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Evaluating ITS Parking Management Strategies: A Systems Approach

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16. Abstract

The development of new technologies in the field of parking management has provided numerous alternatives for improvement in the operation of change-mode parking facilities. Change-mode parking facilities provide parking that enables travelers to move from their private automobiles to a higher occupancy mode of travel. These facilities include parking at airports, train stations, transit stops, as well as commuter carpool lots. Under each of these circumstances, allowing travelers to quickly park their cars is essential. Increasing the simplicity of the parking task can benefit both the traveler and the lot operator. There exists a need for a methodology to evaluate the various alternatives available for improving parking management at change-mode facilities, aiding lot operators in selecting appropriate improvements for a particular location.

The objective of this study has been to develop a methodology for considering potential improvements to change-mode parking facilities and identifying those with the potential to produce substantial benefits. This report describes the steps involved in the proposed methodology and illustrates the methodology with analysis of a hypothetical transit station parking facility. Several aspects of the work performed during this project will benefit the transportation industry:

- The development of supporting techniques appropriate when using a systems analysis method to evaluate improvements to change-mode parking facilities
- The illustration of the feasibility of using discrete-event simulation to assess the potential benefit of new technologies in parking
- A description of several potential improvements to change-mode parking facilities using ITS technologies

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1. Introduction

Problem Definition

The development of new technologies in the field of parking management has provided additional alternatives for improving the operation of change-mode parking at facilities such as airports, railroad stations, bus and rail transit stops, and commuter carpool lots. For each of these facilities, the importance of providing users with the means to quickly park their cars is essential. Minimizing the time required to park by simplifying the parking task will benefit the traveler and the lot operator. The traveler benefits from an easier transfer between the private automobile and the transit mode. Parking facility operators benefit from increased efficiencies in lot operation and increased business. Improvements through the use of information technology are possible in several aspects of the process, including vehicle circulation and lot usage, fee processing, and staffing requirements. A methodology is required to evaluate the various alternatives available for improving change-mode parking facilities that can assist parking officials in selecting improvements that benefit the user and justify the required investment. Within this methodology, computer simulation can be useful in estimating the impact of the potential improvements.

Project Rationale

In order for transit to function in an automobile oriented society, parking facilities are required. During the past two decades, public transportation services have been provided to serve suburban areas along heavily traveled corridors. However, parking facilities must be provided at outlying stations to provide access and to minimize the costs of operating local bus service in less developed areas (Turnbull, 1995: 14). Recent survey research indicates that these parking facilities help attract travelers to transit who previously drove alone during their daily commute (Turnbull, 2000: 9-10). Parking is also a major requirement at airports and railroad stations. Many communities facilitate carpool formation by providing commuter-parking facilities in outlying areas.

Miller and Tsao state that intermodal transportation systems are the most promising means of handling the ever-increasing demand for urban travel. Intermodal passenger transportation systems can accommodate this demand by providing equally appealing options for travelers to reach their destination (Miller and Tsao, 2000: 2). Intelligent Transportation Systems (ITS) contain many potential applications that could improve the operation of change-mode parking facilities, assisting in providing travelers with an appealing alternative to automobile travel. A major goal of ITS is to improve the operation of existing transportation facilities through the application of advanced technology. Thus, ITS programs could provide a new source of support to the field of parking management. These technologies can provide support in several areas of parking management, including operational improvements to accommodate existing demand as well as demand management programs that attempt to influence the demand for parking at particular locations, typically through pricing schemes. ITS enhanced change-mode parking facilities can increase the effectiveness of urban transportation networks by providing a seamless transfer from the automobile to public transportation.

Project Purpose, Objectives and Scope

The purpose of this research is to develop a methodology for evaluating ITS applications in parking management at change-mode facilities. This technique allows the assessment of the benefit of implementing various ITS solutions to problems faced by change-mode parking facilities. The techniques formulated in the methodology conform to the application of a systems analysis procedure to change-mode parking facilities (Smith, 1998; Gibson, 1991) and could also apply to other transportation alternative evaluations.

This project had three primary objectives:

- To research potential applications of ITS technology to change-mode parking facilities.
- To develop a methodology for analyzing potential improvements to change-mode parking facilities.
- To investigate the potential of computer simulation as a decision support tool within the analysis framework provided by the methodology.

Completion of the objectives listed above has resulted in the development of a methodology for analyzing the range of improvements available for change-mode parking facilities. Within the procedure recommended by the proposed methodology, computer simulation is a useful aid in assessing the potential impacts of various technologies.

The scope of the work performed during this project has been limited to development of the methodology and an illustration of its application to a hypothetical transit station parking lot. A demonstration within the sample application of the methodology shows an appropriate technique for using computer simulation to assess the performance of a potential improvement to the facility. The modeling and simulation performed during this research indicates the potential for computer simulation as a supporting tool within the methodology but does not represent a thorough evaluation of the ITS improvement investigated.

Report Overview

This report is organized as follows:

1. A brief review of the literature providing background information essential for this research.
2. An overview of the methodology for analyzing alternative parking management improvements, including a detailed description of each step.
3. An illustration of the application of the analysis methodology to a hypothetical transit station parking lot, including a demonstration of the potential for using computer simulation within the methodology.
4. Conclusions and recommendations for further investigation.

2. Review of Relevant Literature

Change-Mode Parking Facilities

The goal of the methodology developed in this research project is to identify the most appropriate improvements to change-mode parking facilities. Change-mode parking consists of any parking facility that exists to allow individuals to change from their private automobile to a higher occupancy mode of travel. Examples include parking at airports, railroad stations, transit stops, and commuter parking lots. Improving the operation of these parking facilities is paramount to ensure the continued success of the facilities that they support. In each case, since travelers are using the parking facility to change modes, the lots become part of the traveler's trip. Service improvements within the parking lot can help lot operators maintain their satisfied customer base and even attract new travelers to the facility. The similar requirements of parking at each type of transportation facility means that parking operators at these locations share many of the same concerns and can benefit from a methodology for identifying worthwhile improvements.

Historical Development

Parking has been a component of air and rail travel since the early days of automobile and air travel. Change-mode parking has been in use at transit stations for over 70 years, with the first records of operating lots being those operated at gas stations along a Detroit transit line in the 1930s. By the 1960s similar lots were in use in major cities throughout the United States. Since travel to and from the transit station lots was primarily work-oriented, they became known as "commuter lots." The lots originally developed for many of the same reasons they are chosen for implementation today, including:

- improving transit operating efficiency
- attracting new riders to transit/HOVs
- providing alternatives to highway travel in congested corridors
- reducing energy consumption, and air pollution
- addressing the transportation needs of special events

In recent history, the lots have become an important component of management plans designed to increase the effectiveness of urban transportation systems. Interest in parking increased as cities developed transportation systems management (TSM) plans. These were efforts to develop low cost improvements that would enhance the operation of transportation systems. Metropolitan areas are now incorporating change-mode parking facilities into transportation demand management (TDM) programs, which also aim to enhance the operation of transportation networks, but do so by trying to control the demand for travel (Turnbull, 1995: 6-7). Turnbull summarized the characteristics of various change-mode parking facilities associated with urban transportation systems in North America. Table 1 shows estimates of the size and range of utilization levels at various types of facilities.

Table 1. *Typical Characteristics of Change-Mode Facilities.*

Facility Served	*Size (spaces)*	*Fee*	*Utilization*
Commuter Rail	500 - 2,000	No	75% -133%
Heavy Rail	1,000+	Yes	Very well used
Light Rail	400 - 1,000	No	26% - 99%
HOV Lanes (exclusive)	1,000 - 2,200	No	Varies widely, 60% - 100 %
HOV Lanes (concurrent)	100 -600	No	
Express and Local Bus	25 - 100	No	< 50 %
Carpool Parking	small	No	unknown

(Source: Turnbull, 2000: 1-7)

Advantages of Change-Mode Parking Facilities

Development of change-mode parking lots can provide benefits to both the individual traveler, and society. Travelers see benefits in the form of reduced travel expenses and reduced travel time. Cost savings stem from lower vehicle maintenance, fuel, and insurance costs due to fewer miles traveled. Travel times can be shorter for those who use these lots if the higher occupancy mode is given priority treatment, or for those who use a higher speed mode for intercity travel. Examples of priority treatment include the dedicated corridor given to rail transit, or HOV lanes provided for buses and carpools (Bowler, et al., 1986: 2-3 – 2-4, Dueker, et al., 1998: 1, Turnbull, 1995: 13).

Societal benefits of change-mode lots include reductions in energy consumption, traffic congestion, air and noise pollution, and reduced demand for parking at work sites and throughout the central city. These facilities can also increase the patronage on transit systems and provide improved access to jobs for those living in outlying areas (Bowler, et al., 1986: 2-4 – 2-5, Turnbull, 1995: 14).

Disadvantages of Change-Mode Parking Facilities

Bowler briefly describes a few of the disadvantages of change-mode parking facilities. They are the cost of the facility, and the pollution and congestion problems created. The cost of the facilities is particularly burdensome for transit station and commuter carpool parking because they usually do not charge for parking. With no revenue to support operating and maintenance costs, the lots can become a financial burden to the agency. Pollution sources are transferred from the central city to the parking facility location. Local traffic congestion problems can also occur, especially when the surrounding street network cannot accommodate the traffic generated by the lot (Bowler et al., 1986: 2-5).

Planning and Design of Change-Mode Facilities

The planning and design of each parking facility includes site location, demand estimation, and determining the actual configuration of the lot. Lots serving transit stations or carpool locations should be located along heavily traveled corridors, preferably at locations before congestion has occurred. Every effort should be made to avoid travel in the opposite direction of a traveler's destination to reach the lot. Change-mode facilities for which the second mode is a long distance journey, such as those at airports, train stations, and intercity bus depots, need not be as concerned with location in relation to congestion or destination. They should be located to provide easy access from the parking area to the transportation facility. Change-mode lots should also be oriented for ease of access and good visibility from major highways (Turnbull, 1995: 15). Efforts to attract patrons to the parking lots are enhanced by providing an easily accessible alternative to driving through a congested corridor, or offering a smooth transfer from the automobile to a long distance mode.

Estimating the demand for change-mode parking involves defining the market area, or geographic region of travelers likely to use the facility. The market areas are generally parabolas, circles, or ellipses. For transit stations and carpool facilities, these shapes are generally oriented to represent the majority of travelers using the lot originating at a point farther away from the final destination than the facility. Several models exist for determining the demand for parking spaces generated in the market area. These include comparison with similar facilities, estimates based on population, modal split calculations incorporating the destination of travelers, and the ITE model based on traffic volumes of adjacent roadways. There is little variation in the average daily demand at transit or carpool parking facilities because most are work trips that make use of the facilities. The size of these facilities can therefore be based on the demand estimate for an average workday, often with a slight percentage increase to provide extra capacity (Bowler et al., 1986: 4-23 – 4-37, Turnbull, 1995: 16-17).

