUIDEWAY & VEHICLE AT HAGEN TEST FACILITY



ONE OF THREE STATIONS AT HAGEN TEST FACILITY



SERVICE VEHICLE AT ZIEGENHAIN HOSPITAL



CABINLIFT SYSTEM AT ZIEGENHAIN HOSPITAL

FIGURE 1

passenger vehicle whose height will accommodate standees. The three basic vehicle types of different physical dimensions are associated with particular operational strategies, and thus a specific class of applications as shown in Table 1.

TABLE 1. SPECIFIC CLASS OF APPLICATIONS FOR THE THREE BASIC VEHICLE TYPES

	Physical Dimensions			Operational Strategies
	Length (m)	Width (m)	Height (m)	
KK3	2.0	1.7	1.6	Destination Discretionary (Personal Rapid Transit (PRT) - Demand mode)
KK12	4.8	1.7	1.6	Line Transport (Scheduled mode) or mixed Scheduled and Demand mode
Cabinlift	3.94	2.44	2.40	Line Transport (Scheduled mode) or mixed Scheduled and Demand mode

Larger vehicles are under development. A fourth vehicle similar to the KK12 has been developed as a rescue and maintenance vehicle. A less sophisticated rescue and maintenance "cage" is also available.

Vehicle propulsion is accomplished with linear induction motors (LIM). Operational speed is presently 10 m/s for the KK3 and KK12 vehicles and 5 to 8 m/s for the Cabinlift vehicles. Development is underway to increase the operational speed to 15m/s. Linear induction braking (LIB) is supplemented with wheel drum brakes at low speeds and for reinforced emergency braking. An on-board battery provides emergency power for these subsystems.

Vehicle switching is mechanically passive on the guideway and accomplished by fixed form guides which engage a set of steering wheels on either side of the vehicle. Special guide rails are fixed to the track at branching points and the switch wheels are set right or left by the vehicle in response to switching commands.

The narrow guideway, typically elevated, can be constructed to carry two-way traffic on the same beam utilizing both suspended and supported vehicles, or one-way traffic utilizing either suspended or supported vehicles. The guideway is usually of steel construction, but may be fabricated as a steel/concrete composite. Several types of guideway supports have been developed: cantilevered arm, T-form, mushroom, and pylon. Two other support forms, goal post and portal, could be used with the system. The supporting columns can be either concrete or steel. System networks are formed by linked, closed guideway loops, since travel is one-way on a particular level and "crossings" are not feasible.

Stations may be on-line or off-line, and dual level, depending on the operational strategy employed in a given application. They are also modular and prefabricated.

The Cabintaxi/Cabinlift system is automated through a hierachical control system, having three independent levels: 1) vehicle headway and speed regulation, and merge control; 2) station control including vehicle destination coding, switch direction selection, and traffic flow counting; and 3) network control for dispatching, monitoring, and traffic flow management. The first level of control is critical to system safety and general operational capability. Levels two and three are important to passenger processing, system availability, and optimal operation. Failures in either level two or three will degrade but not halt system operation.

The longitudinal control system is asynchronous, using a vehicle follower concept, and permits 1.4 second headway and vehicle platooning. A particularly innovative technique has been applied to the control of merging streams of vehicles which minimizes the perturbation to the speed of successive vehicles in merging platoons, thus improving on the ability to stabilize the system in normal operation.

DEVELOPMENT STATUS

An unusually extensive test facility has been constructed in Hagen, Germany. The facility consists of both supported and suspended vehicle guideway sections, merging and demerging switches, various types of guideway supporting elements, and at the moment three stations, a maintenance facility, nine KK3 vehicles, one KK12 vehicle, a maintenance and recovery vehicle, a maintenance cage, a power collector wear-test track, and the basic elements of the control system, with the exception of the level-three network control, which is rudimentary at this time. This facility has been the source of most of the operation, subsystem, and component test experience to-date, and has permitted refinement of basic design through a repeated sequence of test, modification, redesign and retest. In this manner, components used for a specific application go through a process which should minimize the developmental risks associated with new system implementation.

A single-vehicle shuttle system utilizing the Cabinlift-type vehicle has been installed as a single length of suspended vehicle guideway between two buildings of a hospital complex in Ziegenhain, Germany. This system utilizes selected portions of the overall system technology modified to fit the special application. The system was constructed utilizing prefabrication techniques and components which had gone through the developmental process at the test facility. As a result, the 578 meter long guideway was installed in three months. The total system cost in 1976 of approximately DM 2.2 million ($880,000) was less than 10% over the contracted price of DM 2.056 million ($822,400) in 1975, and only three months of pre-operational on-site testing were required. The system has been operational since July of 1976 and has experienced a 98.7% availability. The Ziegenhain Cabinlift system does not require a central control system, a multi-vehicle headway control system, or a mechanism for switching. It has provided the opportunity to gain operational experience in a real-world application, and

represented the first step in defining certification procedures and safety standards for automated transportation systems in Germany. The Ziegenhain system was certified as a horizontal elevator with some additional considerations.

Computer simulation is being used extensively in the development of the Cabintaxi/Cabinlift systems. Initially, simulation was employed in developing the merge control scheme in conjunction with the vehicle interval measuring system. More recently, it is being used as a planning aid to develop optimum network control algorithms and software for specific application feasiblity studies, to assist in determination of appropriate guideway geometry for safety and ride comfort factors, and to estimate capital and operational costs of specific systems.

FINDINGS AND CONCLUSIONS

The major findings and conclusions of this investigation may be summarized as follows:

System Concept and Operation

- The design philosophy for the Cabintaxi/Cabinlift systems, to fabricate a set of AGT modules or "building blocks," has resulted in a system concept with broad flexibility for application.

- The hierarchical approach to control system implementation will permit safe system operation, albeit with degraded performance, in the event of loss of the central control computer or malfunctions at the station level, thus possibly improving system availability.

- The stations and the guideways are aesthetically pleasing which should increase the probability of community acceptability. The narrow guideway represents an extremely small cross section for two-way traffic.

- The innovative design of the switches strives for the merging of platoons of vehicles with minimal propagation of speed reduction in the platoons, thus further improving the link capacity potential.

- The vehicles are compact, light weight, and generally attractive. The ratio of the maximum loading to empty vehicle weight is 33% for the KK3 vehicle and 50% for the KK12 vehicle.

- The use of linear induction motors for the systems offers significant advantages over friction drives relative to grade, noise, wear, and all weather operations. In addition, recovery of disabled vehicles by pushing or pulling is facilitated by the minimal friction characteristics of the LIM. However, LIMs require stringent alignment of reaction rails and possible greater energy use due to inherently less efficient motors.

Passenger Related Aspects

- The manufacturers have addressed themselves to fire safety in a number of ways, i.e., fire retardant material and insulation, rescue vehicles, etc. A pushbutton is also provided in the cabin which when energized will instruct the vehicle to stop at the next nearest station. In most planning studies to date, the distance between stations is from 400 to 700 meters.

- The system safety philosophy includes door interlocks which cannot be opened on the guideway between stations except by personnel using a rescue vehicle. Therefore, it is not possible for passengers to exit the vehicle on the guideway in the event of emergency or fire without external help.

- Reasonable consideration has been given to handicapped and elderly persons in the system design, e.g., wide doors, leveling devices in the Cabinlift system, elevators in the stations, etc. The current design however, requires the negotiation of a 15 cm (6 inch) step in order to board a KK3 and KK12 vehicle to make entry into the compact vehicles easier for the normal passenger. This could prove to be a difficult maneuver for wheelchairs without assistance.

- The current design of the stations permits access to the guideway on supported vehicle systems. Since there is no provision for automatic detection of people or objects on the guideway, this situation could prove hazardous if restricting doors or other solutions are not provided.

- The present heating and ventilation system in the vehicle, developed for the relatively mild middle European climate, may not be adequate for the more extreme climatic variations in the United States.

- Barrierless fare collection is employed in the Cabintaxi/Cabinlift systems, as in the conventional transit systems in Germany. While this mode of operation may be acceptable in the KK3 type of systems, which combines small cabins and magnetic-card-controlled specific destination selection, the barrierless fare collection approach may not be appropriate for the United States market with KK12 or other large vehicles. Therefore, a barrier-fare-collection system should be considered for the larger vehicle Cabintaxi/Cabinlift systems for use in the U.S.A.

System Development and Deployment

- The aspects of system design which make the system "fail-safe" are currently being developed. These features must undergo rigorous test and evaluation before the system can be considered eligible for public deployment, if more than one vehicle is required in the system.

- The availability of proven components, as well as modular and pre-fabricated guideways and stations, suggests potential savings in construction time, and reduced developmental risk and costs.

- The fact that there has not yet been a deployment of the system serving the general public in a multi-vehicle complex network configuration must leave to future experience the question of achieved performance versus expected and simulated performance in several areas: service availability, schedule maintenance, network management efficiency, failure recovery management, maintenance strategies, computer network operation and reliability, aspects of public acceptance, and the ability to determine and meet realistic system residual development and deployment schedules in the face of political, social, and economic pressures. A demonstration system is currently in the planning stages for post 1980.

- The extensive use of computer simulation by the manufacturer has been an important and beneficial aspect of the development program, and will play a key role in effective system planning.

- The manufacturers have been and are vigorously pursuing optimization of the crashworthiness of their vehicles, even though all AGT control systems must be designed for "fail-safe" operation.

- System certification procedures and development of an appropriate safety philosophy (or standards) for new automated transportation systems are currently under consideration in West Germany, and should be investigated in the United States.

- Planning guidelines for the implementation of elevated guideway systems in urban areas should be developed to assist urban planners considering automated transportation systems.

- The relatively short construction time and small amount of testing required for operational readiness of the Cabinlift system at Ziegenhain hospital was the result of having fully developed and tested the system components and installation techniques at the Hagen test facility.

- The system as installed at the Ziegenhain Hospital is considerate of the handicapped, aesthetically and architecturally pleasing, very quiet, has a relatively smooth ride and is land-use and energy efficient. Maintenance procedures are relatively simple and the system, thus far, has been quite reliable.

- The development philosophy adopted by the manufacturers can be characterized as an intensive, well ordered and directed effort aimed at proving the feasibility of basic design assumptions. Considerable attention has been paid to "front-end" engineering and design tasks with impressive results during test and evaluation. This can be a significant factor in meeting both deployment schedules and system performance and reliability objectives.

APPENDIX A

ZIEGENHAIN CABINLIFT SYSTEM OPERATIONAL CHARACTERISTICS

System Performances	
Max. theoretical one-way capacity	98 passengers/h
Max. practical one-way capacity (80% of max. theoretical)	78 passengers/h
Availability	On demand, 24 h/day (currently 16 h/day, 5:00 AM-9:00 PM)
Type Service	Point-to-point shuttle between two buildings with a single vehicle on a single guideway
Traveling Unit	Single suspended vehicle
Interior Noise (mean level)	59 - 65 dBA
Exterior Noise (mean level in the hospital room next to station A, windows open)	43 - 47 dBA
Vehicle Performance	
Cruise velocity	6 m/s - 21.8 km/h (13.5 mph)
Service acceleration	0.35 m/s^2 (1.15 ft/s^2)
Service deceleration	0.35 m/s^2 (1.15 ft/s^2)
Max. jerk	0.3 m/s^3 (0.98 ft/s^3)
Emergency deceleration (with 1000 kg load)	1.0 m/s^2 (3.28 ft/s^2)
Emergency deceleration (unloaded)	1.5 m/s^2 (4.92 ft/s^2)
Stopping precision in station	10 mm (0.4 in.)
Degradation if guideway is wet	No degradation
Degradation for ice and snow	Minimal degradation
Vehicle design capacity	12 passengers or 1000 kg payload
Energy consumption	1.17 kWh/veh.-km
Stations	
Type	2 stations integral with out-patient clinic and main hospital
Type boarding	Level through doors at end of vehicle
Ticket or fare collection security	Not applicable, self-contained system within hospital complex

Max. wait time	7.3 min
Vehicle in station dwell time	As required
Station spacing	578.2 m (1896.9 ft)
Individual Service	
Privacy	Not applicable, one large shuttle veh. at hospital complex
Transfers	None
Stops	Non-stop
Accommodations	Seated, standees, and patients in hospital beds
Security	No special considerations
Instruction	Staff training
Comfort	Heated and ventilated (no air conditioning)
Cargo capability	Hospital equipment, beds, food serving carts
Reliability and Safety	
Vital safety features	Motor overspeed protection, for service braking two LIM-brakes and 6 hydraulic brakes, for emergency brake 4 spring brakes, plus safety-arresting cable brake.
Fail operational features	Operation to nearer downhill station under battery power. 4 spring-loaded brakes
Strategy for passenger evacuation	Maintenance vehicle operates on top of guideway. Evacuation cage hangs adjacent to vehicle with platform under vehicle door.
Strategy for removal of failed vehicle	Battery power to wheelmotor and operation to nearer station or towing by maintenance vehicle

System lifetime (design goal)	30 years
Guideway lifetime (design goal)	50 years
Vehicle lifetime (design goal)	10 years

Personnel Requirements

Vehicle and stations are unmanned. Hospital elevator maintenance staff function as diagnosticians for routine maintenance. A DEMAG technician is available within an hour for major problems. Vehicles are hand cleaned by custodians.

Cabinlift System Physical Description

Vehicle:	
Length, overall	3.78 m (12.4 ft)
Width, overall	1.96 m (6.4 ft)
Height, overall	2.35 m (7.7 ft)
Weight, empty	2200 kg (4850 lb)
Weight, gross	3200 kg (7050 lb)
Doorway width	1.13 m (3.7 ft)
Doorway height	2.0 m (6.6 ft)
Step height	level

Suspension

Type	Solid-rubber tired wheels on double bogie (hard riding bogie with soft sprung body)
Lateral guidance	Solid-rubber tired guidewheels

Propulsion and Braking

Type, location, and no. motors	2 double-camb horizontal linear induction motors. Both LIMs on one side of vehicle
Type drive	Linear motor drive
Type power	380 V ac, 3-phase
Power collection	Power collectors on bogie, power rails on guideway
Type service brakes	Dynamic through LIB plus electric-hydraulic drum brakes (6 wheels)
Type emergency brakes	Mechanical drum brakes (4 wheels)
Emergency brake reaction time	15 ms

Switching		None
Guideway		
Type		Steel box-beam
Supports		Concrete centilever arm and one pylon support
Gauge		1250 mm (4.1 ft)
Standard span		28.8 m (94.5 ft)
Overall cross section width		1860 mm (6.1 ft)
Overall cross section height		1350 mm (4.4 ft)
Guideway Structural weight		500 kp/m (69.0 lb/ft)
Installation		
Guideway Envelope width, incl. columns	including space for maintenance vehicle	4330 mm (14.2 ft)
Guideway Envelope height	including space for maintenance vehicle	4700 mm (15.4 ft)
Max. grade at site		3.4%
Min. horizontal turn radius		39.5 m (129.6 ft)
Construction process		Prefabricated supports and sections, stations are three modular components
Staging Capability		Sections can be operated while others are under construction

been proven at the test facility. Various classes of personnel have cards with various priorities. For example:

- General personnel: routine
- Doctors : priority

APPENDIX B

Cabintaxi/Cabinlift Systems General Characteristics

	CABINTAXI SYSTEMS		CABINLIFT SYSTEM PLANNED FOR BREMEN HOSPITAL
System Characteristics	KK3	KK12	M18S
Type of traffic service	many-to-many	axial and many-to-many	point-to-point (few-to-few)
Operational mode	discretionary travel	line transport/ discretionary travel	schedule transport/discretionary travel
Station arrangement	off-line	on-line/off-line	on-line/off-line
Train length	single vehicle	single vehicle/ 2 car trains/ multi-car trains planned	single vehicle
Privacy	yes	no	no
Transfer Necessary?	no	depending on operational mode	no
Intermediate stops	none	depending on operational mode	yes
Operational monitoring	TV	TV	TV
Transportation of luggage and baby carriages	yes	yes	yes
Transportation of freight	no	no	yes
Vehicle			
Length (m)	2.0	4.8	3.94
Width (m)	1.7	1.7	2.44
Height (m)	1.6	1.6	2.40
Coupling length (m)	2.3	5.2	-
Empty weight (kg)	900	2000	3000
Payload objective (kg) (max)	300	1000	1500
Operational weight (kg) (max)	1200	3000	4500

	CABINTAXI SYSTEMS		CABINLIFT SYSTEM PLANNED FOR BREMEN HOSPITAL
	KK3	KK12	
Sitting/standing places (-)	3/-	12/-	8/10
Space occupied per seat position (m^2)	0.7	0.45	0.4
Space occupied per standing position (m^2)	-	-	0.25
Total number of doors Doors per side	2 1	4 2	2 1
Door width (m)	0.68	0.68	1.40
Door Height (m)	1.4	1.4	2.0
Opening/closing procedure (man./mech.)	manual	manual	automatic
Step height (cm)	0.15	0.15	level entry
Bogies			
Number of bogies/ rotatable undercarriages	1	2	2
Number of carrying wheels, top-mounted/ suspended	4/8	8/16	8/-
Gauge			
top-mounted (mm) suspended (mm)	1380 1000	1380 1000	1600 -
Wheels	hard rubber	hard rubber	hard rubber
Number of guide wheels	4	4	8
Switching mechanism	4 switching rods	8 switching rods	8 switching rods
Location of steering rods	2 each side	4 each side	4 each side
Number of switching wheels	4	8	8

	CABINTAXI SYSTEMS		CABINLIFT SYSTEM PLANNED FOR BREMEN HOSPITAL
Propulsion and braking	KK3	KK12	
Type of propulsion	D-LIM	D-LIM	D-LIM
Number of motors	2	4	(2 on one side V = 7 m/s 3 (1 opposite V = 10 m/s
Power in (kw)	10	20	20[1] 40[2]
Energy use (kW/veh-km)	0.3	0.7	-
Operation voltage (V-AC)	500	500	380 or 660
Type of braking	D-LIB and drum brakes	D-LIB and drum brakes	D-LIB and hydraulic wheel brakes
Number of dynamic brakes	2	4	2+1
Number of mechanical brakes	4	8	6
Power supply	power rail with power collector	power rail with power collector	power rail with power collector
Performance			
Maximum speed (m/s)	10 (14)[1]	10 (14)[1]	7 (10)[2]
Operation speed (m/s)	10	10	7 (10)[2]
Acceleration (m/s^2)	2.5	2.5	0.35[3] 1.0[4]
Deceleration (m/s^2)	2.5	2.5	0.35[3] 1.0[4]
Emergency braking deceleration	5.0	5.1	1.5
Reaction time for emergency braking (s)	0.1	0.1	0.3
Maximum jerk stress (x/y/z direction (m/s^3)	2.25/1.6/-	2.25/1.6/-	-
Maximum uncompensated lateral acceleration (m/s^2)	2.5	2.5	
Maximum vertical acceleration (m/s)	1.0	1.0	-

1) v = 14 m/s in development test since June 1977
2) v = 10 m/s for other applications
3) b = 0.35 m/s^2 due to the transport of soup bowls
4) b = 1.0 m/s^2 for other application (standing passengers)

	CABINTAXI SYSTEMS		CABINLIFT SYSTEM PLANNED FOR BREMEN HOSPITAL
	KK3	KK12	
Guideways			
Guideway beam	steel carrier	steel carrier	steel carrier
Beam type Double guideway/ Single guideway [1]	box beam	box beam	-
Height (m)	1.83/0.90	1.83/0.90	-1.55
Width (m)	1.76/1.76	1.76/1.76	-/2.1
Guideway elements			
Minimum radius at maximum speed (m)	30	30	30
at reduced speed (m)	16	16	-
Minimum Spiral parameter (m)	25	25	-
Maximum banking (°)	5	5	-
Maximum grade (%)	10	10	4
Maximum grade with speed reduction	15	15	-
Interval between supports (recommended)	25-40	25-40	25-40
Type of switch	passive, branching switch in bogie	passive, branching switch in bogie	passive, branching switch in bogie
Min. switching radius (double track)	40	40	-
Min. switch interval (m)	24.5	27	-
Stations			
Number of docking points	4 max. 12	2 max. 6	2
Platform length (m)	10 max. 30	10 max. 30	8
Braking and accelerating spur track length (m)	27	30	85; 30 [2]
Maximum possible vehicle backup Approach/departure	8/1	4/1	4/1

1) Single track, top-mounted
2) For other applications with v = 10 m/s

	CABINTAXI SYSTEMS		CABINLIFT SYSTEM PLANNED FOR BREMEN HOSPITAL
	KK3	KK12	
Average stop time (s)	15	20	passengers 20-30 freight 60
Travel ticket sales	automatic	automatic	-
Empty vehicle reserve (number of vehicles)	2 max. 6	2 max. 6	-
Stopping precision target point (± cm)	10	10	5
Operational control			
Headway control	asynchronous interval	asynchronous interval	asynchronous interval and block system
Number of blocks between vehicles	none	none	4
Max. interval (s)	1.4	1.6	14;11.0[1]
Avg. waiting time for 90% of the passengers (min) (planned)	less than 1	less than 3	-
Environmental stress			
Exterior noise at 7.5m [1] (dB(A))	60-65	65	-
Exhaust	none	none	none
Capacity (per line)[2]			
Clear track sections			
Vehicles per hour	2571	2250	257
Passengers (max) (per hour)	7714	27,000	4626
Passengers (80% occupancy)	6171	21,600	3700

1) Equivalent constant noise level at 10 m/s at a distance of 7.5 m from the track.
2) See section 4.11 of Referenced Report.

	CABINTAXI SYSTEMS		CABINLIFT SYSTEM PLANNED FOR BREMEN HOSPITAL
	KK3	KK12	
Switches			
demerging	same as clear track[1)]	same as clear track[1)]	-
merging switches	$Q_1 + Q_2 = Q_{\text{clear track}}$[1)]	$Q_1 + Q_2 = Q_{\text{clear track}}$[1)]	$Q_i + Q_2 = Q_{\text{clear track}}$[1)]
Station			
4 docking points (2 docking points for KK12 and Cabinlift)			
Vehicle (veh/h)	450	200	60
Passengers (max)(per/hr)	1350	2400	1080
Safety and reliability (goal values)			
MTBF station (h) with 24 h operational day	770	770	
MTBF Vehicles (h) for 10 h operational day	1920	1920	
Projected useful life (years)			
Guideway beams, supports, switches, and stations	50	50	50
Merging and demerging switch electronics	15	15	15
Elevators	15	15	15
Station control, central computer, control center	10	10	10
Ticket automats, video monitors and intercom systems	10	10	10
Vehicles	10	10	10

1) See section 4.11 of Referenced Report.

PAPER 19

Canadian ICTS Development

N. E. Rudback
Transport Canada

CANADIAN INTERMIDIATE CAPACITY TRANSIT SYSTEM DEVELOPMENT

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ABSTRACT. Development of a steel-wheel on rail intermediate capacity transit system (ICTS) has been underway in Canada since 1974. The ICTS provides a maximum capacity of 20,000 passengers per hour per direction using small vehicles operating at headways down to 60 seconds. Prototype vehicle testing will start in September 1978 on a 2.5 kilometer test track now under construction. The acceptability of ICTS for operational service will be demonstrated during test programs to be completed in 1980.

INTRODUCTION

The requirement for an intermediate capacity transit system (ICTS) has been recognized by transportation planners in Canada for a number of years. Early efforts at implementing a magnetically levitated system of this type (the Toronto Transit Demonstration System) ended in failure in 1974. Learning from this experience the functional requirements for an ICTS were redefined and a step-by-step development of the technology to meet these requirements has been taking place. This paper is intended to provide an overview of the ICTS development work, and outline its current status.

INTERMEDIATE CAPACITY TRANSIT

An intermediate capacity transit system is intended to fill the gap in carrying capacity and cost between a bus system and a subway, while providing high quality and frequency of service. Buses have a maximum carrying capacity of about 4,500 passengers per hour per direction (pphpd) which is not great enough to adequately serve the principal corridors of most cities. Furthermore, buses add to the noise, traffic congestion and pollution in a city and provide a slow and unattractive quality of ride. While light rail transit can provide capacities up to 10,000 pphpd the vehicles must generally operate in mixed traffic, thus limiting the average speed in rush hour to about 10 mph.

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Subways provide rapid dependable all weather transit with no interference to automobile or pedestrian traffic. However, the full line capacity of 40,000 pphpd is only required on the principal routes in a few of the very largest cities. Elsewhere the passenger volume is not sufficient to justify the enormous capital costs involved with subway construction.

Table 1 outlines the characteristics of existing transit systems. Table 2 illustrates the functional requirements which the ICTS system is designed to achieve.

CANADIAN APPLICATIONS

In order to evaluate the potential domestic market for ICTS a study was made of travel demand in Canada's 23 largest urban centres, those with 1975 metropolitan area populations of 100,000 persons or more. The natural travel corridors were examined and estimates were made of the present and expected future travel demand in these corridors. A total of 42 useful travel corridors were identified which have a projected public transit travel demand in excess of 4,000 pphpd in 1985, the minimum necessary to be considered for ICTS application. These corridors which total over 1,000 km in length are located in 8 different cities, all of which have a population of more than 300,000 persons. (Figure 1)

TWO DEVELOPMENT GROUPS

There are two industrial groups working on ICTS development in Canada, one headed by Bombardier-MLW and the other directed by the Urban Transportation Development Corporation (UTDC). The Transport Canada Research and Development Centre (TDC) has funded a major concept definition study which was carried out by Bombardier-MLW in consortium with a group of Canadian and France based companies. This work is now essentially complete. Final reports are being prepared and should be available for distribution within a few months.

Negotiations are underway with Bombardier-MLW for follow-on hardware development which will involve the design and construction of two small, light-weight fabricated bogies. These will be tested in vehicle configuration using a body shell of representative size and weight to that proposed for ICTS application. It will not however be a prototype ICTS vehicle. The government of Quebec will play the lead role in these follow-on activities with funding and technical support from the federal government, and some financial participation by Bombardier-MLW. The overall cost of this program (including concept definition) is in the order of $3.5 million.

In parallel, the province of Ontario has initiated and is funding a five phase program with UTDC leading to the introduction of an ICTS into revenue operation. The phases of this program are as follows:

Phase 1	-	Data Acquisition and Program Definition.	Apr.75 -Aug.75
Phase 2	-	Concept Development and Preliminary System Design.	Sep.75 -Apr.76
Phase 3	-	Prototype System Development and Testing.	Sep.76 -Jan.80

Phase 4	-	Pre-Production Development and Testing.	1980-1981
Phase 5	-	Initial Revenue Production.	1981

Phase 3 of the program is now underway. This phase includes provision of a 2.5 kilometer ICTS test track facility at Kingston, Ontario which is now under construction and will be placed into service in September 1978. Prototype system testing with 3 test vehicles will take place on this track during late 1978 and 1979. Funding of $55 million has been provided by Ontario for the Phase 3 development work. TDC is providing a small amount of funding to UTDC for work in specialized areas relating to ICTS propulsion and bogie design.

STEEL WHEEL ON RAIL DESIGN

The TDC sponsored ICTS concept definition carried out by the Bombardier-MLW group began with the assumption that steel wheel on rail vehicles with track based switching was the most promising principle of operation, and this was a constraint of the study. This choice was made partly on the basis of subjective technical assessment, and partly because it was a logical alternative which designers appeared to be ignoring at that point in time. UTDC subsequently carried out a thorough study of all the suspension and guidance alternatives and, on the basis of rigorous engineering analysis, also selected steel wheel on rail as the preferred design solution. The fact that steel wheel on rail vehicles operate well without the need for guideway heating under Canadian winter conditions was a major factor in this decision.

AT-GRADE OR ELEVATED GUIDEWAY

It is generally accepted that every mile of underground construction which can be avoided will result in a cost saving of $20 to $25 million, regardless of technology. To meet the cost objectives of ICTS an acceptable alternative to underground construction must be found. It is in the selection of this alternative that the Bombardier-MLW and the UTDC design teams have differed. As a consequence each has taken a different design approach and the two efforts have turned out to be more complimentary than duplicative.

Bombardier-MLW adopted the position from the outset that elevated guideway construction would be aesthetically unacceptable in a modern urban environment. They therefore devoted their attention toward evaluating the impact of an ICTS guideway at ground level and finding methods that would allow the construction of at-grade guideway without creating unacceptable community barriers.

UTDC on the other hand concluded that at-grade guideway could not be constructed without creating community barriers and seriously disrupting road traffic. Consequently they set about developing an ICTS design that could be implemented using elevated guideway with a minimum of disturbing visual intrusion and noise.

TABLE 1. CHARACTERISTICS OF EXISTING TRANSIT SYSTEMS

CHARACTERISTIC	BUS	LIGHT RAIL	SUBWAY
RIGHT-OF WAY	MIXED TRAFFIC	MIXED TRAFFIC	EXCLUSIVE
MAXIMUM PASSENGER CAPACITY (PER HOUR PER DIRECTION)	4,500	10,000	40,000
AVERAGE TRAVELLING SPEED (RUSH HOUR)	16KM/H	16KM/H	37KM/H
AVERAGE CAPITAL COST PER MILE ($ MILLION)	$0.5	$5.0	$50.0

TABLE 2. FUNCTIONAL REQUIREMENTS

MAXIMUM CAPACITY	20,000 PPHPD
MINIMUM CAPACITY	4,000 PPHPD
AVERAGE SPEED	55 KM/H
MINIMUM HEADWAY	60 - 72 SEC.
STATION SPACING	1.25 KM AVG.
OPERATION	FULLY AUTOMATIC
ACCELERATION LIMIT	1.2 M/S^2
JERK LIMIT	0.08 M/S^3
INTERNAL NOISE	65 DB(A)
MAX. CAPITAL COST ($ MILLION/MILE)	$25.0

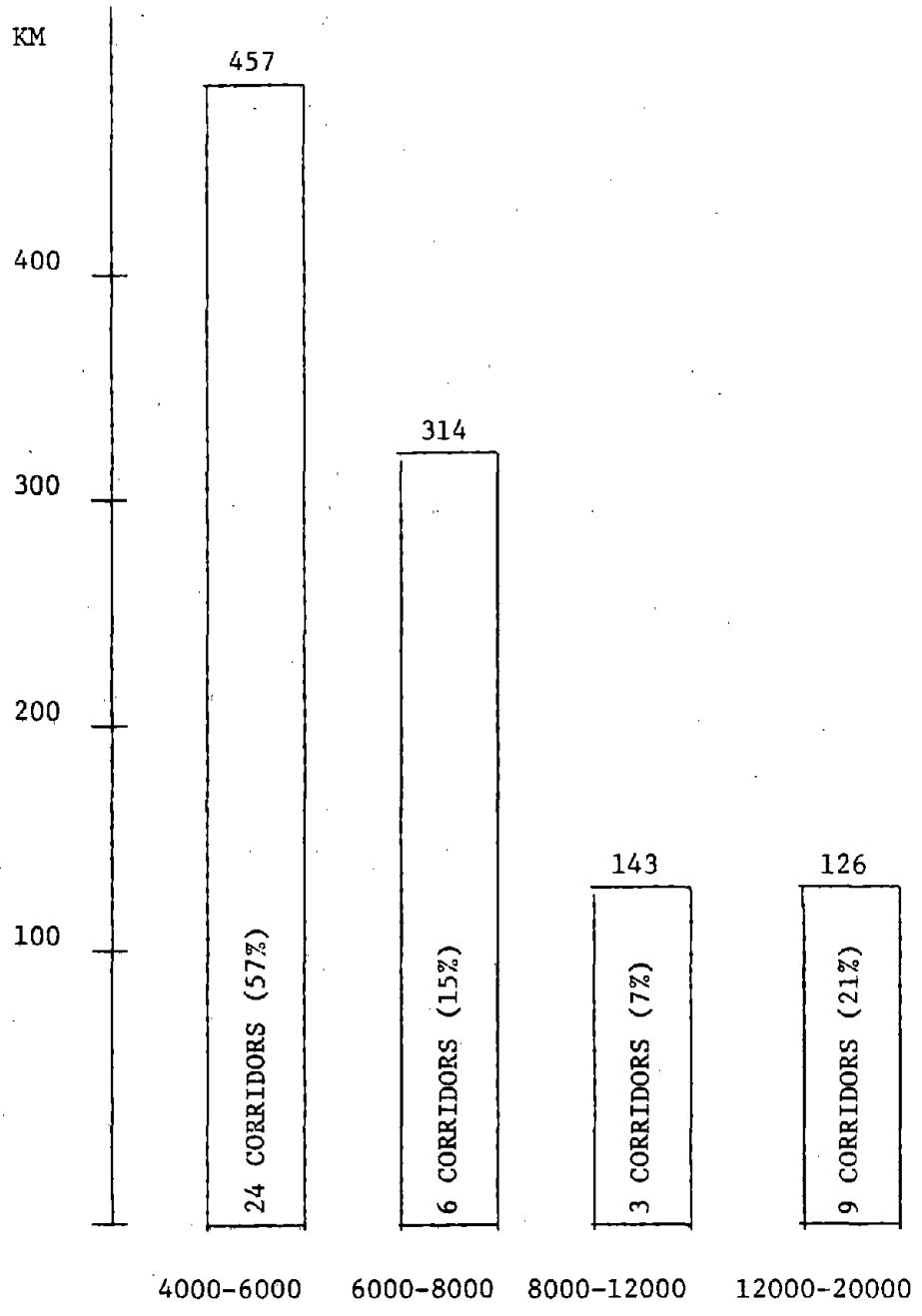


FIGURE 1. CORRIDOR GROUPINGS BY DEMAND LEVEL

ICTS IMPLEMENTATION AT GRADE LEVEL

Insertion on Railway Right-of-Way

While it is difficult to make generalizations regarding insertion of ICTS on existing rights-of-way since so many of the problems are site specific, the results of some preliminary TDC study into using railway rights-of-way are promising. An inventory was made of existing rail lines in major urban areas to determine right-of-way width and the extent of physical barriers such as bridges or highway overpasses. A space availability analysis performed by railway consultants indicated that most of the available Canadian railroad rights-of-way would be able to receive an exclusive trackage for ICTS in a high proportion of their alignment.

To verify the practicality of ICTS implementation along a railway line, site specific studies were conducted on two typical routes, one in Montreal and the other in Winnipeg. Both confirmed that, with the exception of river crossings, the addition of ICTS trackage along railroad rights-of-way involved only minor encroachments on the adjacent land. An average of 2 grade separations per kilometer were found to require modification or reconstruction. Additional space will of course be needed for stations and any related parking facilities.

Edmonton and Calgary are both in the process of constructing light rail systems which utilize in part existing rail lines. Vancouver has announced plans to do likewise. There are other cities in Canada where this alternative could possibly be used to reduce the cost of ICTS implementation.

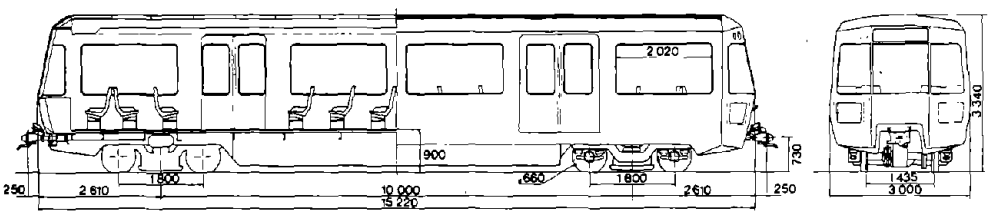
Insertion on an Urban Street

In recent years the use of streets for transit (in the form of reserved strips of the street) has gained some acceptance in North America. The centre strips of parkways or boulevards are favorite targets for planners of light rail transit. There are several examples of on-the-street transit ways in Canada and the United States, especially for bus operations, normally classified as reserved bus lanes. At the lower level of demand it may only be through sharing of the public streets that effective public transit will be economically feasible.

The TDC concept definition study set out to examine the impact that an on-street ICTS insertion would have on automobile traffic using for a case study the street network of a Canadian city. A traffic assignment model was used to assess the impacts of insertion on road traffic. This impact is reflected by an increase in automobile travel times for the same trips in that corridor, or for possible alternative routes. The traffic assignment simulation model Traffic II developed by Nguyen at the Centre de Recherche sur les Transports of the University of Montreal was selected for analysis purposes. In the case studied it was found that automobile travel times increased only about 7% and that the average speed decreased 9% considering the corridor as a whole and assuming one grade crossing every mile with underground construction in the central business district. Similarly efforts were made to obtain a quantitative evaluation of the effect of such an insertion on pedestrian traffic, noise, and visual

TABLE 3. VEHICLE CHARACTERISTICS

	BOMBARDIER	UTDC
LENGTH (OVERALL)	15.72 M	12.7 M
WIDTH	3.00 M	2.50 M
HEIGHT	3.34 M	3.05 M
FLOOR HEIGHT	0.90 M	0.76 M
NORMAL CAPACITY	114	74
- SEATED	48	35
- STANDING	66	39
CRUSH LOAD	138	85
PROPULSION	ROTARY DC	LIM
MAXIMUM SPEED	20M/S (45 MPH)	20 M/S (45 MPH)
WEIGHT EMPTY	21,020 KG	13,400 KG
WEIGHT LOADED (CRUSH)	30,680 KG	19,350 KG
SEATING RATIO (NORMAL)	42%	47%
FLOOR AREA/PASS (NORMAL)	0.34 M^2	0.36 M^2
WEIGHT/PASS. (CRUSH)	222 KG	228 KG



Top:
Dimensional drawing of Intermediate Capacity Transit Vehicle currently under review by TDC.

Centre:
Exterior view of ICTS Vehicle intended to fill the capacity gap between buses and subways in urban transportation systems.

Bottom:
The ICTS Vehicle's interior is designed to seat 48 passengers with a crush load of 137 persons.

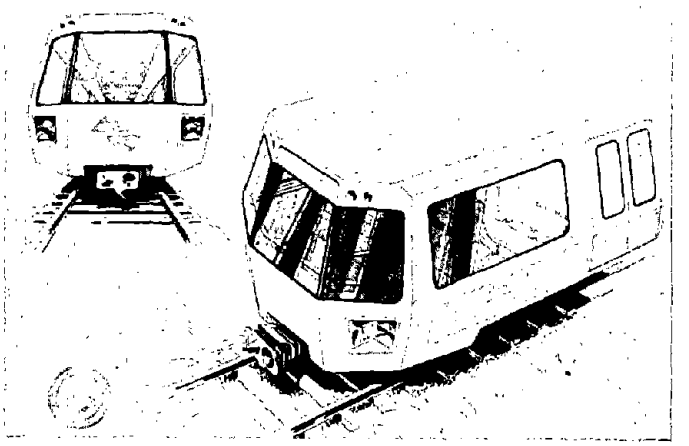




FIGURE 2. BOMBARDIER-MLW DESIGNED ICTS VEHICLE

TABLE 4. SYSTEM CHARACTERISTICS

	BOMBARDIER	UTDC
BASIC CAPACITY	17,000 PPHPD	15,000 PPHPD
MAXIMUM CAPACITY	20,000 PPHPD	20,000 PPHPD
MINIMUM CONSIST	1 CAR	2 CARS
CONSIST AT CAPACITY	3 CARS	4 CARS
TRAIN LENGTH AT CAPACITY	46 M	48 M
STATIONS	ON LINE	ON OR OFF LINE
STATION SPACING (AVG.)	1.25 KM	1.25 KM
AVERAGE SPEED	55 KM/H	55 KM/H
AUTOMATIC CONTROL	VARIABLE MOVING BLOCK	
MINIMUM HEADWAY	72 SEC	60 SEC

intrusion. This work did not show any unacceptable effects which would definitely rule out at-grade construction. The main conclusions were:

1. Insertion is best accomplished on arterial streets that lead to the CBD (but should not enter the CBD at grade), or to rapid transit stations.
2. The most suitable option appears to require an 8 lane (26.3M) street width, although narrower streets can be used under some circumstances. This will allow two lanes of traffic in each direction after insertion.
3. The number of major cross-streets should be small since each will eventually require grade separation. A spacing of 1.2 to 1.6 kilometers between consecutive grade separated intersections seems optimum.
4. Pedestrian overpasses or underpasses are needed between grade separated intersections.
5. The existence of parallel streets with sufficient capacity to absorb part of the traffic diverted from the main arterial street by ICTS insertion is necessary.

BOMBARDIER-MLW TECHNICAL DESIGN

During the TDC sponsored ICTS concept definition the Bombardier-MLW design team tended to take a cautious design approach, opting for proven technology whenever it could be adapted to the purpose. This was no doubt inspired by the long tradition in railroading and public transit of the corporate participants in the study. The result has been a system design having a relatively low technical risk which could be implemented without the need for a major research program, although some development period would be necessary.

The principal dimensions and characteristics of the vehicle are summarized on Table 3. Each vehicle carries 48 seated passengers and 66 standees for a total of 114. The high seating ratio (42%) is in accord with the ICTS philosophy of providing high passenger comfort. While the maximum load is nominally 114 passengers the vehicle will accommodate a crush load of 138 persons at a reduced comfort level. (Figure 2)

Propulsion will be by two chopper controlled 125KW DC motors per car. Independent choppers are provided for each motor for better reliability. Power pickup will be at 600 volts DC via a third rail. At present it must be admitted that all the problems associated with snow removal for a third rail at grade level have not been resolved, particularly since some type of sidewall barrier will be necessary to protect the right-of-way against intrusion.

Each vehicle is bidirectional and can operate alone, or in a train consisting of up to three cars. At a minimum headway of 72 seconds the maximum line capacity at 114 passengers per vehicle is 17,100 pphpd. Under crush loading conditions a maximum capacity limit of 20,700 pphpd can be achieved. (Table 4)

The short headways, planned high frequency of service, and desire to reduce operating cost dictated fully automated, driverless vehicles. The

automation system proposed is a variant of the one originally conceived by Matra for use on the VAL system to be installed in Lille, France. It features distributed logic throughout the system which should aid reliability. Vehicle position, overspeed protection, and communication are obtained from cables laid along the length of the track. The design of the VAL automation has now changed significantly from that used in the ICTS concept definition. Consequently there is no system of this exact type now under active development, and implementation of the proposed automatic control features would require further development work. Alternatively it would be possible to modify this aspect of the design and adapt a system which is further advanced in development.

The work currently being addressed by Bombardier - MLW relates to the bogie design. It will be noted that a low floor height has been obtained through use of an innovative bogie design. Further analysis of the bogie design is underway to be followed by construction and testing. Two bogies, which are of fabricated construction, will be built. A body shell of representative size will be used for vehicular testing which will be conducted on a 1.6 kilometer electrified line near the Bombardier-MLW plant at Lapocatière. A diesel generator set will be mounted in the vehicle to allow more extensive testing on nearly main line railway track. The weight of the motor generator will nicely simulate a passenger load. This work is scheduled to be completed during 1979.

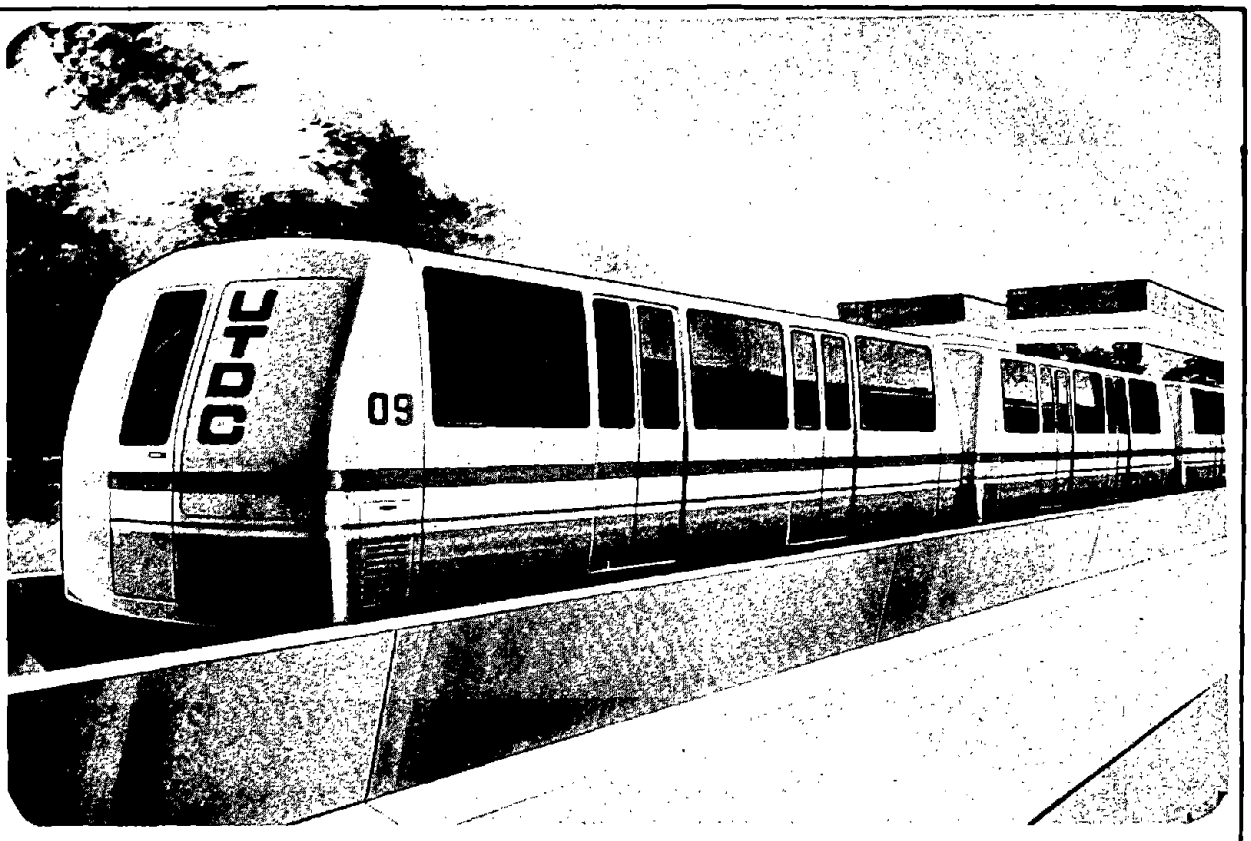
THE UTDC ICTS DEVELOPMENT

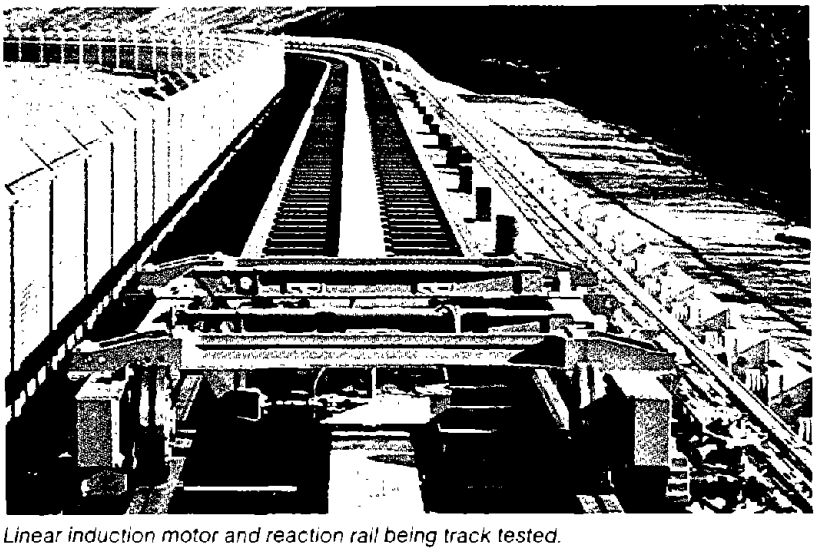
The requirement for elevated operation necessitates small scale vehicles, guideway, and stations to minimize visual intrusion, and very low noise levels. The design objective for external noise has been set at 68 db(A) at 15 m (50 Ft) at a speed of 20 m/s (45 MPH)). The small vehicles require short headway to meet the desired system capacity.

It is felt that a major breakthrough has been made towards achieving these goals with a steel-wheel-on-rail vehicle through development of a linear induction motor (LIM) powered steerable axle bogie. The steerable axle feature permits negotiating sharp (35M) curves without flange contact which produces a significant (15 db) noise reduction compared with conventional rail equipment. The LIM eliminates dependance upon rail adhesion for acceleration and braking which is a key factor in meeting headway objectives, and results in extremely low levels of wheel and track wear as well. The wheels are only 18 inches in diameter which helps account for the low floor and overall vehicle height. (Table 3)

The system operates with a minimum train consist of one married pair, expandable in single units to six cars. Table 3 summarizes the characteristics of individual cars. Each car has a normal maximum capacity of 74 persons (35 seated, 39 standing) with a crush load of 85 passengers. A capacity of 15,000 pphpd is achieved with 3 car consists running at 60 second headways, and requires 35m long stations. The use of 4 car trains and 46m platforms provides a capacity of 20,000 pphpd. (Table 4, Figure 3)

The cars will be powered by two 150Kw linear induction motors, one mounted on each bogie. Individual transistorized inverters will control each motor. The LIM has the disadvantage of lower power factor and





Linear induction motor and reaction rail being track tested.

FIGURE 3. UTDG'S INTERMEDIATE CAPACITY TRANSIT SYSTEM OPERATING AT STREET LEVEL AND LINEAR INDUCTION MOTOR AND REACTION RAIL BEING TRACK TESTED

efficiency than a rotary motor, but offers adhesion independent acceleration and braking which is considered essential for operation at the planned 60 second headways. The greater capital cost of the LIM propulsion subsystem (principally the cost of the reaction rail) is offset by lower operating costs due to reduced maintenance and wear of the motor, brake pads, wheels, and rail. Fleet size is significantly reduced. Overall life cycle costs of LIM and rotary propulsion alternatives are estimated to be equivalent.

The guideway will be fabricated of precast trapezoidal box beams up to 30m in length. The beams will have side parapets not exceeding 0.55m in height to help reduce noise and provide a pleasing appearance to the top of the structure. The outside width of a single-lane guideway is 2.5m, while a dual-lane guideway is 5.5m wide and composed of two single units on a common column. The use of standard railway guage of 1.1435m will permit normal operation with crosswinds up to 120 Km/hr, and ensures good stability against overturning in winds up to 150 Km/hr. (Figure 4)

The noise objectives for the system are extremely stringent, 68 dbA at 15m (50 ft) with the vehicle operating at maximum design speed of 72 Km/hr (45 MPH). It is believed that the combination of a steerable axle bogie, side barriers on the guideway, and the use of resiliently mounted welded rail will allow achievement of this objective. The results of preliminary field tests indicate that the bogie will meet its predicted noise performance. A key factor in achieving continuous low emission is the maintenance of good wheel and rail condition. The low wear characteristics of the steerable axle bogie allow this to be done at a reasonable cost.

The SELTRAC automatic train control system developed by Standard Electrik Lorenz (ITT) will provide automatic and safe operation of the system. SELTRAC is a variable moving black type of system which uses a crossed-wire inductive loop method to verify the vehicle position, and for transmission between the vehicles and the ground equipment. Field experience has been obtained with the SELTRAC system on the Hamburg-Bremen line of the German Federal Railway where it has been used for several years as an overlay on conventional signaling equipment. Tests are now underway with SELTRAC on the Berlin subway where it is expected to be placed into full operational service later this year.

The ICTS test facility which is now under construction will have a total track length of 2.5Km. The main 1.8Km loop will include a 410M length of elevated track, an off-line station lane, a maximum grade (6%) section, and a minum radius (35M) curve. Continuous testing can be carried out at the maximum operational speed of 72Km/hour (45MPH). The power-on date for the site is 1 September 1978. The first fully-powered test vehicle (TV-1) will start trial in September 1978. A second test vehicle (TV-2) will be operational in February 1979. The third vehicle (TV-3) will be delivered in April 1979 with multi-vehicle automatic system operation planned for the August of 1979.

ROTARY MOTOR POWERED STEERABLE BOGIE

TDC is now participating with UTDC in the development of a rotary motor powered version of the steerable axle bogie. While it is believed that the LIM is necessary for minimum headway operation, there are applications in the lower capacity ranges (up to perhaps 12,000 pphpd) where a rotary motor powered bogie could be used to advantage. The design problems of a steerable

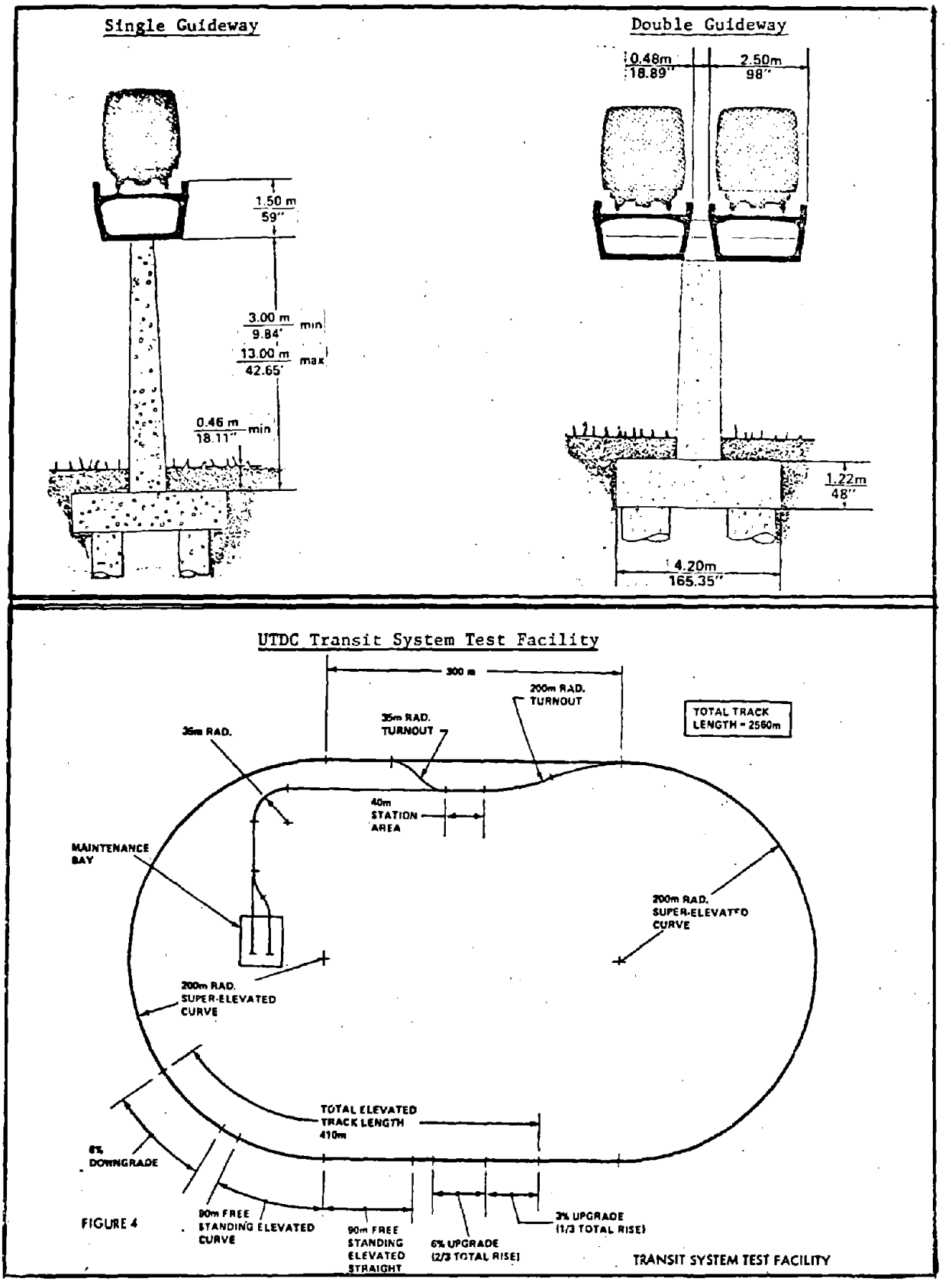


FIGURE 4. UTDC ELEVATED GUIDEWAY DESIGNS AND UTDC TRANSIT SYSTEM TEST FACILITY

bogie are much greater with rotary motor propulsion (which requires transmission of the tractive forces through the wheels and axle), than with LIM propulsion. This activity will be scheduled to parallel the other ICTS development work.

CONCLUSIONS

A need exists in Canada for a new transit system with a service capability superior to the bus and street car but with a significantly lower cost than subways. A steel wheel on rail ICTS can meet this requirement under all climactic conditions using technology that will be developed and proven for operational service during the next few years. Such a system having a capacity up to 20,000 pphpd could serve as a feeder to a main subway line in major cities, or as the primary system in less densely populated metropolitan areas. The ICTS, which is entering the advanced development stage for Canadian requirements, is believed to have potential for application in cities elsewhere in North America, and in other parts of the world.

PAPER 20

French Presentation

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FRENCH PRESENTATION

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ABSTRACT - The special French transportation policy environment is first discussed, introducing recommendations made by a Research Advisory Committee appointed by the French Secretary of Transportation. A survey of the main development projects follows. A brief historical account is given for each system, as well as a description of the latest development and issues. The paper then presents some examples of critical technology and component developments being initiated in France.

TECHNICAL RESEARCH AND PROMOTION OF URBAN MASS TRANSPORTATION

Transportation provides a service; technique can only be found at the level of transportation system components : infrastructures and guideways, vehicles, operation procedures and management.

Our present purpose is not civil engineering research (even if it is very important to transportation), hence we will restrict this paper to :

- research activities which fall within the competence of rolling stock industries or their scientific and technological environment, and
- research activities which are taken into consideration by the main operating companies and their consultants.

It is rather difficult to integrate the above activities into the regular frame of the main scientific branches. Traffic engineering, traffic regulation, and so-called industrial research are all rather a matter of know-how than new knowledge which would be exclusive to transportation. This is particularly true when mechanics, electronics and electrotechnics are to be used.

To be blunt, for a long time, very little technical research was being done by the ground mass-transportation vehicles industries. In France, operating companies which are in a monopolistic position, such as the French National Railroads Company (the "SNCF"), or at least in a leading position, such as the Paris Transit

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Authorities (the "RATP"), imposed their own specifications. Moreover, certification was carried on with their own equipment, i.e., the SNCF Vitry center. They also carried on some research-like activities, but these were not oriented toward radical innovations since they were related to wheel-to-rail technics.

Only the automotive industry, and then only recently, has had scientific means, the purpose of which is not to solve problems related to the companies' program, but to increase their knowledge and to undertake research on subjects which seem promising without associating it directly to production.

One can understand why, in this case, governmental authorities appealed to outsiders to break up the national monopoly behind which the companies were trying to shelter themselves.

The outsiders who responded to the government's offer were motivated either by a somewhat naive belief that it would be easy to transfer certain aspects of aerospace technology or by their hope to be able to enter and use innovation in a well-protected market.

However, we now know that such technological transfers cannot be made without far-ranging adaptation to the physical and socio-economic environment in which innovation must develop. The evolution of ground transportation depends on the guideway networks which can only be changed at a slow rate, depending mainly on traffic capacity shortage and deployment possibilities, especially in urban areas.

A Research Advisory Committee, apointed by the Housing and Public Works Ministry (the Transportation Administration is part of this Ministry) was asked to examine the technical research and research management done in the area of urban transportation over the last 12 years and made the following recommendations:

1. In order to elaborate R&D policy, a clear distinction must be made between upstream research and overall system development. Governmental funds should be used for upstream research projects which should bring long-term (10 to 20 years) improvements. Complete systems should be studied on a short-term basis (5 to 10 years) using results of the upstream research already carried out and should be motivated by the evolution of the user's expectation or by the foreseen industrial market.

2. Upstream research activities should be intensified using incentive procedures.

3. There are two possibilities for overall system development :

a) The work has been initiated by the concerned economic groups. In this case, they should be allowed to use their own initiative, in France and abroad, and a governmental agency should be able to conduct a permanent assessment of these initiatives.

b) The work has not been initiated by the implied social and economic groups. In this case, which should be exceptional, the government should be able to support development programs in connection with local authorities.

4. As far as new system development procedures are concerned, one should insure that all the necessary technical steps leading to complete development will be fully accomplished, whatever the political or industrial pressures might be.

5. Generally speaking, one should strive to have local authorities and middle-size companies more involved in R&D orientation.

6. More specific technical cooperation based upon permanent contacts between laboratories and specialized institutes should be favored, particularly with regard to assessments of innovations which have reached an operational stage of development. For example, the agreements made between the Urban Mass Transportation Administration and the "Institut de Recherche des Transports" have been very positive.

7. Research programs dealing with the socio-economic goals of technical research should be developed.

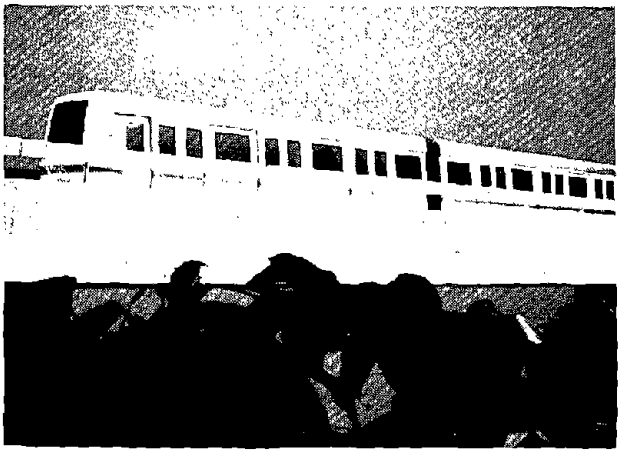
8. Research programs dealing with the organization of multimodal urban trips pattern should be encouraged.

We hope the above recommendations help to show why our research program is doubly-oriented toward upstream research and development of nearly operational systems, and why in France the present trend is to give priority to ground mass-transportation systems which are able to use road networks.

A SURVEY OF DEVELOPMENT PROJECTS

There are three Automated Guideway Transit (AGT) main development projects in France : VAL, which is going to be the Lille Metro, and two cabin systems, POMA 2000 which has passive vehicles, and ARAMIS, a system derived from the original PRT concept. (See Figure 1.)

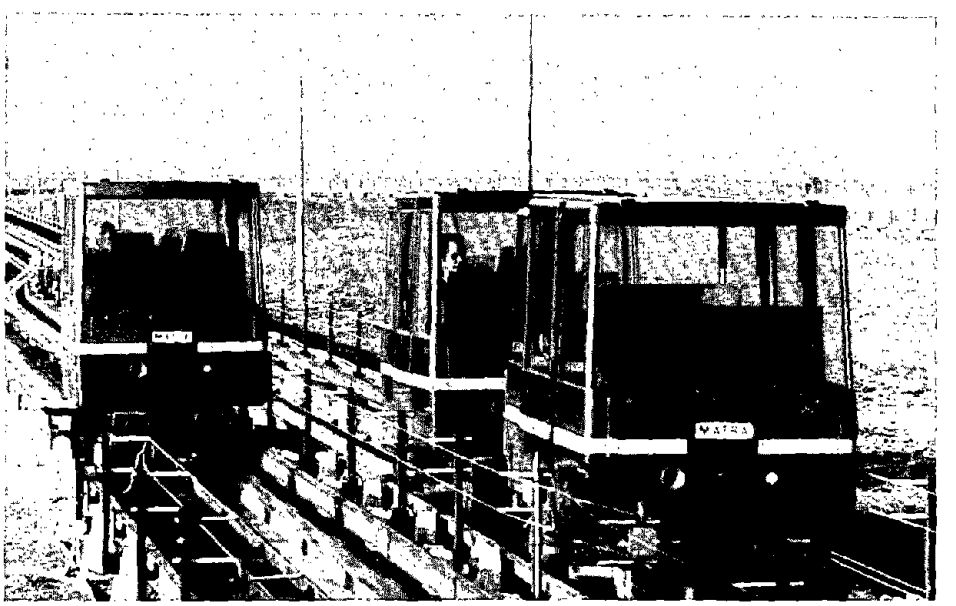
To complete this survey of development projects one should also mention the TRAX, an accelerating moving walkway developed by the PARIS Metro Authority and a dual mode trolley-bus which illustrates the efforts undertaken to improve ground mass-



VAL SYSTEM



POMA 2000 SYSTEM



ARAMIS SYSTEM

FIGURE 1. PHOTOGRAPHS OF THREE AGT SYSTEMS CURRENTLY UNDER DEVELOPMENT

transportation able to use the road network.

- VAL

Now under construction, VAL will be the first unmanned Urban Transportation system to be operated in France.

Started in 1970, the project was first supposed to link the Lille city center to a new urban development in VILLENEUVE d'ASCQ. Revenue operation of an 8 km, 8 station line was originally scheduled for 1975. Peak capacity was estimated at about 6000 passengers per hour.

The request proposal was written by the local urban deployment agency EPALE. It was submitted to about 30 companies by mid-1971. In early 1972, the MATRA company was awarded the contract and was designated as the project leader. Subcontractors included the Compagnie Industrielle des Matériels de Transport (CIMT) for designing the trucks and vehicles, and the Compagnie Electro-Mécanique (CEM)for propulsion and electrical equipment.

In 1973, the initial project was modified. An extension of the line was proposed by the Greater Lille Urban Commission (Communauté Urbaine de Lille). Rather than being a link between the old and the new towns, the project became the backbone of a comprehensive urban transportation network to be built step-by-step.
(See Figure 2.)

At the same time, the VAL project became the LILLE Metro project. The included diagram presents the future network of the LILLE METRO. Line 1 is now under construction.

The test site which is now closed, was first opened in 1974. It had a 1.7 km test loop, a fully equipped station, 2 switches, 2 vehicles, a Control And Command Center, a maintenance shop and a power station. Debugging tests were conducted until June 1975. They were then followed by three months of intensive testing. In this last stage, each vehicle covered over 40 000km. These tests underlined the necessity of redesigning the switch mechanism and modifying the vehicle in order to allow for a reversible operation.

The development phase of the VAL spanned five years, from 1970 to 1975. The total development came to 45 million Francs ($ 9 million).

The LILLE METRO under construction was started in mid 1977. Full revenue operation of line number one is scheduled for the end of 1982. Partial revenue operation is to be initiated in mid 1980 on the first section of the line which is to be built between the Cité Scientifique and Pont de Bois. Thirty-eight vehicles have been ordered from CIMT and should be delivered over a five-year period. The total cost of the project is 1000 million francs in 1977 ($ 200 million).

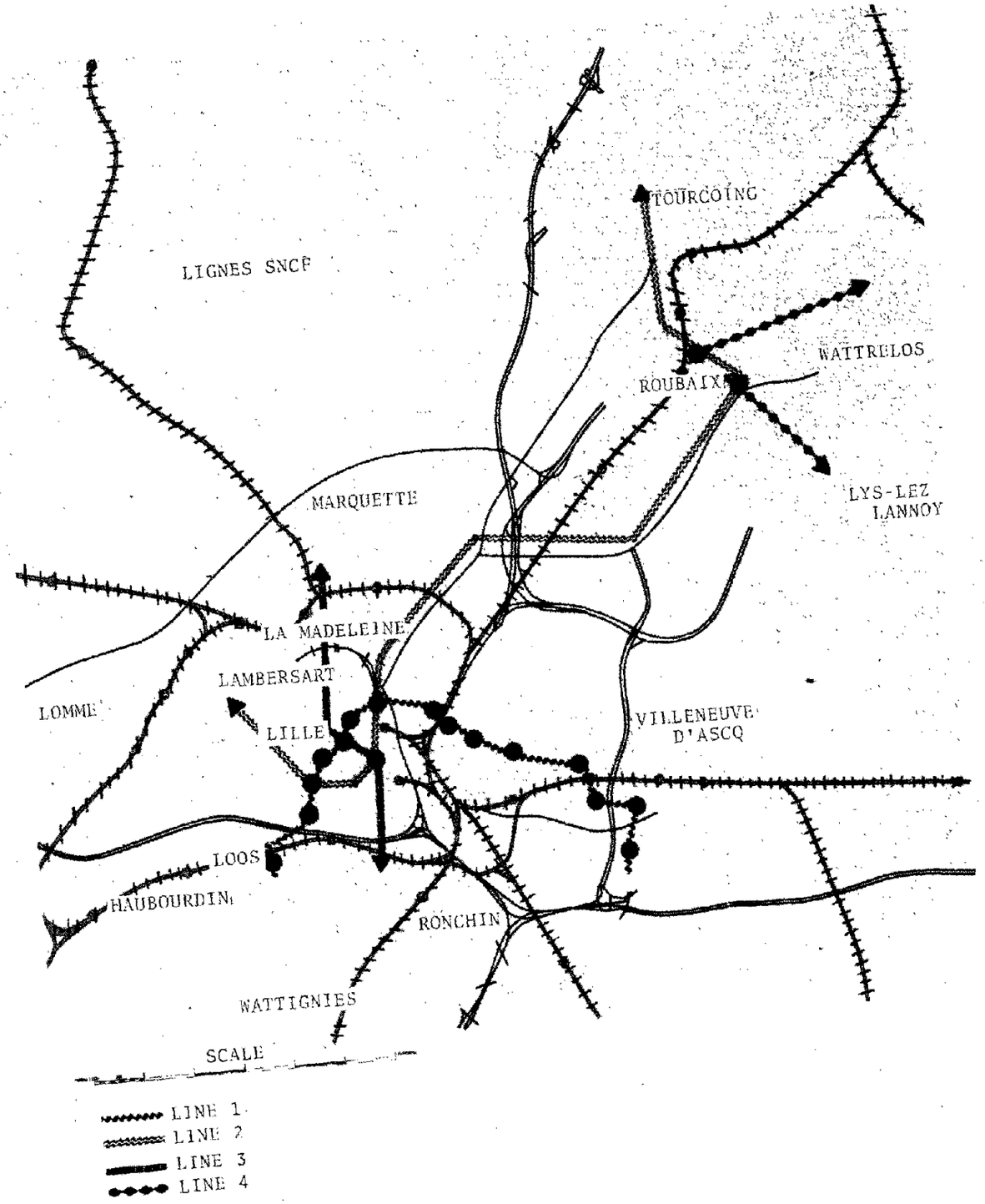


FIGURE 2. LILLE METRO NETWORK

- POMA 2000

Among the four active track systems (1) that have been developed in France, POMA 2000 is the most promising design.

The original idea came from the POMAGALSKI Company which adapted the principle of ski-lift cable propulsion to an urban intermediate cabin transportation system.

Cars are mounted on rubber-tired wheels and are hauled by a cable running at 32 km/h. Lateral guidance is provided by side-tired wheels at the hub level. Its design is similar to the PARIS subway and to the LILLE METRO. Headway in normal operation should be around 32 seconds.

At the entrance of the station, the cars are detached from the propulsion cable. Simultaneously a special grip grabs a decelerating cable that brings the vehicle to a full stop. The maximum dwelling time will be around 20 seconds. Upon departure, doors close automatically and then the vehicle grabs an accelerating cable that brings it to the main cable speed. Then once again, the vehicle drops the accelerating cable and grabs the main cable.

In 1971, a full scale prototype was built to test a vehicle entering and leaving a typical station and coupling and decoupling from a high speed cable.

In 1972 an experimental loop was built. Three vehicles ran over 15 000 km from 1974 to mid 1975, activating the grips twice each lap.

In 1975, tests simulating revenue service (18 hours of service per day) were successfully conducted at 15 second headways (2).

The tests underlined the weakness of the guidance system which had to be redesigned.

Studies have shown that by increasing the headway from 15 seconds to 30 seconds, the same levels of traffic could be achieved at a much lower cost. For instance, the number of fixed blocks in every station could be greatly reduced ; subsequently, wayside equipment, propulsion systems, etc. would drop in the same proportion. It would also permit a different approach to the system operation, such as full stops in the station, simplify acceleration and deceleration subsystems and allow two-car trains, etc.

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(1) POMA (under development) ; VEC (operational) ; TELERAIL (abandoned) ; DELTA V (concept).

(2) This was possible as the system was then semi-continuous.

The result of these studies was a new version of the POMA 2000. The main difference between it and the original one is the full stop in station. This allowed the manufacturer to design new acceleration and deceleration subsystems. Instead of using side wheels to control the vehicle, two ancillary cables are utilized. Even though such an approach seems better, since it suppresses a lot of subsystems which could have had a bad influence on the reliability level of the system, the complexity of the grip partially offsets these advantages. Reliability tests are presently being conducted on the grip to make sure the design is fool-proof.

Started in 1971, the development program is still going on. So far, around 20 million Francs have been invested, half of this amount being subsidized by the government. Today, a demonstration project is under study.

- ARAMIS

The main characteristic of the system is its short headway and platoon concept : vehicles are electronically linked to a lead vehicle picking up data from the track. In the trailing vehicles, the control system maintains a constant distance from the preceding vehicle. Distance is measured by an infrared telemeter mounted on the front of the vehicle. Any vehicle can be either trailing or leading.

The normal operation mode consists of platoons controlled by station computers. Before arriving at a station, vehicles are identified and dispatched. The platoons are reformed and vehicles leaving the station are coupled to the platoon in the leading position. Diagram 1 presents the different phases of the normal platoon operation.

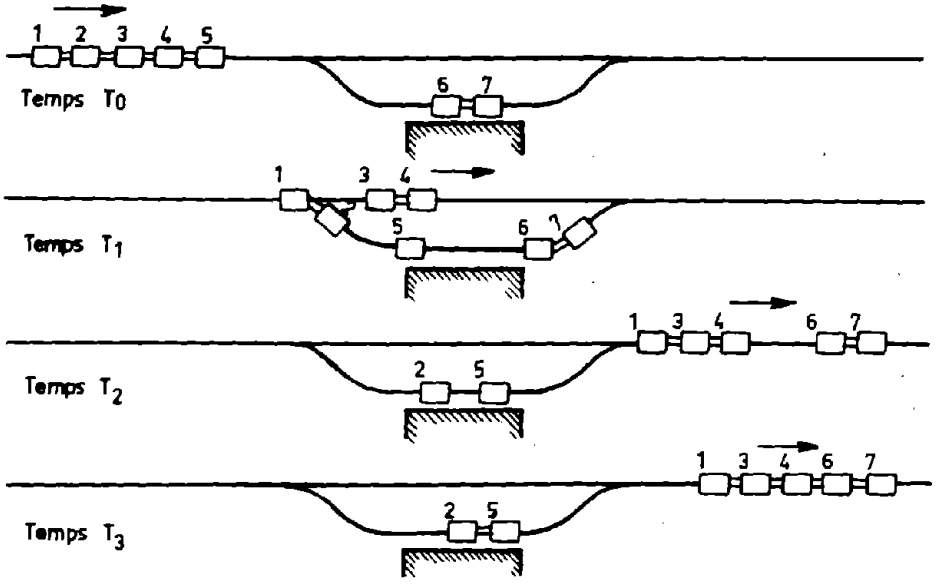


Diagram 1

In 1970, the MATRA Company bought patents from a French inventor who had been working for three years on a new transportation concept.

In 1971, MATRA received a grant from the DATAR (public agency) to carry on studies on the ARAMIS system.

In 1973, a 1 km test track was built at ORLY AIRPORT (Paris).

At the end of this first phase, the PARIS TRANSIT AUTHORITY (RATP) assessed the safety and the reliability of the system. The study showed that with a reasonable amount of design review, the ARAMIS system could reach the same level of safety as that of the PARIS Metro. The RATP is now the project manager.

The development costs have so far reached 45 million Francs, which include development of high-torque reluctance effect motor.

However, as several studies have pointed out, although ARAMIS has been able to provide very high quality of service, its cost has been considered too high for some prospected applications. More specifically civil engineering costs, owing to the construction of off-line stations, are too expensive even though the vehicles have a reduced gauge.

The MATRA Company has been working on a new operating mode of the system called ARAMIS "S", its main purpose being to cut down on the civil engineering costs, all the while maintaining the same quality of service.

The direct origin-destination operating procedure has been abandoned in the downtown area where guideways have to be underground and where the civil engineering costs are at their highest. The service provided is a classical one ; and the vehicles will be circulating in trains stopping at every station. The headway is reduced to a minimum 30 or 40 seconds depending on the platoon size, thanks to ARAMIS' typical electronic coupling.

A comparative technico-economic study of ARAMIS and ARAMIS "S" has recently been presented to the French Department of Transportation. Using as criteria the generalized trip-time, the study shows that ARAMIS "S" provides almost the same quality of service as the original ARAMIS at somewhat lower cost. This study is presently being assessed.

- TRAX

TRAX is an accelerated moving walkway able to run at a maximum speed of 12 km/h (7,46 mph) over a distance of several hundred meters.

It looks like a conventional moving walkway, but its treadway

consists of grooved sliding plates which shift relatively to each other. The movement is obtained by the movement of a quadrangular link having a constant perimeter and linking any two consecutive plates. Each plate combs the grooves of the following one, and all the plates are combed by the entry and exit landing plates.

In the boarding zones, plates are accelerated from 3 to 12 km/h ; before the exit, they are decelerated from 12 to 3 km/h. Safe boarding and deboarding is done facing the walkway. The ends of outgoing and return walkways are connected by two half-turnarounds in order to form an endless loop driven at the high-speed zones.

The handrail moves at the same speed as the mobile deck. The principle behind its construction is very similar to that of the treadway It moves synchronously with the plates. Time equally spaced handgrips provide a hand hold as well as proper passenger spacing for deboarding.

The TRAX principle was demonstrated by a model built for the "TRANSPORT EXPO 73" exhibition by the company "Hydromécanique et Frottement" under the auspices of the Paris Metro Authorities. A prototype loop of 70 meters (230 feet) was begun in April 1973.

Since early November 1975, tests have been conducted carrying passengers at normal operating speed and have confirmed the good functioning of the mobile deck.

The designing and construction of the handrail started in 1976 and it has just been set up. Preliminary tests are now underway.

Assuming that all the results and tests are satisfactary, it will probably be decided to equip a Metro corridor of the "Gare de Lyon" Station. Extensive technical and commercial tests could begin during the second half of 1978.

- Dual-mode Trolleybus

This development project is the most recent one. It was first initiated as a dual mode program. The concept was to use buses also being able to be operated fully automatically and thus guided.

First in 1974, and then in 1976, some preliminary studies were initiated in order to be able to identify different technical solutions. We also proved the feasibility of an original mechanical guidance.

In 1976, the IRT conducted a comparative case study in order to define development project objectives. Technico-economical comparisons were made with different classical solutions such as buses or trolleybuses, over two complete city networks. In 1977 as a result of this, the decision was made to develop a dual-mode trolleybus. It will be a high capacity (about 150 passengers) articulated vehicle, which will be able to be operated on Nickle-Cadmium batteries on up to 50% of its route. The trolleybus will

be able to draw power or separate from overhead wires automatically, as the trolley poles can move up and down.

This would allow for dual-mode trolley routes to cross historical downtown areas where there should not be any wires. It would also provide the system with good operating flexibility.

The project leader of this development is TREGIE, a company totally owned by RENAULT. Subcontractors include SAVIEM and BERLIET (the two major French bus manufacturers), Compagnies Electromécaniques (CEM) for propulsion and electrical equipment, and SAFT for batteries.

The aim of this development project is to realize a prototype vehicle. A final decision will be made later this year, following results of extensive battery testing and after all the main technical options have been chosen.

CRITICAL TECHNOLOGY AND COMPONENT DEVELOPMENTS

As a governmental agency, one of our concerns with regard to transportation systems assessment is safety and reliability. This is quite a difficult and new subject, especially when we consider expected safety and reliability, and in addition, if safety includes security (i.e., freedom from assault or robbery). Our purpose will be to show our approach to these problems, and the attempts we are making to try to adapt technology and methods which have already been used in various other scientific fields.

As an illustration of our upstream research effort, we would like to conclude this paper by showing how promising research can be done on traction motors by using a reduced-scale modeling approach.

Safety

Let us first underline the difficulty in finding, and the necessity of, a realistic definition for "a safe public transit system." We consider that "safe" means "virtually without danger" and the whole problem is to know how much is tolerated. A usual answer to this is the reply "as safe as the Paris Metro," for example.

Setting Safety Goals

Thus, with regard to the ARAMIS project, a study conducted by the RATP was initiated in order to quantify safety objectives. Since it was purely a technical approach, we did not take into account security problems. A statistical survey was then conducted using passengers'claims as to their personal bodily injury. Some of the main results obtained are summarized in following Table 1.

TABLE 1

ESTIMATED RISKS INCURRED BY PASSENGERS RIDING THE PARIS METRO

(Including accesses)

	Probability of being the subject of a claim for bodily injury (1)	Probability of being the subject of a claim for severe bodily injury (2)	ADDENDUM : Probability of death Taking in account : uneasiness	Disregarding uneasiness (3)
For a passenger making a single trip	9.6×10^{-6} (1 chance out of 100 000)	9.5×10^{-8} (1 chance out of 11 million)	3×10^{-8} (1 chance out of 33 million)	5×10^{-9} (1 chance out of 200 million)
For a commuter during one year (470 annual trips)	4.5×10^{-3} (1 chance out of 220)	4.5×10^{-5} (1 chance out of 22 000)	1.4×10^{-5} (1 chance out of 71 000)	2.4×10^{-6} (1 chance out of 42 000)
For a commuter throughout his life (50 years use)	0.2 (1 chance out of 5)	2.2×10^{-3} (1 chance out of 450)	7.4×10^{-4} (1 chance out of 1400)	1.2×10^{-4} (1 chance out of 8300)

(1) Meaning : being the subject of a bodily manifestation, however benign (e.g. a scratch) - (1) includes (2).

(2) Meaning : undergoing a fracture, internal injury, amputation, etc.- (2) includes (3).

(3) As regards the time spent in the Metro, (one can show) that the cases of "uneasiness" followed by death recorded in the Metro are statistically at about the same level of those recorded in Paris generally, outside of the Metro.

Some figures may seem high, considering that the safety of the Paris Metro is very good, but one should remember that an estimated risk of death for a car user in France is 5×10^{-4} chances per year.

In order to be able to use these figures as new transportation objectives, it was necessary to define more detailed indicators which would take into account the type of accident encountered. They were classified as follows:

- Passenger related accidents, which are, for example, the assault of one passenger by another : they represent 19 % of the accidents.

- Passenger-system related accidents, which could be, for example, a passenger falling from a moving car through a door carelessly left open by another passenger (this was possible on the older-rolling stock) : they represent 78 % of the accidents.

- System related accidents : they represent only 3 % of the accidents.

The above figures show that in the case under study of the Paris Metro, the percentage of purely technical and operating failures are very low, especially if you compare them with air transportation, where system-related accidents represent up to 75 % of bodily accidents. These figures may also suggest that we should be developing "passenger-proof" systems.

The last step of our endeavor to define quantified safety goals which might be useful was to determine three major indicators :

S : rate of injured in system and passenger-system related accidents. The liability of the carrier is unquestioned.

M : rate of injured following indisposition. The liability of the carrier is unclear, since in certain cases it could have been prevented.

V : rate of injured in passenger related accidents. The liability of the carrier is relatively low.

It also appeared useful to add two sub-indicators of S :

S_1 : percentage of injured in S during collective accidents, since such accidents are those which appear to have the highest incidence on the passengers' perception of safety.

S_2 : percentage of injured in S during passenger-system accidents. This ratio reflect in some way how "passenger-proof" a system is.

The following figures, which state the tolerated number of injured out of a million passengers, were obtained and can be considered as safety goals for new transportation systems.

Indicator	Any injury	Severe injury
S V M	2,28 (a) 0,54 0.6	0.92 (a) 0,004 0,027
S_1 S_2	1 % 97 %	1 % 95 %
(a) Figures are given out of a million passengers		

Safety Study

If, otherwise, we are able to compute the same safety indicators using blueprints of a future transportation system, we could thus state that the system should be as safe as the reference.

The methodology we are promoting for such safety evaluation is directly derived from aeronautics, more precisely from the one developed around 1970 and applied in France for the Concorde certification. It was later applied to the Airbus and Mercure. Let us just remind you that it uses simultaneously Fault Tree and Failure Mode and Effect Analysis, which is a system approach.

Some ground mass-transportation peculiarities should be taken into account, such as different weight to be given to accidents since, for example, it is difficult to consider that a collision at low speed will be fatal to every passenger in the vehicle.

One other particularity, which we have already mentioned before, is the ability the passengers have to bring about system failures. That problem can only be studied by using a "scenario technique" (i.e., What happens if a passenger ... ?).

Today, such a safety approach has only been conducted by MATRA and the RATP for ARAMIS, and another one is under way for POMA 2000. Using this approach, the IRT has realized some less ambitious work, studying the VAL, the Lyon Metro and the Marseille Metro Automatic Train Operation and Control systems (ATO and ATC systems) safety.

To conclude this subject, we would like to underline the weight in such a study of possible mechanical failures. As a consequence we had to investigate, especially for POMA 2000, the field of mechanical reliability.

Mechanical Reliability

Reliability has been developed as a technic since World War II, for weapon systems and more specifically for its electronics application.

Mechanical reliability, as far as we know, has been developed for nuclear engineering, space and oceanographic technics. French test facilities and technical skills are mainly oriented toward nuclear engineering.

Last year, the IRT initiated a study on the POMA 2000 cable grip, the reliability of which is fundamental. The study was entrusted to NOVATOME Industries, a French nuclear engineering company.

The study advised some slight modifications of the grip, and we are going to start an extensive grip testing program, which was defined during this study.

The methodology uses such technics as :

- Cause and consequence charts;
- Fault tree analysis;
- Evaluation of failure probability using stress distribution, computation and s-N curves (stress/cycles);
- Optimization of testing technics for redundant and substitutive systems ;
- Correlation of a "Product Improvement File" (which is an improved failure mode and effect analysis) with a fault tree using "Action Quality Logic."

Once the current process is completed, it is then possible to reduce failure probability by increasing the reliability of critical components, and to help define a testing program as well as maintenance procedures.