The internal configuration of the lots should accommodate the efficient flow of traffic in the periods of peak demand at the facilities. Consideration must also be given to the transfer from private automobile to transit vehicle or carpool. Adequate signing and pavement markings are important to facilitate traffic flow. Pedestrian amenities ease the transfer from vehicle to vehicle. At transit stations, lots should be arranged to minimize the walking distance required, typically this should be between 120 and 195 meters (400-650') (Bowler et al., 1986: 4-37, 5-12 – 5-19, Turnbull, 1995: 17-19).

Operation

Issues concerning the operation of change-mode parking facilities include marketing, pricing, performance monitoring, and safety and security. Marketing efforts to attract travelers typically include signs, news releases, brochures, and advertisements through radio, TV, and newspaper outlets. Maintaining the effectiveness of facilities is made simpler through efforts to monitor the performance of the lot. These efforts could include monitoring the usage, physical condition, congestion at entrance points, and other characteristics of the lot. Finally, it is important to provide for the safety and security of travelers and their automobiles in order to encourage use of the facilities (Bowler et al., 1986: 6-8 – 6-21, Turnbull, 1995: 27-29).

Intelligent Transportation Systems

The proliferation of information technologies throughout our society inspired researchers to consider their applications in nearly every sector of industry. This includes their application to improving the operation of our urban transportation systems. In 1982, Strobel identified several possible applications of technology in this arena. Many of the concepts listed by Strobel have been developed into components of the National ITS Architecture developed by the U.S. Department of Transportation (USDOT) (Strobel, 1982; USDOT, 1997). Strobel identified two uses of technology in transportation: improving existing systems, and enabling innovative operations strategies (Strobel, 1982: 233-235).

ITS technologies could improve the implementation, management, and operation of change-mode parking facilities. Technologies such as Geographic Information Systems (GIS) could assist the planning and evaluation of facilities through analysis of various characteristics of the market area. For example, a GIS could incorporate demographic characteristics of residents within the market area of a proposed change-mode facility. Such a system would assist planners in estimating the demand for parking at the facility. Other equipment could enhance the performance monitoring of the operating change-mode lots. Operational improvements are possible through the simplified payment of any transit fares and parking fees using a single automated system.

The ability to disseminate timely and accurate traffic, transit, and parking information have perhaps the greatest potential for improving the operation of commuter parking facilities (Turnbull, 1995: 37-39). Obtaining information on congestion and parking availability prior to one's trip or during the trip can greatly influence the decision of where to park and can likely effect a traveler's mode choice. Researchers in Nottingham, England found that disseminating parking information including parking facility location and providing frequent radio updates on parking availability could influence the demand for parking at various locations. They determined that parking information dissemination efforts were likely to increase the use of commuter parking facilities and deemed such efforts a useful expenditure of public funds (Khattak and Polak, 1993).

Alternatives Analysis

Gibson describes the systems analysis methodology as the most promising procedure for evaluating large-scale systems that contain a "policy component." The technique accommodates systems for which the client's personal standards or judgements affect the measures of performance for various alternative designs. One major benefit of this technique is that it allows the analyst to present to decision-makers each alternative, along with its performance under certain measurement criteria (Gibson, 1991: 7). The application of this technique to transportation alternatives analysis has obvious benefits given that many transportation systems, regardless of scale, have a significant impact on the public. The importance of public policy and political decision-making in the implementation of transportation improvements leads to the need for a systems analysis approach when evaluating improvement alternatives.

As described by Gibson, the six major steps of a systems analysis are:

1. Determine Goals of System
2. Establish Criteria for Ranking Alternative Candidates
3. Develop Alternative Solutions
4. Rank Alternative Candidates

5. Iterate
6. Action

(Gibson, 1991: 29)

Kerzner describes the same procedure in terms of four phases:

- *translation* - including steps 1 and 2 above
- *analysis* - the development of alternative solutions to the problem
- *trade-off* - the ranking of alternatives based on measurement criteria
- *synthesis* - incorporating steps 5 and 6 above to identify an appropriate solution from elements of the candidate solutions

(Kerzner, 1998: 83)

Previous transportation studies have also adopted this technique for evaluating alternatives. McCants, et al. recommend comparing the performance of alternative transit station designs under various measurement criteria in selecting an appropriate design for a given location (McCants, et al., 1981: 1). More recently, Kopp and Pitstick recommend using performance measures to determine which transit stations are in need of access improvements. They recommend assessing the values of various measures at all transit stations in a study area and using these values to determine which facilities are in greatest need of improvement (Kopp and Pistick, 2000: 5). Shriner recommended a methodology based on this approach to evaluate landside improvements to airport access (Shriner, 1998). As indicated in its description and supported by previous research, the systems analysis technique appears to be a promising means of selecting improvements to change-mode parking facilities.

Computer Modeling and Simulation

There are two simulation techniques commonly used to analyze existing or proposed systems. These methods are discrete-event and discrete-time, or time-step, simulation. Both methods simulate the operation of the system using a computer model representing the actual system, modifying the state of the system at particular moments during the simulation. The difference between the two techniques is the interval between the times these updates to the system occur. Discrete-event simulation updates the state of the system each time an event occurs within that system. Time-step simulation updates the state of the system at regular time intervals over the duration of the simulation, for example, after every second has elapsed (Evans, 1988: 29-41).

Time-step simulation is particularly useful in transportation for modeling situations were the interaction between vehicles has a profound affect on the operation of the system. This type of simulation has been the primary technique used in simulating traffic flow on highway systems. Many software packages currently used in the transportation profession make use of this type of simulation, including the CORSIM package. The simulations performed by these packages include detailed car-following models that help control the spacing of vehicles relevant to the vehicle in front of them. During the system update occurring at each time interval, the acceleration or deceleration rates of each vehicle are adjusted to maintain an appropriate spacing between the vehicles (Aycin and Benekohal, 1999; Rilett, et al., 2000).

Discrete-event simulation is useful in cases where the essential elements of the system's operation are the arrival times of vehicles and the provision of some service to those vehicles. After each vehicle arrives at the entrance to the system under study, it then proceeds to an appropriate server that can provide the service that the vehicle requires. The simulation software updates the state of the system each time an event occurs. Examples of events include a vehicle arriving in the system, a server becoming available, or a vehicle departing the system. Several previous applications of this technique in transportation have represented the operation of toll plazas. After arriving at the plaza, each vehicle enters a queue for an appropriate tollbooth, waits its turn to use the tollbooth, occupies the tollbooth for an appropriate time, and then exits the system. Two important components of these models are the types of tollbooths available, such as automatic or manual transactions, and the service time required by each vehicle at a particular tollbooth. Previous studies used discrete-event simulation to investigate the potential benefits of electronic toll collection at particular toll plazas (Burris and Hildebrand, 1996; Al-Deek, et-al., 2000).

Modeling and Simulation in Parking Research

Previous research into computer modeling and simulation in relation to parking management has focused on demand estimation techniques. The most common use of computer simulation studies has been in association with mode choice models. These quantitative models seek to estimate the demand for travel on various modes based on population and demographic variables for traffic analysis zones throughout the transportation network. The models are often the basis of large-scale simulations of travel on urban transportation networks. Several studies have investigated these types of computer models in the past.

Bailey and Dimitriou recommended using modal split models to estimate the demand at change-mode parking facilities. The models they recommended included variables representing travel cost, travel time, comfort and convenience. The costs included in the model were running costs of vehicles, parking charges, and transportation fares (Bailey and Dimitriou, 1972). Kavak and Demetsky performed a study on modeling the decision behavior of travelers with the option of using express bus fringe parking for their commute. Their study developed a mode choice model based on the traveler's residence, travel time and the cost of the trip (Kavak and Demetsky, 1975).

Recent research in the modeling of change-mode parking has also focused on the parking facility's role in a traveler's choice of mode. Hendricks and Outwater describe a model similar to the two described above developed for King County, Washington, USA. The King County model incorporates varying fees and capacities at different transit station lots along particular corridor. These differences allow the model to estimate varying levels of demand at different stations along the travel corridor (Hendricks and Outwater, 1998). Liu, et al. recently completed a study of intermodal and intramodal transfers associated with transit trips. Their study assessed the impact of incorporating a penalty function for the time consumed in transferring between vehicles into macroscopic modeling of travel demand. The study emphasized the significant decline in predicted transit ridership after incorporating the effects of transfer time into the demand model (Liu, et al., 1998).

Asakura and Kashiwadani performed a simulation study in the 1990s to estimate the impact of a citywide parking information and guidance system on driver's parking location decision. Based on traveler surveys, the researchers developed models to predict the probability that drivers would respond to various types of parking information displayed on dynamic message signs throughout the city. The results of simulations performed using the developed models indicated that the best information to display on such a system is simple "full" or "parking available" messages. Once many lots in the city reach capacity, the researchers found that information on the approximate waiting time for parking at particular locations had a greater impact than detailed information on the number of spaces available (Asakura, and Kashiwadani, 1994).

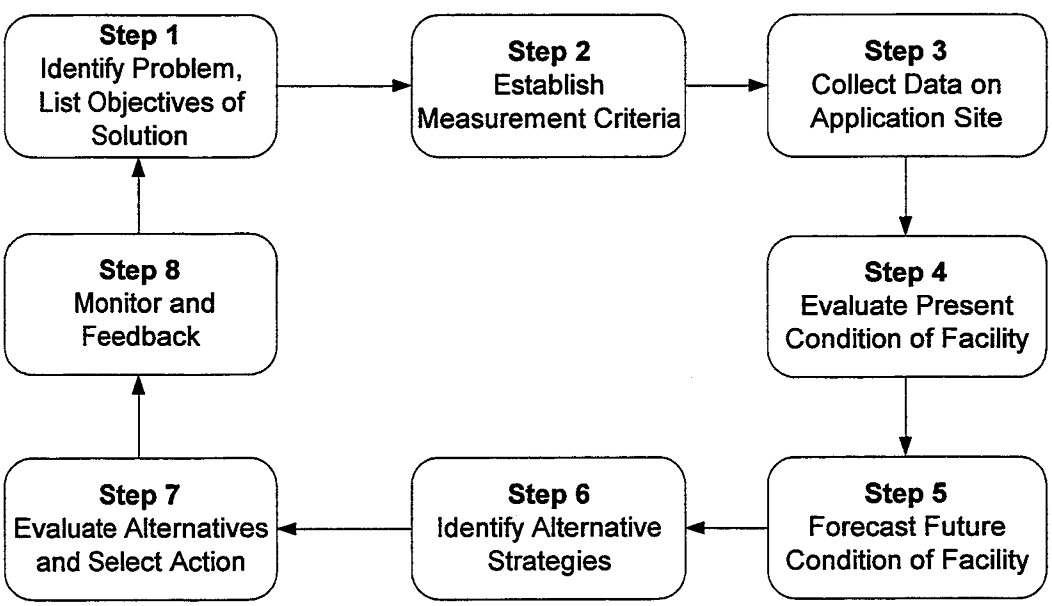
A review of literature available at the time of this study reveals no apparent efforts to use computer simulation to estimate the effects of proposed improvements on the operation of an individual parking facility. The recent interest in modeling the effect of transfer time on overall mode choice indicates the importance of the time spent transferring between vehicles in the mode choice decision for a particular journey. This importance leads to the need for estimates of the time saved by each traveler through a change-mode facility after the operating agency makes a particular improvement. Computer simulation of the operation of individual facilities within a larger transportation network could provide estimates of the reduction in transfer time made possible by various improvements to the facility.