Similar studies are to be made on other transportation subsystems, such as the POMA 2000 guidance and switching subsystems.

UPSTREAM RESEARCH

The IRT has been working for several years on linear induction motors for both high- and low-speed applications. Difficulties in testing and predicting performances have led the New Technology team of the IRT to adapt reduced scale theory to electromagnetism. A laboratory has been set up to conduct the assessment of three high-speed linear induction motor designs. We have also been able to verify experimentally the correlation between reality and reduced scale on a new electrodynamic braking system.

We strongly feel that it will also be a useful tool for urban transportation research, such as improving electrical motor design. For example, thinking of the reluctance electromotor of ARAMIS, it will be possible to define the characteristics required for bus transit.

The electromagnetic scaling laws are based upon the conservation of the magnetic induction field in both machines. Thus, we avoid all distortions due to non-linear electromagnetic phenomena. Ampere Theorem, Faraday's and Ohm's laws are kept. The scale model material has to have the same magnetic characteristic equation as the original model.

The following table shows the relation between the parameters of the model and the reduced scale model :

Parameter	Real size	Reduced scale	Relation
Length	L	l	$l = L\ k$
Fields	H	h	$h = H$
Induction	B	b	$b = B$
Currents	NI	ni	$ni = NI\ k$
Time	T	t	$t = T\ k^2$
Frequency	Fr	fr	$fr = Fr/k^2$
Impedance	Z	z	$z = Z/k$
Electromagnetic forces	F	f	$f = F\ k^2$
Power	P	P	$P = P\ k$

CONCLUSION

This paper is obviously not exhaustive, but we have attempted to describe some of the research programs currently being carried out in France. If, on the other hand, we are still working on the development of nearly-operational systems, we are also trying to generate some new upstream research.

PAPER 21

Status of AGT Development in The Federal Republic of Germany

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STATUS OF AGT-DEVELOPMENT IN THE FEDERAL REPUBLIC OF GERMANY

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ABSTRACT. Research and development in the field of urban transportation have been for several years now a very important aspect of the research funding program of the Federal Ministry of Research and Technology. The urban transportation research funding program was started in 1972 and supported through 1977 with a total of almost 222 million DM. With approx. 50 million DM for each of the next four years the program is now financially in a consolidation phase. During this period more than 40 larger projects in the sector of Automated Guideway Transit (AGT) Systems have been sponsored and given financial support. This paper will summarize only the project status of the AGT developments in the Federal Republic of Germany with a very short description of the technical background.

1. OUTLINE OF THE SHORT-DISTANCE TRANSPORTATION RESEARCH PROGRAM OF THE FEDERAL MINISTRY OF RESEARCH AND TECHNOLOGY

1.1 OBJECTIVES OF THE RESEARCH PROGRAM OF THE FEDERAL MINISTRY OF RESEARCH AND TECHNOLOGY

Research, development and planning in the field of transportation have to work towards an integrated comprehensive transportation system, taking the prevailing land use structure into account. The ideal city, designed for the use of private cars only, has fortunately been abandoned but, on the other hand, an urban transportation system capable of fully satisfying all needs and demands is neither available nor is it realizable. An optimal solution to the permanent problems in this field is hardly - and given present financial restrictions - not possible at all. The objective should therefore be an optimal combination of an improved transportation service provided through an extensive and comfortable integrated multi-modal transportation system with, at the same time, high service frequencies and acceptable individual and total costs. To put it more specifically, short-distance transportation should be designed to ensure a division of functions among the existing modes of transportation, so that each mode

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will provide the type of service for which it is best suited by its specific characteristics in order to achieve maximum efficiency for the entire transportation market and the urban land use structure. Any policy decision in the field of transportation must therefore assume a balanced division of functions between the various modes such as private transportation, existing public transport and new transportation systems. This means that the development of new short-distance transportation systems is not aimed at replacing the private car or existing short-distance transportation modes; on the contrary, this development will increase the existing service and its attractiveness, so that urban transportation can become an alternative to the private car in certain areas.
The promotion policy of the Federal Ministry of Research and Technology is set up in such a way that funds are given for the

- development of new transportation systems and for the
- improvement of existing transportations systems

since it has been shown on many occasions that the "old" transportation systems are far off the ceiling of their maximum performance.

Planning of future short-distance transportation systems is not only focussing on the big city but attributes equal importance to the provisions of satisfactory transportation services in sprawling, sparsely populated suburban regions, small towns and in rural areas.
A certain number of maximum requirements can be derived for transportation systems eligible for further (advanced) development and for new types of transportation systems. They are as follows:

- Improvement of service quality, i.e. greater compatibility with the needs of passengers through improved area coverage, high service frequencies of trains and more comfortable and convenient interchange facilities. Safety and reliability must be considered as basic requirements.

- Reduction of capital and operating costs, i.e. considerably improved economic efficiency for operators while providing a high standard of operating reliability.

- Unobtrusive and harmonious integration in the urban land use pattern and townscape; minimum impairment of the environment and positive effects on transport, economy and social structure of an area.

These requirements are rarely compatible and consequently special evaluation methods have to be used to come to a satisfactory, acceptable solution.

As regards the transportation requirements of future short-

distance transportation systems in terms of capacity, network density and service frequency, there is a wide variety of possibilities. Hence, there can be no such thing as "the transportation system of the future". Different systems will continue to perform side by side and in combination with each other within a comprehensive integrated transportation system.

1.2 MAIN AREAS OF ACTIVITIES OF THE RESEARCH PROGRAM OF THE FEDERAL MINISTRY OF RESEARCH AND TECHNOLOGY

The funding program in the field of urban transportation research focusses on three main areas of activity:

- development of personal and group rapid transit systems,
- further development of urban rail and rapid transit systems, and
- further development of the bus system and of demand-operated road transportation systems,

thus responding to the wide variety of existing requirements and applications by a variety of sponsored programs.
Since 1972 the Federal Ministry of Research and Technology has provided under this program funds in the order of 172 million DM. For the period 1978 to 1982 another 170 million DM are planned to be made available. These funds are exclusively provided for research and development up to the stage of first innovation.

The sponsored systems are developed according to the following stages:

- study and conception phase during which basic results on the feasibility and utility of the proposed systems are obtained;
- component development phase during which novel or critical key components are developed and tested;
- technical demonstration phase, in which pre-tested components are integrated into a system and technically tested on an experimental facility under simulated operating conditions;
- operations demonstration phase testing the operating functions of the system on a network under almost real public transport conditions;
- reference operation phase; i.e. when the system is first commercially operated for public passenger transport.

Final conclusions on the impact of a new transportation system on transport and traffic, economy and land use can only be drawn from reference operation.
It is worthwhile to mention at this point that the Federal Ministry of Research and Technology had realized very early that it was as important to incorporate the socio-economic aspects into the research program as it was to put the technical ones into it. As a consequence, contracts were awarded to companies and

institutes that proposed to give answers to such problems as:

- sociological and psychological behavioral patterns of future users
- aesthetic problems linked with elevated guideways
- adaptation of existing safety, type approval and operating regulations;
- integration into the overall transportation system
- consequences for town and regional planning.

Finally, it has been found that the introduction of new urban transportation systems is based on three main factors:

- The technology
  It must be tested thoroughly before first public use and should at that time not contain any significant problems.
- The operators and communities
  They must select the system and buy it with their own funds or with state or federal assistance.
- The public of the implementation area
  They must be convinced that the system is beneficial for almost all and has negative impacts for only very few.

Even for the first introduction of a new transportation system in a reference installation, all three factors must be included in the introduction strategy. This is especially difficult in that the questions put forward by operators and the public can only be given well-founded answers after the experience of a first operation.

In the following part of this paper the status of the AGT-developments will be described together with a short technical review based on the above points, where the research of the group "operator, community and public" is reviewed in one section.

Automated Guideway Transit (AGT) stands in the context of this paper for:

"A type of urban transportation system in which automatically-controlled vehicles operate on fixed guideways along exclusive right-of-way".

This definition covers all systems such as:

- Shuttle Loop Service (SLT)
- Group and Personal Rapid Transit (GRT and PRT) as well as
- Automated Subway Systems and
- Suburban Train Systems (S-Bahn)

Mentioned in this paper, although not quite by definition belonging to the AGT, - but also of great interest - is:

- Light Rail Transit.

2. AGT-TECHNOLOGY

2.1 PERSONAL AND GROUP RAPID TRANSIT

This sector began with the personal rapid transit (PRT) system development and has expanded largely to group rapid transit. The PRT project was one of the first in the research program. Thus a wide field had to be covered by R & D. All components and subsystems had to be considered, and problems of all sorts had to be investigated. Projects in the other areas of the program that were started later profited partly from the results of these developments and, thus became less voluminous and less expensive. At the present time the Federal Ministry of Research and Technology follows up, after a consolidation phase during the last three years, three system families which are described below.

2.1.1 Cabintaxi and Cabinlift

The Cabintaxi (Figure 1) of the joint venture DEMAG and Messerschmitt-Bölkow-Blohm (MBB) is a development which is designed to fulfill the following characteristics:

1. High average speed
2. Individual usage without unwanted fellow-passengers, without changes "en route"
3. On-call operation and 24-hour service
4. Short walking distance to and from station
5. Non-polluting and low-noise operation

Further characteristics logically result from this:

1. Fully automatic operation
2. Exclusive guideway separated from all other traffic (no dual-mode operation)
3. Small vehicles seating 2 or 3 persons
4. Short headways

The development of the Cabintaxi has been projected in such a way that, from the beginning, the use of larger vehicles has been included in the planning. The conception of the vehicles is such, that as many components as possible are used unaltered, or only slightly adapted, for both the small and large vehicles (see Figure 3).

One of the above-mentioned characteristics does not apply to the larger vehicles. The vehicles seating approximately 12 persons do not provide individual usage without unwanted fellow-passengers, without intermediate stops, and without changes "en route". Thus, on the one hand, the system loses some of its attractiveness for the individual user. On the other hand, however, this modification insures simplifications, as for instance in the concept of automation, and furthermore an increase in passenger capacity.

The family of the Cabintaxi is still growing. Besides the vehicle type KK 12 (12 seats no standees, see Figure 2) and after the

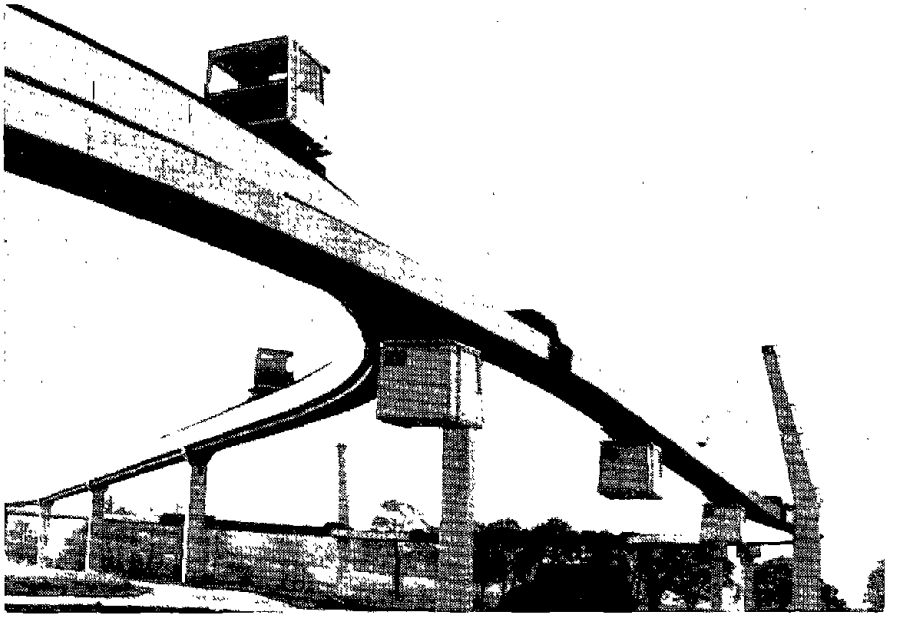


Figure 1: Cabintaxi System - Test Track with KK 3 vehicles

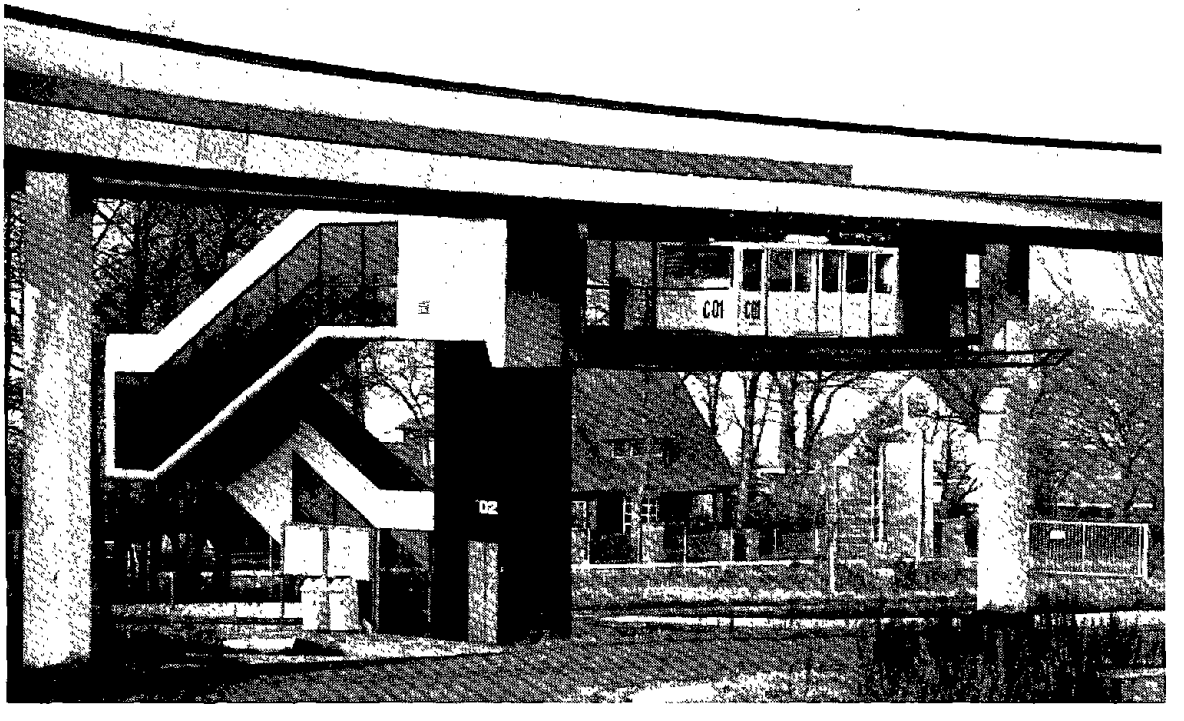


Figure 2: Cabintaxi System - Station on the Test Track with KK 12 vehicle

successful installation and operation of the Cabinlift (vehicle type MK 12) at Ziegenhain District Hospital (see Figure 4) the construction of two new vehicle types MK 25 and MK 50 has begun. The specifications are listed below:

	Vehicle MK 50	Vehicle MK 25
- Size (persons per vehicle)		
· Crush load	60	36
· Design load	50	25
· Seats	10	14
- Speed	30 mph	
- Propulsion and brake	Linear motor and eddycurrent brake	
- Power supply	3 Phase AC	
- Installed power (KW)	70	50
- Coupling for train	Yes	
- Bi-directional	Yes, if necessary	
- Vehicle configuration	Underhanging: MK 50 and MK 25 Overrunning : MK 25	
- Dimension cabin (m)	L 6.0 x W 2.4 x H 2.6	
- Empty weight vehicle (t)	4.3	
- Medium headway (s)	14, with autonomous wayside block system.	
- Specific data		
Installed power per empty weight $(\frac{KW}{t})$	17	11
Design load weight per passenger $(\frac{Kg}{place})$	84	180

The Cabintaxi, at present the most developed German PRT system, has been in the test phase since 1974. On a fullscale test track of 1,500 meters, including two stations, vehicles seating 2 to 3 persons, and more recently also vehicles seating 12 persons are operated fully automatically.

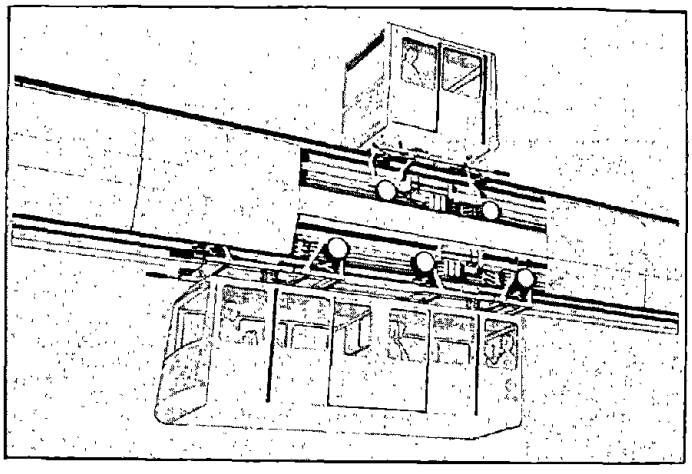


Figure 3: Cabintaxi Small and Large Vehicles on same guideway

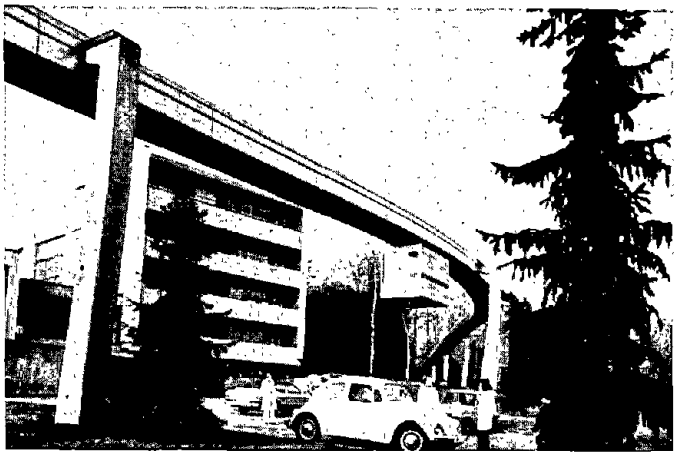


Figure 4: Ziegenhain District Hospital with Cabinlift (MK 12)

The work is concentrated over the next two year period to optimize the economic system performance and to finish certification for safe operation.

Beyond this, in early spring 1978, the detailed planning for a Cabintaxi reference-track in Hamburg will start in order to prove the operation of the Cabintaxi KK 12 version in an environment of public transportation.

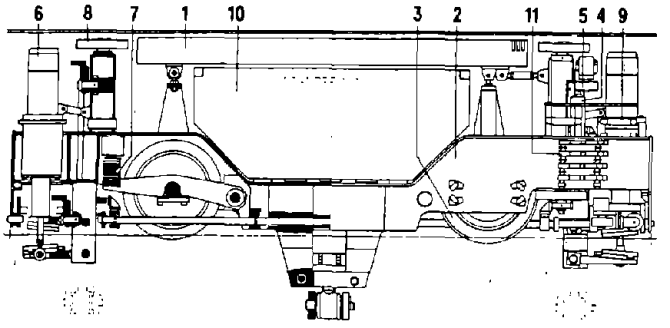
Emphasis is put also on the design of the Cabinlift vehicles (MK 25 and MK 50) and their components that have to some extent be redesigned.
It should be mentioned at this point also, that the Cabinlift system is eligible for the U.S. Downtown People Mover Project.

2.1.2 H-Bahn

Besides the Cabintaxi and Cabinlift the Federal Ministry of Research and Technology sponsors a second development with vehicle sizes from 17 to 69 places. It is the H-Bahn (Figures 7 and 8), a joint venture of the companies SIEMENS and DÜWAG. Its main technical characteristic is that it is a hanging vehicle which has supporting-, guiding- and traction-gear (Figure 5) in the inside of a box-section steel beam closed at the top and at both sides (see Figure 6). Traction is available through dc- and ac-rotory motors as well as through an asynchronous linear motor which is planned for grades up to 15 %.

The same H-Bahn rail is laid out for different vehicle sizes. These sizes allow also demand-operation.
However, the H-Bahn research is concentrated at this time on time-table operation. While the Cabintaxi distance measuring system is based on a signal-reflecting method, the H-Bahn uses a

block system with short block sections that allow short headways.



1 Asynchronous Linear Motor
2 Running Gear Frame
3 Double-Flange Wheel
4 Actuator for Toggle Device
5 Toggle Device
6 Spring Applied Brake
7 Main Wheel Suspension
8 Stabilizing Wheel
9 Informatic Equipment
10 Electrical Equipment Box
11 Current Collector

Figure 5: H-Bahn Cross Sectional View of Running Gear

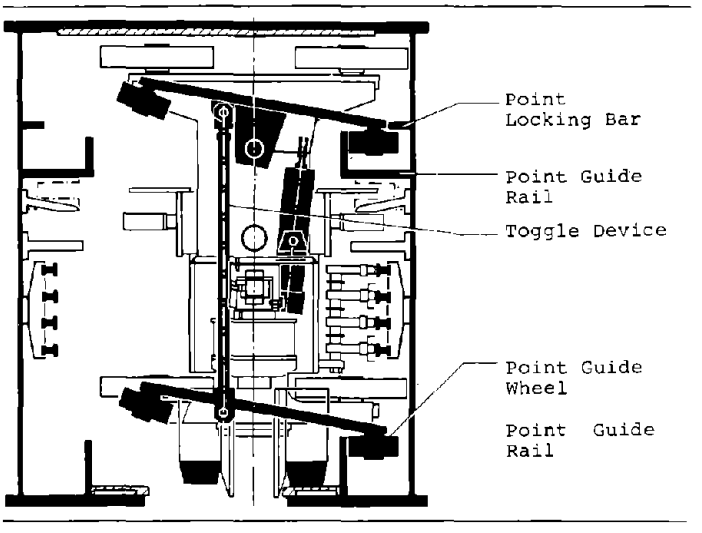


Figure 6: H-Bahn Cross Sectional View of Box-Section Steel Beam in Switch Area with Running Gear

The 1.4 km test track has been completed on the test grounds in Erlangen and extensive component integration tests have begun. It is proposed to test different vehicle sizes (Figure 9) with dc and linear motor drives as well as the command, control and communication system.

Furthermore, the H-Bahn planning group is waiting also for a detail-planning go-ahead for the reference track in Erlangen.



Figure 7: H-Bahn 17-pl. Vehicle on Test Track

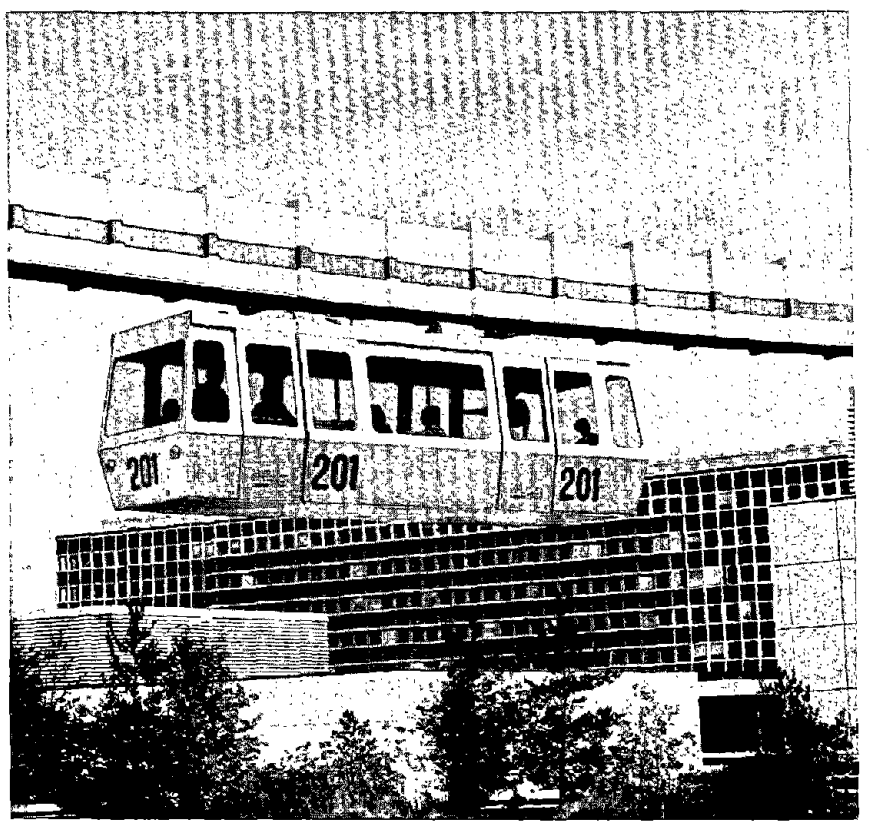


Figure 8: H-Bahn 41-pl. Vehicle on Test Track

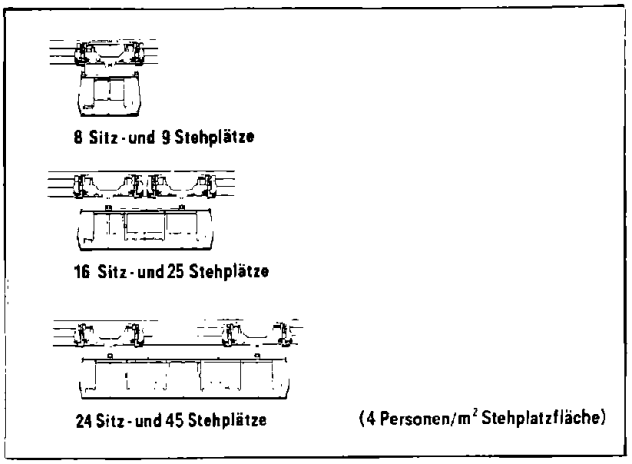


Figure 9: H-Bahn vehicles sizes

2.1.3 M-Bahn

Since two years ago the Federal Ministry of Research and Technology has been sponsoring the development of the M-Bahn (Figure 10) which is characterized through an unconventional magnetic levitation support and traction technique. The advantages of this system, which have been partially supported through tests on the 400 m test-track near Braunschweig, are the following:

- Inactive vehicle because traction, command and control equipment are located in the guideway, due to three-phase travelling field motor (Figure 11).
- No traction transmission in the vehicle, i.e. no third rail.

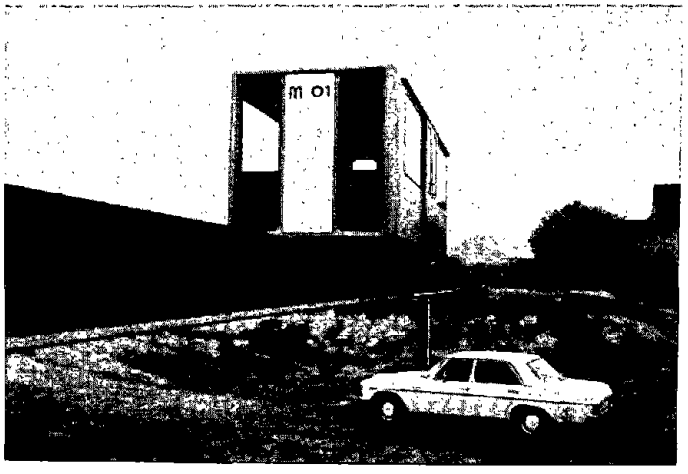


Figure 10: M-Bahn Vehicle

- Low vehicle and guideway structure costs, since weight of vehicle is partially supported by permanent magnets (Figure 12),reduced wear of wheels.
- Very good traction efficiency.

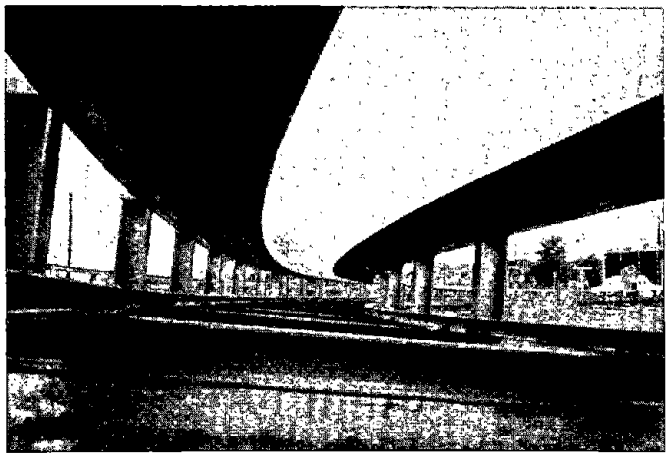


Figure 11: M-Bahn Detail View of the Guideway

Through the design of an inactive vehicle, extremely good cost advantages can be realized. A preliminary study has also shown that the weight of a vehicle is cut almost in half through this technique compared with one of the conventional light-weight vehicles of a Mini-Subway.

During the next year the component tests will be continued. The work concentrates on the trial runs with several vehicles and on the tests of the command and control system.
Furthermore, the specifications for the serial construction have to be defined as well as the safety tests and the approval for public use. Towards the end of the test period a higher speed of the vehicles will also be tried out.

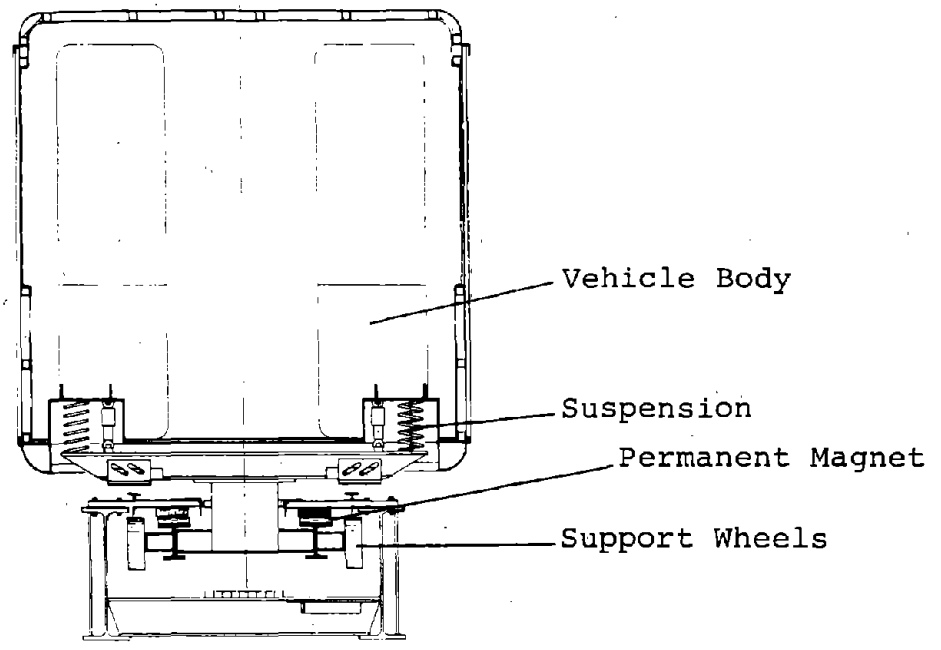


Figure 12: M-Bahn. Vehicle Cross Sectional View

2.2 AUTOMATED SUBWAY SYSTEMS AND LIGHT RAIL SYSTEMS

Over the years, the component parts of the conventional subway and light rail systems have evolved to a level of efficiency which cannot be improved much more through current methods, means and techniques. On the other hand, the present manual operation means rising costs even today and any attempt of improvement by replacement through personnel is condemned from the very beginning to failure, for reasons of economy.

Since the Minstry of Research and Technology could, on the other hand, see that these systems could only be improved mainly through automation and personnel reduction without spending tremendous amounts of money for the infrastructure, it sponsored also this technology sector in the following way.
Between 1973 and 1976, 19 projects in the "Subway and Light Rail Systems" sector were given financial support by the government. The Ministry made funds available amounting to around 44 million DM during this period. As part of the investment program, a further 30 million DM have been set aside for the period 1977 - 1980, for extensive research work in this sector, with the objective of gaining practical experience of the necessary conditions, both in the infrastructure and on the vehicle side, for a fully automated operation.
In addition, private enterprises will also make available consider-

able sums of money for the development projects which they plan to carry out.
The prinicipal objectives of automation in the rapid transit systems sector may be defined as follows:

- service improvements in terms of higher service frequencies, greater degree of punctuality, passenger comfort etc.
- reduction in operational costs by means of a reduction in personnel and more economic use of energy
- guaranteed high reliability and safety standards at operational level.

To achieve these aims simultaneously, it is particularly urgent to find the economic solutions in the following areas:

- complete automation of recurring routine procedures at operational level to achieve low personnel costs and a high standard of service. If possible, personnel should only be used in a supervisory capacity.
- reliabilty tests on all automated equipment (guideway- and vehicle) should guarantee a high degree of practical availability of the automated systems.
- safety approval of the modified command, control and communications sector through the redesign of major safety system parts.
- an analysis of cost-effectiveness should establish whether the total concept will work out to be more economical than the familiar manual operation existing today.

In the following part a review is given of the actual research in this sector. It is important to notice that this work is performed on existing subway and light rail systems.

2.2.1 Subway Automation Hamburg

The work of the subway automation in Hamburg concentrates, after very thorough research in the field of operations (since 1962), on the step-by-step introduction of a subway control system based on a longitudinal inductive control (LZB = Linienzugbeeinflussung) of the trains. The second emphasis is placed on the program that is designed to centralize all dispatching and supervision of the stations.
How valuable such an automation can be, is shown by the following facts of the continuous repeating routine procedures of the subway operations. Actual figures of the subway network Hamburg (90 km; double track) for a daily operation are:

- 32.000 brake applications
- 32.000 corresponding train dispatching procedures
- 5.000 route settings

Two essential features characterize the creation of an operations system for automated subway system networks (see Figure 13):

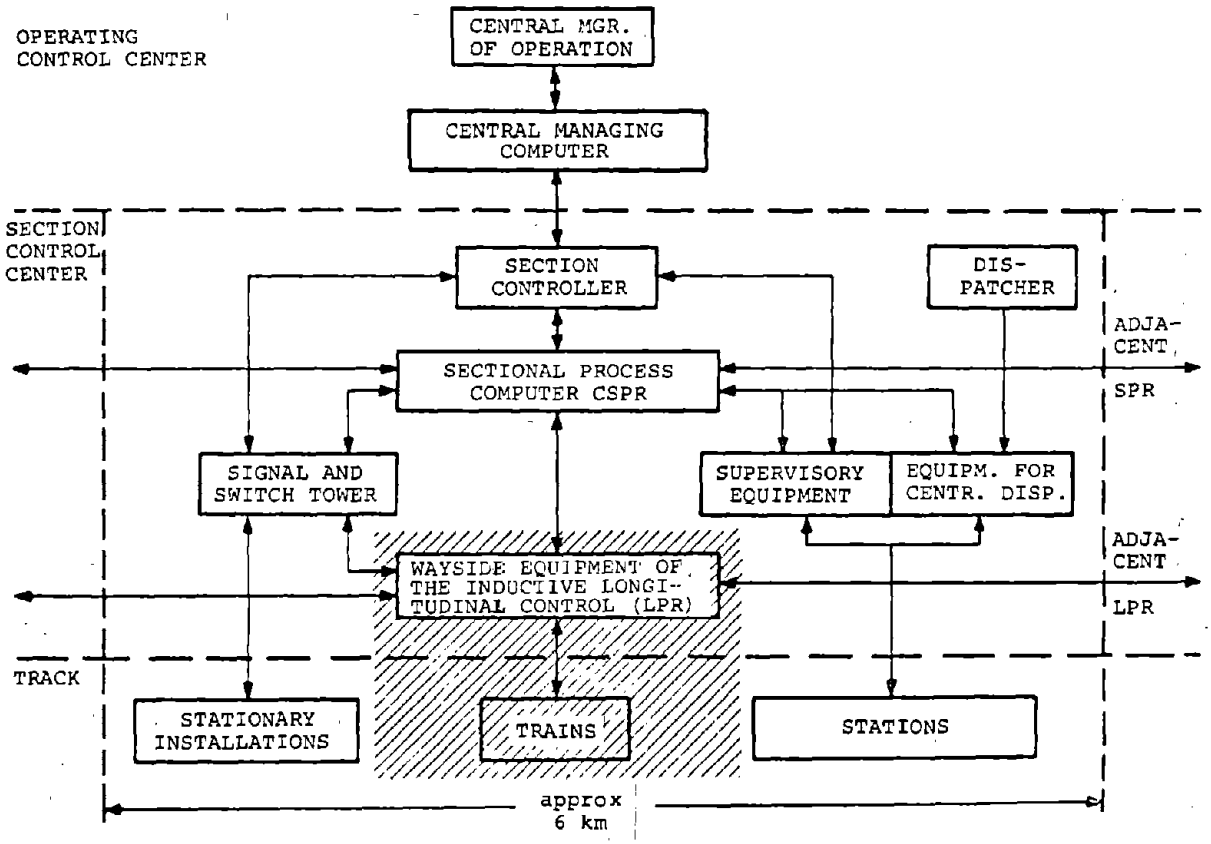


Figure 13: Hamburg Subway System Functional Block Diagram of Automation Principle

- Hierarchical structure composed of several levels differing in the degree to which they can undertake management or safety duties.
- Modular structure of the total system by means of dividing the urban transportation network into several similarly structured traffic centers: all hard- and software components will be similarly divided by the introduction of standardized units and software modules.

The Hamburger Hochbahn AG was awarded a contract in the middle of last year to automate 10 km of its network. The proposed date of operational availability is forecast for December 1980.

The Hamburger Hochbahn is, as operator, the main contractor. Siemens is furnishing the equipment. Besides the demonstration of an automatic train operation also such functions as

- adherence to time tables
- control of train dispatching
- route setting
- train destination indicator setting

- supervision of stations
- etc.

remain to be demonstrated.
The telegram carrying line-wire has been already installed.

2.2.2 Subway Automation Berlin - Operational Demonstration of the SELTRAC Command and Control System

The Standard Elektrik Lorenz AG (SEL) has been under contract since 1972 to design and demonstrate a Command and Control System that allows the personnel-free operation of urban transportation systems. The result after thorough transportation systems studies was the SELTRAC®command and control system.

The SELTRAC system is a totally integrated transportation command and control system; it makes maximum use of the latest techniques and aims at the total automation of the dispatching and control system throughout the complete network of an existing transportation system.
The project places particular emphasis on the automation of vehicles.
The operational control system is composed of three hierarchical levels, each of which is broken down into modular units (see Figure 14):

- Management Center
  - central unit supervising the traffic flow
  - movement of traffic according to timetables
  - control of points/track positions
  - handling of passengers, passenger data
  - operational data compilation
- Operations Center
  - to guarantee a safe, in the technical sense, operation at track level, i.e. supervision of track and speeds of vehicles and/or trains.
- Track Level
  - introduction of fully automated operation based on instructions from the control center. This would include the calculation and communication of point positions and on the other side, the supervision of mechanisms and, in emergencies, the introduction of safety procedures.

The modular structure of the SELTRAC system is designed to make possible, step by step automation of the operation, depending on the following:

- character of the transportation system
- dimensions of the network and passenger quotas
- the degree of existing automation, etc.

Since the system is not primarily designed for specific vehicles, it is possible to use it, with certain modifications, for existing traffic networks, as well as on new networks.

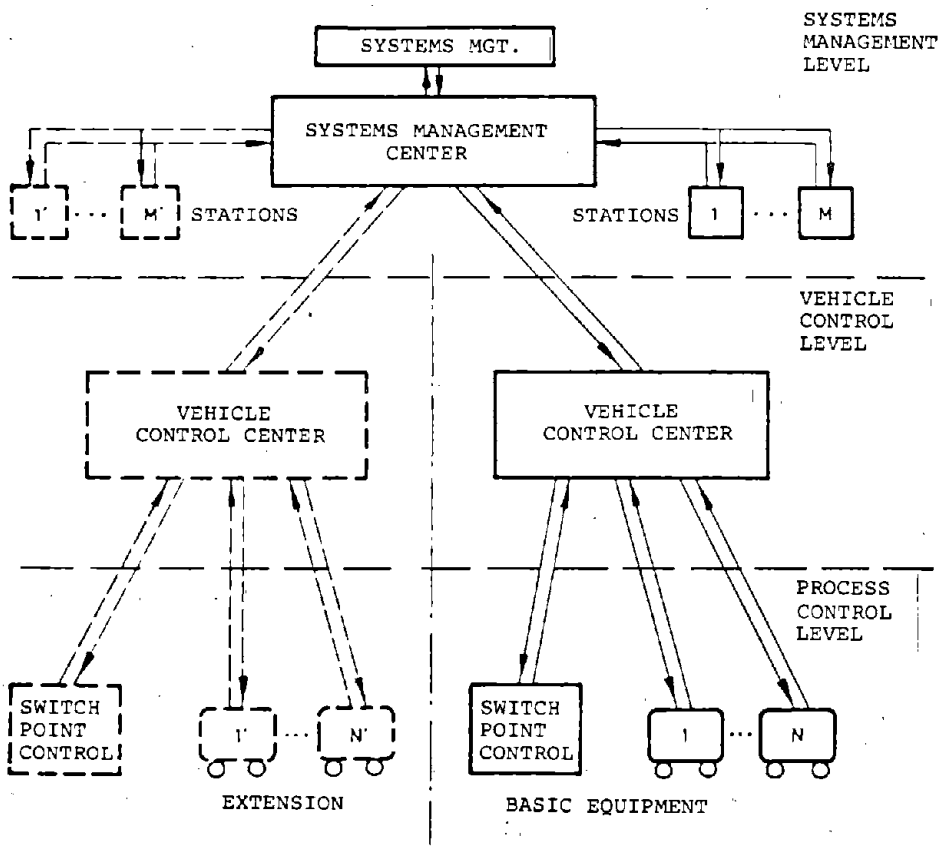


Figure 14: SELTRAC®- Functional Block Diagram

At the beginning of last year the Berlin Transport Authority and SEL were awarded contracts to automate train operation on an old disused test track. For the first time in the Federal Republic of Germany a testing center of this kind has been made available for the use of private industry: a contractual agreement between the Ministry of Research and Technology and the Berlin Transport Authority ensures that the center will be kept available for a period of 10 years and that the Transport Authorities will keep the track in perfect working order. The test track has the following specifications and allows all necessary functions to be tested:

Track:	double track, approx. 1,700 m long
Gauge:	normal gauge, 1,435mm
Points:	7 hydraulically operated points
Track Level:	elevated (surface level +1), ramp surface level (+0), tunnel (surface level -1)
Max. Grade:	3.23%
Min. Radius of Curvature:	108m
Power Supply:	750 V. dc
Max. Speed:	70 km/h schedule of this demonstration

The very tight time schedule of this demonstration project - tests have to be finished by the beginning of the year 1979 -

can only be realized because SEL has already tested parts of its components and functions on another test track. These series of tests in Berlin were mainly set up to demonstrate the adaptability of the SELTRAC system to a subway and to obtain the necessary safety approvals.
In this context a contract was also awarded to the Berlin Transit Authority to install the necessary SELTRAC® equipment on a 5 km double track subway line enabling automatic unmanned operation. According to the time schedule the test runs will begin during the year 1979.

2.2.3 Automation of Light Rail Operation in Hanover

In this project, the emphasis was on the track operation. In the Hanover Light Rail System, two radically different traffic systems are in operation

- in the city centre, an underground track system
- in the suburbs, a ground level operation linked to the above (surface operation).

There are problems in combining the two systems efficiently. For a start, the capacity of the tunnels is limited due to fixed traffic signals installations, emergency exit track and traffic control units. Also, it is impossible to ensure a regulated flow of traffic into the tunnels because of the many delays in the surface operation (level crossings, signals, etc.).
It is hoped that a certain degree of coordination will be achieved through the introduction of a computerized operational control system (Figure 16). The position of trains at surface level will be constantly controlled and corrected by computer, so that the arrival of vehicles at the entrance to tunnels takes place in a sequence as close as possible to the scheduled times. The operational advantages are expected to emerge in the form of fewer interruptions to traffic flow.

The main aim of the Computerized Operational Controls System is therefore to control the intervals between vehicles on the approach sections and thereby ensure a more punctual and regular operation. The Computerized Operational Controls System handles no safety functions as it is limited to control functions in the direction and supervision of the operation.
The main components of the system are:

- mobile data processing unit (vehicle logistics)
- radio link to fix transmitters
- control data processing unit with the necessary peripheral equipment.

In the constant dialogue between the operational center and the vehicle, the driver - as the steering operator - is addressed when necessary over the data transmission unit and receives the relevant driving instructions, for example: accelerate, slow down, start, stop.



Figure 15: Light Rail Operation Hanover
Vehicle with Signalling Equipment

3. DEPLOYMENT AND EVALUATION

It is not only the problem of developing the appropriate technology of an urban transportation system, it is very important also to show that the system

a) is the correct one for a specific city or town considering the transportation requirements (i.e. vehicle size, service form etc.) and
b) that a community, its operator and the citizens want such a system.

In order to get a first impression of suitability, cost and acceptance, the Federal Ministry of Research and Technology has awarded contracts - feasibility studies - to city authorities and operators. In the next section the four contracted feasibility studies will be discussed.

All of these studies follow approximately the same guidelines

- Analysis of present traffic
- Assessment of general suitability
- Selection of a suitable version of transportation systems
- Design of "first" network based upon prognosis for a specified year of service operation (i.e. 1990)
- First estimate of cost and rough selection of network size
- Developing alternative networks and optimizing costs and major evaluation criteria
- Cost - effectiveness analysis for all network alternatives
- Fullscale evaluation of the planning case (including network tracing) for the most promising alternatives
- Sensitivity analysis
- Comparison with alternative transportation solutions on the basis of another cost-effectiveness analysis and recommendation.

This method allows a very strong participation of community, operator and citizen.

3.1 FEASIBILITY STUDIES

The main facts and results of these studies are listed below.

3.1.1 Feasibility Study - City of Marl (Cabintaxi KK3)

- the planning area: City of Marl as a whole, 87 sqkm, 92.000 inhabitants, 40.000 employees;
- characteristics of the system:
  - . basic public transport system for the city of Marl. Bus lines as feeder and distributor to and from the adjacent rural areas;
  - . request transit, direct origin-to-destination service in a closed network of 51 km double guideways with 60 off-line stations and 1600 vehicles (KK3) (see Figure 16);
  - . operational performance: 290.000 passenger-kilometers and 1.0 million place-kilometers per working day;
  - . in the cost-effectiveness analysis the Cabintaxi has been compared to a 13 seat minibus, serving the stations along routes in 2-minute intervals;
  - . result of the cost analysis:

	Cabintaxi	Minibus
operational costs (mil.DM p.a.)	21.111	48.565
amount of investment (mil.DM)	572.875	68.084

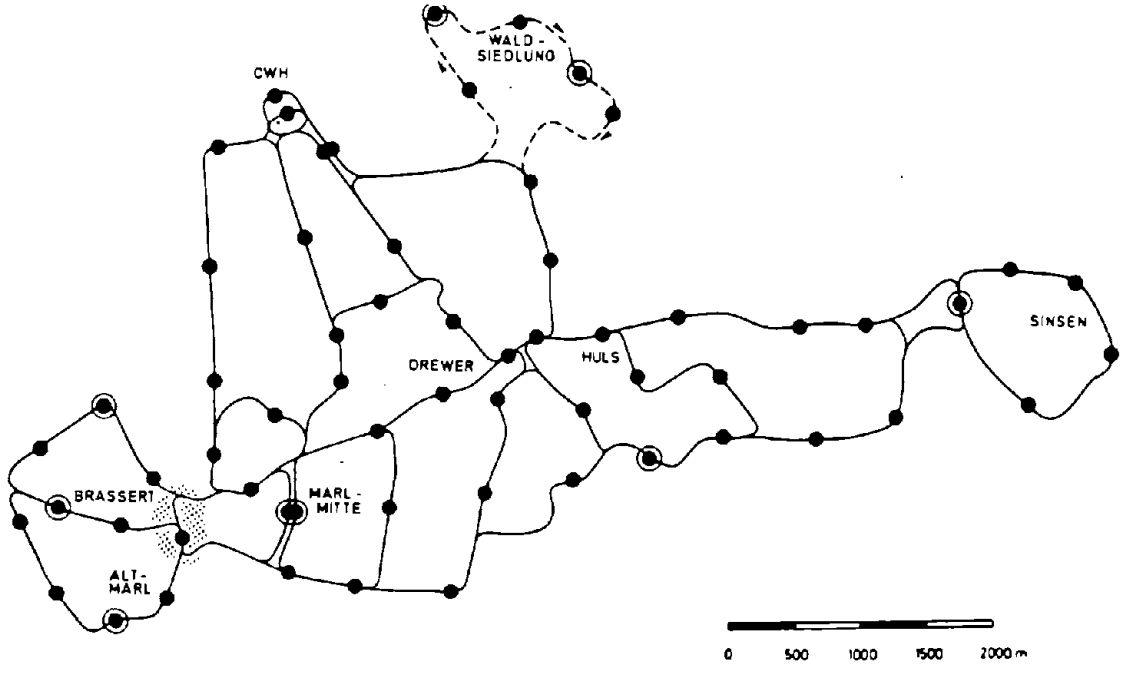


Figure 16: Cabintaxi Network - Marl

3.1.2 Feasibility Study - City of Erlangen (H-Bahn)

- the planning area: City of Erlangen as a whole, 77 sqkm; 100.000 inhabitants, 60.000 places of work, 12.500 students;
- system characteristics:
  - . basic public transport system for the city of Erlangen, bus lines as feeder and distributor to and from adjacent rural areas;
  - . time scheduled service on fixed routes in a closed system with 54 kilometer single guideways, 50 stations and 115 cabins (see Figure 17);
  - . 275.000 passenger-kilometers and 1.7 million passenger-place-kilometers per working day;
  - . in the cost-effectiveness analysis the system has been compared with a conventional city bus, serving the stations at short intervals;
- result of the cost analysis:

	H-Bahn	Bus
operational costs (mil. DM p.a.)	19.144	26.0
amount of investment (mil. DM)	444.519	83.058

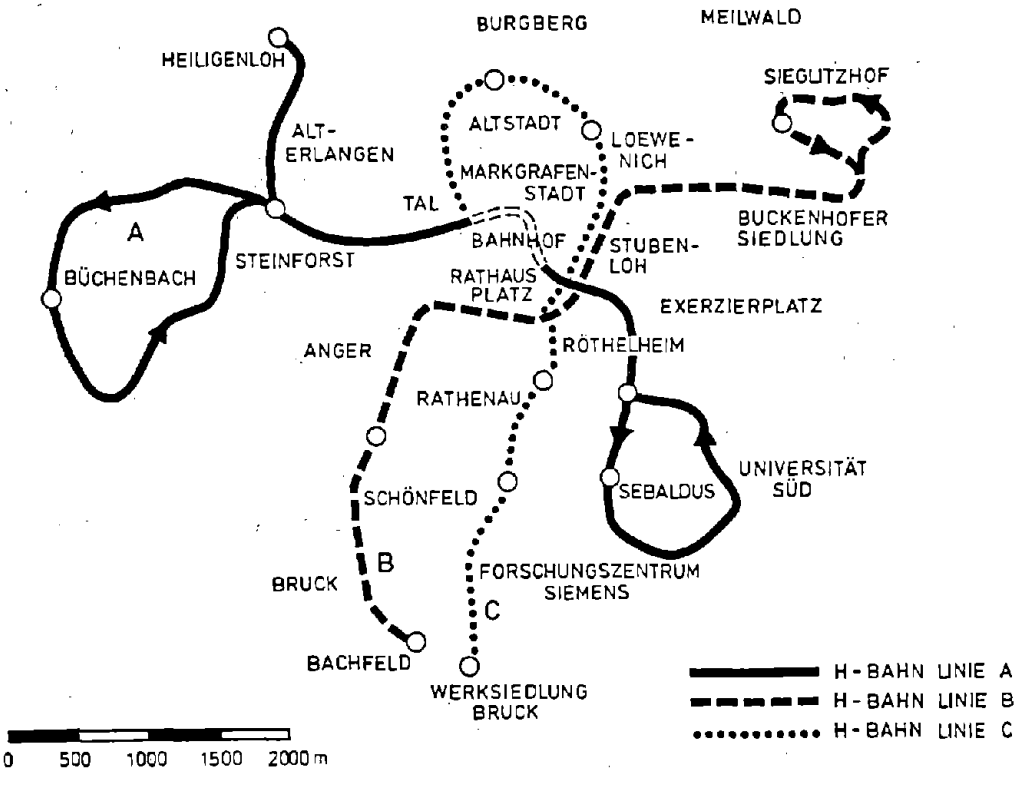


Figure 17: H-Bahn Network - Erlangen

3.1.3 Feasibility Study - City of Hamburg (Cabintaxi KK12)

- the planning area: A district in the northern part of the city of Hamburg, 12.4 sqkm, 100.000 inhabitants, 51.000 employees;
- characteristics of the system:
  - . feeder and distributor for the subway and commuter system, serving the whole area exclusively;
  - . demand actuated service in a closed network of 30.2 km double-guideways with 38 stations and 180 vehicles (KK12);
  - . 0.138 million passenger-kilometers and 0.518 million passenger-place-kilometer per working day;
  - . in the cost effectiveness analysis the existing conventional bus-service and a fictive combination of conventional bus-service and an additional subway section have been compared to the cabintaxi.
- result of the cost-effectiveness analysis:

	Cabintaxi	bus	bus/subway
effectiveness	7.5	5.2	5.2
operational costs (mil. DM p.a.)	6.7	9.1	11.1
amount of investment (mil. DM)	367.7	19.8	323.2

3.1.4 Feasibility Study - City of Berlin (Cabintaxi, Cabinlift, H-Bahn)

- planning areas: 2 districts in the northern and northwestern part of the city of West-Berlin, 14.17 resp. 11.57 sqkm, 79.000 resp. 62.000 inhabitants, 22.000 resp. 16.000 employees;
- system characteristics:
  - . feeder and distributor for the subway and commuter system, serving the districts exclusively;
  - . demand actuated resp. time scheduled service in closed networks of around 30 resp. 25 kilometers routes with around 39 resp. 33 stations;

Since the study is still in progress no further data are available up to now.

3.2 CITIZEN PARTICIPATION

An unknown factor of implementation, especially for elevated track systems, are the neighbors and users of the system, or, in other words, the kind of necessary public participation in the planning. Planning games with citizens have produced up to now the following results:

1. The citizens showed an extraordinary willingness to participate intensively.

2. Their ability to understand the economical and technical problems of a system and to present well-founded arguments amazed both the representatives of the city council and the planning experts.
3. The planning games showed that the public understands formalized assessment methods and cost-effectiveness analysis and that they are able to establish goal hierarchy and to assess their varying degrees of importance.
4. The arguments of the public participants were mainly concerned with general interest concepts. Individual concerns remained in the background.
5. As intended, the public participants did not only play but also planned in the planning game. In the process, for example, they found a route in a densely populated residential area which was adopted by the planners and city officials, as it was based on the participant's more intimate knowledge of local conditions.
6. The advantage of the citizen-participation as tested here shows its importance not only in providing a basis for legitimatization of community planning by including the public in the decision-making process, but also to improve the planning itself through utilization of the public's better knowledge of local conditions.

These constructive results show that the public participation, even at a very early stage, can only be evaluated as positive.

For this reason the Federal Ministry of Research and Technology also sponsors with emphasis in the research program studies testing and analyzing the reaction of citizens. The collaboration concentrates on basically two sectors:

- Participation in the planning process selecting network alternatives.
- Participation in distributing emphasis in order to create a realistic goal hierarchy in the framework of a cost-effectiveness analysis.

4. TECHNICAL SUPPORT STUDIES

While the above described research program had as its goal the design and development of a new transportation system or a part of it, many problems did either not fit into the project, or were recognized at a later point or as problems which had interdisciplinary character (i.e. the operation problems). Only a few of these are mentioned below. Because they are of limited financial size, compared with the designing or redesigning of a system, the status is explained together with the objective.

4.1 SUPPLEMENTARY OPERATIONAL AND TRANSPORTATION REQUIREMENTS FOR THE UNMANNED OPERATION OF AGT

Parallel to the activities of the private sector there were many

questions put forward by the future operator of AGT such as:
- the real practical value of an unmanned operation in terms of passenger problems
- research on working models to establish the most practical size of vehicles as the basis for the development of a small underground vehicle.

This resulted in the study with the above title.

The emphasis of the research is not on the development of new techniques, but on the construction of a small underground transport vehicle, suitable for automation. Particularly high standards are of great importance in this context, since any errors in an unmanned operation would be certain to have a much greater effect on the total operation than in the traditional manned set-up, where the driver still has the chance of intervening.

The development of an error identification and evaluation system for installation in vehicles is of prime importance:
its function would be to investigate the appropriate corrective procedures in the event of errors.

Operational procedures for the elimination of break-downs and disturbances should be examined and laid down, together with the work listed above. These should cover all operational functions, and in particular, the automatically controlled operations (e.g. broken-down vehicles, power cuts) and the communication system.

4.2 DC - CHOPPER TECHNIQUES FOR LIGHT RAIL SYSTEMS

This project is concerned in particular with the following points:

- the effects of electrical interference on command and control systems (vehicle and guideway) as well as on power supply installations
- energy conservation by regenerative breaking
- economic analysis of conventional traction methods.

It should be mentioned at this point that the Light Rail System in Hanover will be equipped with the dc-chopper technique and the Authority has placed an order of 100 new vehicles.

4.3 "COMPARATIVE STUDY OF EXISTING AND FUTURE SHORT-DISTANCE TRANSPORT TECHNOLOGIES" AND "INVESTIGATION OF OPERATIONS"

While the feasibility studies listed unter section 3 were oriented towards one city and one system, with the exception of the latest one for Berlin, the Federal Ministry of Transportation has initiated two studies, the one of which had as objective the comparison of different systems for the same application (SNV I-Study).

Since it became clear during the work on the SNV I - Study that many technical points had to be left unanswered due to a lack of accuracy in the data base and calculation, the Federal Ministry of Transportation expanded the work with the objective to design a planning and decision instrument. The emphasis was to be on an operations simulation and an evaluation program that allows the production of several alternatives in quick succession so that decisions could be made in very short time periods (SNV II - Study).

Acknowledgements

The author wishes to thank the German Federal Ministry of Research and Technology and the German Federal Ministry of Transportation as well as all mentioned Companies and Transit Authorities for their help in furnishing details for this paper.

PAPER 22

Automated Highways

Fred Okano
Federal Highway Administration

AUTOMATED HIGHWAYS

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Good afternoon, ladies and gentlemen. As Arthur Priver just said, my name is Fred Okano. I am from the Federal Highway Administration and I am the program manager of the project called the Automated Highway System. Duncan MacKinnon and Arthur have asked me to introduce our next speaker, but before I do, I would like to express my appreciation to Duncan for giving us this opportunity to address such a distinguished international group and for letting the other side of the house, namely, the automobile group, make its presentation. Duncan and I have been in touch now for a number of years and my presence here is proof that the automobile people and the mass transit people do talk to each other.

The Automated Highway System is a system of vehicles that are driven manually on ordinary streets, and automatically on special guideways. Now, many of you are going to say, "Say, wait a minute. That is a Dual Mode system." Well, within the DOT a distinction has been drawn between these two systems. The Automated Highway is a privately operated vehicle. Automobile-sized vehicles, trucks, and buses are included and all are capable of both local trips and also long distance, high-speed driving. Dual Mode, on the other hand, is an urban mass transit vehicle and all of the driving is done by employees of the mass transit company.

Now, the objective of our program is to evaluate the technical and human factors, and the social, the economic, the legal, and the environmental feasibilities of the Automated Highway System.

Yesterday Duncan stated that his current program is at 12 million dollars. Our comparable figure for that is several hundred thousand dollars. So our effort is at a much lower level than UMTA's.

Presently we have two contracts. One is with the Ohio State University, and our next speaker will discuss that part. The other contract we have is with the Calspan Corporation, and their objective is to study the costs and benefits of these systems.

Well, both our study and an earlier one by TSC have indicated that these kinds of vehicles are applicable, or have potential for application, in the northeast corridor and in the Los Angeles to San Diego corridor, plus 44 urban areas. A coast-to-coast automated trip does not seem feasible within this century.

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As our previous speaker mentioned, an automated system is very difficult to justify. The issue of subsidy has been raised, and, as you all know, this is a dirty word. And so we are trying to determine whether subsidies are really needed. As Duncan pointed out yesterday, our eventual goal is to develop the system specifications, but first we must settle things like subsidies and lack of standardization.

Let us say that we would like to drive this vehicle automatically from City "A" to City "B", and within both of those cities we would like to share guideways with the local Automated Guideway Transit vehicles. Now, if City "A" and City "B" have different systems, this is going to be difficult, if not impossible, to do. However, it is too early for each of these cities to standardize on one mass transit type vehicle. These are the kinds of problems we are faced with. So before we can develop the systems specifications, we will be making further studies.

Now, without further ado, I would like to introduce the next speaker, Dr. Robert E. Fenton, who is a Professor of Electrical Engineering at the Ohio State University. He is the Principal Investigator on our contract.

PAPER 23

Automated Highways: Research Activities at Ohio State University

Robert Fenton
Ohio State University

AUTOMATED HIGHWAYS: RESEARCH ACTIVITIES AT OHIO STATE UNIVERSITY[1]

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ABSTRACT. Research activities, which are focused on the achievement of safe and efficient control of automated vehicles under high-speed (to 93 ft/sec), small time-headway (1-2 sec) conditions have been in progress at Ohio State University (OSU) for some thirteen years. The general focus of this program has been directed toward developing the essential control technology with a strong emphasis on the field evaluation of designed components and control subsystems.

Various past accomplishments are summarized, and present efforts are discussed in some detail. The primary focus of the latter is the implementation of a physical test facility for evaluating various aspects of: sector-level control, communications between each vehicle and a sector computer, the development of techniques for obtaining accurate estimates of a vehicle's longitudinal and lateral states, and the control of individual vehicles.

OVERVIEW

A general control hierarchy, which could be employed with an automated vehicle system, includes a central controller to oversee network operations with this including the coordination of activities in the individual geographic regions comprising the network. A second level of control would be at the regional level. Each regional controller would supervise the activity in a number of sectors and control the vehicles in those sectors via appropriate commands to the sector computers which comprise the third level of control. The fourth, and lowest, level of control is that of the individual vehicle. This hierarchy could be employed in conjunction with either a synchronous or a quasi-synchronous control strategy.

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[1]This work was sponsored by the Federal Highway Administration. Its findings reflect the views of the author who is responsible for both the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This work does not constitute a standard, specification or regulation.

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The present OSU efforts are focused on the development of a physical test facility which can be employed to study control and communication problems at, and below, the sector level.[2] This facility, which is located at the Transportation Research Center of Ohio (TRCO), has the geometrics shown in Fig. 1. The length of the shown closed-loop path is some 21,000 ft, and this is considered sufficient to approximate a "typical," single-lane highway sector.[3]

The instrumentation to be installed (or already installed) in this facility includes:

a) A sector computer;

b) Communication links for achieving both computer-to-vehicle and vehicle-to-computer transmissions;

c) Information sources embedded in, or located nearby, the guideway and intended to supply state reference information to the sector computer; and

d) Information sources to supply state information to each controlled vehicle.

This facility, when completed, will provide an embodiment of the sector configuration shown in Fig. 2.

SECTOR COMPUTER

The tasks to be performed by the sector computer include the following:

a) The generation of acceleration, speed, position, and lateral motion commands for each vehicle within the sector. (Under normative conditions, these commands would be selected at a regional (or higher) level, generated at the sector level, and transmitted to the controlled vehicles in a condensed form).

b) The initiation of emergency operations when necessary (such a decision would be based on status information received from various sources such as a regional computer, adjacent sector computers, the controlled vehicles within a sector, and guideway-based information sources. The actions taken would include (a) The revision of previously specified vehicle command trajectories, and (b) The communication of an "emergency alert" to other control sources).

c) The accomplishment of vehicle transfer via communications with

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[2]Control at the regional and network levels was considered in an earlier effort (1).

[3]In addition to the closed-loop path, it is planned to provide additional segments for merging, diverging and lane-changing operations.

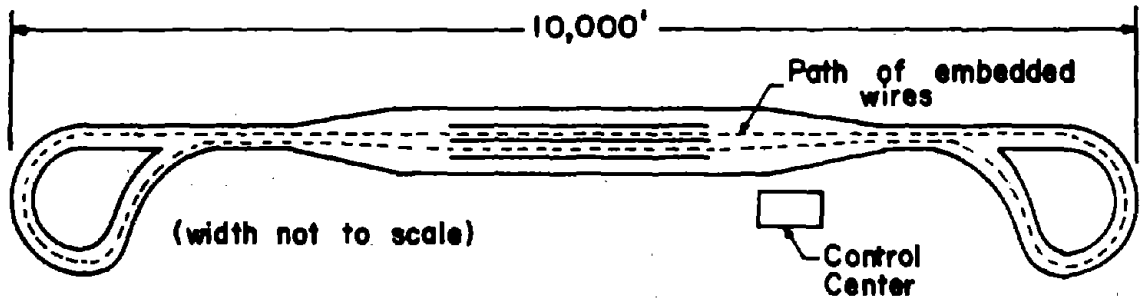


Fig. 1 Geometrics of automated-vehicle test facility.

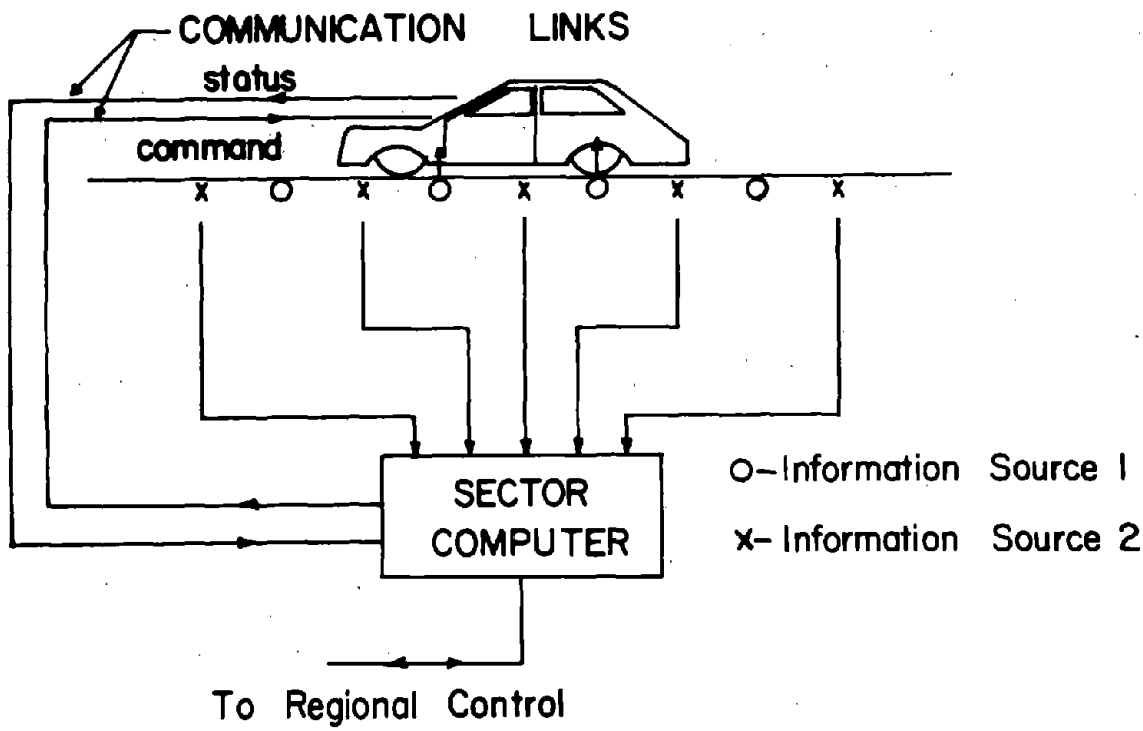


Fig. 2 The basic elements of a sector-level control configuration.

adjacent sector computers, the vehicles, and/or the regional computer.[4]

The required functions could be performed by a general-purpose microprocessor provided appropriate special-purpose hardware (digital processors, memories, interfaces, etc.) were also employed. A commercially available unit (a DEC LSI - 11/03) was selected for implementation, and it is currently being interfaced with the necessary external units (2). The composite unit, when completed, should be a flexible, high-performance controller capable of handling up to 200 vehicles simultaneously.

SECTOR-LEVEL COMMUNICATIONS

In general, little effort has been devoted to studying communications between a sector-level computer and the vehicles under its control. The efforts at OSU have thus far been confined to the specification of the communication requirements for a typical sector.

Note from Fig. 2 that the computer is the source of command information (command acceleration, command speed, and command position) and the controlled vehicle(s) is a source of status information -- vehicle acceleration A(t), vehicle speed V(t), vehicle position X(t) and other data. The information content of these sources is largely dependent on the operating policy of a sector, and is thus strongly influenced by technical and economic constraints and safety considerations. For one particular policy, it was estimated that a two-way bit rate of approximately 300 bits/sec/vehicle would be required (2).

As reliable communications must be maintained at all times, a large signal-to-noise ratio ($\geq$ 20 db) would be necessary to decrease the probability of random errors; also, cyclic block codes should be employed to protect against spurious (burst) noise sources. In addition, strict synchronization must be maintained for two reasons:

a) To provide effective clocked communications between all transmitters and receivers; and

b) To provide the necessary time reference for the vehicles' commands.

Initially, it is planned to achieve communications via a radio-frequency link. Subsequently, it is planned to employ an induction-field approach -- if the required bit rates can be achieved in a safe and efficient manner.

INFORMATION SOURCES -- LONGITUDINAL CONTROL

There are two types of information-source configuration for longitudinal control -- one to provide state information to each controlled vehicle,

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[4]When a vehicle leaves one sector and enters another, the control must be transferred from one sector computer to a second. This involves coordination of both sector computers, the vehicle and the regional computer.

and a second to provide this information directly to the sector computer. The efforts undertaken to date have dealt only with the former.[5] Here, several sources have been evaluated in terms of the following requirements:

i) The signal(s) available at the receiver onboard each vehicle should be easily processable to yield accurate measurements of X(t) and V(t)[6] (e.g., to within 0.1 ft and 0.5 ft/sec, respectively);

ii) This signal sould have a large signal-to-noise ratio and be essentially unaffected by the environment;

iii) The signal should be available in an unambigious form over the expected range of vehicle state deviations -- both in the lateral and longitudinal direction; and

iv) The information source must be highly reliable so that the probability of a failure is extremely low.

The general approach taken toward obtaining a continuous measurement of X is depicted in Fig. 3. Here, widely spaced position markers, hereafter referred to as absolute position markers, would be employed to provide a positive indication of a vehicle's absolute position when that vehicle passed over a given marker. This would be achieved by employing the detected signal to zero a vehicle-borne counter. Intermediate position markers would be located between the absolute markers, and the vehicle counter would be advanced as it passed each such marker.

The probability of an error buildup could be greatly reduced if a unique signal were available at every nth marker as shown. Between markers, position interpolation would be employed.

A number of devices, including permanent and ac-excited magnets and laterally positioned, current-carrying wires could be employed as guideway-mounted position markers. A desirable choice for an absolute marker is a magnet because of its high reliability, good reported position resolution (within 1 in), insensitivity to environmental factors, and low-noise properties. Permanent magnets would have the additional advantage of being passive and requiring no maintenance. Another desirable choice is a very narrow, current-excited loop. The position of one side of this loop can be detected to within ±0.06 in at high speeds (3) and, if desired, the loops could be excited so that a vehicle's passage over a specific loop could be uniquely identified.

It was decided to employ very narrow (1-ft wide in the longitudinal

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[5]Even if sufficient control information were available from this type, the second type would still be highly desirable for purposes of redundancy and hence reliability.

[6]Ideally, A(t) should also be obtainable; however, there is presently no efficient, accurate and economical approach for obtaining this quantity from a guideway-based sensor.

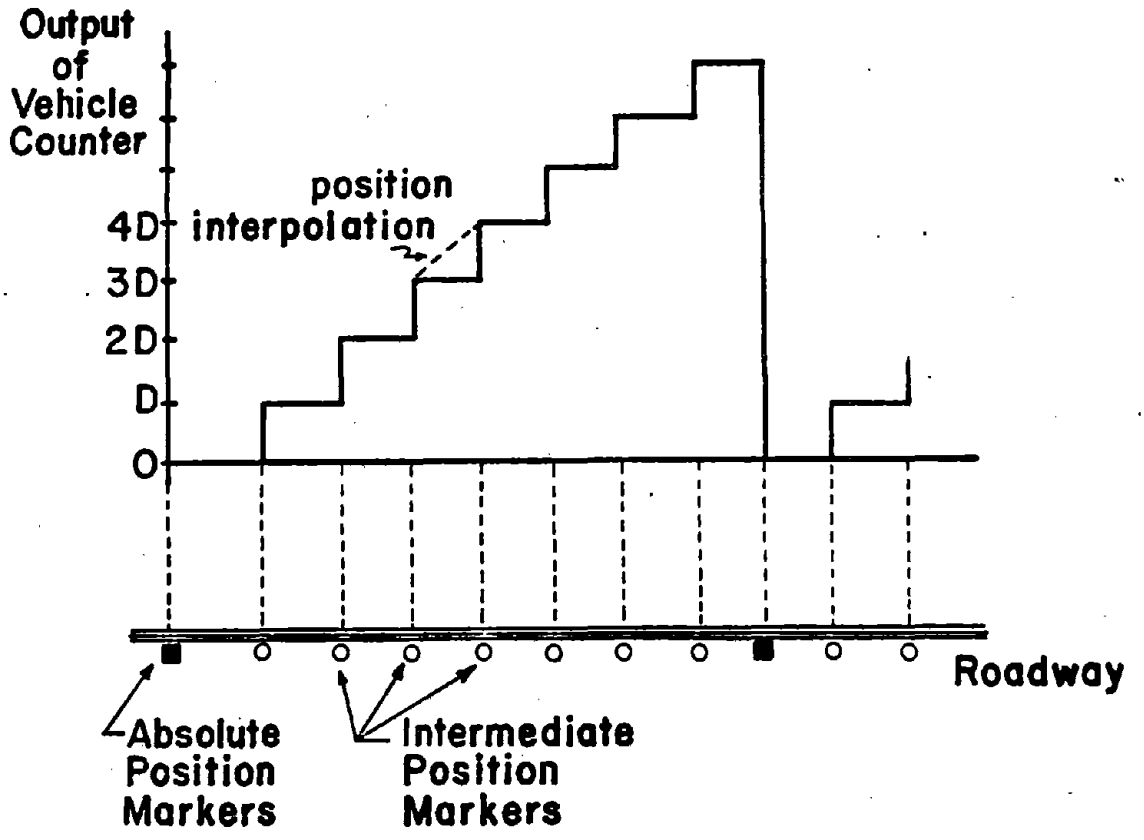


Fig. 3 A discrete-element, information source with position interpolation.

direction), current-excited loops, spaced at 500-ft intervals for the absolute markers. Two such loops, spaced two feet apart, are employed to mark the beginning (and end) of the 21,000-ft "sector."

Two approaches toward the realization of intermediate position markers with a position interpolation feature have been evaluated at OSU. In the first, Mayhan (4) employed a pair of current-excited, helically wound, circular, transmission lines, set in a roadbed to produce an induction field which was detected by probes onboard a vehicle. Via relatively simple processing of the detected signals, a periodic "sawtooth" waveform, stationary in space, was obtained. This provided both intermediate position marks as well as a continuous linear signal between marks. Mayhan is currently developing a "flat" helical transmission structure which can be more easily implemented than a circular structure (5).

In a second approach, a current-carrying wire, in the configuration shown in Fig. 4, is employed to provide a position signal every 2 ft. Here the phase reversal of the vertical component of the magnetic field, which occurs at each crossover (every 2 ft in Fig. 4), is sensed by appropriate vehicle-mounted coils. These phase reversals tend to remain directly above the wires, even

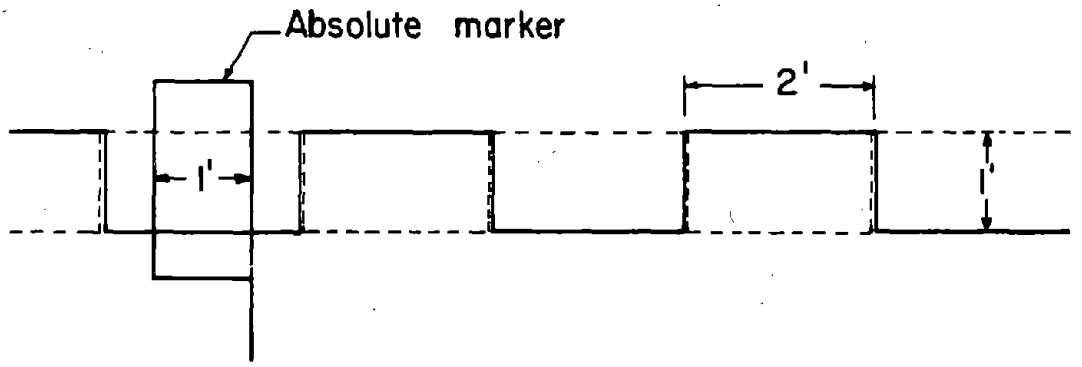


Fig. 4 Spatial square waves of wire installed under the roadway surface.

when steel-reinforced, roadway materials are present, and wire position can be measured to an accuracy within 0.06 in at speeds up to 100 ft/sec (3). This configuration has been installed over the complete extent of the path shown in Fig. 1. The frequency of the current flowing in these lines is different from that employed in the loops spaced every 500 ft; thus, a unique signal is available from the latter.

Position interpolation between the 2-ft marks can be accomplished in various ways with virtually any of these being satisfactory in so far as normative control is concerned. One approach is to use a wheel tachometer, filter the noise, and appropriately integrate to obtain the required interpolation. This works well in situations where V is not rapidly changing, as one can employ dynamic calibration procedures to obtain a good estimate. Such effects as slipping wheels would not be especially critical here.

However, the effects of wheel slippage are exceedingly important in one essential mode of vehicle control -- emergency operation. There are two primary reasons for this importance:

a) The need for an accurate V signal in the control of a rapidly decelerating vehicle; and

b) The need for such a signal in the detection of an emergency situation.

Thus, one concern was obtaining as accurate a measurement as possible. Given such a measurement, it can be used for position interpolation under normal conditions and in emergency detection and subsequent control.

Several approaches toward obtaining an accurate velocity measurement were evaluated, and two of these appeared quite promising. The first involved a Doppler radar speedometer used in conjunction with small metallic reflectors beneath the roadway surface. The latter resulted in an extremely

strong returned signal which could be processed to yield V to within ±0.5 ft/sec under both normal and high-deceleration situations (3), (6). In addition, the returned signal was virtually unaffected by vehicle pitch and roll, i.e., a JANUS configuration was not required.

A second approach, which is currently under study (2), would involve a conditional-feedback scheme wherein an accelerometer, tachometer, and crossed-wire detector would be employed to yield continuous estimates of A, V, and X. The signals would be processed in a manner which would reduce (or eliminate) the effects of various measurement errors (accelerometer bias, wheel-slip, variations in the crossed-wire spacing, etc.).

INFORMATION SOURCES -- LATERAL CONTROL

A detailed study was made of various approaches toward achieving "electronic" steering. This included the evaluation of magnetic fields set up by various configurations of current-carrying conductors, the magnetic-distortion effects caused by nearby steel structures, and data-processing techniques to overcome the effects of such distortion and provide an accurate indication of a vehicle's lateral state (7).

This effort culminated in the selection of a one-wire configuration -- primarily since the magnetic-field distortion was relatively small in this case. This configuration was installed over the 21,000 ft closed-loop path of Fig. 1, and it is located in the "center" of the spatial, square-wave configuration as shown in Fig. 4.

At present, an evaluation of two or more lines, each excited at a different frequency, and intended for use at lane changing and/or diverge points, is being conducted under both laboratory and full-scale conditions.

VEHICLE LONGITUDINAL CONTROLLER

In the mid-1960's, it was decided to employ a car-following approach to vehicle control. The corresponding studies were conducted over a 6-year period and ranged from analytical investigations to the full-scale evaluation of a multi-mode controller. Here, the control mode in a following vehicle was dependent on its state relative to the nearest lead vehicle (8) - (12). The full-scale evaluation was conducted at speeds up to 100 ft/sec in various lead-car overtaking, emergency braking, and car-following situations, and the following vehicle was safely, efficiently and comfortably controlled in all cases.

In the early 1970's, it was decided to adopt a quasi-synchronous approach to vehicle control for various reasons including the following:

a) The lack of an accurate device (e.g., a radar unit) for providing a following car with sufficiently accurate state information for safe operations at moderate-to-small headways;

b) The communication problems associated with vehicle control at complex traffic interaction points; and

c) The increased collision costs associated with a "serial" buildup of reaction delays in an emergency situation.

All subsequent work was thus focused on vehicle controllers which would be controlled (in normative situations) relative to an absolute desired state. The previously described efforts on information sources were consistent with this emphasis.

An initial focus of this work was the specification of a model of vehicle dynamics which could be employed for both small- and large-signal input conditions.[7] A nonlinear model was empirically derived (13), and employed in the design of a point-following, vehicle controller (14) - (15). This controller was extensively tested under field conditions and excellent tracking (≤0.6 ft position error in online situations under both small- and large-signal conditions over a wide speed range), a comfortable ride, good insensitivity to large disturbance forces, and a virtual insensitivity to variations in critical controller parameters were obtained.

The current efforts are focused on the development of a generalized vehicle model, which would pertain to both propulsive and braking situations, and its validation for several vehicle types. In addition, vehicle control under emergency braking conditions is under study.

VEHICLE LATERAL CONTROLLERS

Various vehicle lateral controllers have been designed and evaluated under field conditions. In all cases, the guidance signal was provided electronically (i.e., by means of either a one-wire or a two-wire reference configuration). Excellent tracking (lateral tracking errors ≤ 0.21 ft. on both straight and curving roadway sections at speeds up to up to 117 ft/sec (80 mph)), good insensitivity to disturbance forces, and a comfortable ride (lateral acceleration <.05 g for all speeds up to 117 ft/sec) were obtained with a relatively simple controller (16). One minor deficiency of this controller, which however, did not affect either controller performance or ride comfort, was a decrease in damping with increasing speed. This was due to the velocity dependence inherent in the test vehicle's lateral dynamics.

This controller is presently employed for the lateral control of a dual-mode test vehicle; however, another controller, whose characteristics are velocity independent, is being evaluated.

SUMMARY

Research activities, which are focused on the achievement of safe and efficient control of automated vehicles under high-speed (to 93 ft/sec), small time-headway (1-2 sec) conditions have been in progress at OSU for some thirteen years. The general focus of this program has been directed toward

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[7] The previously designed car-following controller utilized only small and/or slowly varying signals over the range of expected line speeds, and a relatively simple model could be employed in the design process (10). However, this model was unrealistic for large-signal, rapidly-varying inputs over the range from 0-93 ft/sec.

developing the essential control technology with a strong emphasis on hardware evaluation; thus, many of the reported activities have involved field studies of designed components and control subsystems.

The present focus is on the implementation of the sector-level facility shown in Fig. 1. This facility is now partly operational as the information sources for both lateral and longitudinal control have been installed, checked out and employed for both the lateral- and longitudinal control of individual vehicles. However, it will be at least 12 months before the sector computer and the communication link are installed, and the complete facility will not be fully operational until the Fall of 1979.

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PAPER 24

Transportation Advanced Research Projects/ University Research

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Office of University Research
U.S. Department of Transportation

TRANSPORTATION ADVANCED RESEARCH PROJECTS/UNIVERSITY RESEARCH

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I will try to be very brief as I know it's getting late. First I am going to thank Art Priver and Duncan MacKinnon for inviting me here. I'm here to give testimony to the fact that the advanced research and modal people also talk to each other. I will cover the Transportation Advanced Research Program (or TARP Program) first.

The program was initially located within the Office of the Secretary of DOT and is now in the Research and Special Programs Administration. The major objective of the TARP Program is to fund research in selected multi-modal transportation technology areas. At the present time there are three major areas of endeavor. The first is flow management and control, and the two major subareas of interest here are large-scale network analysis and the automatic control of large-scale transportation systems. I might add that Bob Crosby, who is with us here today, has the primary responsibility in the flow management and control area.

The second major area of endeavor is transportation system design, and the major subareas include behavioral aspects of transportation system design such as ride quality, passenger attitudes and behavior as related to system attributes, and guideway design.

The final area is that of non-contact suspension propulsion technology. The major endeavor in that area at the moment is an investigation of the high-speed application of the integrated suspension-propulsion concept using a single-sided linear induction motor. This is basically the ROHR concept, although I understand that the patents on this concept have recently been licensed to Boeing.

The Program of University Research was also initiated in the Office of the Secretary of DOT, but now it too is located in the Research and Special Programs Administration. The Program of University Research was founded in 1972 with the purpose of ensuring that the resources of the higher education community were brought to bear on mission-oriented high-priority transportation problems. The program also encourages greater involvement in colleges and universities with the Department of Transportation, state and local governments and the transportation industry.

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Since the inception of the program in 1972, the Office of University Research has sponsored 188 contracts in diverse areas of transportation research. We have expended 18 million dollars over a five year period. The program has, I believe, been very successful in stimulating relevant, high quality, and innovative transportation research at the universities.

I might add that the budget for the University Research Program is 3.7 million dollars and for the TARP Program for this fiscal year I believe it's about $500,000. Both programs are viewed as seed-money efforts; as the technology becomes applicable, it is transferred to the proper modal agency. For example, the Program of University Research funded some of Bob Fenton's initial projects on longitudinal control of automobiles at Ohio State, and this work is now with the Federal Highway Administration where it naturally belongs.