3. Improvement Alternatives Analysis Methodology

The methodology developed for evaluating various improvements to change-mode parking facilities is based on a systems analysis procedure. Given the prominence of this procedure among previous alternatives analysis techniques for transportation applications, the systems approach holds great promise for evaluating improvements to change-mode parking. The ability of systems analysis to allow for consideration of the complex nature of operating transportation systems as well as the many outside influences that enter into the transportation decision-making process make it an appropriate method.

The steps of the methodology proposed in this chapter closely follow established analytical methods for generating and evaluating alternatives as described in the previous section of this report. This research project tailors the procedure to the evaluation of technologies applicable to change-mode parking lots. Figure 1 shows the eight step methodology recommended by this study.

Figure 1. *Methodology for Improvement Alternatives Analysis*



The eight steps of the methodology are: (1) identifying the problem and listing the objectives of solutions, (2) establishing measurement criteria, (3) collecting data on the site under investigation, (4) evaluating the facility based on collected data, (5) predicting the future condition of the facility, (6) identifying alternative solutions, (7) evaluating the alternatives and selecting an action, and finally (8) monitoring the implemented solution to provide feedback. A detailed description of each step follows.

Step 1: Identify Problem, List Objectives of Solution

The first step in selecting appropriate parking management improvements for a change-mode parking lot is to identify problems with the current lot. Generally, the problem to be addressed at these facilities is to attract more commuters to the facility, enabling them to make use of higher occupancy vehicles to complete journey. Occasionally, facilities may be operating at capacity, with no additional spaces available for commuters. Under these circumstances it may be desirable to divert travelers to other facilities along a corridor or other modes of accessing the transfer facility (most commonly transit feeder systems). Other problems may involve lot circulation, or access/egress issues. These and other problems may arise at change-mode parking lots and identifying them is the first step in selecting appropriate improvements to the parking facility.

After identifying the problem or problems to be addressed by improvements to the lot, the individual analyzing the lot must identify the objectives of a solution to the problem. For example, if the facility is operating well under its capacity, the objective of any solutions may be to increase the number of occupied parking spaces on a typical workday. The objective for improving locations already operating at capacity may be to divert travelers to other nearby facilities. If access and egress problems are occurring at the lot, the objective could be to reduce the delay experienced in entering and exiting the lot. Stating the objective of any improvements early in the planning process helps ensure that investment will be made only in solutions that could have a positive impact on the operation of the lot.

Step 2: Establish Measurement Criteria

Following the establishment of the objectives for solutions to the problem, the investigator must establish criteria for measuring the effectiveness of any solutions in meeting the project objectives. These performance measurement criteria consist of measurable qualities of the parking facility that planners can use to both evaluate the present condition of the facility and determine the effectiveness of implemented solutions. Table 2 lists potential measurement criteria for various project objectives.

Table 2. *Performance measures and applicable measurement criteria.*

Time
Parking time (average in seconds)
Delay (maximum in seconds, average in seconds/vehicle)
Cost
User cost ($)
Agency costs (capital, operating and maintenance)
Convenience
Queue length (# of vehicles, maximum and average lengths)
Walking distance (average and maximum in meters or feet)
Lot Usage
Lot usage (percent of capacity)
Parking duration (average in minutes)
Vehicle turnover (vehicles/space/day)

Two measurement criteria listed here measure the time associated with the parking task. The first is the parking time or average time in seconds it takes for drivers to park their vehicles after entering the lot. A second measure is the delay experienced by vehicles within the lot. Sources of this delay could be congestion within the lot resulting in delay at internal intersections, or queues forming behind vehicles waiting for others to exit in order to park.. The average delay experienced during peak periods can be determined by comparing average vehicle travel times within the lot during peak and off peak periods. Measuring the time required to accomplish the parking task can help establish the performance of a change-mode parking facility.

Establishing the cost components of a change-mode lot can also aid in determining its performance. Two suggested measurement criteria for cost are the user costs associated with a lot and the operating and maintenance costs assumed by the lot operator. Both of these measures can be assessed in monetary values, with the user cost estimated on a per vehicle basis and the agency cost established over an appropriate period of time. User costs would include any fees charged for parking at the facility. The agency cost should include the operating and maintenance costs for the facility in its current condition. Establishing the costs of the change-mode parking lot in its current form is important in determining its performance.

The third performance measure that should be considered for a particular parking facility is convenience. Criteria for measuring the performance of a lot in this area include the queue length and walking distance. Both the average and maximum value of both measures should be assessed, with the queue length measured in number of vehicles and the walking distance from parking to transfer facility measured in meters or feet. Establishing the average values helps determine the typical experience of a traveler using the lot. Measuring the maximum queue length and walking distance can help determine if the average values are a reasonable representation of the typical experience or if significantly longer queues or walking distances occur.

Determining the usage of a lot can also assist in assessing its performance. Measuring the percentage of available spaces in use on a given day, as well as the traditional parking analysis measures of parking duration and turnover are valuable means of measuring lot usage. The percentage of a lot's capacity in use on a daily or hourly basis establishes whether the lot is reaching its capacity to store vehicles, resulting in the need for capacity improvements or tactics to divert travelers to other facilities. Vehicle turnover, measured in vehicles per space per hour, coupled with the average duration of parking establishes the volume of vehicles served by the lot. This value helps determine the number of patrons affected by a particular improvement and can be helpful in assessing the value of a particular improvement.

Measurement criteria allow analysis of candidate solutions to the problems faced by a particular change-mode parking facility. This analysis consists of comparing the impacts of each solution on the relevant measurement criteria. Performance measures for the problem of attracting additional commuters would most obviously include usage statistics for the facility. Determining the effects of attempts to divert travelers to available space in other lots would be measured through increases in the usage of nearby lots. Measuring the vehicle delay in entering and exiting the lot would assist in determining the effectiveness of solutions for access and egress problems. Based on the problems faced at a particular lot, appropriate performance measures can assist in establishing the value of various alternative improvements.

Step 3: Collect Data on Application Facility

After selecting measurement criteria to represent the objectives of the project, the planner must obtain data on the existing condition of the facility. This data should include values for the measurement criteria as well as other information on the operation of the facility at present and in the near future. Table 3 summarizes the types of data required and potential sources for acquiring the necessary information. This information should include transit service to the lot, proximity to major highways and employment centers, the time the lot reaches capacity in the morning, and any other information that could be valuable in understanding factors influencing the lot's operation.

Table 3. *Data necessary for evaluation, potential information sources.*

Data Type	**Potential Sources**
Lot Characteristics (location, capacity, available transit service, *etc.*)	Operating agency, transportation planning agency, transit provider
Lot Usage Statistics (% spaces available, space turnover)	Operating agency, transportation planning agency, site visits
Future demand for parking	Operating agency, transportation planning agency
Convenience Measures (queue length, vehicle delay)	Site visits, existing studies or performance monitoring
Existing ITS Implementations (at or near facility)	Operating agencies, local and state DOTs, transportation planning agencies
Simulation Data	Site visits, operating agency

Gathering data for weekday peak periods will allow for observation of the facilities performance during its periods of heaviest use. Observations during the morning and evening would be necessary to evaluate problems entering and exiting the lot. Data necessary for evaluating the facility may be available from the lot operator or planning agency for the facility. Site visits will also aid in collecting the necessary data.

In addition to collecting the data necessary to determine values for the performance measures, it is also worthwhile to collect information required to create a computer simulation of the change-mode lot. Basic data essential for simulation of the lot includes times between vehicle arrivals, the physical characteristics of the lot, and average speeds of vehicles within the lot. Simulation may require other data depending on the intensity of the modeling effort associated with the project. The following chapter of this report provides a more thorough description of the data requirements for simulation.

Step 4: Evaluate Present Condition of Facility

Reviewing the data collected from the appropriate sources, the analyst should determine the operational condition of the facility. This involves establishing the performance of the facility with regard to the established measurement criteria. Completing an evaluation checklist similar to that shown in Figure 2 will assist in determining the performance of the facility under present conditions. Information contained in the evaluation matrix can assist in identifying appropriate solutions to address any problems with the current facility. These recommendations can be made by identifying problem areas at the facility within the evaluation list. Various solution packages can address these concerns and candidate improvements can be selected from the technologies available at the time, similar to the list of potential improvements given under Step 7 of this methodology (Table 4).

Figure 2. *Change-mode parking evaluation worksheet.*

Lot Characteristic	**Value**
Lot Type	(parking structure, surface)
If structure, # of floors	(#)
Lot Capacity	(# of spaces)
Percent available spaces	(% available at peak occupancy)
If lot full, time capacity is reached	(time)
Parking Duration	(minutes, average)
Space Turnover	(vehicles/space/hour)
# of entrances and exits	(#)
Highway access	(excellent, good, fair, poor)
Queues present?	(yes/no)
Max. Length?	(# of vehicles)
Avg. Length?	(# of vehicles during peak period)
Parking Fee?	($)
Transit Service Available?	(yes/no)
Service type?	(local, commuter)
Service frequency?	(minutes)
Mode?	(bus, rail)
Walking Distance to transfer facility?	
Average	(meters or feet)
Maximum	(meters or feet)
Future demand increase?	(yes/no)
Estimated increase?	(# of vehicles)

Step 5: Forecast Future Condition of Facility

Efforts undertaken during this step of the methodology should endeavor to estimate the use of the parking facility in the future. The purpose of this consideration is to determine if actions should be taken during the current improvement effort to accommodate any future increases in the use of the facility. Depending upon the level of analysis warranted by the size of the facility and the scope of the improvement project, the effort expended on this estimation could vary.

Demand forecasts may range from simple consideration of impending development in the area to more complex analyses involving one or more of the demand estimation techniques listed in the literature review. Smaller projects, such as lots used primarily for carpool formation, may rely on a simple consideration of development trends and the possibility for increases in travel along the corridor served by the facility. Complex projects could include detailed estimates of patronage on the second mode of the journey and the effect this could have on the number of patrons accessing the station by car. A heavily used transit station might incorporate ridership projections on the transit system in estimating the demand for parking at the station under study. Based on the predicted number of travelers with journeys originating at the station, estimates of the percentage of travelers using each mode of access to the station would help identify the future demand for parking at the station. Regardless of the level of effort expended on determining the future usage of the facility, the purpose of obtaining the information is to ensure that any improvements made to the facility can accommodate any predicted increases in facility use.

Step 6: Identify Alternative Strategies

After establishing the current performance of the system, and identifying any needs expected to develop in the near future, the analyst must identify potential improvement strategies. This step is most easily accomplished by reviewing a list of potential solutions and identifying those that might produce improvements in the areas needed by the facility under investigation. Communication with all stakeholders in the project is important during this step of the methodology. Reviewing alternative improvements with the facility operators and all other involved parties will greatly improve the quality of the improvements identified. Public hearings and design workshops can also assist in formulating potential alternatives.

For a complete analysis, no attempt to screen out undesirable solutions should be made at this stage in the analysis. Each technology or physical improvement that may yield the desired results should be identified for future consideration. By identifying all potential solutions to the problem, the analyst can be sure to consider all possible solutions when developing a recommendation for the site.

Potential Improvements to Commuter Parking Facilities

Considering the numerous technologies developed within the field of Intelligent Transportation Systems, there are several possibilities for improving parking facilities. Many improvements combine several available technologies to improve the operation of parking facilities, others require construction or lot reconfiguration to improve the lot. While not a comprehensive list, Table 4 identifies potential improvements to change-mode parking facilities.

These improvements fall into several categories.

1. Lot circulation improvements that improve the flow of vehicles within the facility.
2. Capacity improvements that increase the number of travelers served at a location.
3. Traveler information improvements that provide information about available parking at a large facility or at one or more lots along a particular travel corridor.
4. Fee collection improvements that decrease customer inconvenience and reduce the operating expenses associated with collecting parking fees.

Appendix A describes the cost analysis of these potential improvements. The figures presented in the table are based on the estimated cost for implementing the improvement at a 500-space change-mode parking facility discussed in the next chapter of this report. The cost values presented here provide some context of the relative level of investment required for each of these improvements. These costs are derived from the database of ITS component costs included in the ITS Deployment Analysis System software package (IDAS, 1998). During implementation of the methodology, these cost estimates should be improved through discussions with suppliers of the various technologies required by the improvements under consideration. This will ensure that the cost values obtained provide a reasonable estimate of an improvement's implementation under the circumstances faced by a given facility. Table 4 also lists the performance measures discussed in Step 2 that each improvement has the potential to affect.

Table 4. *Potential improvements to change-mode parking facilities.*

Improvement	**Description**	**Enabling Technologies; Implementation Requirements**	**Estimated Cost* ($ thousands (1995))**		**Performance Measures Affected**
			Capital	**Operating (per year)**	
Lot Circulation Improvements					
Automated Directional Signs	Automated signs within parking facility to direct drivers to available parking	Dynamic Message Signs Loop Detectors Communications	$252.5 - $373.25	$14.5 - $21.75	Time
Construction of Lot Improvements	Construction to improve lot circulation, address access/egress issues		Varies depending on improvement and site characteristics		Time
Lot Signage	Additional permanent signage within parking lot to improve vehicle circulation		Low cost		Time
Numbered Parking Spaces	Labeled spaces and permanent directional signs allow drivers to locate their assigned space	Ticket dispenser Computer and software for space assignment Enforcement	$20 - $40	$42 - $64	Time
Robotic Parking	Automated vehicle storage system: patrons park in an entrance bay, system transports vehicle to storage and retrieves when driver returns	Robotic Parking System available for multistory parking facilities	High cost system typically considered for implementation during initial construction		Time User cost Lot usage Convenience

Table 4 (continued). *Potential improvements to change-mode parking facilities.*

Improvement	Description	Enabling Technologies; Implementation Requirements	Estimated Cost* ($ thousands (1995))		Performance Measures Affected
			Capital	Operating (per year)	
Capacity Improvements					
New Capacity Construction	Additional spaces added through construction		Varies with size of capacity increase and site characteristics		Lot usage
Preferential Parking	Reservation of desirable spaces for carpools, etc.	Enforcement	minimal	$40 - $60	Lot usage Convenience
Variable Parking Pricing	Varying the fee charged for parking based on demand	Transponder ID Tags, Barcode IDs, or Farecards	$179.5 - $262.5	$10.8 - $16.9	User cost Lot usage
Traveler Information Improvements					
DMS Availability Notification	Counter at entry gate allows display of appropriate parking available/unavailable sign on adjacent highway	Entry/Exit Counts Communications Dynamic Message Signs	w/ 2 New DMS Signs $377 - $566 w/ Preexisting DMS Signs $5.5 - $9	 $12 - $18 $1.1 - $2	Time Lot usage
Radio Availability Notification	Available parking spaces announced over Highway Advisory Radio	Entry/Exit Counts Highway Advisory Radio	$21 - $28	$1.3 - $1.8	Time Lot usage
Internet Availability Notification	Parking availability displayed on the Internet	Entry/Exit Counts Communications	w/o existing ATIS $19 -$29 w/ existing ATIS $5.5 - $9	 $46 - $57 $1.1 - $2	Time Lot usage

Table 4 (continued). *Potential improvements to change-mode parking facilities.*

Improvement	**Description**	**Enabling Technologies; Implementation Requirements**	**Estimated Cost* ($ thousands (1995))**		**Performance Measures Affected**
			Capital	**Operating (per year)**	
Fee Collection Improvements					
Fee Prepayment	Automatic deduction of parking fees from existing accounts	Transponder ID Tags, Barcode IDs, or Farecards	\$67 - \$125	\$5.2 - \$10	Time Convenience
Advanced Reservation System	Reserve parking spaces for those willing to pay a monthly fee	Identification tags Enforcement	minimal	\$40 -\$60	User cost Time Convenience

* Cost estimates are for the 500-space sample parking lot described in Chapter 4. Estimates are derived from data provided with the IDAS Software System (IDAS, 1998).

Step 7: Evaluate Alternatives and Select Action

Once the potential solutions to the problems faced at a particular location have been identified, the solutions must be evaluated and an appropriate action recommended. This process will involve comparing the performance of each possible solution under each of the project objectives. An appropriate method of performing this comparison is the consideration of the values generated by each alternative in each of the measurement criteria. Some of the values in the resulting evaluation matrix will have numeric values, while others will be qualitative estimates. Computer simulation can assist with the computation of quantitative estimates of a particular improvement's impact on various performance measures. Cost estimates for implementing and operating various improvements could be generated from similar implementations at other facilities. Another possible source for cost estimation is the ITS Deployment Analysis System (IDAS) software package, which contains unit costs for many of the supporting technologies required by Intelligent Transportation Systems (*IDAS*, 1998). Many of the cost estimates in Table 4 are derived from data provided with the IDAS system. Comparing the performance of each candidate solution under the relevant measurement criteria will assist the analyst in recommending an appropriate action for the facility.

The Role of Simulation in the Analysis Methodology

A limitation to the application of systems analysis to transportation projects is the inability to develop real models of the facilities operating under future conditions at a transportation facility. Computer simulation is therefore important to the analysis of parking management techniques. Simulation allows the estimation of the affect of a proposed modification to a system through experiments performed on a computer model of the system under study.

For applications of ITS technologies, the effects of the technology in improving the values of measurement criteria can be difficult to establish. If one or more jurisdictions has implemented a technology and recorded its effects, planners in other areas can use these impacts to estimate the effect of a technology on particular measurement criteria applicable to a given situation. Previous implementations will be of the greatest value when those implementations have occurred in areas facing conditions similar to the facility under study. For new technologies or those untried under similar circumstances, these experiences are not available and engineers face the difficult challenge of estimating the impacts of implementing such a technology at a particular location. Computer simulation is a tool that allows engineers to estimate the potential impacts of a particular improvement to a change-mode parking facility prior to implementing the actual system. Indeed, simulation may even be desirable before implementation of improvements that other areas have tried. This would be desirable if a model can be developed that would accurately represent the operation of the lot under study with particular regard to the characteristics that differentiate it from other facilities that have implemented a similar improvement. In these situations, the computer simulation could identify differences in the performance of a particular solution at a proposed location and its performance in other areas.

Computer simulation has considerable potential as a decision support tool when evaluating improvements to change-mode parking facilities. Within the methodology described in this report, simulation will be of great value to the analyst during Step 7:

Evaluating Alternatives and Selecting Action. Simulation will have the greatest benefit in efforts to estimate the performance of alternatives with few previous implementations; allowing analysts to develop values for performance criteria based on model of the facility under consideration. If other jurisdictions have implemented the improvements, in addition to learning from the results of these implementations, analysts can gather data on the operating system for use in simulating its operation at the investigation site. If no previous implementations exist, specifications for the proposed system can help the engineer create an appropriate model for simulation of the improvement. The following chapter of this report describes the application of the analysis methodology to a hypothetical transit station parking facility. The two simulations created during this project and described in Chapter 4 demonstrate the use of simulation to assess the value of implementing the automated directional sign system described in Table 4.

Step 8: Monitor and Feedback

After implementing improvements recommended through the completion of this methodology, it is important to monitor the performance of the commuter parking facility. Data should be collected periodically for each of the performance measures used, as well as the other aspects of lot operation considered in the methodology. This data will help determine the effectiveness of the solution used in meeting the objectives of the improvement. Continued monitoring can provide information for use during future improvement projects to the same facility, or as background information on any improvements used for studies of improvements to other lots. In addition, the practice of monitoring the facility regularly will help identify when future improvements may be necessary.

Iteration within the Analysis Methodology

Iteration within the methodology presented here can assist the analyst in making appropriate recommendations to decisionmakers. After developing and analyzing candidate solutions to a particular problem, it often becomes apparent that some combination of elements from several solutions may provide the best result. Iterating within the methodology to consider these combinations of technologies can help determine if such recommendations are the best means of addressing the problem. In the case of change-mode parking facilities, this type of iteration would involve developing a solution alternative comprised of the newly identified combination of technologies and other improvements. The analyst should then repeat Step Seven of the methodology, considering the new solution package along with the original alternatives.

Iteration is also important on the scale of the entire analysis methodology. The arrow connecting Step Eight to Step One in Figure 1 represents this type of iteration. This arrow represents the need to repeat the analysis procedure each time additional improvements appear necessary based on the monitoring of the facility described in Step Eight. In addition, future iterations of the methodology at a particular location will be less time consuming than the original analysis due to the improved data available from this performance monitoring.