Four brief presentations which are representative of TARP and the University Research projects, and which are applicable to AGT technology, will be given here this afternoon. I might add that the papers which will be given by Professor Tony Healey and Professor Jim Wilson are sponsored by the University Research programs, while the presentations by Don Sussman and Dave Wormley are funded through the TARP program.

PAPER 25

Passenger Acceptance Feature Cost vs. Passenger Satisfaction

E.D. Sussman
Transportation Systems Center

PASSENGER ACCEPTANCE FEATURE COST VS. PASSENGER SATISFACTION

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Our assignment within the Transportation Research Program (TARP) was to establish the relationship between passenger acceptance and cost critical features of transportation systems. Table 1 illustrates our approach, which was to: (1) understand passenger values; (2) relate them to system design; (3) establish the costs of features of the system believed to impact passenger acceptance; (4) disseminate our work through symposia and workshops; and (5) use the results to develop and support standardization efforts.

Our goal in applying this approach was to assure an acceptable level of ride comfort while avoiding a prohibitively costly system. Ride quality was selected for study because: (1) in many rapid rail systems the guideway represents up to 80% of the system's cost; (2) the control of ride motions entails the use of highly complex, and therefore costly, suspension systems; and (3) guideway and suspension maintenance are also quite costly. Table 2 illustrates these considerations.

Once having selected ride quality as the cost critical element, it was necessary to develop techniques for quantifying passenger acceptance. While individual passenger preference is subjective, it is possible to obtain reliable and valid estimates of passenger requirements through rigorous and careful experimental design and statistical analysis. Table 3 lists the steps necessary to quantify passenger acceptance.

In order to quantify ride quality acceptance, we first studied past and ongoing efforts to quantify human responses to ride motion. These were divided into simulator studies and field studies. Characteristically, the simulator studies were tightly controlled experiments in which the subject was exposed to selected vibrations in a laboratory which simulates various critical aspects of a real vehicle, and his reports of comfort or discomfort were recorded. These studies therefore permitted development of the relationship between vibrations (which were subsets or components of those experienced in real vehicle motions) and subjective reports of comfort. Comfort can be conceived as a component or subset of the factors influencing passenger acceptance of an overall ride experience.

The field studies generally were fragmentary and rarely related reports of passenger acceptance to ride motions which had been measured simultaneously. The sole exception to this was research done for the NASA Langley Research Center (NASA/LRC) to determine the acceptability of ride motions in aircraft.

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TABLE 1. APPROACH

1. THROUGH TSC AND CONTRACTOR EFFORTS, PERFORM APPLIED AND ADVANCED RESEARCH TO:

   ESTABLISH AGGREGATE AND DISAGGREGATE MODELS OF PASSENGER NEEDS
   RELATED THESE NEEDS TO SPECIFIC ASPECTS OF SELECTED TRANSPORTATION SYSTEMS
   ESTABLISH RELATIONSHIPS BETWEEN PASSENGER NEEDS AND SYSTEMS COSTS

2. DISSEMINATE INFORMATION ABOUT THE NATURE OF PASSENGER NEED/SYSTEMS COST RELATIONSHIPS THROUGH TECHNICAL REPORTS, SYMPOSIA, WORKSHOPS, AND TRB COMMITTEE EFFORTS

3. INCORPORATE THE RESULTS OF THE PROGRAM INTO STANDARDS AND GUIDELINES SUCH AS THOSE PREPARED BY ANSI (THE AMERICAN NATIONAL STANDARDS INSTITUTE) AND ISO (THE INTERNATIONAL ORGANIZATION FOR STANDARDIZATION)

TABLE 2. RIDE QUALITY

INFLUENCED BY:
- GUIDEWAY DESIGN
- SURFACE SMOOTHING
- SUSPENSION DESIGN
- PROPULSION SYSTEM DESIGN
- GUIDEWAY MAINTENANCE
- VEHICLE MAINTENANCE
- OPERATING VELOCITY

  OPERATING ACCELERATION

which yielded an analytic technique for estimating the probability that given percentages of the potential user population will find the ride acceptable.

The work described above was performed by Dunlap and Associates and the University of Virginia under contract to DOT, and the relevant reports are currently in press.

The second stage of this project was to quantify the physical nature of the critical element (ride quality). Dr. Anthony Healey of the University of Texas discusses this in detail in a later paper, but it is valuable to briefly describe the work he did under DOT/University Research Contract Funding, as it was monitored under and forms an integral part of this TARP effort. Dr. Healey and his associates developed techniques for measuring the guideway configuration and vehicle motions on the Dallas/Fort Worth AIRTRANS System, obtained appropriate data, analyzed the results, and modeled the vehicle ride dynamics.

Dr. Healey found that the characteristic motion of the AIRTRANS vehicle included periodic alternate hard contacts of the guidebar-guide wheel steering assembly against the guideway parapet walls. These contacts were found to occur at the same point on each wall on each circuit of the guideway. Further, Dr. Healey and his associates found that an excess proportion of the latteral forces were being transmitted through the guidebar assembly to the parapet walls rather than through the tire contact patches to the guideway surface as per the design. The repeated contacts between the guidebar and the parapet wall and the excessive forces which characterize these contacts here resulted in a degraded ride and accelerator wear to both the vehicle and the guideway. Based on his research and that of others, improvements have been developed to ameliorate these problems at AIRTRANS. Another important aspect of this work was the quantification of the ride performance of the vehicle, which has been satisfactorily represented as a six degree of freedom mathematical model.

The final effort was the quantification of guideway costs. This was performed by the Massachusetts Institute of Technology and the sub-contractor, C.E. McGuire and Company. Again, their work will be described in detail later. Table 4 illustrates the general process and the results of this work, which is available in Report DOT-TSC-057-77-54.

The MIT study developed a methodology for establishing the inter-relationships between financial cost and AGT concrete guideway characteristics. The methodology included an analysis of guideway configurations and construction related guideway characteristics. The establishment of guideway-ride vibration relationships, and a ride motion guideway cost "tradeoff" analysis.

The methodology was applied by MIT to the analysis of a hypotetical concrete elevated guideway system for Group Rapid Transit (GRT) vehicles with span lengths ranging from 60-100 ft. and vehicle weights ranging from 10,000-20,000 lbs. The results of the application of the analysis indicated significant cost savings associated with the use of precast boxbeems as opposed to AASHTO I beam sections, shorter span lengths down to 60 ft, cast-in-place round piers rather than precast trapazoidal piers and "spread-footings" where possible.

TABLE 3. QUANTIFICATION OF PASSENGER ACCEPTANCE

- STUDIES OF EFFECT OF VIBRATION ON COMFORT
- STUDIES OF PASSENGER ACCEPTANCE OF VEHICLE RIDES
- STUDIES OF RELATIONSHIP BETWEEN VIBRATION AND OTHER PHYSICAL FACTORS AND PASSENGER COMFORT

- ESTABLISHMENT OF STATISTICAL RELATIONSHIPS BETWEEN PHYSICAL COMFORT PARAMETERS AND PASSENGER REPORTS OF COMFORT
- DEVELOPMENT OF QUANTITATIVE MODELS WHICH RELATE PHYSICAL PARAMETERS TO MEAN COMFORT LEVELS
- DEVELOPMENT OF ANALYTICAL TECHNIQUES WHICH RELATE MEAN COMFORT LEVELS PROPORTION OF THE POTENTIAL PASSENGERS WHO WILL FIND THE RIDE ACCEPTABLE

TABLE 4. QUANTIFICATION OF COSTS

CAPITAL COSTS

- DEVELOPMENT OF MODELS RELATING GUIDEWAY CONFIGURATIONS AND SURFACE ROUGHNESS TO VEHICLE VIBRATION
- ESTABLISHMENT OF ALTERNATIVE CONSTRUCTION TECHNIQUES AND GUIDEWAY CONFIGURATIONS
- DETERMINATION OF COSTS ASSOCIATED WITH CANDIDATE TECHNIQUES AND CONFIGURATIONS
- DETERMINATION OF COSTS ASSOCIATED WITH GUIDEWAY SMOOTHING

The LRC research, while extremely important to design had only heuristic value to ground system design due to the radical difference between the dominant ride motions of aircraft (particularly the great vertical excursions) and the motions of ground vehicles. For this reason, DOT instituted field studies on ground vehicles. In these studies passenger responses were systematically solicited while simultaneously motions in all six degrees of freedom, vehicle interior temperature, and acoustic noise levels were measured. Statistical analysis of the data permitted the development of mathematical models relating passenger comfort to such conditions. The following two equations depict typical models for inter-urban rail transportation and urban commuter buses:

$$C' = 0.87 + 1.05\ w_r \text{ (for commuter buses)}$$

$$C' = 1.0 + -.96\ w_r + 0.1\ [dB\ (A) - 63] \text{ (Amfleet coaches)}$$

where C' = passenger comfort rating, ranging from 1 ("Very comfortable") to 7 ("Very uncomfortable")'

w_r = roll rate (degrees/second); and

dB (A) = Weighted acoustic noise level.

These equations are "roll dominated," that is they indicate that the comfort level of the two transit vehicle types covered in the study can best be predicted from consideration of their angular motions about their longitudinal axes. The equations were developed through use of a regression analysis technique, which was used to determine the portion of the subject comfort response variance which could be attributed to each physical variable (motion in each of the six degrees of freedom: temperature, humidity, accoustic noise, illustration level and seating space). This analysis revealed that the amplitude of the roll rate provided a more accurate prediction of passenger comfort than any other single comfort variable or any combination of other variables. Further, the only variable which, when used inconjunction with roll, would increase the accuracy of prediction was accoustic noise and then, only for rail coaches. This outcome is not intuitively obvious, but it is well supported by other DOT and NASA research.

In this work motion simulators in labratory settings were used to determine the thresholds or minimum amplitudes of motion which result in human discomfort for longitudinal vertical and rotational acceleration. The results indicated that the miniumum levels of vertical and transverse vibration associated with human discomfort are well above the vibration levels found in trains and buses but that the roll motions associated with discomfort are well within the range of roll rate characteristic of such vehicles. This indicates that comfort and acceptability will be enhanced by reduction in roll motions, which are generally uncomfortable, but not by improvements in linear accelerations, which are not uncomfortable in commonly used fixed guideway vehicles.

Determining the mean comfort level was necessary for our purposes, but in order to plan, design, and evaluate ride quality, it was necessary to be able to estimate the percent of the population which would find a given ride comfortable. This was atcomplished through further statistical data reduction,

The study revealed the cost effectiveness of multiple span guideways for GRT systems and indicated that ride vibration is primarily a function of construction tollerance rather than guideway stuctural design.

The application of the results has already begun. TSC in working with the car equipment specification group at AMTRAK in their attempts to improve passenger accommodations. DOT is incorporating many of the findings of this as well as other TSC research efforts into the design and evaluation of new UMTA vehicles. In particular, the ride quality work is being used in the New Systems efforts and in the Downtwon People Mover evaluation process. Finally, TSC staff participating in standardization efforts at the national level through the American National Standards Institute (ANSI) and the International Organization for Standardization (ISO) are using the results to improve existing ride quality standards and prepare new ones.

PAPER 26

Performance of Mechanically Steered AGT Vehicles

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PERFORMANCE OF MECHANICALLY STEERED A.G.T. VEHICLES; RIDE AND MAINTAINABILITY IMPLICATIONS

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ABSTRACT. The performance of mechanically steered A.G.T. vehicles is examined by means of simple mathematical model to show that steer-performance, vehicle quality and steering loads are interrelated. Steering system gain and other system design parameters affect ride quality and the vibration levels in the steering linkage. Reducing steering gain to improve lateral ride quality results in an increase in steering linkage accelerations and therefore in anticipated maintenance costs. Use of a mechanical spring isolator reduces system steering forces but requires increased vehicle/guidewall clearances. The effect of wear in the steering linkage system on the vehicle ride quality and steering performance is under current investigation.

INTRODUCTION

One important consideration in the design of A.G.T. vehicles is the performance of the lateral control system. Various concepts have been employed in existing systems ranging from the "brute force" concept employed by the system at the Houston Intercontinental Airport, to the mechanically steered AIRTRANS system at the Dallas-Fort Worth Airport. Power steering boosters may be employed as with the Morgantown System which can be coupled with electronic sensing.

The dynamics of the steering system affect the steering forces required, the requirements for vehicle-guidewall clearance and the lateral accelerations imposed on the passengers.

With the "brute force" concept, a bogie is employed with side wheels that contact the guiderail and turns are made by forcing the main tires to undergo appropriate slip angles.

Mechanically steered vehicles such as AIRTRANS employ a wall following system with guidewheels connected to a steering arm that transmits steering errors mechanically to turn front and rear wheels.

This paper explores the effect of the steering system dynamics on the dynamic steering loads and vehicle lateral ride quality. The steering inputs come from the changes in lateral location of the guidewall. These variations are assumed here to be decomposable into components at various

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wavelengths and will be described statistically in terms of a power spectral density function. Steering performance in switching and merging can be analysed deterministically and is not discussed here. The treatment here is organized toward understanding the performance in following guidewalls that are rough and have geometry that can be described statistically. The vehicle is assumed to have rubber tires.

VEHICLE MODEL

Combined vertical and lateral models of rubber-tired vehicles have been developed previously [1, 2]. These models are of high order and have been found to agree reasonably well with experimental data. Their complexity however, can obscure the pertinent response characteristics.

In what follows, a highly simplified steering model is utilized to illustrate the major design trade-offs present with mechanically steered vehicles.

The model, shown in Figure 1, consists of a guidewheel, following a rough sidewall, which is connected through a primary isolator to a guidebar assembly. The guidebar linkage has significant mass and transmits movements to turn the wheels of the vehicle. The vehicle has mass and provides an inertial load against which lateral tire forces act.

A steering damper is required to prevent excessive vibration of the guidebar relative to the vehicle axle.

The steering forces in the tires are assumed to be proportional to the instantaneous slip angle at the contact patch and an aligning moment is also assumed to act proportional to the slip angle. Tire steering lags can become important when tire rotational frequency is low and could be included by additional dynamic terms as explained in [1].

The foregoing steering model results in a two degree of freedom system in which the steering gain, vehicle speed, guidewheel spring stiffness and steering damping rate play important roles in its performance.

The equations of motion for lateral motion become

$$m_1\ddot{x}_1 + b\left(\frac{n}{R}\right)^2(\dot{x}_1-\dot{x}_2) - C_t\left(\frac{n}{R}\right)\frac{\dot{x}_2}{V} + kx_1 + C_t\left(\frac{n}{R}\right)^2(x_1-x_2) = ku$$

$$m_2\ddot{x}_2 + b\left(\frac{n}{R}\right)^2(\dot{x}_2-\dot{x}_1) + C_t\left(\frac{n}{R}\right)\frac{\dot{x}_2}{V} + C\frac{\dot{x}_2}{V} + C\left(\frac{n}{R}\right)(x_2-x_1) + C_t\left(\frac{n}{R}\right)^2(x_2-x_1) = 0$$

---

[1] Nathoo, N., "Coupled Vertical-Lateral Dynamics of Pneumatic-Tired Vehicles Subject to Roadway Roughness Inputs" Ph.D. Dissertation, The University of Texas at Austin, December 1976.

[2] Kwak, Y. K., "Investigation of Dynamics of Rubber-Tired Automated Guideway Transit Vehicles for Ride Quality Assessment" Ph.D. Dissertation, The University of Texas at Austin, May 1978.



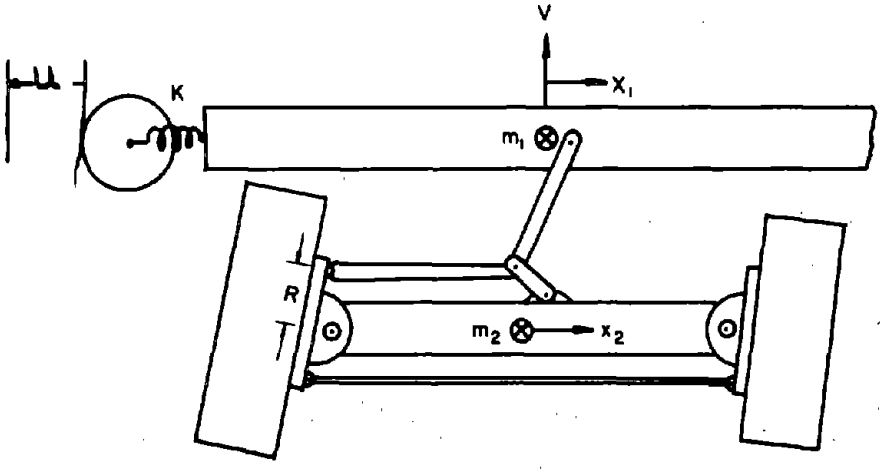


FIGURE 1. SCHEMATIC OF A MECHANICALLY STEERED VEHICLE

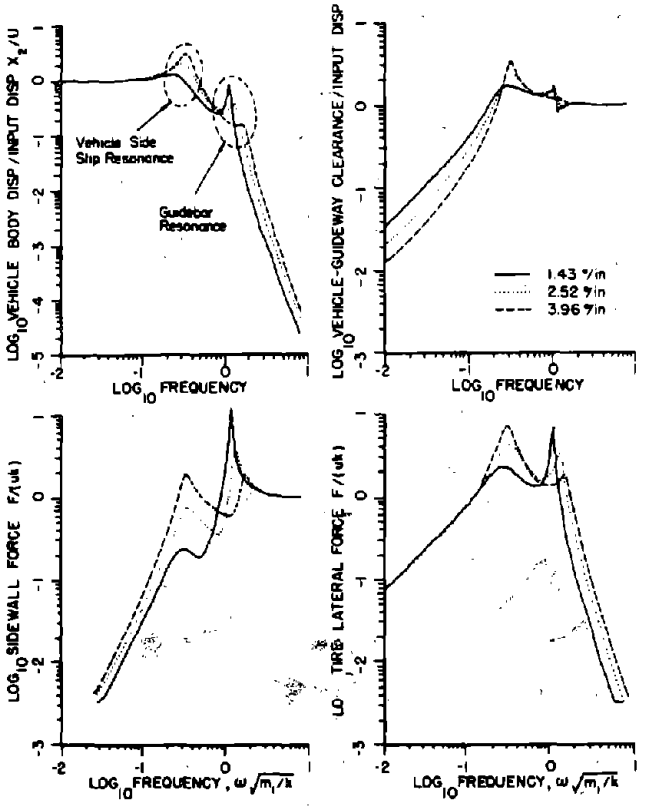


FIGURE 2. EFFECT OF STEERING GAIN ON SYSTEM FREQUENCY RESPONSE

where m_1 = guidebar mass

m_2 = vehicle mass and inertial reflected to the front axle

k_1 = guidewheel spring

u = guidewall displacement

b = steering damper rate

c = tire lateral force coefficient

c_t = tire restoring moment coefficient

n = steering gain

R = radius arm

V = forward speed

It is important to note that this simplified model is not designed for predicting the response to steering around curved paths because the yaw degree of freedom has not been specifically included. The model is primarily useful for examining response to input variations about a nominal straight path.

INPUT MODEL

The lateral displacements of the guidewall from a reference line are the steering inputs to the vehicle. It is assumed that they can be represented by a power spectral density function

$$\Phi_{uu}(F) = \frac{A}{\{1 + KF^2\}} \quad ; 0 < F < \infty$$

in which F is the frequency in cycles per foot and $\sqrt{K}$ is the critical wavelength in feet. Lateral displacement components having wavelengths much longer than $\sqrt{K}$ occur roughly with equal amplitudes while components with wavelengths much less than $\sqrt{K}$ have amplitudes that reduce with the wavelength itself. The assumption of this form of input is convenient because it has a finite r.m.s. value. This could approximately model guidewall roughness variations about a path of large radius of curvature even though it is easier to view this work as a study of deviations from a nominal straight line path.

The standard deviation of the guidewall input displacements is

$$\sigma_u = \sqrt{\frac{\pi A}{\sqrt{K}}}$$

and has been chosen here as a unity value.

VEHICLE STEERING PERFORMANCE

To illustrate the basic nature of the vehicle response, the frequency response of the axle displacement, the vehicle-guidewall clearance, the sidewall steering force and the lateral tire force variables are given in Figure 2 for variations in steering gain. The two resonances, vehicle sideslip mode and the guidebar resonance mode, can be clearly identified.

Vehicle Side-Slip Mode and Effect of Speed and Steering Gain

The lower frequency side slip mode is controlled primarily by vehicle speed and steering gain. This may be seen by considering the steering force to come completely from the tires and the steering angle to be determined directly by the steering gain and difference between sidewall and vehicle displacements.

Thus

$$m_2 \ddot{x} + \frac{C}{V}\dot{x} + Cn\,x = Cn\,u$$

$$\frac{X}{U} = \frac{1}{\left[(s/\omega_n)^2 + 2\zeta(s/\omega_n) + 1\right]}$$

$$\zeta = \frac{1}{2V}\sqrt{\frac{C}{m_2 n}} \quad ; \quad \omega_n^2 = \frac{Cn}{m_2}$$

This illustrates that the side-slip damping ratio is inversely proportional to speed and the square root of the steering gain. The above formulas serve to estimate initial design values for steering gain.

For the case under study here, with two modes, the steering gain is seen to effect the damping oppositely for each. Thus increased damping in the side slip mode is obtained at the expense of a reduction of damping in the guidebar mode. Reduction of steering gain is seen to affect adversely, the low frequency vehicle-guidewall clearances. This, of course, is expected.

Effect of Steering Gain on Response to Random Inputs

Using the model described earlier, the guidewall displacements were treated as the outputs of a first order system excited by a white noise source of unit intensity. Thus the following differential equation is added to the main two equations of the model.

$$\dot{u} + \left(\frac{2\pi V}{\sqrt{K}}\right)u = \frac{2\pi V}{\sqrt{K}}\sqrt{\frac{A}{V}}\cdot w(t)$$

This, in effect, results in a fifth order system excited by white noise from which the covariance matrix E can be found [3]. The value of A was

[3] H. Kwakernaak and R. Swan "Linear Optimal Control" Wiley, pg. 104.

determined by making the variance of u equal to one inch with the critical wavelength set to 25 ft.

Figure 3 shows the effect that steering gain on the r.m.s. response of motions, clearances and accelerations, while Figure 4 shows that an optimum exists from the point of view of minimizing the guidewall force. Figures 3 and 4 show that in order to reduce lateral body accelerations and improve riding comfort, lower steering gains should be employed. The result of that is then expected to lead to higher accelerations in the steering linkage parts and higher guidewall load forces.

Effect of Guidewheel Spring Rate

Reducing the stiffness of the guidewheel spring will, in general, reduce both sidewall load force and tire forces. Ride quality, in terms of lateral acceleration of the vehicle body, will be improved. The adverse effect which is expected is shown in Figures 5 and 6 to be the increase in vehicle-guideway clearance requirements.

Effect of Speed

Figure 7 shows that increases in vehicle forward velocity will proportionately cause increases in steering forces.

IMPLICATIONS FOR RIDE QUALITY AND MAINTAINABILITY

One of the current concerns with A.G.T. vehicles is that of the long term maintainability of the system. One aspect of system maintainability is the life of the mechanical parts of the steering and suspension systems. Life of the components can be related to material factors and loading factors: the higher the load forces and the higher the motions (accelerations) of moving parts, the lower the component life.

Figure 3 shows clearly that for the type of mechanical steering system considered, reductions in lateral acceleration levels are achieved at the expense of larger guidebar and steering linkage accelerations.

Figures 5 and 6 show that if larger guidewall-vehicle clearances can be tolerated, lower guidewheel spring rates will yield lower accelerations in the steering linkage parts and will thus improve the maintenance frequency.

Current work under contract with the University Research Program of the U. S. Department of Transportation is aimed at investigating the relationship between wear rates in the mechanical steering system of the AIRTRANS vehicles and the vehicle vibration and ride quality levels.

The first part of the work has begun and is concerned with the changes in the performance of the steering system when wear takes place. The effect of wear is to change or modify the effective values of spring and damping rates by introducing non-linear effects due to the presence of clearances. The sensitivity of vehicle ride quality and steering gear vibration to these wear induced clearances is being examined by use of both

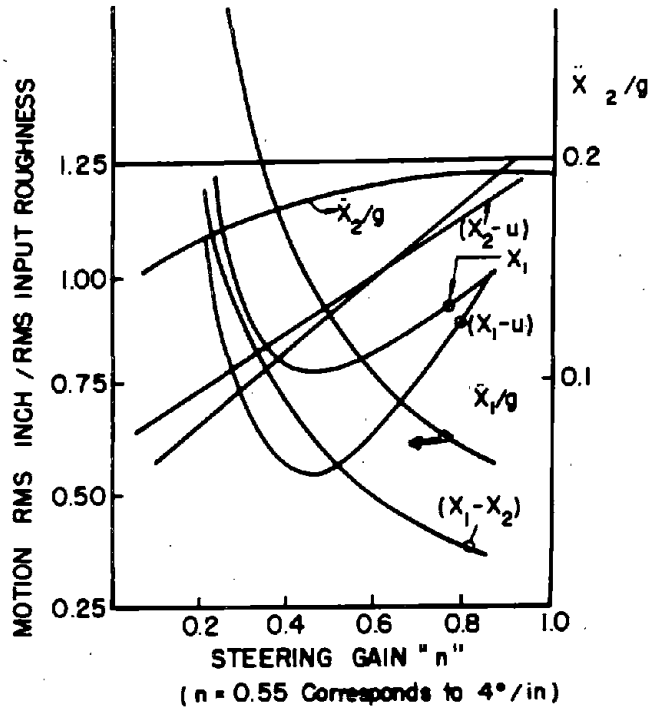


FIGURE 3. EFFECT OF STEERING GAIN ON R.M.S. MOTION

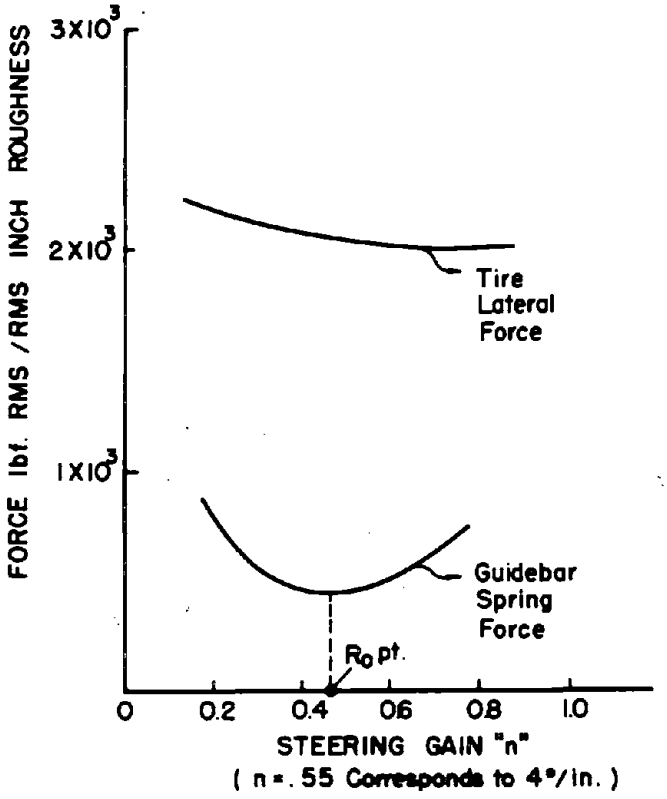


FIGURE 4. EFFECT OF STEERING GAIN ON R.M.S. FORCES

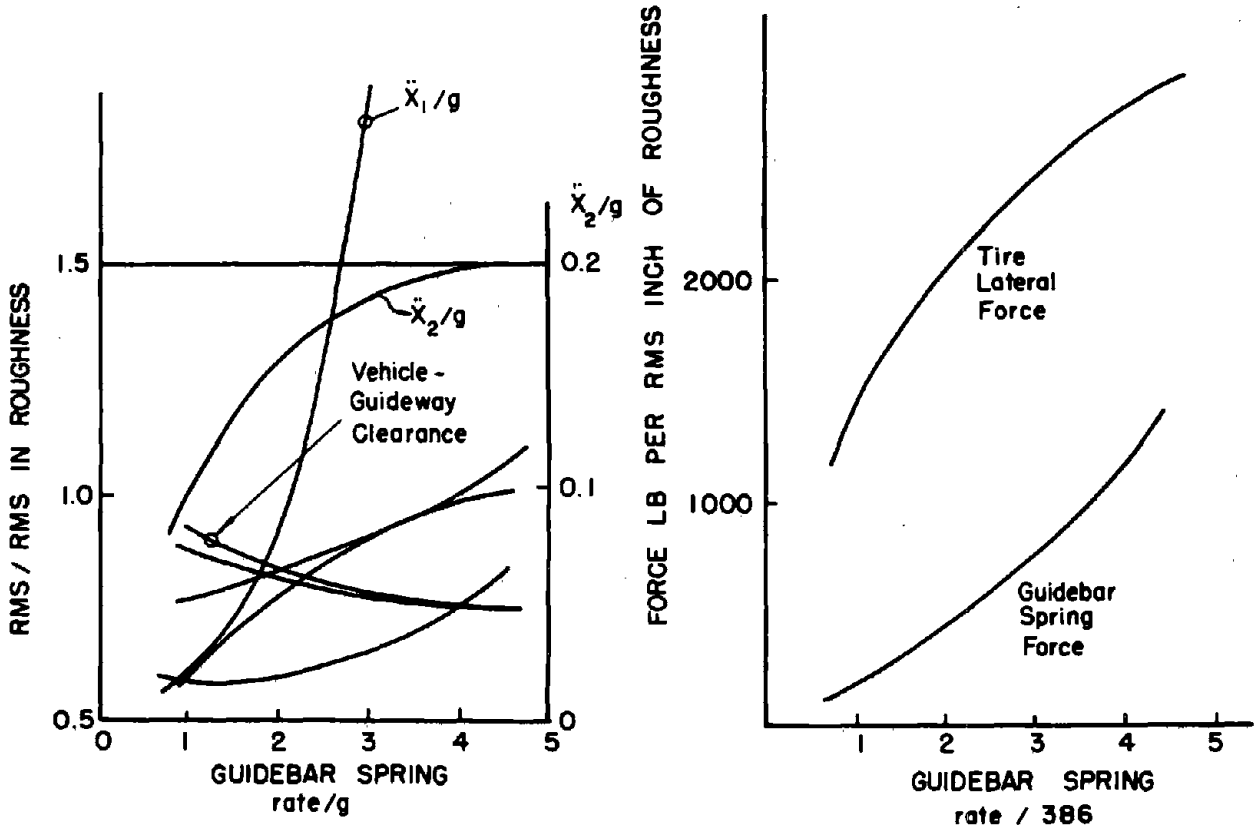


FIGURE 5. EFFECT OF SPRING RATE ON R.M.S. MOTIONS

FIGURE 6. EFFECT OF SPRING RATE ON R.M.S. FORCES

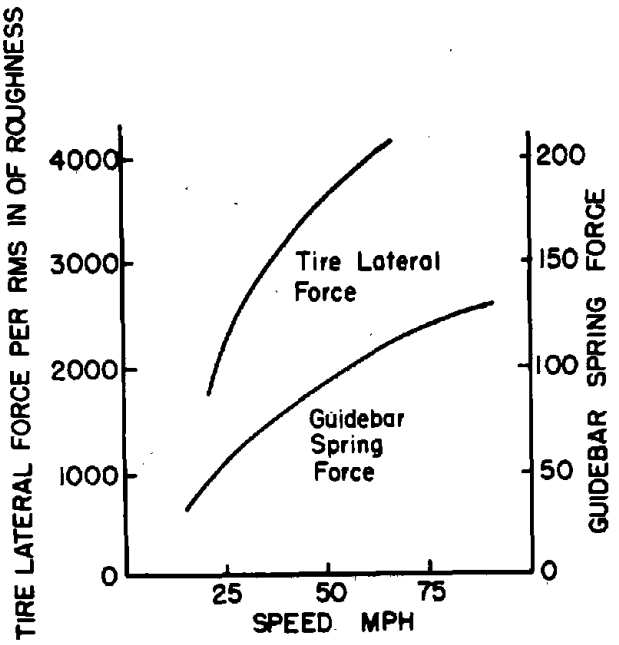


FIGURE 7. EFFECT OF SPEED ON R.M.S. FORCES

mathematical models and experimental measurements on an AIRTRANS vehicle.

In parallel, an examination of steering system maintenance records has been conducted. Table 1, prepared with the help of L.T.V. Inc. and the Dallas-Fort Worth Airport Staff, is given here to show typical numbers for maintenance actions, maintenance man-hours and mean miles between failure statistics for the AIRTRANS vehicles.

The results of the program are expected to show the increase in system vibration that occurs during a life cycle of wear in the main steering elements. Also, by obtaining typical wear rate information for systems of this type, it is expected that designers of other vehicles will have a data base by which to assess new concepts for achieving good ride quality with long life.

ACKNOWLEDGEMENT

The author wishes to thank R. Ravera, E. D. Sussman and J. Marino of the U. S. Department of Transportation who have contributed to the conduct of this research program of the author under Contracts Nos. DOT-OS-50126 and DOT-OS-70075 sponsored by the U. S. Department of Transportation University Research Program.

TABLE OF PARAMETERS

m_1 = 1.32 lb sec/in^2

m_2 = 37.5 lb sec/in^2

k = 400 lb/in

b = 3000 lb sec/in

n = 0.35 in/in

R = 8 in

C_t = 114,600 in lb/rad

C = 34,400 lb/rad

V = 25 ft/sec

TABLE 1. TABLE OF MAINTENANCE ACTIONS FOR STEERING SYSTEM OF AIRTRANS VEHICLE

STEERING ASSEMBLY

MAINTENANCE AND RELIABILITY PARAMETERS

JANUARY - SEPTEMBER 1975

NOMENCLATURE	EMT (HOURS)	MMH	NO MACT	EMT/ 10K MI	MMH/ 10K MI	MACT/ 10K MI	MMBF	MMH/DAY	ACT/DAY	MILES/ DAYS	FAILURES
Coupler Assembly	1.0	1.0	1	-	-	-	2,219,526	-	-	$\frac{2,219,526}{273}$	1
Reversing Actuator Assembly	172.5	214.5	141	0.777	0.966	0.635	76,535	0.786	0.516		58
Guidebar Hanger Assembly	241.3	397.8	140	1.087	1.792	0.631	103,233	1.457	0.513		43
Guidebar Assembly	213.9	307.6	107	0.964	1.386	0.482	123,307	1.127	0.392		36
Guide/Switch Wheel Assembly	1184.6	1320.4	1325	5.337	5.949	5.970	126,830	4,837	4.853		70
Steering Linkage, Fwd, Aft and Interconnecting	144.9	211.1	95	0.653	0.951	0.428	43,520	0.773	0.348		51
Collector Installation	107.6	145.6	73	0.485	0.656	0.329	341,465	0.533	0.267		26
Shock Absorber, Reversing Actuator	6.7	10.4	5	0.030	0.047	0.023	1,479,684	0.038	0.018		3

EMT - Elapsed Maintenance Time

MMH - Maintenance Manhours

MACT - Maintenance Actions

MMBF - Mean-Miles-Between-Failures

PAPER 27

Dynamics of Curved Guideway Spans for AGT Vehicles

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DYNAMICS OF CURVED GUIDEWAY SPANS FOR AGT VEHICLES

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ABSTRACT. Laboratory-scale experiments provide an effective means of evaluating the dynamic interactions of horizontally curved guideways and Automated Guideway Transit (AGT) vehicles. Strain measurements at the midspan of single and multiply-supported spans yield time histories of bending moments produced by the transit vehicle loads. Scale model vehicles are instrumented with fore and aft accelerometers. These data are recorded on magnetic tape and computer-processed to obtain statistical parameters such as the spectral density and rms values of heave accelerations needed for ride comfort studies. Since both span data and vehicle data are reducible to non-dimensional form, the laboratory results are useful for both, verifying the available theoretical results (the simple curved span, for instance); but also for generating new data for multiply-supported, curved spans with unevenly-spaced piers, with multiple transit vehicles. Theoretical studies of multiply-loaded redundant structures are just beginning.

INTRODUCTION

Previous analytical studies of curved span dynamics with transit loads have been limited to simply supported, beam-type configurations [1,2,3]*. Also, the limitations of employing curved beam theory, as opposed to classical plate theory for modeling guideways has been investigated [4]. In the latter studies, it was found that the Bernoulli-Euler type beam theory (neglecting shear deformations and rotatory inertia) is generally adequate for dynamic studies of elevated curved guideway/vehicle interactions. Even curved beam theory, however, with its coupled fourth and second order partial differential equations for bending and torsion, represents a rather formidable boundary problem when applied to multiply-redundant or continuous-type spans with transit loading.

The current approach to this problem, then, was an experimental one. Previous experience with straight, multiply-redundant spans on the laboratory scale [5] was used to design the experiments described below. Emphasized here is the measurement of critical nondimensional curved span dynamic

*The numbers in square brackets are the References at the end of the paper.

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strains. Measurement of model vehicle accelerations are discussed elsewhere [5].

EXPERIMENTAL DESIGNS

Scale model guideway configurations were designed to be within the practical range of prototype designs. The five system parameters which need to be preserved from model to prototype, derived elsewhere [3], are:

$$\theta_o = \ell/R \quad , \text{ total arc angle}$$

$$\xi = R/R_g \quad , \text{ beam geometry}$$

$$A = GJ/EI \quad , \text{ rigidity ratio}$$

$$\omega/p \quad , \text{passage frequency ratio}$$

$$T_o/R_g P \quad , \text{transit torque ratio}$$

where the ℓ is the arc length of curved beam centerline and R is its radius, shown in laboratory layout sketch of Figure 1. The reference frequency p is that of a straight simple beam of equal length ℓ and equal bending stiffness EI. The term $\omega = \pi v/\ell$ is the passage frequency of the vertical load P moving at constant speed v along the arc. The transit torque T_o, due to vehicle side loads, applies a twist to the beam which is resisted by its torsional rigidity GJ. Finally, $R_g = (I_p/A_c)^{1/2}$ is the radius of gyration based on I_p, the second moment of the cross section A_c about its polar axis.

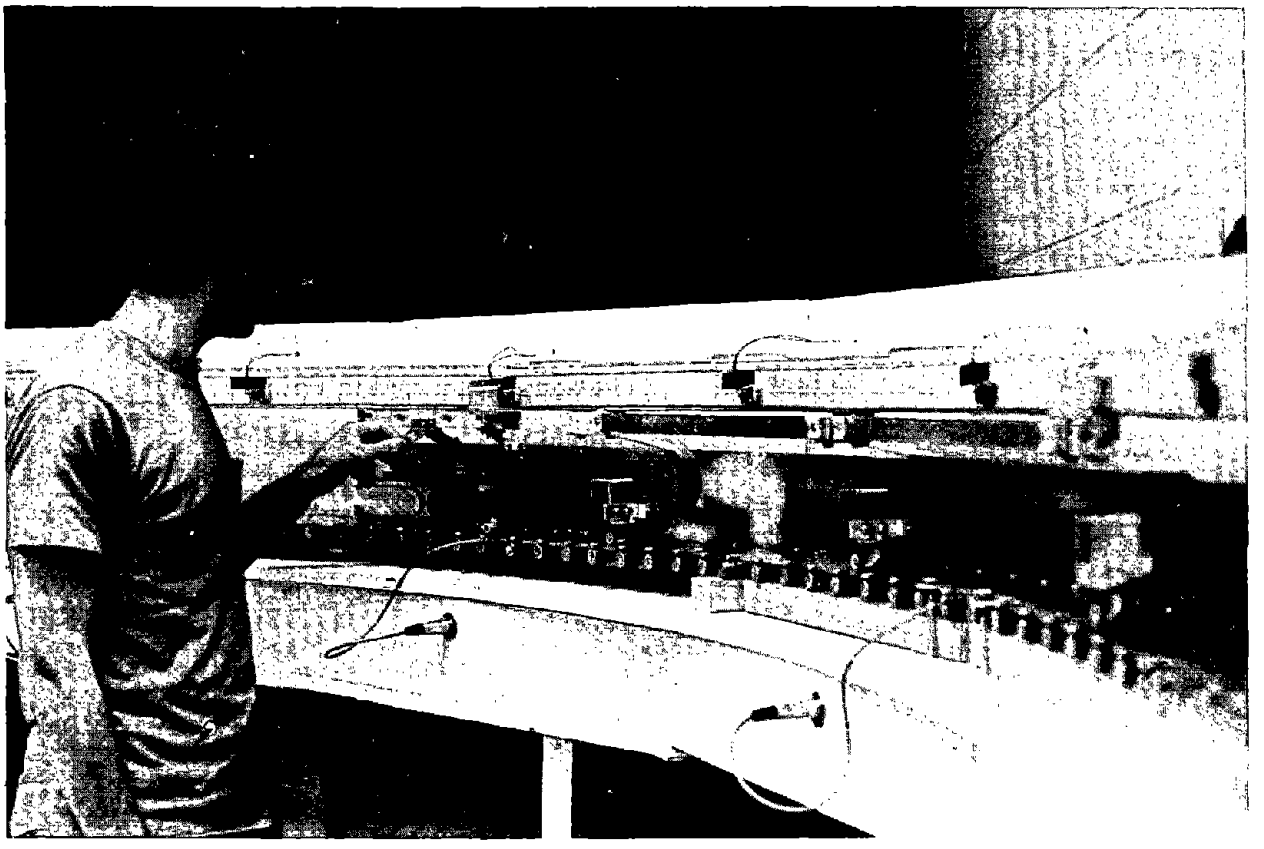
The dimensionless responses of the curved span model at a position x along its arc, subject to the same support conditions and the same relative load distribution (as a fraction of ℓ) as the prototype, are given in the form

$$w/w_s \quad ; \quad \beta/\beta_s$$

where w and β represent the deflection and angle of twist as a function of the dimensionless dependent variables x/ℓ and ωt, where t is time. The subscript s refers to the peak static responses at midspan for the load at crawl speed.

Typical calculations for practical prototype guideways for θ_o in the range of 30 to 60 deg. show that $0.5 \leq A \leq 2.0$ and $50 \leq \xi \leq 200$. Further, except in the narrow range $0.9 \leq \omega/p \leq 1.0$, the transit torque ratio has negligible effect on curved beam responses. Thus the model guideway was designed without side loading ($T_o = 0$), for the realistic values A = 1.54 and $\xi = 55.6$. Calculations showed that response data for a simple, curved span were relatively insensitive to values of A in the range $0.5 \leq A \leq 2$ and to a factor of two variation in ξ from the experimentally chosen one of 55.6.

The experimental setup shown in Fig. 1 was designed to accommodate all of the experimental spans and vehicle load configurations listed in Table 1.