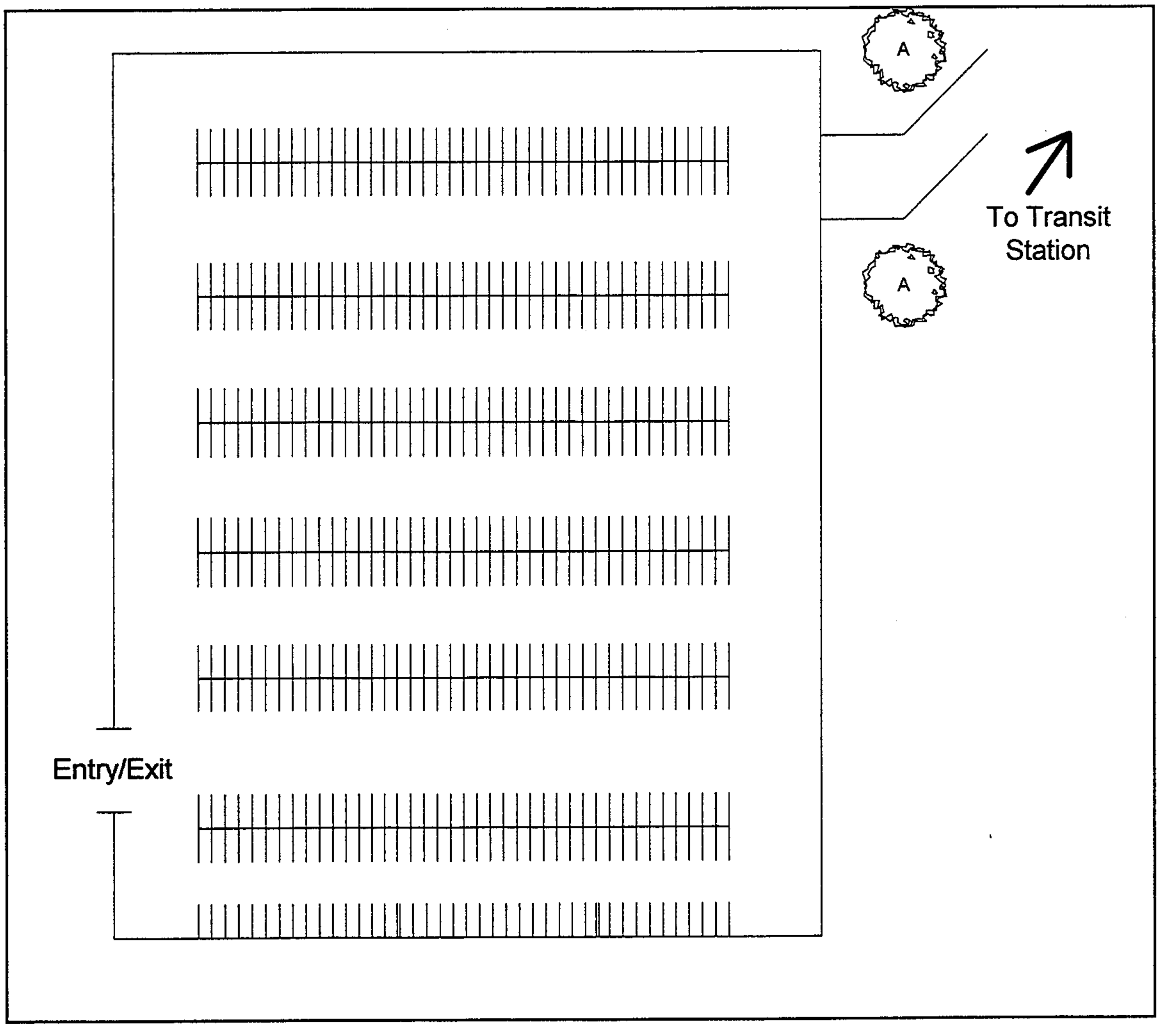
4. Illustration of the Analysis Methodology with Simulation of a Change-Mode Facility

This chapter describes an illustration of the use of the analysis methodology at a transit station parking facility. Reviewing each step within the methodology, this illustration demonstrates appropriate techniques for accomplishing the tasks required. This chapter also discusses, under Step Seven of the methodology, a demonstration of computer simulation as a decision support tool.

Scenario Description

The hypothetical parking facility analyzed in this illustration is a 500 space surface lot serving a rapid rail transit station. Figure 3 shows the physical layout of the facility. The lot provides all day parking at the transit stop, serving commuters who arrive in the morning peak period and depart during the evening peak. There are no fees for parking at the facility, yet lot usage remains well below capacity. With the hope of attracting additional patrons to the transit system and reducing congestion on the roadways leading to the central city, the lot operator is considering ITS improvements to the facility. The operator feels that travelers may be unaware of the facilities extra capacity. Another concern is that the amount of time travelers must spend locating a parking space and parking their vehicles discourages additional patrons from using the facility. Any improvements implemented should strive to improve the awareness of facility and increase the convenience of changing between modes.

Figure 3. *Layout of hypothetical transit station parking lot.*



Step 1: Identify Problem, List Objectives of Solution

Reviewing the scenario described above, characteristics of the parking facility have lead to low utilization of the facility. In the opinion of the operator of the lot, this low usage level is due to traveler uncertainty about the availability of parking and the inconvenience caused by the time it takes to transfer between travel modes. During this step of the methodology, further discussions with the operator indicate that static signs along the adjacent highway corridor describe the presence of parking at the facility. The facility is also easily accessible from the highway corridor. These facts indicate that the operating characteristics within the greatest impact on the delay experienced by travelers in making their transfer.

Establishing the objectives of solution to the problem identified for this lot involves stating the desired impact of any improvements. This process can be aided by further discussions with the operator and surveys of travelers in the area. In this case, appropriate objectives for the solution of the facility's problem include:

- reduce the time required to transfer from automobile to transit
- increase awareness of the availability of parking at the facility

These objectives will assist in brainstorming potential improvements to the facility and measurement criteria for analyzing the improvements.

Step 2: Establish Measurement Criteria

Appropriate performance measures will help assess the impact of any proposed improvements on the facility. Improvements in the performance measures of time, cost, convenience, and lot usage would indicate the ability of a modification to the change-mode lot under study to attract additional customers. With the exclusion of user costs and walking distance, each of the measurement criteria described in Table 3 of the previous chapter can help assess the appropriateness of potential improvements to the lot in question. Measurement of user costs is unnecessary, as there are no user fees at this facility. The fixed nature of the location of the transit station and the relatively small size of the facility indicate that any improvements will not affect the maximum walking distance required of travelers. These considerations indicate that appropriate measurement criteria for analysis of this facility include:

- parking time
- delay
- lot usage
- parking duration
- vehicle turnover
- operating agency costs
- queue length

Determining the impact of any proposed improvements on the above measurement criteria will help determine which improvement is most suitable for the lot under consideration.

Step 3: Collect Data on Application Facility

The next step in the analysis is to gather additional data necessary for evaluation of the facility and alternative improvements to it. This data can be obtained from site visits and continuing discussions with the lot operator. An appropriate technique for collecting the necessary data to assess the current performance of the facility is video monitoring. Combined with field measurements taken during site visits, video surveillance of the facility in operation for a period of several typical workdays would allow the analyst to compute values for each of the measurement criteria under consideration. Traditional license plate studies would also be valuable in establishing parking duration and turnover, as these may be difficult to determine from video of the facility. Video records of the lot in operation will also be useful when the analyst develops computer models of the lot for simulation of the effects of various alternative improvements.

Step 4: Evaluate Present Condition of Facility

After collecting the data required to determine the values of the measurement criteria in use by this study, the analyst can use the collected data to evaluate the present condition of the facility. The completed evaluation checklist in Figure 4 displays the appropriate data for this site.

Figure 4. *Completed change-mode parking evaluation worksheet.*

Lot Characteristic	Value
Lot Type	*surface*
If structure, # of floors	*n/a*
Lot Capacity	*500*
Percent available spaces	*50% at peak occupancy*
If lot full, time capacity is reached	*n/a*
Parking Duration	*600 minutes*
Space Turnover	*approximately 1*
# of entrances and exits	*1*
Highway access	*excellent*
Queues present?	*no*
Max. Length?	*n/a*
Avg. Length?	*n/a*
Parking Fee?	*none*
Transit Service Available?	*yes*
Service type?	*commuter rapid rail*
Service frequency?	*12 minute headways*
Mode?	*rail*
Walking Distance to transfer facility?	
Average	*n/a*
Maximum	*n/a*
Future demand increase?	*yes*
Estimated increase?	*250*

Step 5: Forecast Future Condition of Facility

The last two entries of the evaluation checklist in Figure 4 indicate the results of forecasting the future condition of the facility. For this case, the development and traffic flows in the area appear adequate to support a change-mode facility of this size. The goal of improvements to the facility is to bring the number of patrons using the facility up to the lot's capacity. Consequently, improvements to the lot must take into consideration the operation of the lot with a customer base twice its current level, an increase of 250 vehicles per day.

Step 6: Identify Alternative Strategies

At this stage of the methodology, the engineer should develop a list of candidate improvements to the facility. Possible solutions expected to bring an improvement in the performance measure of time are the most appropriate means of addressing the problem faced at this lot. Impacts on the measure of lot usage are likely to be a secondary effect of improvements to address the transfer time problem that exists at this facility. Each of the improvements listed in the Lot Circulation, Traveler Information, and Fee Collection sections of Table 4 are expected to bring improvements under this performance measure. Identifying these alternative improvements results in a list of ten possible improvements for further consideration:

- Automated Directional Signs
- Construction of Lot Improvements
- Lot Signage
- Numbered Parking Spaces
- Robotic Parking
- Dynamic Message Sign (DMS) Availability Notification
- Radio Availability Notification
- Internet Availability Notification
- Fee Prepayment
- Advanced Reservation System

Step 7: Evaluate Alternatives and Select Action

Before estimating performance values for each of the potential improvements to the facility, it is necessary to screen out candidate alternatives incompatible with the situation under consideration. In this case, physical improvements to the lot do not appear necessary, as the lot meets current design standards and congestion points within the lot are not evident. Permanent lot signage is also unnecessary due to the relatively small size and simple layout of the lot. The fee collection improvements do not apply to this situation, as there is no fee charged for parking and insufficient demand to warrant payment for reserved parking. Robotic parking systems serve the function of parking structures, providing a large capacity within a limited space. Consequently, a robotic parking system is not a suitable improvement for this site. After screening the potential candidates for incompatibility with the site under study, the list of candidate improvements contains five alternatives:

- Automated Directional Signs
- Numbered Parking Spaces
- DMS Availability Notification
- Radio Availability Notification
- Internet Availability Notification

Under the circumstances faced by this transit station parking lot, each of these improvements has the potential to increase usage of the facility.

The next step in analyzing the remaining alternatives is to estimate values for each of the measurement criteria for each alternative. There are several means of determining values for the measurement criteria under consideration. The most accurate means of assessing these values would be through a test implementation of each potential improvement. Implementing and closely monitoring the performance of each type of improvement, perhaps as part of a government funded transportation demonstration project, would provide valuable information on the impacts of these types of improvements. As demonstration projects are not available for many of the alternatives available to these facilities, computer simulation provides a promising means of estimating the impacts of various improvements to change-mode parking facilities. Simulation can provide reasonable estimates of these impacts without requiring the investment of numerous demonstration projects. The third technique for assigning values to performance measures is to make qualitative estimates of the effect of each improvement on the operating facility. While not an accurate means of determining subtle differences between candidate improvements, this technique would at least require the thoughtful consideration of the potential improvements. This consideration may highlight unforeseen differences between the alternatives, indicating the most promising improvement for the lot under consideration.

After assembling the values for each of the measurement criteria, an evaluation matrix should be developed. This matrix should present the performance of the lot under each measurement criteria with regard to its performance under the base case. The following section of this report demonstrates that modeling and simulation show promise as a means of estimating values for the various measurement criteria. The example presented assesses the value of an automated navigational sign system on a facility similar to the one discussed in this chapter. Following the discussion of simulation, the final sections of this chapter describe an evaluation matrix for the alternatives under consideration in this illustration, and the completion of the final step of the analysis methodology.

Simulation of Change-Mode Parking Facilities

An important element of this study has been the investigation of computer simulation as a decision support tool within the proposed alternative analysis methodology. The literature review discussed prior studies of computer models in relation to parking facilities and outlined the use of computer simulation to evaluate the implementation of improvement strategies at a particular site. This section of the report discusses an effort to create two models of a hypothetical transit station parking facility. The first model allows simulation of the operation of the lot before implementing a possible improvement. The second model enables simulation of the lot with an automated directional sign system. In practice, the results of similar simulations will allow an analyst to establish values for the measurement criteria of parking time as described under the performance measure of time in this report. Combining the results with simulations of other possible improvements at the site, the analyst can establish values for the performance measures for each alternative under consideration. These values will aid the engineer in establishing an appropriate course of action for the facility.

Computer simulation provides a means to study models of actual systems using software that mimics the system's operation, typically over time. Modeling the system on a computer allows an analyst to evaluate changes to the system without the expense or disruption of altering the physical system. The effort required in understanding the operation of the system in order to model it can also yield valuable observations about the system (Kelton, et al., 1998: 4-7). Simulation could provide detailed statistics on numerous operating characteristics of a parking facility, including travel time of a vehicle within the lot, the average and maximum length of any queues forming in the lot, and the delay experienced by vehicles spending time in those queues. After collecting basic data on the facility under investigation, an analyst can create a model that mimics the operation of the parking lot. Simulations developed using this model can represent the operation of the system during an appropriate period of time.

As described in the literature review, there are two techniques for performing simulations. This study has investigated the use of discrete-event simulation to assess the impact of improvements to parking facilities. Discrete-event simulation assesses any changes to the state of the system each time an event occurs (Evans, 1988: 38). Events occurring in the operation of a parking lot include the arrival or departure of a vehicle and the use of parking stalls, ticket dispensers, or other resources by vehicles within the system. The second method of simulation, especially common in traffic flow simulations, is discrete-time, or time-step simulation. These types of simulation modify the state of the system at specified time intervals, such as every second (Evans, 1988: 25). To incorporate vehicle interaction, these simulations often include car-following models that reassign acceleration or deceleration rates to each vehicle, ensuring appropriate vehicle spacing in the system (Aycin and Benekohal, 1999; Rilett, et al., 2000; Al-Deek, et al., 2000). Regardless of the type of simulation used, the engineer must perform both structural and quantitative modeling of the system under study.

Structural modeling involves defining each entity within the system, the paths followed by the entities and the resources available to them (Kelton, et al., 1998: 128). For the case of change-mode parking facilities, the entities would be vehicles using the lot. The paths followed by the entities through the system correspond to the vehicle circulation patterns within the lot. Resources needed by the vehicles might include parking stalls, ticket dispensers, entry and exit gates, passenger drop-off areas, or any other resources needed by vehicles at a particular location. Establishing the location and other characteristics of these resources within the change-mode facility allows the analyst to develop a structural model of the parking area.

After creating a structural model of the parking lot, an engineer should perform quantitative modeling of the facility. Quantitative modeling involves collecting data on both the deterministic characteristics of the lot such as the dimensions of the facility, as well as other elements of the system that often vary with time. In order to capture the random elements of a parking lot operating in reality, several components of a computer model are represented by random variables assigned values from particular probability distributions (Kelton, et al., 1998: 128-129). The quantitative modeling necessary to simulate a system includes establishing which probability distributions should be used to assign values to random variables representing various components of the system. In the context of change-mode parking facilities, random variables may be used to represent several elements of lot operation, including:

- the arrival rate of vehicles
- processing times at gates
- parking duration
- vehicle speed within the facility
- the time it takes drivers to park their car after locating an empty space

Gathering data at the facility under investigation and determining which probability distributions best describe the data will allow the engineer to determine appropriate distributions for modeling the lot's operation. As described under Step 3 of this illustration, video surveillance of the facility in operation is a promising means of collecting the necessary data for simulation.

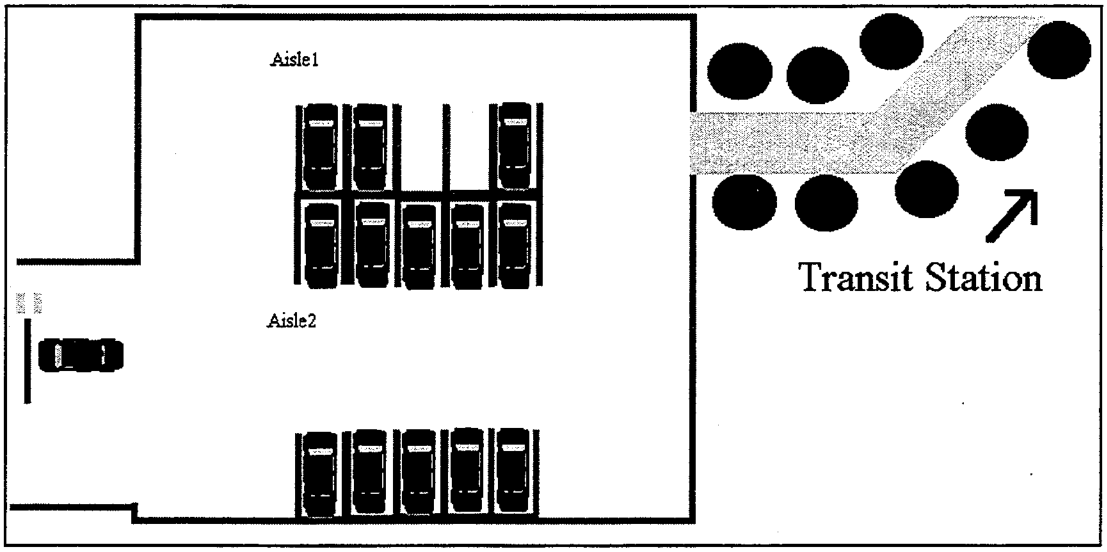
After selecting an appropriate probability distribution, sensitivity analysis should be performed in order to establish the impact of that particular element on the output of the simulation (Kelton, et al., 1998: 129). Consideration of the technologies within the proposed alternative and the results of sensitivity analysis will help the engineer establish which elements of the model must be random variables. Determining which elements of the model will have a significant impact on the outcome of the simulation helps minimize the data collection required and allows the simulation effort to correspond to the level of investment required by the improvement program.

Modeling and Simulation of a Transit Station Parking Lot

Simulation Scenario Description

The hypothetical lot studied in this investigation consists of two aisles of parking spaces with five spaces in the first aisle and ten in the second. The size of the lot was limited by the simulation capabilities of the Academic Version of the Arena software used for this project (*Arena,* 1997). Figure 5 depicts the lot modeled during this project, as seen within the software package. In all other respects, this facility is similar to the lot under investigation through the illustration discussed in this chapter. The simulation effort undertaken here attempts to estimate the impact of a system of automated navigational signs on the travel time required within the lot.

Figure 5. *Hypothetical transit station parking lot for simulation.*



In order to simulate the operation of the lot under the two cases under consideration, separate models of the lot for each situation are necessary. The Arena software package allows the creation of the models in the two steps described previously, structural and quantitative modeling. The following two subsections describe the modeling work required to obtain an estimate of the average travel time within the lot encountered by travelers under the two operating cases.

Base Case: Conventional Parking

Under the existing conditions at the facility, the base case, drivers entering the lot are unaware of the location of the closest available parking space to the transit station. The desire to minimize the time spent transferring from their automobile to the transit system leads the drivers to seek out the closest space to the walkway leading to the station. Therefore, as each vehicle enters the facility, they proceed to the parking aisle closest to the station and traverse the aisle searching for a space. Naturally, if a driver comes upon an available space, they park at that location. If no spaces are available in the first aisle, the driver proceeds to the second aisle and continues the search. If no spaces are available in the second row, the driver returns to the first aisle to determine if a space has become available. After establishing that no spaces are available in the lot and exhausting their patience for waiting for spaces to become available by circling the lot a third time, the driver exits the parking lot.

ITS Case: Automated Directional Signs

Following the installation of an automated directional sign system, the experience of a driver entering the change-mode parking facility is much different. Sensors within the lot notify a computer system where spaces are available in the lot. As each car enters the lot, signs throughout the facility display appropriate messages directing them to the available space closest to the station entrance. This allows drivers to eliminate the time spent searching the lot for the closest space, allowing them to proceed directly to the closest available space. Should the lot reach capacity, the system displays an appropriate message on a sign near the entrance. This eliminates the need for drivers to search the lot and notifies them of the need to proceed to the next available change-mode parking facility or continue their commute by auto.

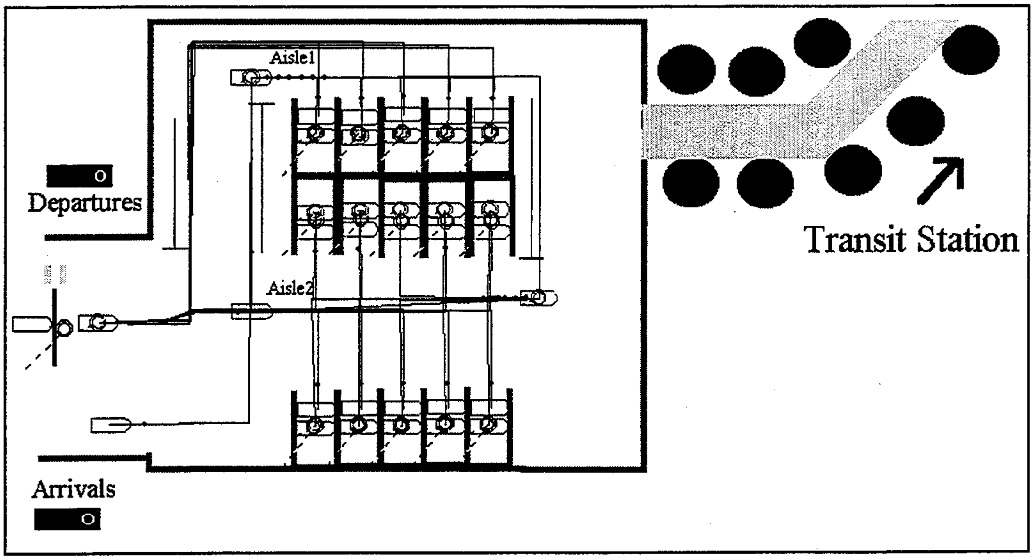
The operation of the automated sign system described above is possible through the installation of loop detectors, dynamic message signs (DMS), and computer software at the facility. The system would consist of loop detectors at each end of each aisle and at the entrance to the parking lot. Communication lines connecting each loop detector to a central computer dedicated to operating the system would allow software to track the number of available spaces in each aisle at the facility. Upon the arrival of a vehicle, the loop detector at the entrance would notify the software that a vehicle has arrived. Based on the status of available parking in each aisle, the software would send appropriate messages to the DMS signs, directing the driver of the vehicle to the space closest to the station entrance. DMS signs would be required at the entrance to the facility, and at the beginning of each aisle.