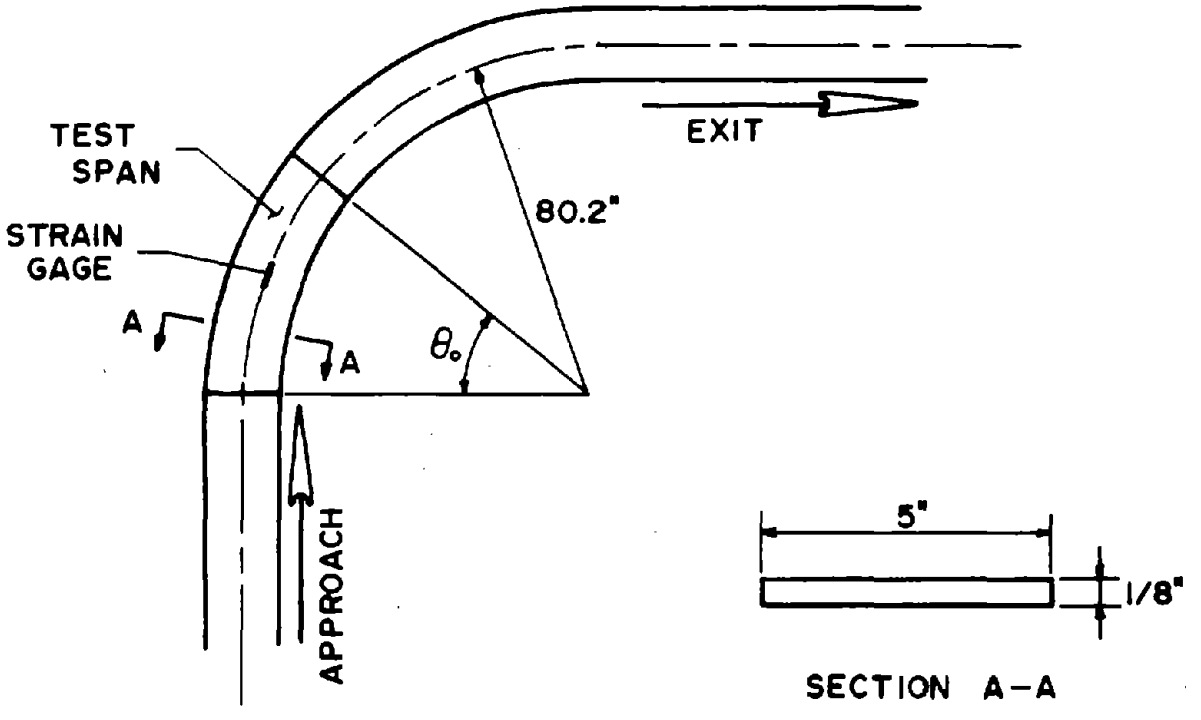


Figure 1. Curved guideway and vehicle models.

Table 1. GUIDEWAY-LOAD COMBINATIONS TESTED.

Guideway Configurations	Load Configurations
30° simple span	1 point load 2 point loads @ L/4 spacing 3 point loads @ L/4 spacing 2 point loads @ L/2 spacing 3 point loads @ L/2 spacing AGT vehicle
45° simple span	1 point load 2 point loads @ L/4 spacing 3 point loads @ L/4 spacing 2 point loads @ L/2 spacing 3 point loads @ L/2 spacing AGT vehicle
30°-30° 2-span continuous	1 point load 2 point loads @ L/4 spacing 3 point loads @ L/4 spacing 2 point loads @ L/2 spacing 3 point loads @ L/2 spacing AGT vehicle
45°-45° 2-span continuous	1 point load 2 point loads @ L/4 spacing 3 point loads @ L/4 spacing 2 point loads @ L/2 spacing AGT vehicle
30°-30°-30° 3-span continuous	1 point load 2 point loads @ L/4 spacing 3 point loads @ L/4 spacing 2 point loads @ L/2 spacing 3 point loads @ L/2 spacing AGT vehicle

The photograph shows three point loads in tandem, followed by a model of an AGT vehicle. Each front load has a ratio of moving mass to guideway mass (between consecutive spans) of about 1/7, which simulates approximately a constant moving force. The AGT vehicle model simulates an 8 to 10 passenger prototype whose uncoupled pitch and heave frequencies are in the range of 1 to 3 hz. In scaling, the ratio of each of these frequencies to the reference guideway frequency p needs to be preserved as do the vehicle length to span length ratio and the vehicle mass to span mass ratio. In the laboratory, these vehicles are towed by the specially designed linear induction motors contained in the parallel track above the guideway.

TYPICAL EXPERIMENTS

At this writing, an extensive experimental program is underway to

determine the time histories and thus the peak midspan strains and twisting angles of single and multiple spans in Table 1 in response to the variety of transit load configurations listed there. Figure 2 shows typical nondimensional responses derived from measured time histories. The peak dynamic to static bending moment (M/M_S) and twist angle (β/β_S) ratios at midspan are shown for a simply supported, 30 deg. span with a transit point load at various transit speed ratios. Results agree reasonably well with the theoretical calculations which lends credibility to data obtained from more complex configurations.

Further results are shown in Figure 3, based on a two-span (30°-30°) configuration, also simply supported on each end. Here, results for the two point tandem loading (spacing $\ell/4$) are compared with those for an AGT model vehicle with the same ($\ell/4$) wheel base. Here, the pitch motion of the AGT vehicle contains the kinetic energy which would otherwise be imparted to the guideway, giving smaller peak responses than for the two point tandem loads. The dashed line shows the peak responses for the two tandem loads on two, simple 30 deg. spans, end-to-end. Results show that this configuration is more efficient for the tandem loads, but less efficient than the two-span configuration for supporting the AGT vehicle, at least for $\omega/p \leq 0.8$. Extensive data for cases of Table 1 are reported elsewhere [6].

CONCLUSIONS

Results show the feasibility of experimental studies for obtaining curved guideway/vehicle response interactions. For simple, curved spans, calculated and measured responses are in good agreement. This versatile laboratory facility is especially valuable for comparing responses of alternative curved spans; for studying the effects of span restraints; and for evaluating vehicle acceleration responses as well [5]. Such data form a basis for direct dynamic evaluations of alternative prototype designs.

Acknowledgments

This research was supported in part by the U.S. Department of Transportation, contract no. DOT-OS-60130, with Robert J. Ravera as program monitor. The experimental contributions of D. Preston Lowrey are greatly appreciated.

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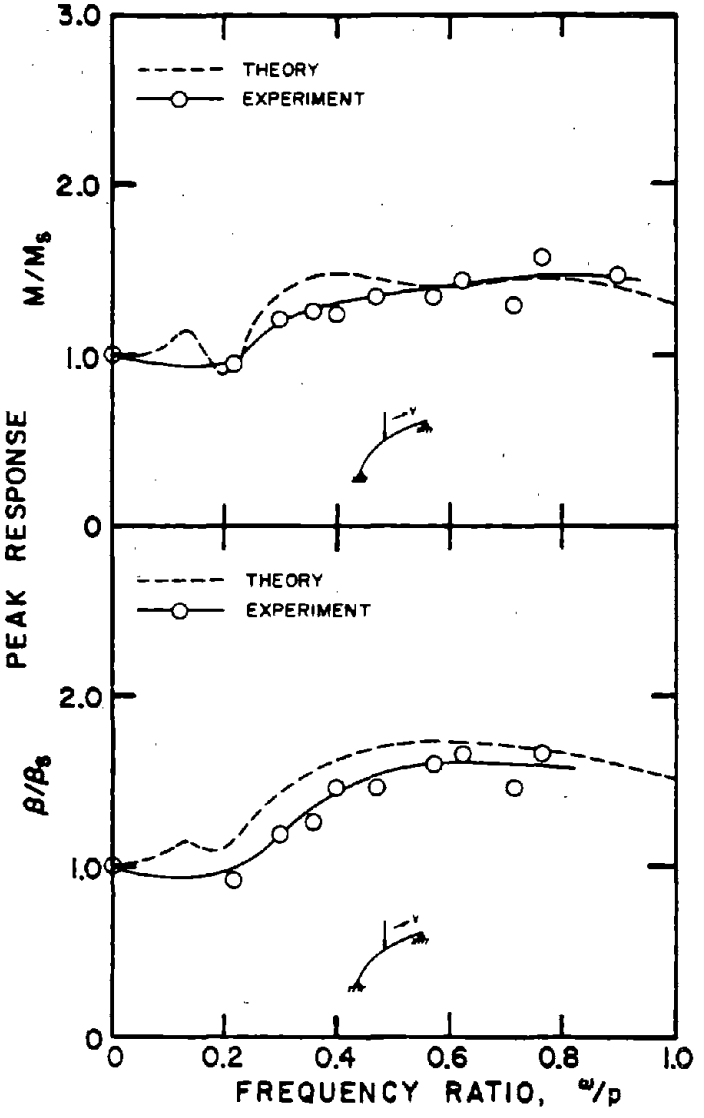


Figure 2. Midspan bending moment (M/M_S) and twist angle (β/β_S) response envelopes of a 30 deg. simple span curved guideway with a transit point load.

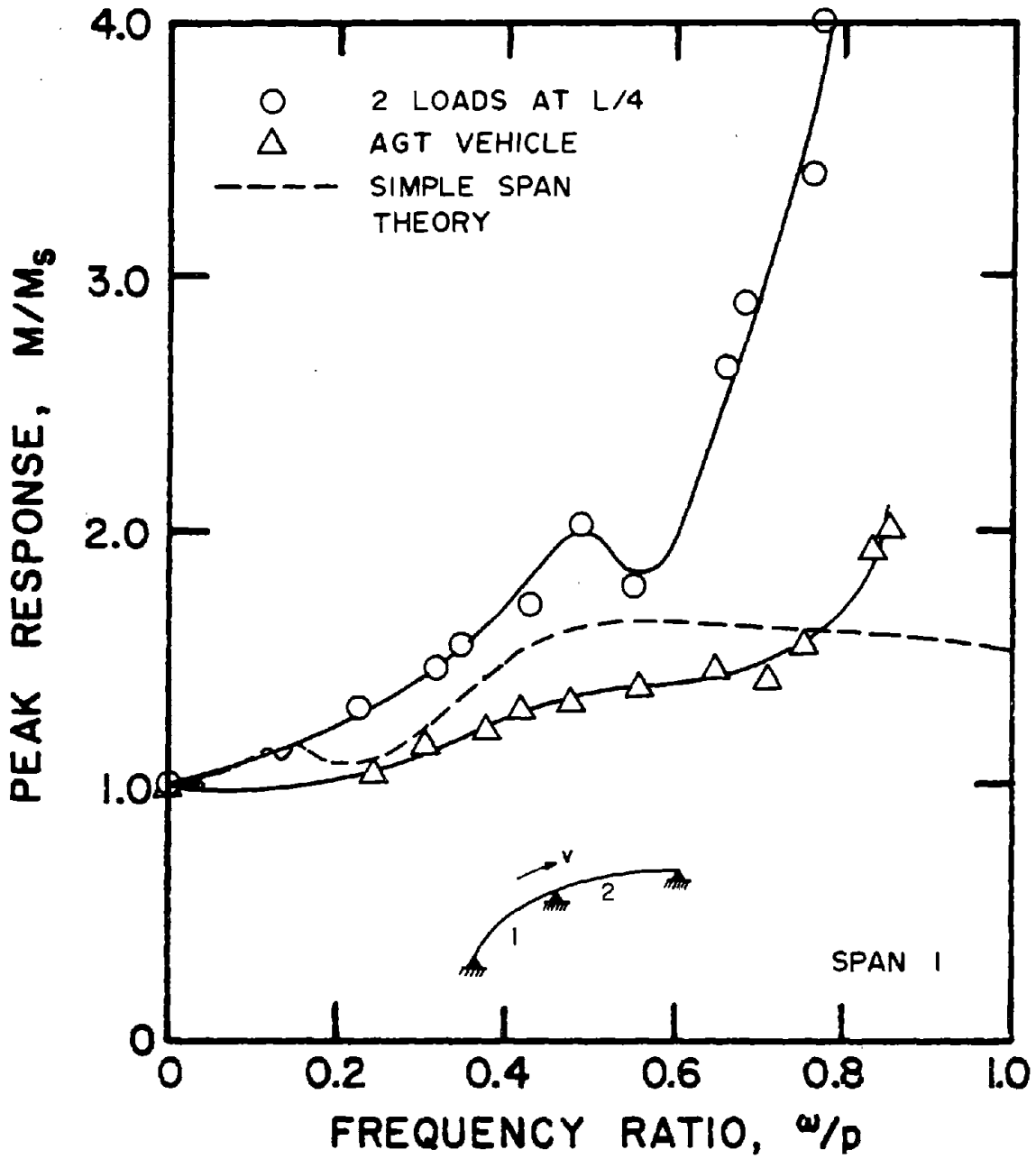


Figure 3. Midspan bending moment response envelopes for the entrance span of a 30°-30° two-span continuous curved guideway for two point loads spaced at ℓ/4 and an AGT vehicle with an ℓ/4 wheelbase.

PAPER 28

Single-Beam Elevated Structure for the Two-Way Passage of AGT Vehicles

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SINGLE BEAM ELEVATED STRUCTURES FOR THE TWO-WAY PASSAGE OF AUTOMATED GUIDEWAY TRANSIT VEHICLES

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ABSTRACT. A preliminary static and dynamic analysis of an elevated structure consisting of a single beam for the two-way passage of cantilever suspended automated guideway transit vehicles is performed. Several guideway cross-sectional shapes are compared with respect to their torsional and flexural characteristics. The material saving in torsional guideways is compared to conventional guideways and the use of cutouts as a means of optimization of the guideway material requirements is analyzed. A vehicle dynamic model consisting of vertical, lateral and roll motions is employed to investigate the effects of guideway geometric and strength characteristics on ride quality.

* Research Assistant
** Professor

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INTRODUCTION

Guideway costs represent a major fraction of the total cost of an automated guideway transit (AGT) system. Optimal utilization of the guideway structural properties is important in designing low cost AGT systems. In the present investigation the use of an elevated single beam loaded in torsion as well as in bending (Torsional Guideway Transit) for the two-way passage of AGT vehicles is studied. This arrangement is shown schematically in Fig. 1. Such a guideway configuration has the potential for reduced size and cost for two-way passage of vehicles in comparison to two separate beams loaded primarily in bending as in conventional guideways (Normal Guideway Transit) in which the guideway supports a conventional rubber tired vehicle. The salient features of the Torsional Guideway Transit (TGT) system with respect to guideway size, material requirements and ride quality are compared to conventional normal guideway transit (NGT) systems.

GUIDEWAY STATIC ANALYSIS

Basic Assumptions

Closed (hollow) structural sections have excellent torsional characteristics with respect to torsional stiffness per unit weight. Three types of closed sections are compared in the present analysis - the circle, the rectangle and the equilateral triangle. In order to simplify the analysis the following assumptions are made: (a) single span guideways are considered; (b) the connection at end supports does not allow end twist, bending deflection or the transfer of bending moments; and (c) vehicles are modeled as point loads. Assumption (b) yields conservative results for deflections because in practice a certain amount of end twist and some bending moment transfer are present. Assumption (c) also yields conservative deflections. The analysis can be extended directly to vehicles of finite length having nonzero footprint.

The torsional analysis is based on Bredt's thin wall approximation of Saint Venant's theory [1]. This approximation is in fact better than the results obtained from a more complex stress function technique [2] for thickness/perimeter ratios $\mu < 0.03$ (See Fig. 2 and the Appendix for nomenclature). Classical bending analysis of beams is utilized. These analyses have been used to compute the bending and torsional stiffness and resulting stresses in various shape sections.

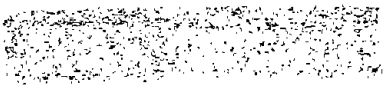
GUIDEWAY CROSS-SECTIONAL TRADE-OFFS

Different cross-sectional shapes having equal material volumes are compared with respect to their nondimensional stiffness and maximum

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[1] Kallbrunner, C.F. and Basler, K., Torsion in Structures, Chap. 1, Springer-Verlag, New York, 1969, p. 12.

[2] Abramyan, B.L., "Torsion and Bending of Prismatic Rods of Hollow Rectangular Section", NACA Technical Memorandum 1319, Nov. 1951.



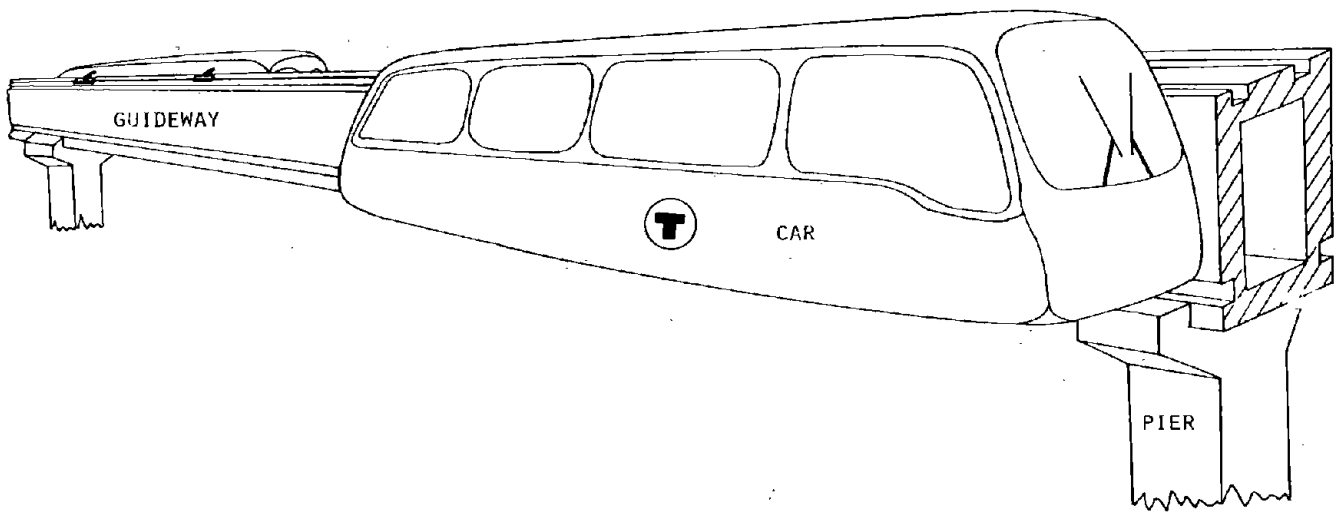
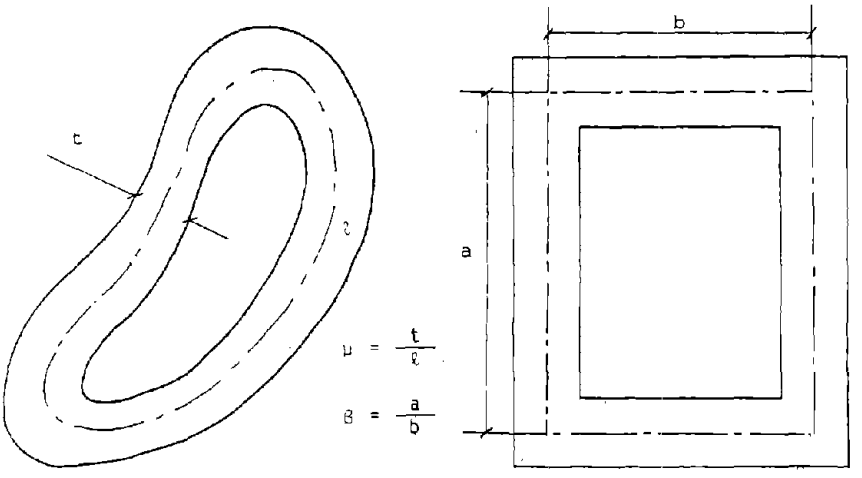
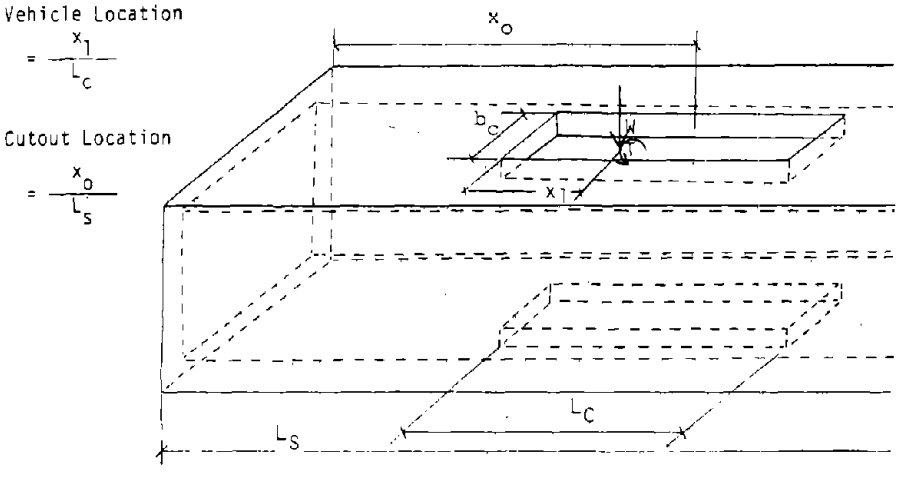


FIGURE 1. TORSIONAL GUIDEWAY TRANSIT SYSTEM SCHEMATIC



(a) GENERAL SECTION (b) BOX SECTION



(c) GUIDEWAY (BOX) WITH CUTOUT

FIGURE 2. GUIDEWAY NOMENCLATURE

non-dimensional stress characteristics in Figs. 3 and 4 respectively. Each solid curve corresponds to a fixed value of μ. The circular section has the best overall torsional characteristics. For small μ (less than approximately 0.02) the square section has a smaller bending (normal) stress which is an advantage in comparison to other sections. Bending stiffness of the box section can be improved at the expense of its torsional characteristics by increasing the height/width ratio β. For a typical box section the equivalent torsional stiffness computed with respect to static deflection at the beam centroid is several times greater than its bending stiffness. Increasing β is therefore a convenient way of reducing the material requirements for a guideway. However, buckling of the walls and other elastic instability problems set an upper limit for β. There is an added benefit of increasing β illustrated in Fig. 4. Increasing β decreases the maximum bending normal stress until a minimum value is reached. For thin sections this minimum stress occurs at $\beta \simeq 3.0$. As μ increases, the value of β corresponding to the minimum bending stress also increases. However, increasing β above unity increases the maximum torsional shear stress.

In the following paragraphs only box sections are considered in detail. Apart from having good torsional and bending characteristics, box sections are also relatively easy to manufacture.

GUIDEWAY MATERIAL REQUIREMENTS

A significant material reduction in comparison to normal guideways is possible with torsional guideways due to their optimizable loading configuration. A typical NGT cross-section, for one-way passage, is as wide as the vehicle. Its height/width ratio is usually less than unity. On the other hand, TGT guideway sections can be made with large height/width ratios to exploit their flexural characteristics while trading off a fraction of their excess torsional strength. The material savings that can be achieved by this procedure is presented in Fig. 5. This analysis was based on torsional and normal guideways having equal bending stiffness. The width of the NGT guideway employed in this analysis was assumed to be twice the vehicle width* for two-way vehicle passage. It is observed that the material savings can be significant and is typically of the order of 50%. From Fig. 5 it is also clear that the same material savings may be achieved with a smaller TGT guideway width by increasing its wall thickness in comparison to that of a normal guideway having identical bending stiffness.

GUIDEWAY OPTIMIZATION

Balanced Guideway Section: Allowable shear stress and buckling of section walls set an upper limit for the height/width ratio β of a torsional guideway section. The equivalent torsional stiffness of the section can be considerably larger than its bending stiffness even after increasing β to its allowable value. A balanced guideway is defined as one having equal torsional and bending stiffness. A balanced guideway can be obtained by reducing the span length. For standard loading conditions and acceptable

*Note the dimensional data in Table 1 on page 14.

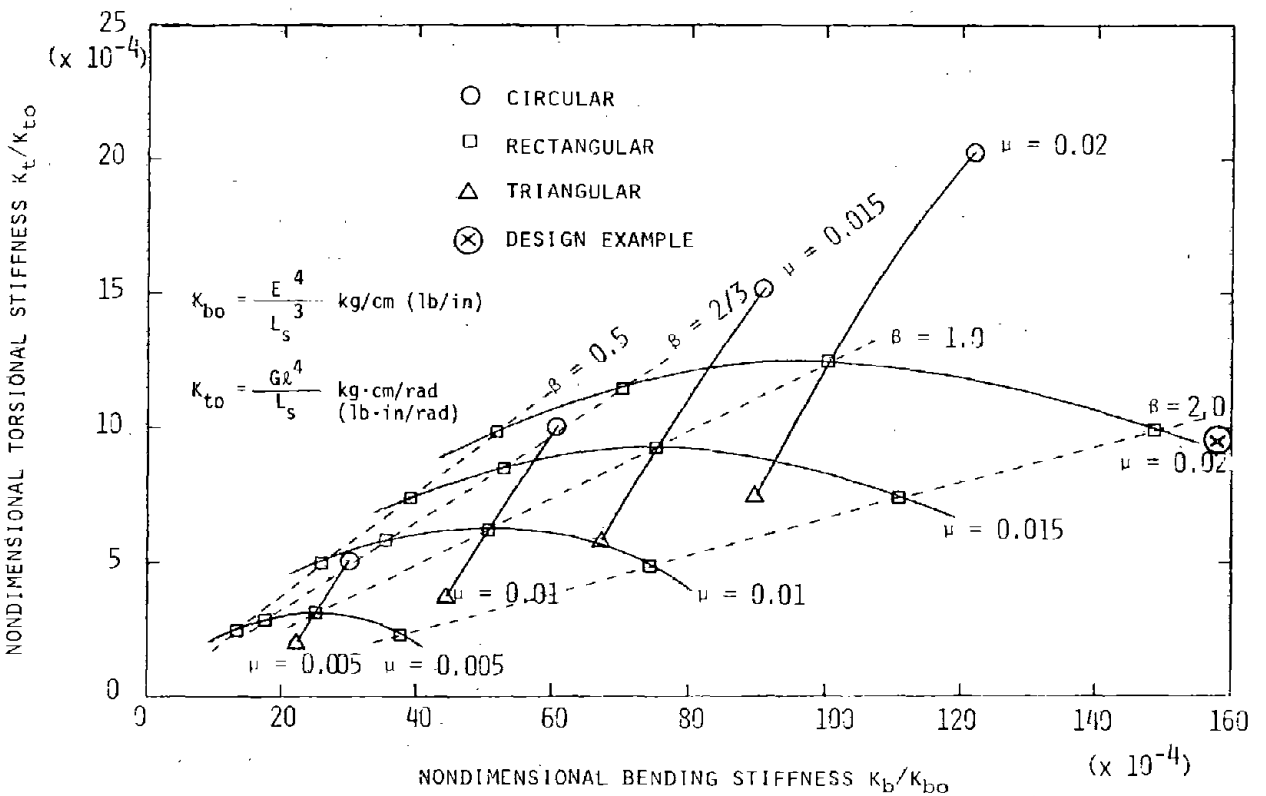


FIGURE 3. TORSIONAL STIFFNES VS. BENDING STIFFNESS CURVES

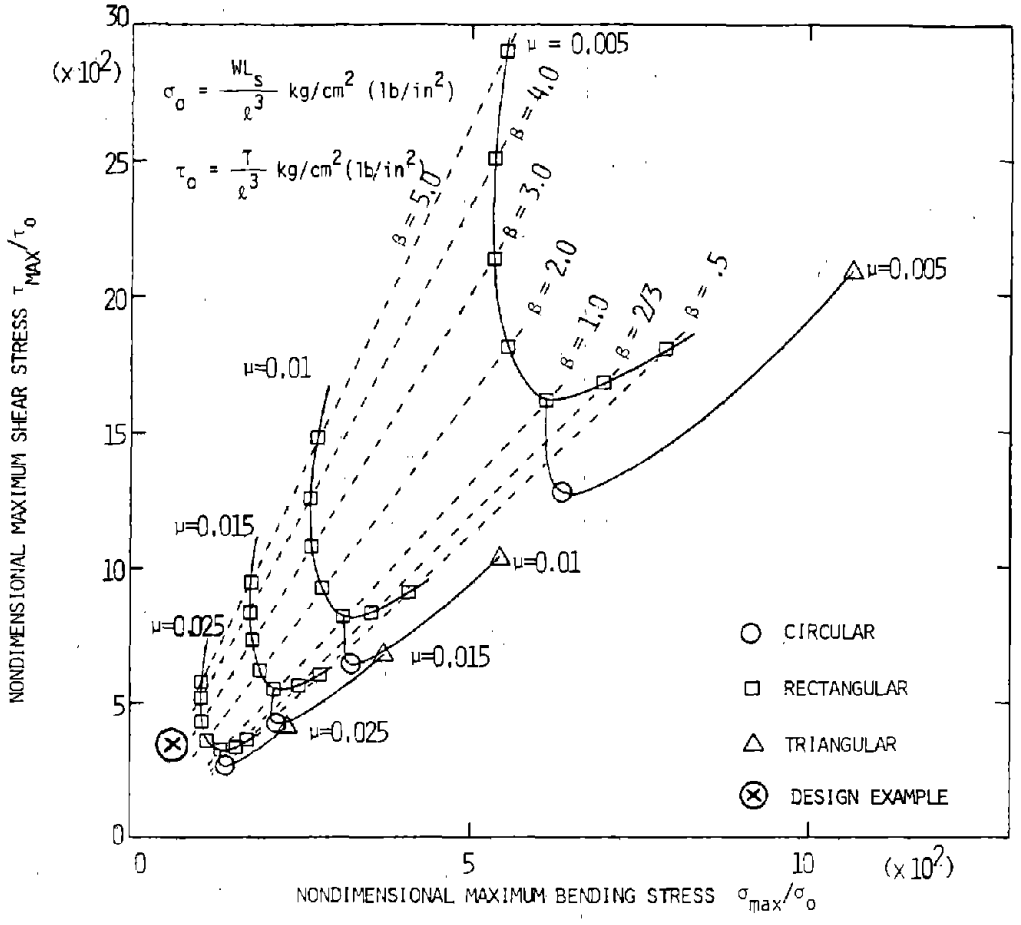


FIGURE 4. MAXIMUM SHEAR STRESS VS. MAXIMUM NORMAL STRESS CURVES

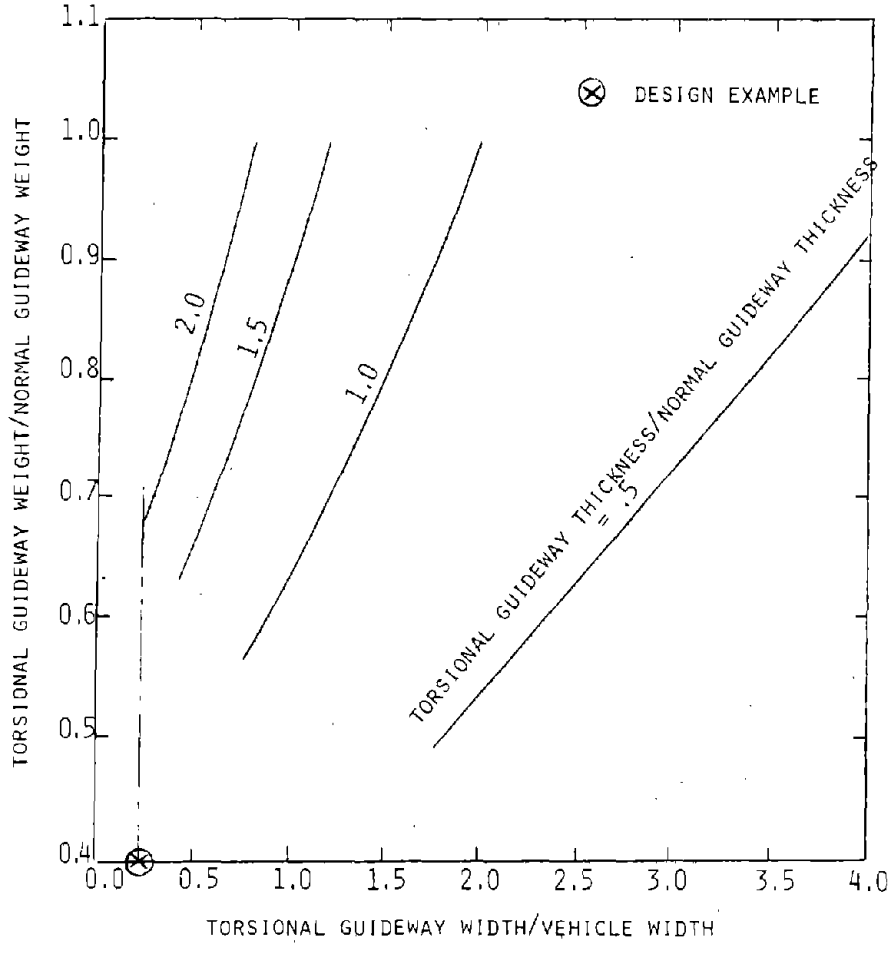


FIGURE 5. COMPARISON OF GUIDEWAY MATERIAL REQUIREMENTS

guideway section geometry, this method of achieving the balance usually leads to very small span lengths with an associated increase in the guideway construction cost and the cost of the support structure. One way of overcoming this situation is by employing guideway spans that are most economical to manufacture disregarding their excess torsional strength.

Cutouts: Once an economical span length is selected, one may proceed to remove the excess torsional stiffness of the guideway by making cutouts at suitable locations. In the present study, only rectangular cutouts of the form shown in Fig. 2(c) are considered. They may be located either on the vertical sides or the horizontal sides of the guideway. The former arrangement is preferred in order to minimize the reduction of bending stiffness. While St. Venant's theory is used in the analysis of closed segments of the guideway, warping torsion theory [3] is employed in the study of the behavior of cutout (open) segments. Fig. 6 illustrates the manner in which the increase in guideway angle of twist due to a cutout varies with respect to the cutout location along the guideway and the vehicle location along the cutout. Fig. 7 presents analogous results for bending deflections. A minimum increase in the angle of twist is obtained when the cutout is located at the midspan whereas the minimum increase in the bending deflection is achieved by locating the cutout at the end span. However, the percentage increase in the angle of twist is quite large compared to the percentage increase in bending deflection. The former is therefore, the deciding factor for cutout locations.

In addition to serving as a means of guideway material optimization, cutouts are useful as service openings.

VEHICLE - GUIDEWAY DYNAMIC ANALYSIS

Vehicle Model

The vehicle dynamic model employed in the present investigation is shown schematically in Fig. 8. The vertical, lateral and roll motions of a TGT vehicle are expected to be considerably different from those of a comparable NGT vehicle. Only these modes are included in the dynamic analysis and the effect of vehicle length is neglected in this preliminary study. The vehicle is assumed to be sprung by two suspension systems, one located near the top of the guideway at the end of the cantilever suspension arm and the other located near the bottom of the guideway. The unsprung mass inertia of the suspension system is neglected (or lumped to the sprung mass). The suspension systems are modeled by linear springs and dashpots and for analytical convenience their effects are resolved into vertical and horizontal components (See Fig. 8).

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[3] Timoshenko, S., Strength of Materials Part II Advanced Theory and Problems, D. Van Nostrand Company, Inc., Princeton, N.J., 3rd Edition, 1956, pp. 261-264.

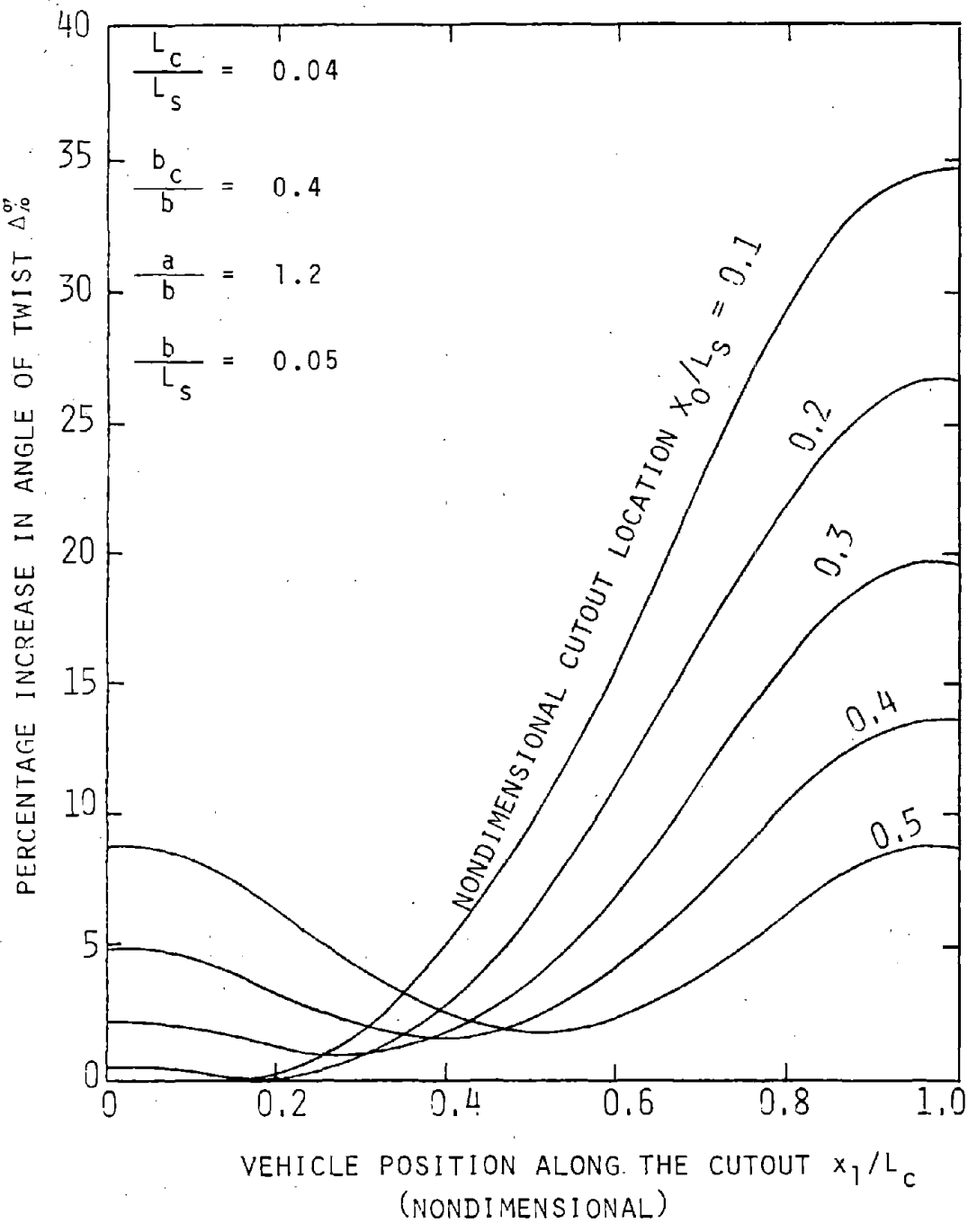


FIGURE 6. EFFECT OF CUTOUT ON TORSIONAL DEFLECTIONS

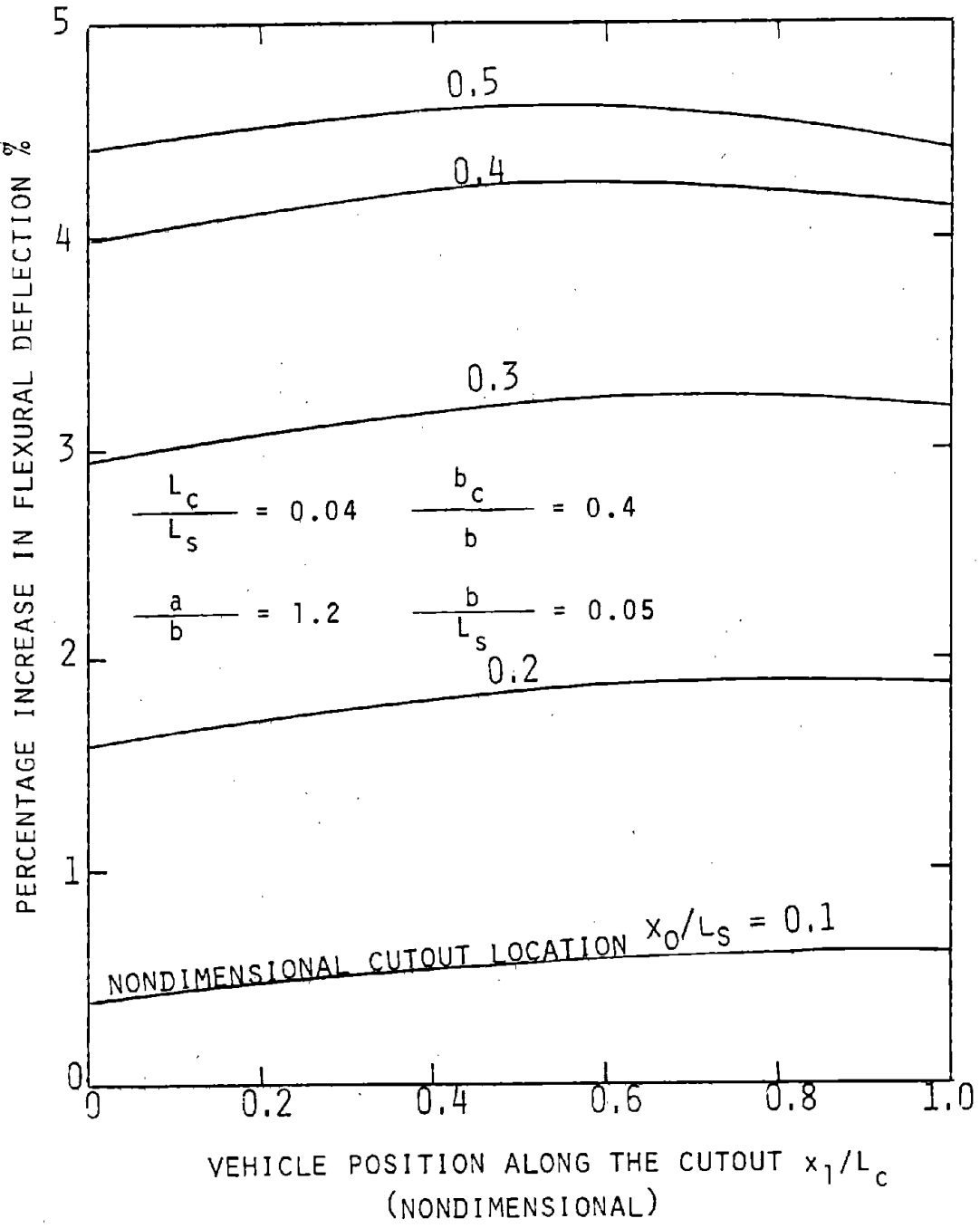


FIGURE 7. EFFECTS OF CUTOUT ON FLEXURAL DEFLECTIONS

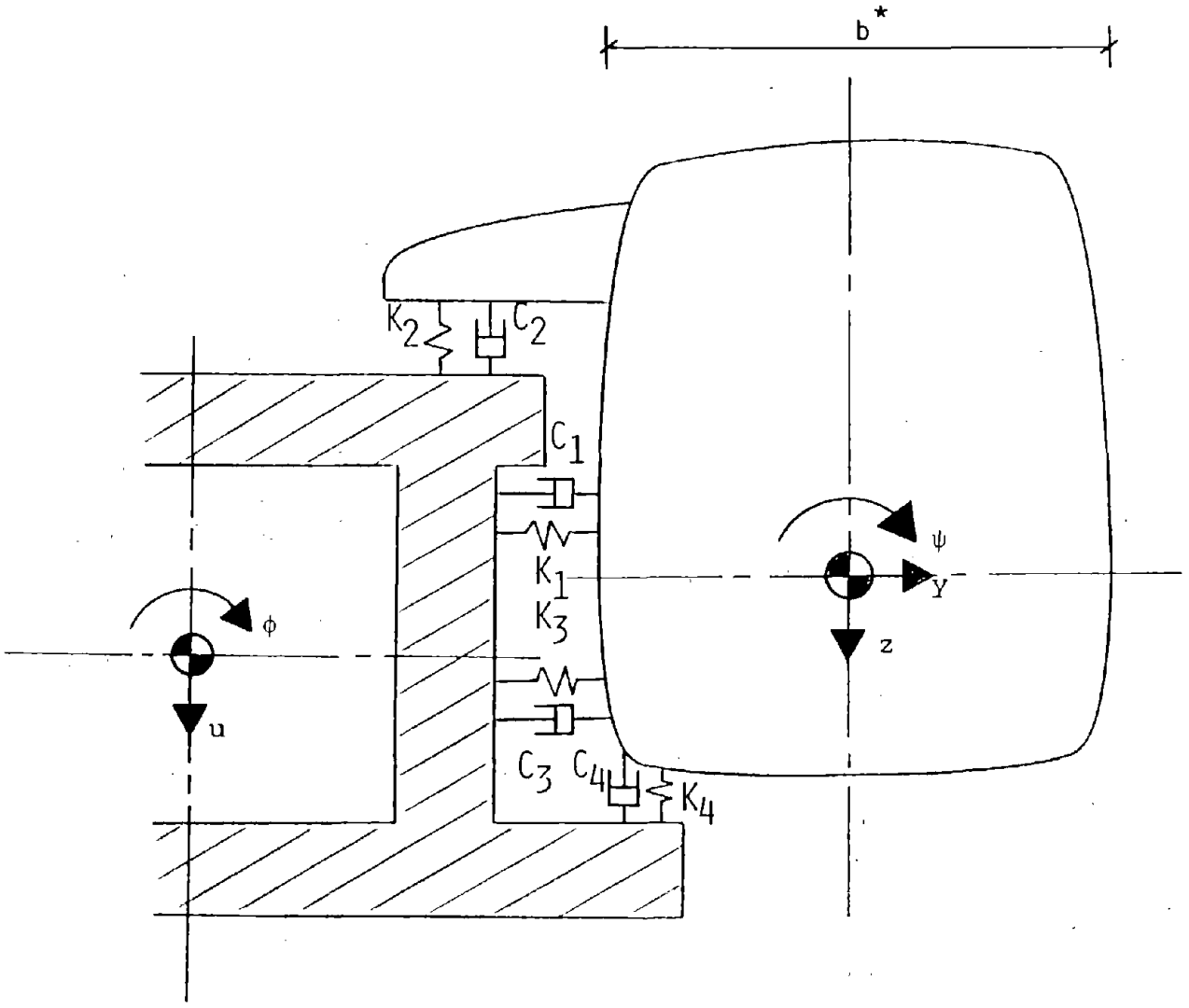


FIGURE 8. PRELIMINARY DYNAMIC MODEL SCHEMATIC

Analytical Procedure: The partially coupled constant force approximation described in Ref. 4 is employed in the dynamic analysis. In this analysis the primary force from the vehicle on the guideway is due to the vehicle weight, and because the vehicle has low levels of acceleration, vehicle inertial forces are neglected in comparison to weight forces. A set of vehicle transfer functions is obtained for the vehicle traveling at constant velocity with the bending deflection and angles of twist as inputs for the guideway deflection response analysis. Vertical and horizontal displacement profiles at the two suspension points on the guideway are considered as inputs for the guideway irregularity response analysis. Guideway bending deflection and angle of twist time histories are computed using a modal analysis technique in conjunction with the boundary conditions corresponding to assumption (b) stated under the static analysis. These are fourier transformed and used as inputs to vehicle transfer functions. Guideway irregularities are described by their power spectral densities. The deflection and irregularity inputs are combined to determine the overall vehicle ride quality.