Structural Modeling

The structural modeling required to simulate the two cases involves inputting the basic layout of the parking facility into the software package. This step requires the definition of the resources used by vehicles in the lot and the paths followed by the vehicles in traveling through the facility. The resources necessary are the fifteen parking stalls and the required paths are the routes between the spaces and the entrance and exit gates. These paths are a significant difference between the models of the two cases under investigation. In the base case, vehicles follow a prescribed path through the lot until the driver locates a suitable available space. In the improvement case, the vehicle follows a path directly from the entrance to the best available parking stall. In both cases, the vehicles exit the lot via the most direct path from their space to the exit.

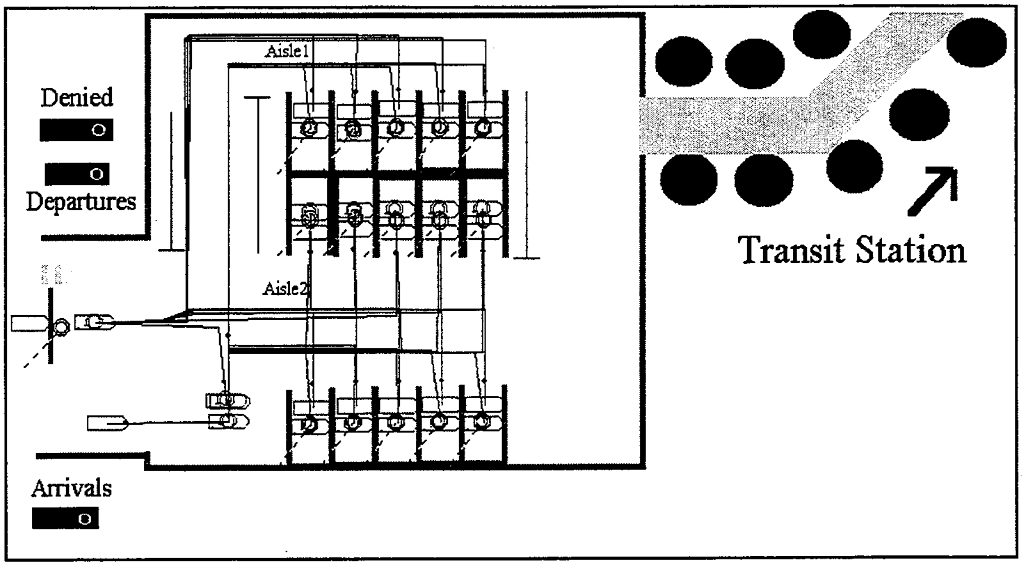
Another important element of the structural modeling of the parking facility is modeling the logical components of the system. In Arena, logic modules allow the software to control the flow of entities through the system. These modules do not delay the simulated travel of the entities within the system. This capability allows an engineer to simulate the decision processes that a driver would make within a change-mode parking facility. In this example, the logical elements allow the vehicles to determine the appropriate path to travel through the lot. This logic differs significantly between the two cases under investigation. Figures 6 and 7 display the models used for each case.

Figure 6. *Base Case model of transit station lot.*



In the base case, Figure 6, vehicles enter the lot and travel directly to a logic module located at the beginning of the first aisle. At this location, the software assigns the vehicles to the available space within the aisle that is closest to the transit station entrance. If no spaces are available, the vehicle travels through Aisle 1 and on to a logic module at the beginning of Aisle 2, where the software performs a similar assignment. If no spaces are available in the second parking aisle, the vehicle moves to a logic module representing a decision. Here the driver decides whether to leave the lot or keep searching for a space. In this simulation, the vehicle returns to Aisle 1 unless it has circled the parking lot three times, at which time it exits the lot.

Figure 7. *Model of transit station lot with automated directional signs.*



The improvement case, shown in Figure 7, is actually a simpler case to model. Vehicles arrive at a logic module immediately after entering the lot. This module mimics the system of navigational signs by assigning the vehicle to the available space closest to the station entrance. The vehicle then travels directly to the appropriate space via the shortest path through the lot. If no spaces are available in the facility, the vehicle exits the lot, simulating a driver's response to a "lot full" sign.

There is another resource depicted in the figures representing both models. This resource is the exit gate which vehicles travel through when leaving the parking lot. Under these two cases, there is no parking fee for using the change-mode facility. Consequently, vehicles travel through the gate with no time delay. Within Arena, the presence of this gate allows the software to keep track of the travel time experienced by vehicles within the lot. The software accomplishes this by determining the difference between the entrance and exit times for a vehicle and subtracting the parking duration from the total time in the lot. This travel time value is stored for statistical analysis of all vehicles using the lot during the simulation.

Quantitative Modeling

Several elements of the two models described in the previous paragraphs require quantitative modeling. These elements include:

- lot dimensions
- vehicle travel speed
- time required for a vehicle to park
- arrival rate of vehicles
- parking duration

For the investigation into the feasibility of modeling potential facility improvements undertaken by this study, the intent of the quantitative modeling effort was to determine reasonable estimates for the various quantitative aspects of the model. The lot under investigation is hypothetical and the values described here are not accurate depictions of an operating system. As this section describes, the goal of quantitative modeling for these sample cases was to enable the models to generate reasonable values. This allows a demonstration of modeling concepts and the types of quantitative modeling that should occur during a simulation study of improvements to change-mode parking facilities.

Accurate values do exist for the dimensions of the parking facility. For the lot under consideration, these values are the recommended values typical to parking facility design, shown in Table 5. These values and the layout of the lot shown in Figure 6 and 7 establish the overall dimensions of the facility. Combined with an assumed length of 60 feet for the entrance and exit to the lot, these dimensions allow the calculation of all distances traveled by vehicles in the model.

Table 5. *Dimensions of parking lot elements.*

Dimension	***Length (feet)***
Stall Depth	20
Stall Width	8
Aisle Width	22

(Source: Garber and Hoel, 1997: 712-713)

In order to establish the time required by vehicles to travel between two points within the model of the lot, an estimate of the vehicle speeds within the lot is necessary. For the purposes of this investigation, this speed is assumed to be 5 miles per hour. Changing this value will alter the travel times experienced by vehicles in the lot. The travel speed value is constant for all vehicles in the simulation, however, and the relative value of the predicted benefit of installing the system will remain the same regardless of the travel speed.

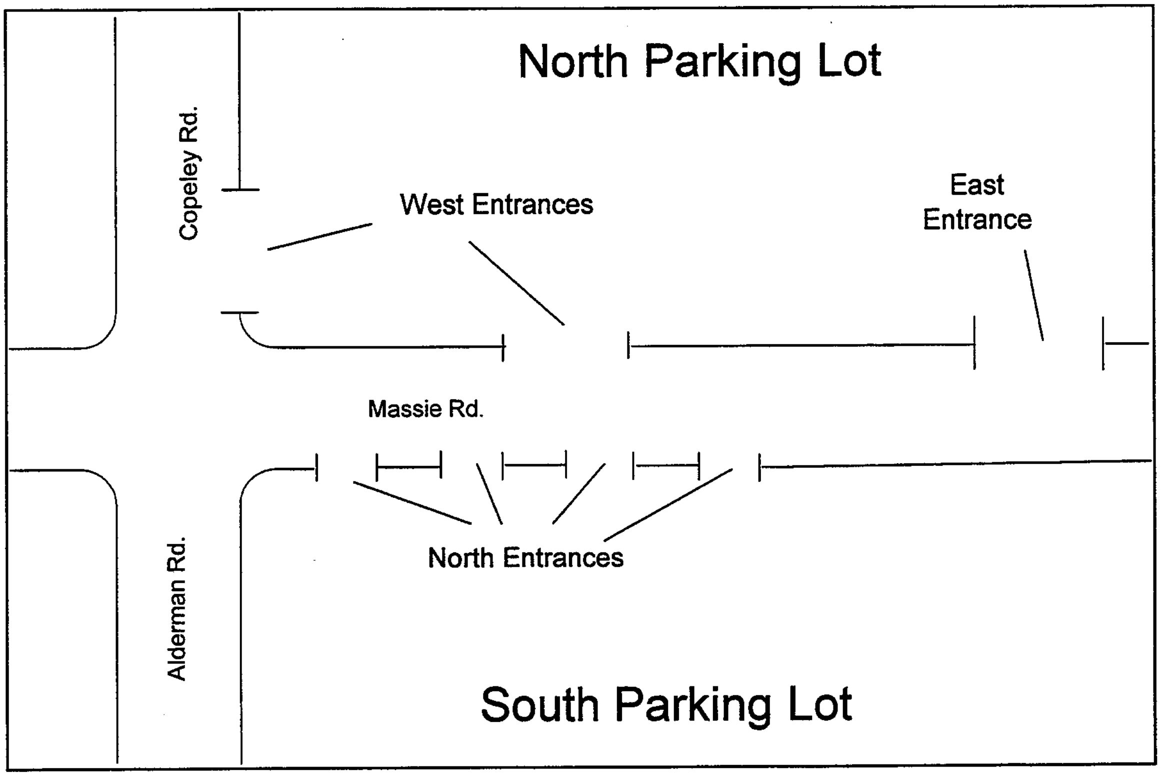
The time it takes a typical driver to park their car after arriving at a space also contributes to the travel time between various points within the lot. For this simulation, the duration of this parking time is assumed to be 3 seconds for both entering and leaving a parking space. Future simulations might represent this time with a random variable representing the characteristics of the driver population. Computation of the travel times for each possible travel route within the lot is a simple matter using the vehicle travel speed, the lot dimensions, and whether a parking movement is required for particular route in the model. Appendix B displays the results of these calculations. Inputting these travel times into the models of the lot allows the software to perform a reasonable simulation of the operation of the lot.

In the two models constructed during this investigation, there is no difference in the time it takes vehicles to exit the lot. Under both the base and improvement cases, vehicles exit the lot by the shortest possible path. Consequently, the time vehicles need to exit the lots was constant during both simulations and did not effect the results of the study.