Vehicle Dynamic Response

The system parameters for the baseline case analyzed are given in Table 1. The case was evaluated to determine vehicle accelerations, a measure of ride quality, as the vehicle crossed a series of guideway spans.

Effect of Guideway Topology: The dynamic analysis of vehicle passage over semi-continuous guideways (two or more spans per guideway beam) indicates that as the number of spans per guideway beam increases, the R.M.S. vehicle accelerations due solely to bending and the maximum bending deflection decrease quite rapidly up to about 3 spans/beam and then reach almost a constant value as more spans are added. A suitable design value is therefore 3 spans/beam for this particular system. The torsional effects are independent of the number of spans/beam because there is no transfer of twist across pier supports as assumed in the analysis.

Effect of Guideway Stiffness: The influence of flexural and torsional stiffness on vehicle accelerations is illustrated in Fig. 9. As the flexural and torsional stiffnesses are increased, in the range of 0 to 0.16 m^4, the vehicle accelerations decrease significantly while further increases in stiffness have only minor reductions in vehicle accelerations. Initially in the low stiffness range, the guideway motions are quite large and generate relatively large vehicle accelerations. As the stiffness increases, the guideway deflection, due to vehicle traveling loads, is reduced and vehicle accelerations are reduced.

COMPARISON OF TORSIONAL AND NORMAL GUIDEWAY TRANSIT

Table 2 presents a comparison of a TGT system with an equivalent NGT system. For two-way passage, two normal guideways having a net bending

[4]Wormley, D.N., Smith, C.C. and Gilchrist, A.J., "Multispan Elevated Guideway Design for Passenger Transport Vehicles", Chapter 3, Report No. FRA-OR&D-75-43-I, U.S. Department of Transportation, April 1975.

TABLE 1: BASELINE SYSTEM PARAMETERS

VEHICLE PARAMETERS:		
Number of vehicles	=	1
Weight	=	7200 kg (16,000 lb)
Roll Inertia	=	6731 $kg \cdot m^2$ (161,000 $lb \cdot ft^2$)
Speed	=	97 km/hr (60 mph)
Vehicle Cross-section	=	2.4m x 2.4m (8 ft x 8 ft)
Natural Coupled Frequencies	=	1.47 (hz) - vertical
		0.48 (hz) - lateral
		0.19 (hz) - roll
GUIDEWAY PARAMETERS:		
Number of Spans	=	1
Span Length	=	18.3m (60 ft)
Second Moment of Area of Bending	=	0.06m^4 (7.0 ft^4)
Area of x-section	=	0.46m^2 (5.0 ft^2)
E	=	2.82 x 10^5 kg/cm^2 (4.03 x 10^6 lbf/in^2)
G	=	1.09 x 10^5 kg/cm^2 (1.55 x 10^6 lbf/in^2)

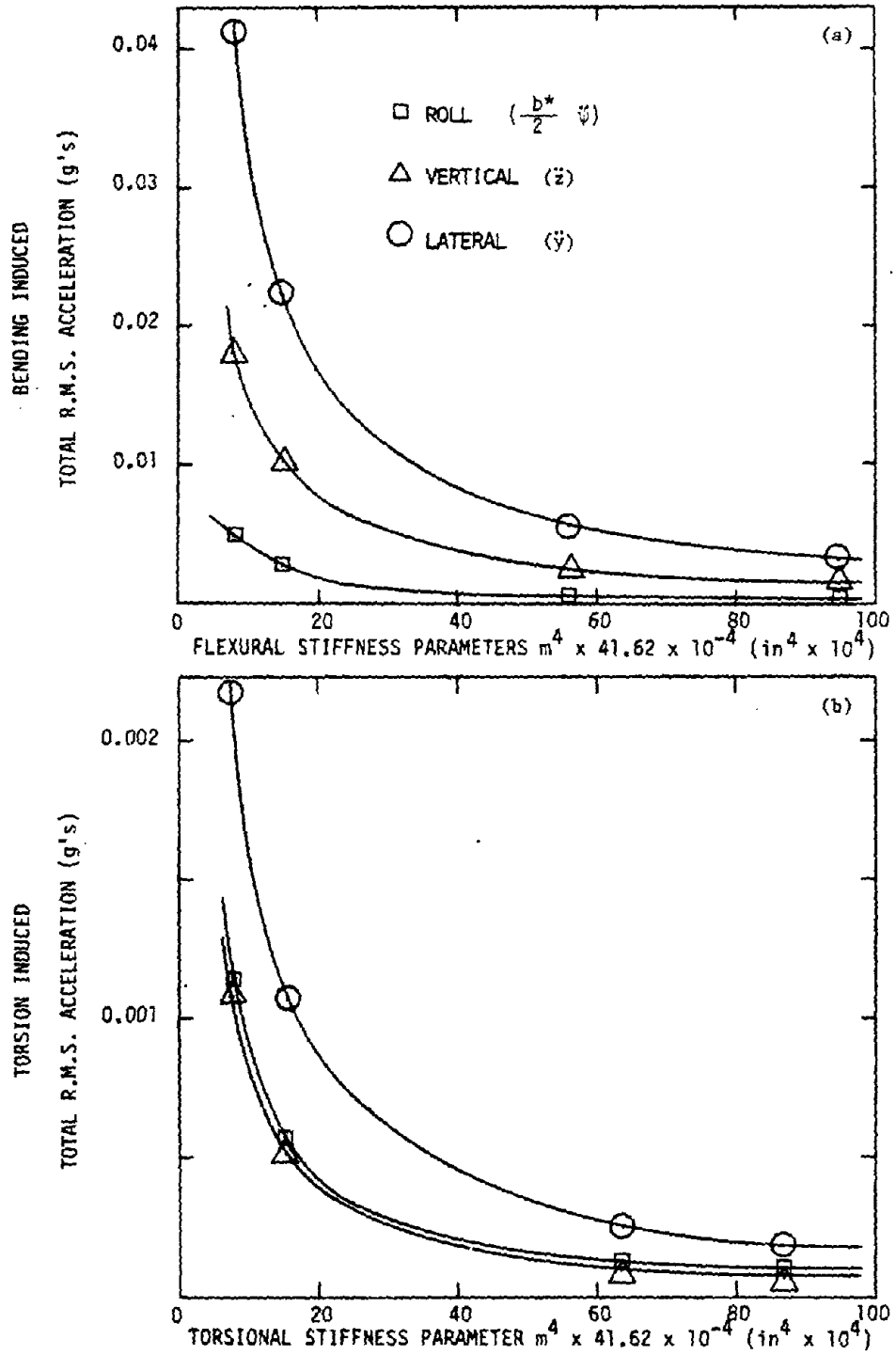


FIGURE 9. EFFECTS OF GUIDEWAY STIFFNESS ON VEHICLE ACCELERATIONS (A) BENDING (B) TORSIONAL

TABLE 2: DESIGN EXAMPLE (SINGLE VEHICLE - SINGLE SPAN)

QUANTITY	TGT	NGT
VEHICLE:		
Weight kg (lb)	9,000 (20,000)	9,000 (20,000)
Roll Inertia kg m^2 (lb ft^2)	8,080 (193,200)	
Cross Section	2.7mx2·7m (9 ft x 9 ft)	2.7mx2·7m (9 ft x 9ft)
Natural Frequencies (Hz)	1.36 0.43 0.17	Sprung: 1.0 Unsprung: 6.32
Speed km/hr (mph)	97 (60.0)	97 (60.0)
GUIDEWAY:		
Span length m (ft)	18.3 (60.0)	18.3 (60.0)
2nd Moment of Area of Bending m^4 (ft^4)	0.21 (24.5)	2.0.10 (2 x 12.2)
Area of Cross Section m^2 (ft^2)	0.67 (7.2)	2 x 0.9 (2 x 9.65)
μ	0.035	Variable
β	2.3	Variable
Max. Bending Deflection cm (in)	0.38 (0.15)	0.38 (0.15)
Equivalent Torsional Stiffness/Bending Stiffness	4.36	Variable
Guideway Weight/Normal Guideway Weight	0.4	1.0
1st Natural Frequency (Hz)	9.0	5.5
Crossing Frequency Ratio	0.16	0.268

stiffness equal to that of the torsional guideway are considered. Only a single vehicle is included in the analysis because for two vehicles moving in opposite directions, torsional effects are subtractive whereas the flexural effects are additive.

The design points in Figs. 3-5 show that a weight reduction of 60% has been achieved with a sectional height/width ratio of 2.3. The equivalent torsional stiffness of the torsional guideway is over 4 times its bending stiffness. Further weight reduction (material saving) can be achieved by trading off this excess torsional stiffness with the bending stiffness by increasing β. However, this tradeoff is restricted by elastic instabilities such as the buckling of guideway section walls and care must be exercised to avoid such conditions. An alternative and more preferable way of achieving further material saving is by means of cutouts. The size of these cutouts can be selected so that the guideway is balanced in both torsional and flexural characteristics.

Vehicle response to guideway irregularities and deflections have been determined. Results to date show that the vehicle accelerations are determined primarily by the guideway surface irregularities and only secondarily by guideway deflections for the baseline TGT cases considered. Similar results have been obtained for NGT systems.

Another point of interest in TGT systems is their lower crossing frequency resulting from reduced guideway mass. This reduces the possibility of reaching resonance conditions.

CONCLUSIONS

The present investigation has considered, in a preliminary manner, the potential of torsional guideway transit systems with respect to guideway loading and vehicle ride quality. The results, to date, indicate that the system has the potential to provide two-way passage of automated guideway transit vehicles with reduced guideway material requirements and ride quality which is comparable to normal guideway transit systems. A lower crossing frequency resulting from lower guideway mass in TGT systems in comparison to NGT systems, reduces the danger of reaching resonance conditions. Because of these features, torsional guideway transit merits further study. A number of significant technical areas, including the details of switching and of vehicle attachment to the guideway, require further study before the technical feasibility of this type of system can be fully determined.

ACKNOWLEDGMENT

This work was supported in part by the Urban Mass Transportation Administration and by the Transportation Advanced Research Projects of the U.S. Department of Transportation.

APPENDIX - NOMENCLATURE

a	=	mean height of box section
b	=	mean width of box section
b_c	=	width of rectangular cutout
b^*	=	vehicle width
E	=	Young's modulus of elasticity
G	=	Shear modulus
g	=	acceleration due to gravity
K_b	=	bending stiffness
K_{bo}	=	nondimensionalizing bending stiffness parameter
K_t	=	torsional stiffness
K_{to}	=	nondimensionalizing torsional stiffness parameter
L_c	=	cutout length
L_s	=	guideway span length
ℓ	=	mean perimeter of guideway section
T	=	torque on guideway due to vehicle weight
t	=	wall-thickness of guideway section
W	=	vehicle weight
x_o	=	location of cutout center measured from left end of guideway
x_1	=	location of vehicle along cutout measured from left end of cutout
y	=	lateral displacement of vehicle centroid
z	=	vertical displacement of vehicle centroid
β	=	box section height/width ratio (=a/b)
μ	=	thickness/perimeter ratio of guideway section (=t/ℓ)
τ_{max}	=	maximum shear stress in guideway due to torsion
τ_o	=	nondimensionalizing parameter for shear stress
ψ	=	vehicle roll angle
σ_{max}	=	maximum normal stress due to bending of guideway
σ_o	=	nondimensionalizing parameter for normal stress

CHAIRMAN'S SUMMARY OF WORKSHOP SESSION A

System Operations

Arthur Priver, TSC
Session Chairman

SYSTEMS OPERATIONS WORKSHOP

Arthur S. Priver

U.S. Department of Transportation
Transportation Systems Center
Cambridge, Massachusetts, 02142

Proceedings

The participants in the Systems Operations Workshop addressed the following five subject areas:

1. System Operation Studies--Shuttle-Loop Transit Analysis
2. Operation Studies in West Germany
3. Morgantown System Management Algorithms
4. Simulation Considerations
5. Advanced Group Rapid Transit System Operation

Each topic was introduced by a short, formal presentation followed by discussions.

1. System Operations Studies--Shuttle-Loop Transit Analysis

Jim Thompson and Ron Lee of General Motors briefly addressed the System Operations Studies (SOS) program's Shuttle-Loop Transit (SLT) analysis approach. They described a set of 11 SLT scenarios that were evaluated. The major discussion was on performance goals selected. (An average wait time of four minutes and a maximum wait time of nine minutes, as well as average travel speed goal was 3.5 meters/sec.) The values were chosen based on a review of Morgantown, AIRTRANS, other existing systems, and the DPM proposals. It was noted that studies in Germany suggest that an average wait time goal of two to three minutes be used when smaller vehicle AGT analyses are performed.

From the simulation studies that started with system level goals, it was found necessary to evaluate performance at the individual station with the worst average wait time. The results were very sensitive to the design point, particularly in terms of demand, since performance limits of the system were being assessed. With this approach, it was found that in almost every case, the system that met the goals at least cost was the system that did so with the smallest vehicle fleet. Therefore, the SLT vehicle sizes tended to be toward the high end of the capacity range that was considered in each case.

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It was pointed out in the discussion that the minimum cost system did not always provide the maximum passenger benefits, and that it might be appropriate to establish the goals so that AGT systems provide higher benefits than conventional transit. It may be worthwhile to investigate where the maximum passenger economic benefit, or performance benefit, occurs in order to design systems which will have a good competitive posture for installation in urban areas.

For off-nominal operation analysis, trip logs are recorded for both faultless and failed cases to establish the availability impact on both vehicles and passengers.

2. Operation Studies in West Germany

Uwe Haferstroh of SNV in Hamburg described some of their own study efforts. The importance of having accurate demand data to derive the analysis was emphasized. There are a large number of factors that influence the modal-split, with travel time being one of the most significant factors. Travel time is a composite of access time (origin to station and station to final destination), waiting time, transfer time, driving time, dispatching time, door opening time, and dwell time.

The travel time (or on-vehicle time) can be related to energy consumption. SNV considered alternative strategies in their computer simulation (see Figure 1). The example shows a 1500 meter trip between stations. The first strategy has a sequence of accelerations followed by coasting, until it is time to brake for a station stop.

The second strategy is similar in terms of a sequence of accelerations and coastings, but the vehicle velocity variation is kept within a range of 10 km/hr.

The last method is a variant of the above in which the minimum velocity at the end of coasting is 40 km/hr. It is termed the passenger sensitivity level strategy because the passengers complain if the speed drops below 40 km/hr.

The trade-off curves show that an increase in travel time from 100 to 120 could allow a savings of almost one-third in energy consumption.

The justification for AGT systems in West Germany is not based solely on performance improvements. With automation, headways between trains can be reduced. One study of an 800 meter trip between stations on the Hamburg subway would allow a reduction in travel time from 89 to 55 seconds.

With automation, it is shown in Figure 2 how 28 seconds of delay in departure time can be reduced to a 10 second delay in arrival time, based on a distribution of 50 cases. The automated systems can better meet scheduled arrival times based upon a distribution of departure times.

The subject of power regeneration came up, but it does not appear to be useful in this context. It was pointed out that in a study in Canada, vehicles would be available to receive this power only 30% of the time.

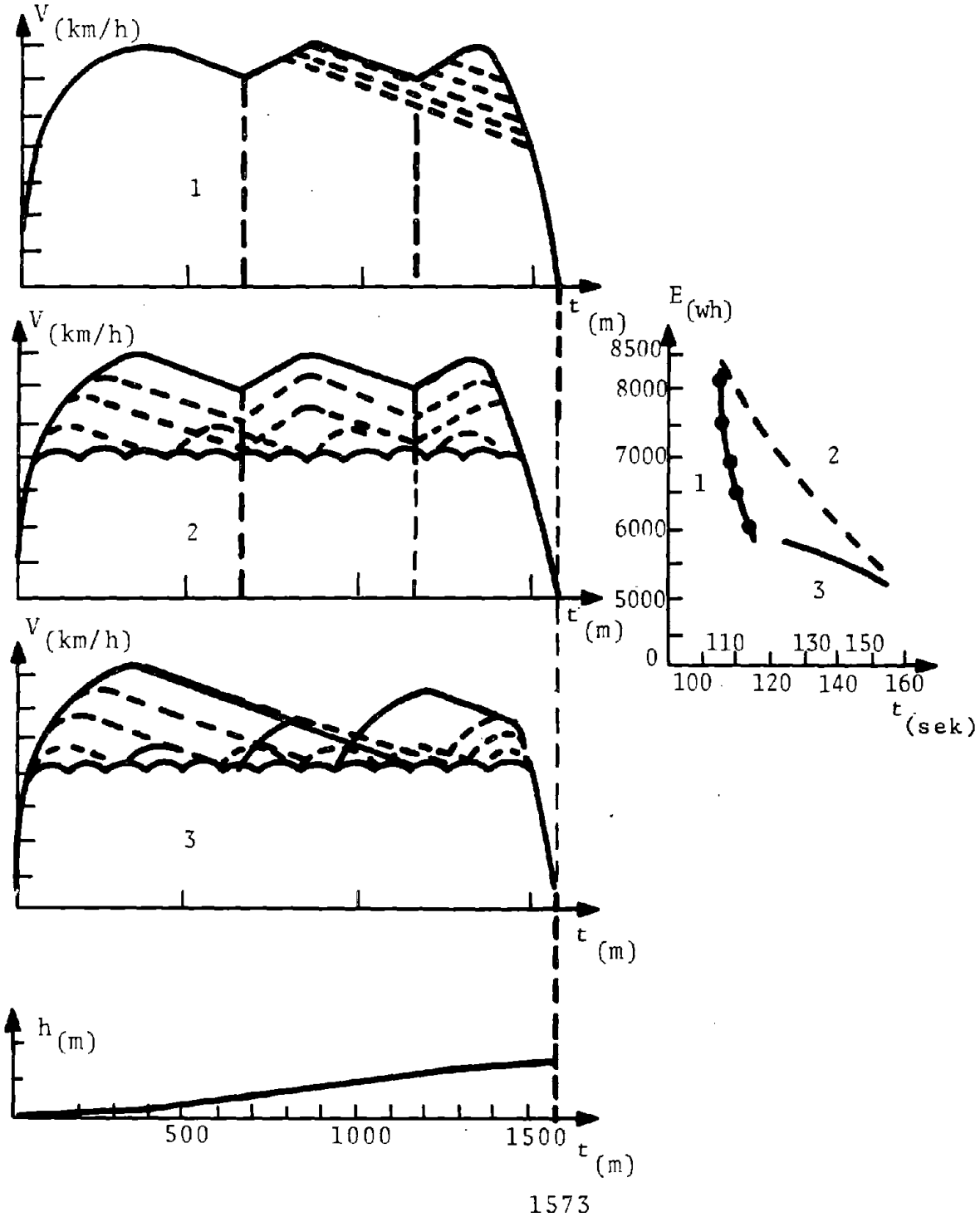

V (km/h)
1
t (m)
V (km/h)
2
t (m)
V (km/h)
3
t (m)
h (m)
500
1000
1500
t (m)
1573
E (wh)
8500
8000
7000
6000
5000
0
1
2
3
110
130
150
100
120
140
160
t (sek)

FIGURE 1.

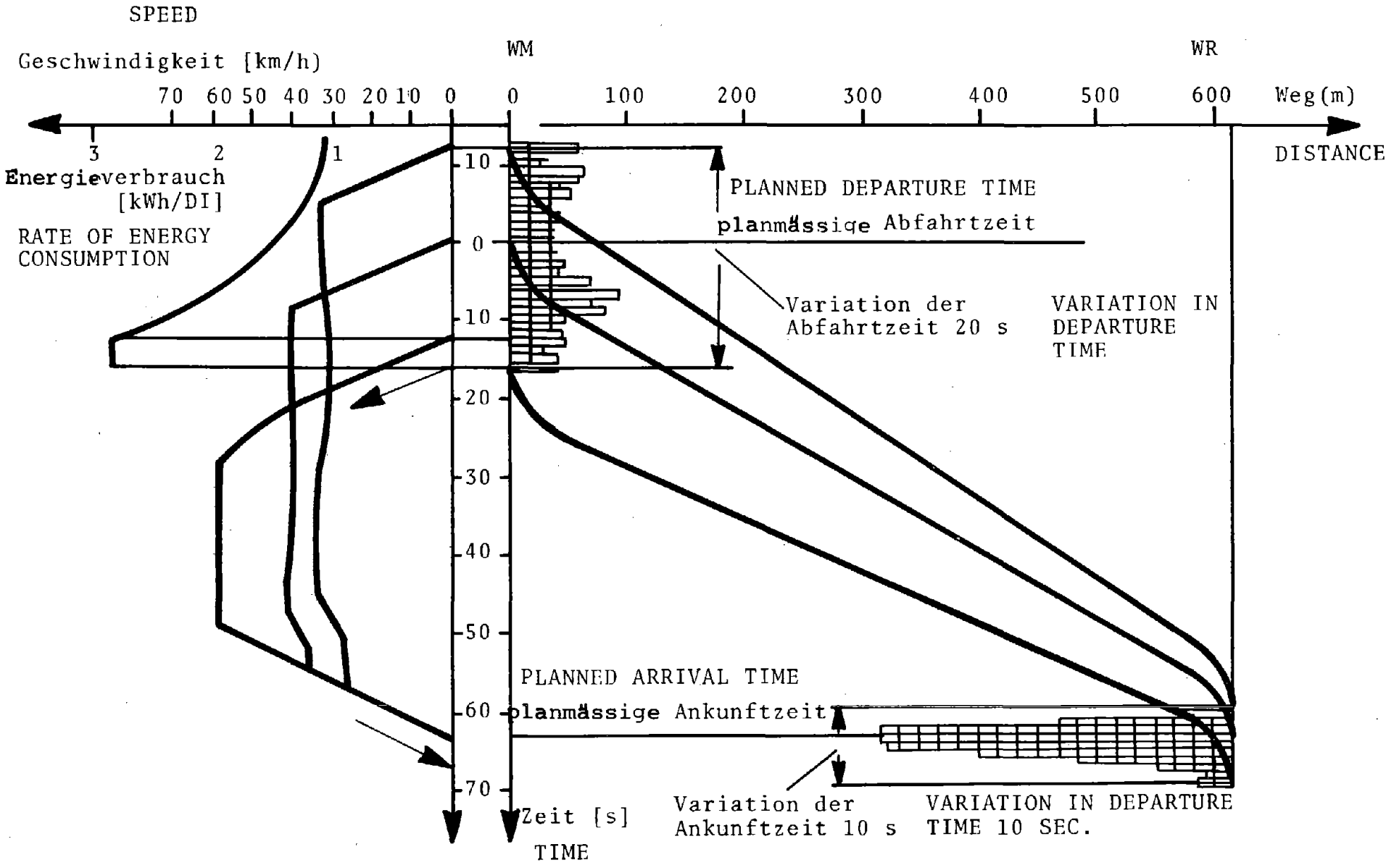

SPEED
Geschwindigkeit [km/h)
WM
WR
70 60 50 40 30 20 10 0
0 100 200 300 400 500 600 Weg(m)
DISTANCE
3 2 1
Energieverbrauch [kWh/DI]
RATE OF ENERGY CONSUMPTION
10
0
10
20
30
40
50
60
70
PLANNED DEPARTURE TIME
planmässige Abfahrtzeit
Variation der Abfahrtzeit 20 s
VARIATION IN DEPARTURE TIME
PLANNED ARRIVAL TIME
planmässige Ankunftzeit
Variation der Ankunftzeit 10 s
VARIATION IN DEPARTURE TIME 10 SEC.
Zeit [s]
TIME

FIGURE 2.

3. System Management Strategies for Morgantown

Richard Hacker of Boeing reviewed the experience gained from its Phase IB System and showed how demand-responsive operation for Phase II was impacted. The demand mode was initially oriented toward one party per vehicle and positioned vehicles in each channel based on some expected demand level. In Phase IB the schedule mode was used almost exclusively.

A new demand mode has been defined for Phase II which is more adaptable to partitioning the system and responding to demand after a failure, and allows the portion of the system not affected by an anomaly to remain in operation providing limited service. This demand mode is applicable to a very wide range of demand levels so that only a limited use of schedule mode is anticipated.

It was noted that it is harder to schedule a five-station system than a three-station one. The demand mode establishes threshold values for two parameters: group size and waiting time. Higher values are suggested for heavier demand periods to improve the efficiency of operation, e.g., reduce vehicle mileage.

The system operators have the capability of selecting the group size and waiting time. When a group of passengers achieves either threshold value, a vehicle is designated and a trip is made. It is currently suggested that for low demands--about 500 to 2,000 passengers per hour--the wait time threshold be set at 30-60 seconds, and the vehicle capacity be between 1 and 10 passengers. For demand from 2,000 to 5,000 passengers per hour the time threshold could be 2-3 minutes and the capacity setting from 10 to 15. For demand levels of 5,000 to 8,000 a time of 5 minutes and capacity of 21 are suggested.

Empty vehicle goals are now defined in terms of actual demand levels rather than anticipated demands. Boeing's efforts were in part motivated by the fact that their fee is based to some extent on availability and O&M costs.

Station bypasses will be reduced in Phase II by evaluating available station space approximately one minute before the planned divergence into the station area, and "kicking out" a vehicle if necessary.

4. Simulation Considerations

Peter Alexander of General Research Corporation led a discussion about some considerations involved in simulating a system which is either totally or to a large degree computer controlled. The major uses of simulation are to evaluate performance, assess alternatives, conduct low-cost experiments, develop algorithms, and serve as a deployment aid. The construction of the simulation is very beneficial in that it requires a complete definition of the system.

Most simulations are R&D tools that are frequently changing, and thus good software standards are needed. Simulation often turns into a major project and often too many runs are made and the output is too voluminous. Post-processing routines should be included to better present the results.

There is often a steep learning curve for new users of a simulation. It was suggested that higher level languages with simulation features be used. Validation and verification tools are often hard to use. Adaptive or automated testing should be considered to determine the performance surface of the system being tested.

It was suggested that a transportation language be developed for AGT for both simulation and operational software.

5. Advanced Group Rapid Transit System Operation

Jerry Roesler of the Johns Hopkins University Applied Physics Laboratory discussed their work in examining the operation of Advanced Group Rapid Transit (AGRT) systems (12 passenger vehicles, 3 second minimum headways, off line stations) in a variety of network scenarios ranging from loops to area-wide systems. They examined how service policies (such as the number of intermediate stops, maximum waiting time), traffic management policies (dispatching and routing), and failure management policies (failure recovery time) impacted performance. The primary service parameters examined were maximum wait time, maximum number of intermediate stops, and the number of transfers allowed. Other major performance parameters calculated were delays due to failures, load factors, fleet size required, and the least operating headway required on the busiest link. The work was done using an analytic flow model and associated dependability and cost models.

Conclusions

1. SLT operation results are very sensitive to the design conditions if the system is operating near saturation.

2. The SLT solution meeting the performance requirements with the smallest vehicle fleet appears to be the most cost-effective.

3. The minimum cost system may not provide very desirable service.

4. Acceleration-coasting strategies can result in energy conservation in AGT systems.

5. Energy savings and performance improvements are major justifications for AGT in West Germany.

6. A revised demand responsive operation is expected to be the primary operating mode for the Phase II Morgantown system.

7. Good software standards are required to control the development of a simulation.

8. A post-processing capability can reduce the number of computer simulation runs.

9. A higher level transportation simulation language could simplify simulation use.

10. AGRT operational strategies had to be adapted to each network studied.

11. Several relaxations in service requirements can result in significant improvements in service dependability and reduced cost.

12. Station design in the central business district is critical to assure maximum throughput and minimum passenger confusion.

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Richard Faris - Transportation & Distribution Associates Inc.

Louis Frasco - Transportation Systems Center

Donald Gardner - SO. California Rapid Transit District

Stanley Gershwin - M.I.T.

Richard Hacker - Boeing Co.

Uwe Haferstroh - SNV Studiengesellschaft Nahverkehr mbH

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Paul Houpt - M.I.T.

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S.W. Ladouceur - Urban Transportation Development Corporation

Ronald Lee - General Motors Corporation

Thomas Luglio - Dynatrend Inc.

A.G. Maier - General Railway Signal Company

Donald Marsh - General Motors Corporation

Patrick McEvaddy - Johns Hopkins University

Harley Moore - Multisystems, Inc.

A.S. Morse - Yale University

George Mouchahoir - The Mitre Corporation

Ronald Neville - ITT Industries of Canada LTD

Hendrik Pater - Universal Mobility, Inc.

Vernon Poulter - CADEC Systems, Inc.

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W.J. Roesler - Johns Hopkins University

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George Swede - S.E. Michigan Transportation Authority

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C.J. Weatherred - General Motors Corporation

Robert Whitten - Consultant

Li Shin Yuan - Transportation Systems Center

CHAIRMAN'S SUMMARY OF WORKSHOP SESSION B

Vehicle Systems and Reliability

Robert Hoyler, UMTA
Session Chairman

VEHICLE SYSTEMS AND RELIABILITY WORKSHOP

Robert C. Hoyler

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Proceedings

The Vehicle Systems and Reliability Workshop was attended by 23 participants. The workshop addressed the following general topics:

1. Longitudinal Control
2. Reliability
3. All-Weather Operation
4. Ride Quality

Each topic was discussed in the context of vehicle operation as opposed to operation of the entire system where other tradeoffs might be available.

1. Longitudinal Control

In the longitudinal Control area, the discussions centered on whether new longitudinal control technology should be developed with specific applications in mind, or to expand the pool of technology available, and the extent of interaction there should be between the ultimate users and the research and development effort.

Mr. Bolton raised a question concerning the longitudinal control employed by the WEDway passive vehicle system, concerning security precautions available to prevent sabotage which could result in excessively high speeds. Mr. Sulkin described the details of the system, including a comb-type steel plate arrangement fastened to the vehicle which, in conjuction with coils in the wayside, operates to control and limit the speed of the vehicle. The discussion revealed that the vehicle has no emergency braking, although braking can be applied by reversing the polarity of the wayside motor coils.

Mr. Bolton expressed concern that development efforts should be directed toward AGT applications, and although the passive vehicle is interesting technologically, it is not of particular interest to his clients. He questioned the amount of effort that should be put into new concepts when a simple, basic system could be developed for the transit authorities which have limited resources.

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Mr. Sulkin pointed out that a program balanced between immediate applications and long range technology is required if progress is to be achieved. Mr. Hoyler discussed the overall Federal transportation program ranging from Capital Grants for buying buses and trains for existing systems, to the Downtown People Mover project, to the basic research being performed in the Automated Guideway Transit Technology (AGTT) program, which includes basic research on longitudinal control concepts. Since this conference relates specifically to the AGTT program, there is naturally an emphasis on basic research. However, this does not mean that this is representative of the entire Federal program, which is, in fact, a balanced program addressing all facets of transportation.

Mr. Baker brought the discussion back to the security of the longitudinal control equipment, noting that in England wayside components along the guideway, whether it be copper wire, signal and control equipment, etc., are easily and eventually stolen at night, whereas the vehicle and its equipment can be secured in the maintenance area.

2. Reliability

The reliability discussion touched on whether classical methods of reliability enhancement were still valid for modern technology such as microprocessors. The answer was "yes", but bearing in mind that these are new types of components to be dealt with. The primary emphasis in the discussion was how can reliability be obtained between the manufacturer and his need to be low bidder, and the user with his need to maintain the equipment after it is purchased.

Mr. Bitts described the classical approach to reliability in which, once the application is identified, the most reliable components available are identified and used during design, engineering, and manufacturing. Once the equipment is installed, the technology has been committed, and a given component will continue to be used barring a major reliability problem. At this point the important factors are: availability, service, and keeping the system in operation. Detailed records for sub-system reliability are not kept unless substantial funds are available for this purpose.

Mr. Watt mentioned that the AIRTRANS reliability information is quite interesting as it illustrates the improvement which occurs as particular problems are solved. Mr. Bolton suggested that more money should be spent in the design stage not only on reliability engineering and testing, but on maintainability with a view towards the particular people who are going to perform the maintenance operations. It was pointed out in the ensuing discussion that the maintenance personnel often don't exist when the system is designed. Mr. Baker suggested that there should be more emphasis on locating components which require maintenance in easily accessible locations. This principle should be particularly applied to electromechanical systems such as doors which have high failure rates. Mr. Watt concurred that from his AIRTRANS experience the most frequent failures have been associated with the brushes for power and signal pickup, brakes, doors, and traction motors - all mechanical or electro-mechanical components. Electronics very seldom appeared in the list of failures. Mr. Lerchenmueller added the same behavior has been experienced with the Morgantown system. Mr Sulkin pointed out that

the Morgantown Phase II design reviews are being attended by people from the maintenance organization who have made many comments leading to substantial improvements on the maintainability and reliability of the system.

Mr. Schumacher suggested that the procurement specifications should include a technology qualification requirement, which would help to gurantee the life-cycle costs for buying, maintaining, and operating the equipment. In the aircraft industry, a new product is put through a thorough certification procedure which is not done in the transit industry. A certification process would make it much easier to introduce new technology into the transit industry. Mr. Kaiser raised the question concerning the responsibility for defining and performing certification procedures. In France, certification is performed by the operating companies based on their extensive experience with system operation. The main operating company in France is the Paris Transit Authority (RATP). The existing Paris "Metro" is used as a standard for new systems.

Mr. McLean indicated that a new transport aircraft must be certified by the FAA before purchase by the airlines. The airlines work very closely with the aircraft manufacturers on the design of many items involving maintenance. Mr. Bolton indicated that this approach was unsuccessfully followed in the case of the new MBTA Light Rail Vehicles because the projected use and maintenance procedures were not adhered to after the vehicles entered service.

Mr. Lerchenmueller questioned the advisability of using high reliability parts without assuring strict control of maintenance. Reliability can be compromised if a high reliability $60-part is required and a technician decides that a $1-part will do just as well. Mr. Bolton indicated that many MIL standard components cost 10 times more than the commercial equivalents. He also indicated that certification of components can lead to a false sense of security unless the certification tests closely duplicate in-service conditions.

Mr. Kaiser reported a result of a survey on transportation safety and reliability which indicated than in air transportation, which is subject to certification, 75% of all failures are due to component failure, whereas in ground transportation only 3% of failures are due to component faults. This survey revealed that the major cause of problems in ground transportation is due to the passenger and others involved in the system operation.

3. All-Weather Operation

Although all-weather operation is often thought of in terms of the wayside problems of snow removal, guideway heating, and other forms of weather protection, many problems arise on vehicles as a result of components affected by factors such as icing. This topic is directed towards vehicle design improvements for all-weather operations.

Mr. Sulkin recommended, as a result of Morgantown experience, that careful attention be paid to all-weather operation during design. Morgantown experience indicated that mechanisms with sliding parts should be avoided and that the splash protection should be provided in critical areas to prevent ice formation on lower parts of the vehicle and power collection. In Morgantown ice formation increased the inertia of the steering system parts to such an extent that the vehicle was unable to follow sharp curves.

Mr. Toye pointed out that on the North Shore line of the MBTA which uses Buddliners and is normally one of the most reliable and dependable lines, 21 vehicles out of a fleet of 85 were completely out of service, and another 62 were only in limited service after the recent February snowstorm.* Mr Sulkin indicated that the AGT system was the only transportation system in operation during the recent snow storm in Morgantown. Mr. Watt indicated that it is very important to bring the wealth of all-weather operation experience in existing transit to the attention of some advanced equipment designers. Mr. Schumacher raised the question of whether or not it was desirable to keep a transit system running during extreme weather conditions, when passengers from other modes might overload the system and cause additional problems. Mr. Watt remarked that in Boston they banned work and traffic and told everyone to stay home. Mr. Baker added that there is not much point in running a system during extreme weather conditions if people cannot get access to the stations. The cost of providing a total all-weather operation capability may not be justified by the potential benefits of such operation.

a. Mr. Sulkin indicated that in his opinion a totally covered guideway is the most effective way to assure all-weather operational capability. However, some people believe that such a guideway may result in unacceptable aesthetics for urban deployment.

b. Mr. Toye added that flooding in tunnels poses a significant all-weather operation problem. Vehicle components should be located to minimize the effects of passage through shallow water.

c. Mr. Adams pointed out that certain AGT systems such as the Jetrail and the German Cabintaxi system eliminate weather problems by suspending the vehicles under the guideway.

d. Mr. Sulkin indicated that an all-weather solution is not necessarily more costly. The redesign of the Morgantown system to handle all-weather operation resulted in a less complex and less expensive design.

e. Mr. Schumacher reported that steel wheels are superior to rubber tires for operation in snow and ice. Application of a linear induction motor to provide acceleration and braking forces eliminates the problems of wheel adhesion. However, this approach is not without its problems relating to safety and airgap maintenance.

f. Mr. Baker noted that all-weather operation must include hot weather conditions. Mr. Lerchenmueller stated that a Morgantown-type system was operated in Okinawa in August in very hot and humid conditions without related problems.

g. Mr Bolton suggested the desirability of formulating five to ten descriptive all-weather operation profiles which could be used as standard reference conditions by transit operators and manufacturers.

*February 6, 1978.

The validation of all-weather operating capability was discussed next. Thorough validation using elaborate environmental test facilities may not be practical for small vehicle production runs. Mr. Bolton indicated that vehicles should be manufactured to meet different climatic conditions by interchanging components in the same way as automobiles produced for different locations are modified. Mr. Bitts added that another factor relative to all-weather operation that had not been mentioned was climate control in the vehicles. The Sea-Tac car presently contains air conditioning, but since the system was in a tunnel which maintains fairly cool ambient temperature, future cars will probably not contain air conditioning.

4. Ride Quality

The vehicle systems are major contributors to the ride comfort as a result of the effects of suspension, steering, longitudinal dynamics, and even size and interior design. The purpose of this discussion was to determine vehicle design concepts which could be adopted to improve ride quality and/or reduce guideway running surface construction tolerances.

Mr. Lerchenmueller started out the discussion by saying that although the subway vehicles in Boston have a rougher ride than the Morgantown vehicle, the ride comfort of the Boston system has not been criticized. Mr. Toye noted that improvement in the ride comfort of the Boston system has not been a major objective because of the captive nature of the subway ridership. Good ride comfort is important if a system operates in a more competitive environment. Mr. Bitts suggested that highway standards for smoothness, curves, etc. could usefully contribute to AGT ride quality criteria because of their established nature. Ride quality can also be improved by installing radials instead of bias tires on the vehicle. Mr. Sulkin felt that the ride quality should be sufficient so that the passenger should at least be able to read or write on a vehicle. Mr. Ledoucer commented that the interface between guideway and vehicle should be a question of not just ride quality but noise and on-board reliability as well. He also indicated that perceived roughness usually results from dips in the guideway or rail in the vehicle, as opposed to surface roughness which has a minor effect. Mr. Baker pointed out that in his experience in Canada, highway standards for curves and alignments were found to be unsuitable for AGT guideways.

Mr Kaiser reported on two major findings from a ride quality survey on systems in France. The results relate to the interior layout and the size of the vehicle. With respect to the layout, the disposition of the seats, the location of the standees and handholds, the door entrance design and the size of the door are all extremely important in determining the perceived vehicle ride quality. The above factors have to be coupled with the purely mathematical and mechanical qualities such as accelerations, roll etc. The size of the vehicle can significantly affect the perceived level of ride quality. It was found that the "Aramis" system, which employs very small vehicles, produced better dynamic ride measurements than the Paris Metro, but the ride quality of the Aramis system was perceived to be worse.

Mr. Healey pointed out that the passenger's expectation of a system plays a significant role in determining the perceived quality of ride comfort. Mr. Healey also stressed the importance of a detailed ride comfort data base so that the ride characteristics of new systems can be compared to that of existing systems in similar applications.

Mr. McLean mentioned that as a manufacturer he was just recently involved with a specification which stated that the ride comfort be better than that of a specified vehicle. This therefore required measurements of that vehicle in order to establish the specified standard.

Mr. Baker stressed the importance of the location of the accelerometer instrumentation pack in the car for ride quality measurements. Several examples were presented for both transit systems and automobiles which showed that parameters measured on the floor of the vehicle would indicate a very poor vertical ride quality, whereas the ride was actually considered very good as a result of comfortable seat design. It has been observed that ride quality on an urban transit bus is generally not dictated by the wheels or suspension system, but rather by the frequency of starts and stops. Mr. Baker went on to say that ride quality does not appear to be a strong factor when a passenger makes a choice to ride a bus.

It was pointed out by the chairman that baseline data is presently being gathered by TSC in order to correlate between measurements and perceived ride quality for different trip types. The measurements are being made in six degrees of freedom including angular accelerations and roll angle. The measurements are then correlated with passenger responses. The preliminary findings of this work indicate that roll has the greatest effect on passenger comfort. The type of trip (pleasure, work, etc.) is also an important factor.

Mr. Haines expressed concern that basing ride quality criteria on existing systems would result in maintenance of the status quo rather than progress towards improved levels of ride comfort. He also noted that changes in vehicle design such as size could actually result in a change in perceived ride quality although the dynamic behavior may be unchanged.

Conclusions

1. Development of longitudinal control concepts should be balanced between long-range R&D projects and near-term applications.

2. More emphasis should be placed on reliability and maintainability in procurement specifications including detailed performance and environmental test programs at the prototype and production stages.

3. There was a diversity of opinion as to whether certification along aircraft industry lines would be worthwhile in the transit industry.

4. Designs utilizing high quality components can enhance reliability if properly used and properly maintained.

5. Although the inclusion of maintenance personnel in the design process appears desirable it is not always feasible or effective.

6. Experience with all-weather operation should be collected from existing transit systems and made available to AGT system operators and developers.

7. Vehicles should be offered by manufacturers for a range of general environmental conditions to permit elimination of unnecessary features for specific climatic conditions.

8. Design details, such as placement of ducts, splash protectors, and good engineering, are probably the best solutions to all-weather operation from the vehicle side of the trade-off.

9. Perceived ride quality is difficult to predict on the basis of measurable dynamic parameters because it also depends on type of trip, length of trip, and size and layout of vehicles. Consequently, it is difficult to specify, design to, or verify specific levels of ride quality.

10. The specification of ride quality "as good as" some other system raises problems which tend to limit the usefulness of this approach as indicated in Conclusion 9.

PARTICIPANTS
VEHICLE SYSTEMS AND RELIABILITY WORKSHOP

Robert Hoyler - Urban Mass Transportation Admininstration, Chairman

George Adams - Mobility Systems and Equipment Co.

Roy Baker - British Aerospace Dynamics Group

Randy Bartlett - City of Norfolk, Virginia

Max Bitts - Port of Seattle

Floyd Bolton - Gannett, Flemming, Cordry & Carpenter, Inc.

Jochen Glimm - Ohio State University

James Greeson - United Technologies Research Center

Gordan Haines - Otis TTD

A.J. Healey - University of Texas

Alan Johnston - Jet Propulsion Laboratory

Rémi Kaiser - I.R.T. (France)

Dennis Kershner - Johns Hopkins University

Stan Ladouceur - Urban Transportation Development Corporation

Werner Lerchenmueller - Boeing Company

Gerard Levy - Engins Matra (France)

William McLean - Boeing Vertol

Peter Schumacher - Otis TTD

Sidney Sklar - Charles Stark Draper Laboratory

Maury Sulkin - Daniel, Mann, Johnson & Mendenhall

Charles Toye - Transportation Systems Center

C.W. Watt - Transportation Systems Center

Tony Yen - TRAC

CHAIRMAN'S SUMMARY OF WORKSHOP SESSION C

Safety and Security

Donald Sussman, TSC
Session Chairman

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SAFETY AND SECURITY WORKSHOP

Donald Sussman

U.S. Department of Transportation
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Proceedings

The following is a summary of the Safety and Security Workshop. The Workshop was organized and conducted by Drs. E. Donald Sussman and Walter H. Hawkins of TSC's Human Factors staff. During the Workshop, three topics were discussed:

1. Security Threats Against the AGT System
2. Problems in Safety and Evacuation
3. Fare Collection

1. Security Threats Against the AGT System

Dr. Jack Hobbs of TSC began the discussion of the first topic by describing how the FAA and airlines handle the problems of sabotage and highjacking. He noted that it is not anticipated that the same procedures the FAA and the airlines successfully employ, i.e., armed security guards and metal detectors in corridor boarding areas, will be needed to prevent highjackings of AGT vehicles. However, there is concern for the potential problem of threats against stations, guideways, and vehicles particularly when it is anticipated that AGT systems will be constructed in heavily populated urban areas and pass through office buildings.

The participants considered a range of sabotage problems that might be events directed at the AGT system. These problems range from the low probability bombings, or such incidents as damage to signal equipment along the guideway or vandalism of vehicles in the storage yards.

The following conclusions were drawn, from the discussion of sabotage and hijacking of airplanes, which are applicable to AGT systems:

1. It probably will be important to have intrusion sensor-equipped perimeter fences to protect vehicles in storage yards and prevent people from gaining access to guideways that are at or below grade level.

2. Urban AGT systems may require important security measures such as the presence of highly visible uniformed patrols. It was noted that the

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presence of a uniformed police officer commands respect and reduces the likelihood of criminal activity.

3. A close association with local police departments should be established during the early design and construction stages of AGT stations. The local police departments will be handling threats against the system and they should be made aware of the design features. Often, they can provide good information and recommendations on what to avoid. When help is needed, the people who are familar with the system and have a working relationship with transit officials will be more prepared to respond.

4. It was suggested that helicopters be used for surveillance of AGT systems. Helicopter usage might be most useful in the protection of vehicle storage yards but somewhat limited in the core areas and while the vehicle is passing through buildings. The effectiveness of helicopter surveillance might be enhanced by coupling it with a carefully developed security publicity program.

5. Dr. Hobbs pointed out that all 12 FAA regional centers have access to explosive detecting dogs. When a bomb threat is made against the system, and it has been determined that the threat may be more than a prank or crackpot call, these dogs may be used to detect explosives. AGT system managers and the local government officials should contact the FAA individuals responsible for bomb detection and make them aware of the layout of the AGT system early in the construction phase. It is also important to have procedures for handling bomb threats worked out well in advance of system operation, and they should be well understood by transit employees.

6. It has often been suggested that closed-circuit television (CCTV) systems be considered for use in AGT systems. A CCTV system could be coupled with a video recording system. Banks use surveillance recording systems and the Washington Metro uses recording systems in their money-handling facilities. These are video tape systems where activities are taped; however, the tapes are not examined unless an incident occurs.

It was concluded that a CCTV system would be a good system for certain kinds of crimes against the AGT system for the following reasons: (a) It would serve as a deterrent to crime. The video tape of criminal activity can be used to help identify offenders. (b) It will permit the AGT operator to determine what sort of sabotage might have gone on by examining the video tape after a threat is made against the system. (c) It may make the public feel more at ease to know that potential problem areas are under surveillance. (d) It will aid in the prosecution of offenders.

2. Problems in Safety and Evacuation

For the second discussion, the workshop participants turned their attention to the problem of safety onboard the vehicle and along the guideway. A major problem was identified which currently has no satisfactory answer: "What should be done when the AGT vehicle is stopped on the guideway?" A self-powered rescue vehicle may have to be used during automatic power shutdown if passengers cannot leave the vehicle. In cases where there are parallel guideways, if power is shut down on one guideway containing the

failed vehicle, persons on the guideway may wander onto one of the powered tracks risking electrocution or being hit by a moving vehicle.

It was concluded that if vehicles are developed which are relatively impossible to burn and which do not give off smoke, the chances of keeping people safely in the vehicles are fairly great. In order to reduce the likelihood of passengers panicking onboard vehicles, or leaving the vehicles in an emergency, a two-way communications system should be provided between passengers and the command and control center. In addition to the communication system hardware, provisions must be made to insure that people are available in the command and control centers who will communicate with passengers in emergencies. There must be system staff whose primary duty in an emergency is to take information from and provide communication to the passengers. It was the group consensus that CCTV surveillance onboard the vehicles is probably not practical and probably not a reasonable solution. A two-way voice communication system, however, should be a requirement on all AGT vehicles.

As part of the discussion, Mr. David Benjamin of the Vought Corporation gave a slide presentation on station design problems that have been encountered and some of the possible solutions. He pointed out in a study Vought is performing for DOT that emergency walkways on existing rapid transit systems quickly get obstructed by trash, maintenance equipment, signal equipment and other sorts of miscellaneous material to the point where they are passable only to the most agile of ambulatory passengers. Thus, the use of emergency walkways, in addition to being costly and probably negatively impacting the aesthetics of the system, may be questionable because the walkways may not be passable when needed.

It was suggested that vehicles which contain non-ambulatory or other handicapped people might be automatically tagged. The appropriate rescue equipment might then be more efficiently directed (and response time reduced) for tagged vehicles in an emergency situation. This is a practical procedure, and the Vought Corporation feels they have efficient ways of accomplishing this.

3. Fare Collection

The last area discussed by the workshop participants was fare collection. Most of the AGT systems now look towards a very simple fare collection coin system. While this is relatively simple, the Vought Corporation has noted certain problems in automation of coin systems. The people at Airtrans have had to hire people, who have as one of their major duties, to assist patrons in fare collection problems. Such coin systems are prey to theft. The quarters remain in the fare boxes in unattended stations. This can be an attractive target and such systems require that patrons have exact change or require change-making machines which hold folding money and are, thus, another potential target for criminals.

Other fare collection solutions suggested include credit card systems (as opposed to magnetic card systems which we use now) where most of the money would be obtained through periodic billings, and coupon systems, such as are currently in use in Europe. Magnetic card systems such as those that are used in BART were discussed, but seem very cumbersome and create

considerable problems in the area of maintenance and also seem to significantly retard passenger flow. It may be more effective for the occasional transit user to purchase one-time cards, tokens, or to use exact fare instead of obtaining a transit credit card. Poor people in particular will have problems in obtaining and maintaining the charge account such transit cards require.

Transit fare machines can be designed to reject invalid cards, flash a light, take the user's picture, or keep cards which are being used fraudulently and/or have been reported lost or stolen.

The workshop participants described several European transit fare collection systems. These systems generally involve the purchase of a ticket from a store, newsstand, or a nearby vending machine. Once the passenger enters the vehicle, the ticket is inserted into a cancelling machine to be stamped with the date and time. Transit employees can periodically check for passengers with appropriately cancelled tickets. Passengers unable to produce an appropriately cancelled ticket are subject to a fine. This semi-honor fare collection system reduces the need for transit employees to handle cash.

The capital maintenance and operating costs of conventional fare collection may be so prohibitive that AGT planners may choose to utilize this semi-honor fare collection system on cost alone.

The panel discussed methods for catching fare evaders. In one transit system, a random digit is added to the valid fare cards. Anyone using a counterfeit card (which does not contain that day's random digit) will not be able to enter the system. The user will then be arrested for using a counterfeit card. In New York City, plainclothes officers observe fare evaders from unused restrooms or while standing near turnstiles. The subsequent process of arrest has been so embarrassing and effective that fare evasion has been drastically reduced.

The workshop ended with a discussion of the psychology of helping in emergency situations. Placing people together in large groups tends to aid in a transit passenger's perception of security. This can be achieved by reducing the station platform size during off-peak hours with station barriers. Some systems close off several vehicles on a train. Limiting the number of vehicles forces more passengers to ride together. Conversely, researchers at Columbia University have demonstrated, in a variety of situations, that one is less likely to get aid in crowded conditions. People are more willing to come to the aid of a fellow passenger when there are few people on the vehicle. The implication is that one may be safer riding in smaller AGT vehicles providing one chooses his company carefully.

Conclusions

1. Security techniques developed by the FAA and the airlines for countering security threats can be usefully applied to protect AGT systems.

2. Intrusion sensor systems may be desirable to protect at-grade facilities associated with the AGT system.

3. Highly visible patrols may be required to assure security in high crime areas.

4. Liaison with local police authorities during the AGT design and implementation stages can contribute to increased security in the deployed system.

5. FAA-developed techniques for handling bomb threats should prove effective for AGT systems.

6. Closed circuit television systems including video tape recording equipment should prove an effective deterrent to crime.

7. Based on current experience and technology, it appears highly desirable to hold passengers in failed vehicles until help arrives because of dangers associated with wayside facilities.

8. Onboard television surveillance and emergency walkways are probably not practical solutions for AGT systems.

9. Exact change fare collection systems are prey to theft.

10. Credit card fare systems are attractive but pose problems for the segment of the population with a poor credit rating.

11. Honor fare collection systems may prove attractive as a result of their low capital and operating costs.

12. Arrest and prosecution of fare evaders has proved an effective deterrent.

PARTICIPANTS

SAFETY & SECURITY WORKSHOP

Donald Sussman - Transportation Systems Center, Chairman

Dave Benjamin - Vought Corportation

John Benson - Kaiser Engineers Inc.

Frank Condos - Los Angeles Community Redevelopment Agency

Steve Denlinger - Mobility Systems & Equipment Co.

Roy Field - Urban Mass Transportation Administration

Walter Hawkins - Transportation Systems Center

John Hobbs - Transportation Systems Center

David Jessup - Metropolitan Transit Authority - St. Paul, Minn.

Richard Pepler - Dunlap and Associates, Inc.

CHAIRMAN'S SUMMARY OF WORKSHOP SESSION D

Wayside Systems and All-Weather Operation

George Izumi, UMTA
Session Chairman

WAYSIDE SYSTEMS AND ALL-WEATHER OPERATIONS WORKSHOP

George Izumi
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Proceedings

The Workshop session was divided into the following categories:

1. Guideway and Station Technology
2. Site-Integration and Aesthetics
3. Ride-Quality and Vehicle/Guideway Dynamics
4. All-Weather Operation.

The panel Chairman gave a brief introduction to the main topic and one or two panel members gave a five to ten minute lead-off presentation of the topic. The introductory presentations were followed by discussions between all workshop participants.

1. Guideway and Station Technology

Charles Dolan, ABAM, presented a description of potential areas for reducing guideway costs. One of the promising areas is the standardization of guideway sections. Increased production of one section would result in reduced cost because of "quantity" savings and increased competition. Guideway structural costs can be divided into beams, columns, and footings. Beams represent approximately 50% of the total guideway costs and should be the major focus of a cost reduction effort. The other major guideway cost is in the footings. The cost impact of the footing design may have a greater impact on the total AGT system than even the beam costs. The footing design can affect site integration problems such as right-of-way interference and relocation of utilities. The cost of the columns is less significant than the cost of the beam or footings. A problem area in analyzing guideway cost is to break down and separate costs for comparison. Guideway costs have large capital components which are not strictly related to the guideway such as rights-of-way acquisition costs and the cost of relocation of utilities.

Robert Stevens, DeLeuw Cather, presented an overview of the AGTT Guideway and Station Technology (GST) project's effort in the station task area. Many of the AGT stations that now exist have been built as part of AGT systems in airports, amusement parts, hotels and shopping centers where the system has been built at the same time as the surrounding development. Many of the AGT systems do not have fare collections, are simple and the stations

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depend on shared access. The amount of graphics on existing AGT systems is limited. These items, i.e., site integration, access, and graphics, are more critical for new AGT systems in existing urban areas. These issues are being addressed under the GST project. Conventional rail transit station designs are being evaluated because of similarities with AGT station requirements. Both station types have similar basic functions, particularly on the newer rail stations which feature increased automation in terms of fare collection, security monitoring systems, communications and graphic information systems. The primary difference between AGT and rail stations is size, because of the difference in volumes of people and vehicle size handled.

The AGTT program data base system was discussed by the panel. It was the consensus that the data base would be a useful tool for predicting costs. Torgersen (Universal Mobility) expressed concern that life cycle costs of different guideway designs could not be compared because of variations in demand, market, and site specific requirements. It was explained that the cost models that are being developed by the GST project will allow for regional and market variations. Raven (Vought) stated that guidelines and specifications for guideway design would be a potential area for cost reduction and also would be a useful aid to AGT designers. When AIRTRANS was built there was no guidance on specifications and requirements as to use, and in many cases highway bridge specifications were used. George Grant (Porter Company) stated that a major emphasis should be placed on power distribution cost reduction.

2. Site Integration and Aesthetics

Clarence Roy, of Johnson, Johnson and Roy (JJ&R), gave an overview presentation of site integration and aesthetic factors which must be considered when implementing an AGT system. Mr. Roy used examples from JJ&R's preliminary analysis of the Detroit DPM site. Roy recommended that site integration and aesthetics criteria be site specific and developed early in the guideway and station design cycle. Many times, the guideway and station structures are designed first and modified later to accommodate site integration and aesthetic requirements. This approach often results in a compromise design that is not completely satisfactory to the structural designers and the environmentalists and usually results in additional cost. Installation of a guideway in an existing urban environment is a very difficult task. To minimize the site integration impacts, Mr. Roy recommended the following steps:

a. Pre-identification and evaluation of urban design values for the city.
b. Pre-establishment of system urban design criteria for site integration and aesthetics.
c. Urban design analysis of all potential AGT corridors.
d. Design of a guideway amenity package (lighting, graphics etc.) that will go with the guideway when it is implemented.

Mr. Roy presented slides to demonstrate examples of his recommended site integration process.

Discussion

A major concern expressed during the panel discussions was that the cost of site specific aesthetic requirements may dominate other design cost reduction efforts. Site integration and aesthetics costs are difficult to predict because of site specific factors. Shellhorn mentioned that the Morgantown installation encountered interference problems with sewer lines, utilities and other objects that were not on the construction drawings. These items contributed to schedule delays and cost impacts. Site integration problems make it very difficult to price AGT contracts.

3. Ride Quality and Vehicle Guideway Dynamics

David Wormley, MIT, presented an overview of the Guideway and Station Technology projects' ride quality effort. MIT will evaluate current ride quality requirements and recommend specifications for ride quality requirements. The MIT effort will be coordinated with Dunlap and Associates' ride quality work relating passengers' acceptance to ride quality measurements.

It was expressed by the panel that ride quality specifications should be measurable and interpretable. A problem has been measuring and determining if an AGT system meets contract ride quality specifications.

4. All-Weather Operation

Dale Shellhorn, Boeing Aerospace, introduced the topic by showing a film on the operation of the Morgantown people mover in the snow and by discussing more of the system's winter operational problems. The Morgantown guideway heating system works effectively down to -15°F, but it is very expensive to operate. Energy costs are high and the maintenance of the water heating boiler plants has been very costly. Traction at Morgantown has not been a problem even during switching. Once the wall follower steering system loses contact with the wall the vehicle stops. Most of Morgantown's winter problems were caused by ice on the power rail. Because of this the Morgantown phase II power rails will be heated. Mr. Shellhorn said that one of the problems with the heated guideway was caused by water from the melted snow or ice splashing onto the underside of the vehicle resulting in an accumulation of ice that impaired vehicle steering. The costs of guideway heating have been very expensive and Mr. Shellhorn believes that even with the site integration and aesthetic problems that covered guideways should be investigated for AGT systems in severe climatic areas.

Thomas Nicarico, DeLeuw Cather presented an overview of the Guideway and Station Technologies' weather protection task. DeLeuw has completed an all-weather protection technology review. The major problem area is icing of the power rails. Heating power rails and traction surfaces provides a solution, but the cost and energy consumption is very high. Areas to investigate include:

(1) Hydronics vs. electric heating systems
(2) More efficient methods for heating guideway such as heating only running surfaces and insulation and load sharing to reduce peak power of electrical heating systems

(3) Anti-icing techniques
(4) Changes to operational policy to allow for degraded operation in severe weather conditions
(5) Use of abrasives and non-heating techniques such as plowing to reduce energy costs
(6) Determination of the necessity of a bare pavement policy.

Clarence Roy (JJR) stated that guideway structures are intrusive and that an enclosed guideway makes the system even more unacceptable. However, Roy felt that there may be enclosed guideway designs that are acceptable. George Grant (Porter Company) discussed the weather protection tests being conducted by the Chicago Transit Authority and the MBTA system. Dale Shellhorn (Boeing) mentions that the Morgantown heating cost and the predicted costs were reasonably close. The last couple of years the heating costs have been very high differing by approximately a factor of two from the predicted costs. Earl Torgersen (Universal Mobility) discussed his company's planned weather protection effort at the Minneapolis Zoo AGT during the coming winter. Universal Mobility will heat sections of the power rail and will also use a special purpose vehicle with flame throwers, plows, and brushes. In previous winter operation tests at Hersey Park, Universal Mobility found that plowing was satisfactory except during ice storms. Dick Renfrew (Urban Transportation Development Corporation) suggested that based on their experience steel wheel on rail vehicles should be considered for AGT systems in northern cities. David Turner (Lawrence Berkeley Laboratory) discussed his work for the Department of Energy on an induction power pick-up system scheduled for tests this June. At one inch of separation from power cable and collector the efficiency is 90%. Turner felt that this may have promise in solving the power rail icing problem.

Conclusions

The major concerns of AGT guideway and station designs are being addressed under the Guideway and Station Technology project. The conclusions of the workshop are:

1. The AGTT Guideway and Station Technology project outputs should accommodate market, regional and site dependent factors.
2. There are no guideway, station or weather protection concepts that are the best for every application, but these must be decided on a site-by-site basis.
3. Guideway and power rail heating techniques do work and permit all-weather operation, but more energy and cost efficient designs must be developed.
4. Power rail icing is the major winter operational problem being experienced on AGT systems.
5. To reduce added costs, aesthetic requirements should be incorporated into the guideway and station design criteria early in the design cycle.

PARTICIPANTS
WAYSIDE SYSTEMS AND ALL-WEATHER OPERATIONS WORKSHOP

George Izumi - Urban Mass Transportation Administration, Chairman

Timothy Barrows - Transportation Systems Center

Charles Bingham - Gannett, Flemming, Cordry & Carpenter

Frank Caiati - General Motors

Emanuel Diamant - DeLeuw, Cather & Co.

Charles Dolan - ABAM Engineers

George Grant - H.K. Porter Company

Thomas Nicarico - Deleuw, Cather & Co.

John Putukian - Transportation Systems Center

Roland Raven - Vought Corp.

R.M. Renfrew - Urban Transportation Development Corp.

Charence Roy - Johnson, Johnson and Roy

Dale Shellhorn - Boeing Co.

Paul Spencer - Urban Mass Transportation Administration

Robert Stevens - DeLeuw, Cather & Co.

Earl Torgersen - Universal Mobility

David Turner - Lawrence Berkeley Laboratory

Helmut Volk - Honeywell

David Wormley - M.I.T.

CHAIRMAN'S SUMMARY OF WORKSHOP SESSION E

Innovative Transit

Duncan MacKinnon, UMTA
Session Chairman

INNOVATIVE TRANSIT WORKSHOP

Duncan MacKinnon

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PROCEEDINGS

The panel on Innovative Transit was attended by 19 people representing local, state and federal government agencies, operators, university and industry researchers. Topics considered in the workshop were:

1. Automated Highways
2. Innovative Propulsion and Suspension Systems
3. Accelerating Walkways
4. Automated Mixed Traffic Vehicle Systems
5. Passive Vehicle Automated Guideway Transit Systems
6. Innovative Automated Guideway Transit Operating Concepts

1. Automated Highways

Fred Okano opened the meeting with a short presentation on Automated Highways research sponsored by the Federal Highway Administration (FHWA). Mr. Okano is with the System Development and Technology Group of the Office of Research of the FHWA and has been directing research on automated highways for a number of years. The major development effort to date has been performed at Ohio State University where substantial progress has been made towards the development of lateral and longitudinal control systems for automated highway vehicles. Accuracies of $\pm$ 2 inches in lateral tracking error at speeds up to 130 kph have been achieved with very satisfactory levels of ride comfort. Tests are currently in progress to refine a point-follower longitudinal control system design. The FHWA has initiated research to develop technology for the coordinated control of automated highway vehicles. This control technology would permit vehicles to perform the merge and divert maneuvers required for operation of an automated highway network.

Discussions indicated that the FHWA system control research could benefit from the results of the System Operations Studies currently in progress at General Motors and the operational control techniques currently being developed for the Advanced GRT system. The panel also discussed the requirements for failsafe vehicle operation. The requirement for positive retention of the vehicle in the event of lateral control failure could be met by barriers between lanes or a slot concept similar to that used by the "CVS" system in Japan. Strategies for failed vehicle recovery were discussed.

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Dr. Fruin indicated that the Port Authority of New York and New Jersey effectively solves the recovery problem in tunnels by reverse operation of the recovery tow vehicle after the lane in front of the failed vehicle has cleared (lane-crossing in the tunnel is prohibited). Operating headways for automated highways were also discussed. In view of the fact that highway vehicles are currently operated at separations less than the stopping distance of the following vehicle (as contrasted with currently operational automated transit systems where vehicle separations are generally greater than the stopping distance) the FHWA is concentrating its research on operation at separations less than the stopping distance with headways down to one second. The problems of all-weather operation of automated highway systems were considered by the panel. Conventional snow and ice removal techniques coupled with degraded operation (lower speeds and longer headways) appear to offer promise for solving this problem.

2. Innovative Suspension and Propulsion Systems

The next topic, "Innovative Suspension and Propulsion Systems", was introduced by Dr. Robert Ravera who is with the Office of University Research of the Office of the Secretary of Transportation. Dr. Ravera discussed the high speed magnetic levitation and propulsion system developments in West Germany (Messerschmitt-Bolkow-Blohm attractive and Siemens superconducting repulsive maglev systems), Japan (Japan Air Lines attractive and Japan National Railways superconducting repulsive maglev systems), Canada (superconducting maglev research), and the United States (Rohr attractive ROMAG and Otis air-bearing linear induction motor systems for the Advanced Group Rapid Transit Program), It was felt that the technology for innovative suspension and propulsion was well in hand and near-term deployment of such technology was possible. While much research has been done on high speed systems, it was felt that the first application of maglev and linear induction motors would be to low speed systems. More study is required to establish if the advantages of innovative propulsion and suspension such as all-weather operation, elimination of moving parts, reduced guideway maintenance, and noise reduction, are sufficient to justify the cost of development and deployment.

The efficiency and power factor of linear induction motors was identified by the panel as an area where improved performance was desirable. A potential solution is provided by the linear synchronous motor which is still in an early stage of development. Pierre Patin indicated that an improved linear induction motor design is being developed in France. Gerald Meisenholder indicated that the Jet Propulsion Laboratory has developed some very sophisticated computer programs for magnetic circuit design which could be used to optimize linear motor performance. The panel also discussed air cushion suspension systems. Pierre Patin, the developer of the French "Aerotrain", indicated that the air cushions on the Aerotrain operate a three to five centimeter gap compared to a few tenths of a millimeter for the Otis "Hovair" air-bearing suspension. Air suspension systems require a smooth running surface to reduce skirt or pad wear.

3. Accelerating Walkways

Dr. John Fruin of the Port Authority of New York and New Jersey introduced the next topic "Accelerating Walkways." Dr. Fruin discussed the accelerating walkway demonstration site at the Path-Conrail station in Hoboken, New Jersey. The proposed demonstration site will permit a 100 m system installation. Currently the station serves 18,000 passengers during the peak hour. Approximately one third of these passengers could use the walkway. The repeat nature and broad population cross-section of the users at this site are major advantages. Currently five potential system technologies are being considered for the demonstration. Human factors appear to be the most significant problem area for these systems. Experience with the Port Authority's 334 escalators indicates that accelerating walkways are potentially very safe devices. There appear to be many applications in cities for walkways which could substantially improve the quality of urban existence.

The panel discussed the human factors problems associated with accelerating walkways. The development of acceptable hand rail designs was identified as a significant development task. Bunching of users in the deceleration section was also identified as a problem although an independent experiment at the Applied Physics Laboratory appears to indicate that the problem is not severe. The panel also considered the feasibility of networks of walkways in the central business district. Such networks appear feasible if constructed of segments one block long to minimize impact on traffic and to achieve convenient access. It was felt that early urban deployed walkways should be covered for weather protection. Accelerating walking utilizing a series of belts each at a higher speed were considered. The reason such systems are not practical is that transitions must be made between the belts when the passenger is already travelling at a very high speed - a feat humans can perform well. The accelerating walkways considered for the demonstration avoid this problem by smoothly accelerating users.

4. Automated Mixed Traffic Vehicle (AMTV) Systems

The next topic was introduced by Gerald Meisenholder of the Jet Propulsion Laboratory (JPL) who provided an excellent summary of the human factors and other operational problems experienced during the test of a AMTV on a 610 m loop at JPL. Most of the problems were precipitated by vehicles parked on or adjacent to the AMTV route. No significant problems were encountered boarding or alighting from the vehicle. The JPL legal counsel required JPL to post "Automated Vehicle" warning signs at strategic locations such as the main gate and to carry observers during the test. Otherwise no special provisions were made to meet liability insurance requirements.

AMTV product liability was discussed in some detail by the panel. The high level of awards common in product liability cases makes it very difficult to introduce new transit concepts. It is essential for new systems to be thoroughly tested and demonstrated prior to wide deployment to assure that an adequate data base exists to establish insurance rates. In the case of AMTV it is essential to design the vehicle to minimize the potential for

injury even if a vehicle-pedestrian collision occurs in the mixed traffic zone. This will require special skirts, bumpers, door interlocks and other features to assure safe operation.

5. Passive Vehicle Automated Guideway Transit Systems

The next topic considered by the panel was "Passive Vehicle Automated Guideway Transit Systems". Many system concepts using passive vehicles have been proposed. Concepts have been developed in the United States ("Carveyor", "WEDway", "Electravia", "Transette"), and in Europe ("Vec", "Poma"), and in Japan. The passive vehicles may be propelled by a moving belt ("Vec", "Carveyor"), or by a distributed series of motors ("WEDway", "Electravia"). It was felt that these systems offer potential savings in guideway structure cost, energy consumption, and vehicle cost. Vehicles featuring low weight per unit length appeared to offer the best advantages. Problems associated with the provision of vehicle utilities such as heat, light, etc., were identified.

6. Innovative Automated Guideway Transit Operating Concepts

The final topic was "Innovative Automated Guideway Transit Operating Concepts." Innovative operating concepts feature mixed online/offline station operation. Offline stations would be used on routes where high guideway capacity/short (3-15 second) headway operation is required to meet passenger volume requirements. The high capacity guideway feeds low capacity loops featuring online stations which are less costly and much easier to install in urban sites than offline stations. The AGT vehicles would operate in platoons on the online station loops behaving for all intents like a group of coupled vehicles. The online stations would require all vehicles on the loop to stop at all stations. However the additional trip time resulting from extra intermediate stops would be offset to some extent by the shorter vehicle processing time associated with online station operation compared to offline stations.

In addition to the topics discussed by the panel several other topics suggested by panel members deserve mention. James Wilson of Duke University recommended that the panel consider innovative approaches to guideway implementation to reduce cost. Some work in this area is being done at MIT where two directional guideway concepts (such as the "Cabintaxi" or "System 21" concepts) are being considered. Further work will be done in the Guideway and Station Technology project. Optimization of the vehicle/guideway interface to reduce costs could be a fruitful area for further research. The possibility of replacing commuting with communications was also considered briefly by the panel. It was felt that such a topic had to be considered in a much broader context of a world with dwindling energy and raw materials supplies.

CONCLUSIONS

The major conclusions of the panel discussions have been summarized as follows:

1. Automated highway system research is required to examine failsafe design requirements for automated highway vehicles.

2. The problems of failure management including the removal of failed automated highway vehicles needs to be studied.

3. Research should be continued on techniques to coordinate the operation of automated highway vehicle fleets. This work can benefit from similar research currently underway in UMTA.

4. Research is required to improve the efficiency and power factor characteristics of linear electric motors.

5. Innovative suspension and propulsion systems offer a number of technical advantages in areas such as all-weather operation, reduced maintenance and noise which are sufficient to justify further research.

6. Accelerating Walkway systems have similar human factors problems to conventional moving walks. Special problem areas such as handrail design will require additional research and development.

7. Liability problems with accelerating walkways are expected to be similar to those of conventional walks. The Port Authority experiment should be carefully monitored to provide a firm basis for establishing liability characteristics.

8. Automated mixed traffic vehicle (AMTV) systems appear to have many potential applications in urban transit.

9. AMTV vehicles and control systems must be carefully designed to minimize the possibility of injuries to riders or pedestrians. Operation at higher speeds will require separated rights-of-way.

10. Initial demonstrations of AMTV systems should be in relatively benign locations where the AMTV vehicles would only interact with each other and pedestrians. The demonstrations must be carefully monitored to establish product liability characteristics.

11. Passive vehicle AGT systems appear to offer advantages in terms of guideway cost and size, energy consumption and vehicle cost. Research to evaluate the characteristics of such systems and to identify the best configurations appears justified.

12. Innovations in AGT operating concepts combining operation at short headways with offline stations on high traffic volume guideway segments with operation at longer headways with online stations on low traffic density loops is a promising method to reduce the problems of integrating advanced AGT systems into cities or expanding limited AGT system deployments as improved technology becomes available.

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INNOVATIVE TRANSIT WORKSHOP

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George Anagnostopoulos - Transportation Systems Center

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Donn Fichter - Consultant

John Fruin - Port Authority of New York and New Jersey

William R. Hershey - Sverdrup & Parcel and Associates

Michael Lenard - Mitre Corporation

Gerald Meisenholder - Jet Propulsion Laboratory

Terry Nettles - ABAM Engineers

Fred Okano - Federal Highway Administration

Pierre Patin - Regie Autonome des Transports Parisiens

Robert Ravera - Office of University Research, DOT

N.E. Rudback - Transport Canada

Sam Rudofsky - Michigan Department of State Highways and Transportation

Steven Shladover - M.I.T.

J.F. Sutton - Transette

James Wilson - Duke University

CHAIRMAN'S SUMMARY OF WORKSHOP SESSION F

Social and Economic Factors

Howard Evoy, UMTA
Session Chairman

SOCIAL AND ECONOMIC FACTORS WORKSHOP

Howard D. Evoy

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Proceedings

The participants in the Social and Economic Factors Workshop discussed the following subject areas:

1. Institutional and Implementation Issues
2. Availability and Uses of Cost Data
3. Aesthetics Issues
4. Safety and Security Issues

Each topic was introduced by a short presentation followed by group discussion.

1. Institutional and Implementation Issues:

Mr. Bruce Douglas of Peat, Marwick and Mitchell introduced the topic by posing questions including : "How can region-wide support be obtained for an AGT system? What level of citizen participation is appropriate? How can relatively slow citizen participation processes be coordinated with grant application schedules? Are UMTA guidance and requirements too restrictive and demanding?"

A lively discussion of citizen participation followed. The sense of the discussion was that realistic goals must be set and fully communicated to many levels of the public. The general public is interested in the basic purpose for the system, what problems are to be solved or what improvements are offered. Individuals and businesses along proposed routes will be interested in very specific design features which change the relative impact. Information must be tailored to the interests of the particular audience to be addressed.

The appropriate amount of public participation was discussed at length. Too little public participation can result in project failure for general lack of support, or project delays due to unforeseen legal challenges. For AGT specifically, "anti-technology" sentiment may cause system rejection if unrealistic projections are made.

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The maximum amount of public participation is limited by the number of interested individuals and groups, and their relatively short attention spans for technical detail. Public attention frequently begins in earnest only when construction impacts are felt in a particular neighborhood.

The recommended course of action which evolved is: (1) to maintain public interest, identification of interest groups must be completed early in the project planning stages; (2) to clearly identify issues to be addressed and problems which a system is intended to remedy; (3) to make realistic projections of service levels to maintain credibility of the planning effort; and (4) to target appropriate levels of information to the various concerned segments of the public in as much detail as early as possible in each stage of the project.

2. Availability and Uses of Cost Data

Mr. Tom McGean of N.D. Lea & Associates introduced this topic by summarizing cost data obtained from UMTA's assessments of 10 operational AGT systems. He mentioned factors which cause the cost estimates to vary from system to system: differences in record-keeping procedures, cost allocation methods, type of facility and operation, system capacities, construction techniques, etc. He outlined current work underway at N.D. Lea to review, normalize and analyze the assessment data.

The basic questions discussed were: "Is the existing data base adequate for projecting future AGT transit applications? What other data is needed? What analyses must be undertaken to make the data comparable to conventional transit modes for conducting an alternative analysis process?"

The basic target of the cost analysis was questioned as to what type of system is to be described and in what urban context. Since each urban area is different, will any generalized model be universally applicable? The group consensus was that a working model can be developed from the assessment information with additional input from selected elements of conventional transit systems.

A question was raised regarding the needs of DPM cities for cost information. It was stated that early in project development, overall system costs projections are important. As preliminary engineering is accomplished, specific information on each element of the system will become necessary.

It was noted that the precision of cost data for AGT systems now far exceeds the precision of other projected factors, such as demand levels. In addition, the precision of data sought for AGT exceeds the precision of available documentation on the conventional modes, so comparisons may be difficult or misleading.

It was pointed out that the large range of cost values on the 10 assessed AGT systems partly represents the diversity of technology options available to planners, rather than a problem of non-standard conditions to be resolved by cost analysis.



3. Aesthetics Issues

Mr. Henry Nejako, Acting Director of UMTA's Office of Socio-Economic Research and Special Projects, initiated the discussion of aesthetics by quizzing the workshop members on their personal responses to typical AGT aesthetic issues. Sample questions and responses were:

- "I would allow an AGT system to be built in front of my house." (6 agreed, 5 disagreed)
- "The neighborhood where I work would be just as pleasing with an AGT system as it is now." (13 agreed, 4 disagreed).
- "I would pay $20 per year in additional property tax to ensure good design and system integration with urban surroundings." (15 agreed, none disagreed).
- "I would prefer an apartment building with an AGT station to one without a station." (18 agreed, 1 disagreed).
- "AGT systems can be made sufficiently quiet and unobtrusive to go through parks without disturbing their settings." (14 agreed, 1 disagreed).
- "Advertising space for signs and billboards should be rented out along AGT guideways." (None agreed, 18 disagreed).
- "Sheltering waiting passengers has a higher social value than minimizing local visual intrusion." (18 agreed, none disagreed).

There was considerable discussion concerning the binary nature of the quiz in view of the subjective nature of the issues addressed. It was pointed out that other factors such as security and accessibility during emergencies affected some answers, emphasizing that aesthetics cannot be addressed independently of other equally important technical, social, environmental and economic concerns.

The issues of the willingness on the part of the public to pay for "aesthetic" designs was debated. The consensus was that consideration of aesthetics early in the design of a system can result in much more attractive systems and only slightly increased cost. Although the principle involved was agreeable, the application of it to specific existing systems caused heated debate. In general, persons who had been involved with a particular system defended its design as the best solution given the constraints involved; those not involved thought that improvements could have been made.

New rolling stock was cited as a potential source of improvement in system aesthetics as perceived by the users, without any change in the system infrastructure. The "aesthetics" improvement is somewhat offset by operator unhappiness with more complex equipment exhibiting new and different maintenance problems. The point was made that "system aesthetics value" is

determined by all of the elements which characterize the systems for the user or viewer of it.

4. Safety and Security Issues

Mr. Chuck Elms, President of N.D. Lea & Associates introduced this topic by pointing out the differences between "safety" and "security". Safety is well-defined, quantifiable, and has been assessed for existing AGT systems. It must be considered for passengers, for the non-user public, and for operating and maintenance employees. Security is less well-defined, because it relates to user perceptions. The overall security of a system is not controllable by the operator or designer, but must in part rely on public law enforcement agencies. Existing AGT systems are in "benign" environments and therefore no data exists which can be applied to urban situations.

The concerns expressed about security included the problem of isolated cars with small numbers of people aboard; the need for effective, rapid human response to emergencies detected by TV surveillance and other means; and the problem of captured offenders being immediately released by the criminal justice system.

A safety comparison with non-automated modes was made. The question was raised of possible over-emphasis on AGT safety. Conventional systems operate on a daily basis with a lesser emphasis on safety. The potential capability of AGT to apprehend offenders was cited, using automation to prevent a criminal from leaving the car or station. The question of the desirability of publicizing such a capability as a deterrent to future problems was discussed.

The need for configuration control and failure detection was cited. This need affects AGT particularly because incipient failures on conventional transit are usually detected by an operator. It was also noted that in many cases an operator cannot prevent all problems (such as suicides), and this type of problem will never be fully controlled regardless of automation levels.

Conclusions

1. Citizen participation is critical to project success and must be solicited early in the life of a project. It must be conditioned by targeting appropriate audiences with information tailored to their needs and interests, which will change as a project progresses. Realistic projections must be made to retain credibility in the planning process. The need for public participation may conflict with desired implementation schedules if the participation process is not initiated well in advance of the need of its results.

2. Cost data on existing AGT systems will be helpful to planners of future systems, such as the DPM's, if it is carefully analyzed and converted to reflect urban use conditions. Data for other modes is not as precise as data now available on AGT, so comparisons may be difficult.

3. An "Aesthetics Quiz" was given which forced workshop participants to consider their own reactions to such issues as: intrusion into their neighborhood, costs of "good design," and the value of sheltering passengers. All participants agreed that good design was attainable at minimal cost if emphasized from the beginning. Another interesting conclusion was broad support for "tailoring" AGT guideway design to particular neighborhoods rather than requiring a uniform system-wide design.

4. Safety and Security were noted to be two distinct areas of concern. Safety is quantifiable and data is available from existing systems. Security is, as yet, an unknown because AGT has not yet been deployed in an urban setting. It was noted that safety constraints being placed on AGT exceed those placed on non-automated technologies. Security problems in this area are sometimes beyond the control of the system designer and operator and are more a reflection of local social conditions and the efficiency of the law enforcement and criminal justice systems.

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