The Arena modeling software does not permit modeling of the interaction between vehicles within the lot; consequently, a relatively slow travel speed for vehicles provides a conservative estimate of the travel time between points within the lot. This conservative estimate attempts to account for vehicles not experiencing delays due to other vehicles as they travel through the facility. If the model could account for vehicle interaction, then modeling the speed of vehicles within the lot more accurately would allow a more realistic simulation. Using random variables to represent vehicle speeds might provide this greater level of accuracy, or a microscopic simulation similar to existing traffic simulation models might allow vehicle characteristics such as acceleration to be included in the model.

Field data collection supported the effort to establish a reasonable distribution of inter-arrival times for vehicles entering the parking facility. In order to model the random time between vehicle arrivals, the simulation software generates vehicle arrival times from a probability distribution which best describes data collected at an existing parking facility. This allows the arrival times for vehicles at the simulated parking lots to approximate the random arrivals of vehicles arriving at an actual lot. The following paragraphs describe the collection and analysis of data necessary to establish the appropriate probability distributions used to generate values for the random variables in the model.

Figure 8. *Lot used for collection of sample inter-arrival times.*



The data gathered for this study was collected during the morning commuting hours at a major commuter lot serving the University of Virginia's bus transit system. The arrival time of each automobile between approximately 6:45 am and 8:45 am was recorded using a traffic counter. The difference between each arrival time gives the inter-arrival times whose distribution establishes an appropriate random number distribution for the model. The lot used for data collection had numerous entrances as depicted in Figure 8. Analysis of the data on every arrival at the facility as well as arrivals at each of the three groups of entrances shown in the figure determined the distribution with the best fit for the data in each instance. The Beta distribution with varying values Alpha and Beta parameters was the best fit in three of the four cases. The Beta distribution takes the form of the equations below:

$$f(x) = \frac{x^{\beta-1}(1-x)^{\alpha-1}}{B(\beta,\alpha)} \quad \text{for } 0 < x < 1$$

$$= \quad 0 \qquad \text{otherwise}$$

where:

$$B(\beta,\alpha) = \int_0^1 t^{\beta-1}(1-t)^{\alpha-1}\,dt$$

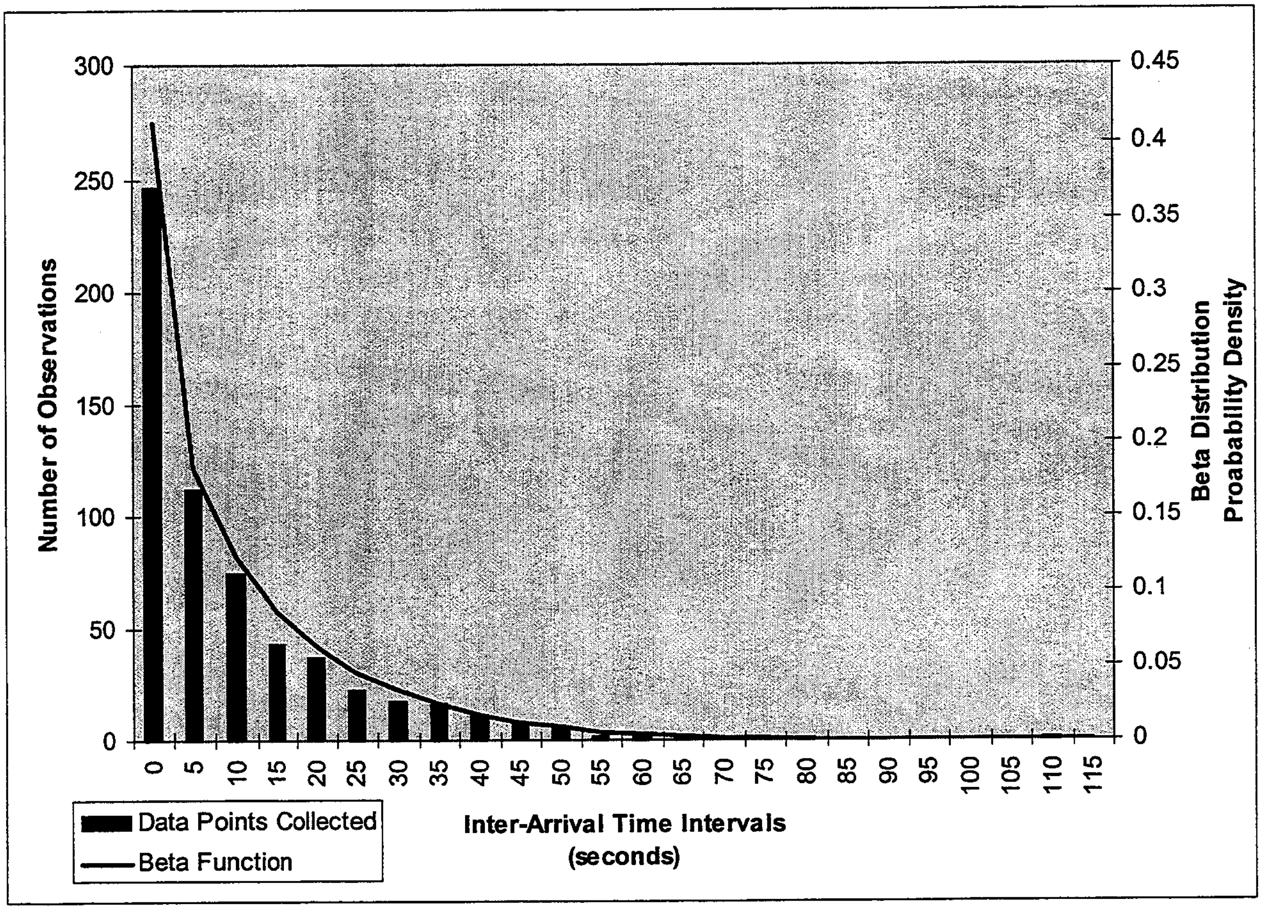
The best description of the data for vehicles entering the south lot from any of the four northern entrances was an exponential distribution with a mean (β) of 0.81. The following equations describe the exponential distribution:

$$f(x) = \frac{1}{\beta}e^{-x/\beta} \quad \text{for } x > 0$$

$$= \quad 0 \qquad \text{otherwise}$$

For both of the functions described above, x represents the interarrival time between vehicles arriving at the lot and $f(x)$ is the number of occurrences of an interarrival time of x. The four groups of entrances considered were all entrances to both lots, the north entrances to the southern lot, the western entrances to the northern lot and the east entrance to the northern lot. The best fit of all the distributions, based on the mean square error between predicted and actual values, was achieved when arrivals at all the lot entrances were considered. This distribution is a Beta distribution with a Beta parameter of 0.641 and an Alpha parameter of 5.65. Figure 9 shows a plot of the distribution over a histogram of the collected data. Sensitivity analysis indicates that the arrival rate did not affect the average travel time for each vehicle under the simulation constraints imposed during this investigation. The following section of this chapter describes reasons for this insensitivity.

Figure 9. *Distribution of inter-arrival times over histogram of collected data.*



A similar analysis could be performed to establish a probability distribution for a variable representing parking duration for each vehicle. The lot under investigation is a transit station assumed to serve travelers on their daily commute, however, and a reasonable assumption of an average parking duration of 10 hours was used in this demonstration model. To provide some variability in the departure times in addition to that induced by the arrival times of the vehicles, the duration of parking was assumed to be uniformly distributed between 9 hours and 11 hours. The results of the simulations performed on these models were also not sensitive to the parking duration of vehicles.

Simulation Description

The simulation software used during this investigation can only develop models and perform simulations of a limited size. For this reason, the sample lot investigated in this study was unrealistically small. The small size of the lot under consideration restricted the duration of the simulation run on the models. The inter-arrival time distribution is derived from data gathered at a large commuter parking facility at the University of Virginia. This facility held approximately 2000 vehicles. Consequently, the arrival times used in the two models lead to the sample lot filling to its capacity very rapidly. If the simulation continues to generate arrivals after the lot reaches capacity, a dramatically shorter average parking time for the improvement case results. This is due to the time saved by individuals turned away by the "lot full" message sign. Under the base case, these drivers would circle the lot three times before exiting. In order to make a fair comparison between the two cases, the simulation was limited in duration to the arrival and departure of fifteen vehicles, the capacity of the hypothetical lot. Due to the low usage at the lot under study, there is little need to consider the affect of improvements on vehicle arriving after the lot reaches capacity. If the improvement package under investigation included traveler information components designed to increase the number of arrivals at the facility, then consideration of arrivals after the lot reaches capacity would be appropriate.

The arrival rate of vehicles does not influence the results of these simulations for two reasons. First, the software's inability to simulate the effects of vehicle interaction within the lot means that two vehicles arriving immediately after each other do not experience any delay in the two models under consideration. Secondly, the short duration of the simulation leads to no vehicles arriving when a space is not available. The combination of sufficient capacity to meet the simulated demand for parking and the lack of interaction between vehicles during the simulation eliminate any effect that the randomly distributed vehicle arrival times have on the simulation results.

The constraint on the number of vehicle arrivals also eliminates the affect of the parking duration times on the results of the simulation. The duration of time that vehicles remain parked does not affect the average travel time in the lots due to the nature of the simulation performed with the models. The combination of frequent arrivals and no parking turnover results in the lot filling based on the characteristics of the two models. Near the end of the simulation the facility empties based on the random parking duration assigned to each vehicle. This disparity in arrival rates and parking duration means that no vehicle must truly search for parking during the simulation, rather they drive the assigned route to an available space. This route is longer under the base case, due to the simulation of the driver's lack of knowledge as to the location of an available space. Due to these characteristics of the simulation, arriving vehicles never park in a space vacated by a vehicle that has recently departed. This means that the duration of time vehicles remained parked has no impact on the travel times of all vehicles using the lot.

<u>Simulation Results</u>

Table 6 contains the results of simulations with each model and for each inter-arrival time distribution described earlier. The values shown are the mean of the average travel time statistic over 50 runs of the simulation described in the previous section. The insensitivity of the model to the random distributions used resulted in identical values of the mean travel time for each simulation run and for each inter-arrival time distribution.

Therefore, the 95% confidence interval around the mean values has a length very close to zero and the difference between the mean average travel time under the two cases is statistically significant.

Table 6. *Results of Simulation*

Entrances to Sample Lot Considered	***Arrival Distribution*** BETA(β, α) *or* EXPO (β)	***Mean of Average Travel Time***	
		Base Case (seconds)	*Improvement Case (seconds)*
All Entrances	2 * BETA (0.641, 5.65)	54.7	39.4
N lot, E Entrance	6 * BETA (0.5, 5.67)	54.7	39.4
N lot, W Entrances	4 * BETA (0.628, 2.91)	54.7	39.4
S lot , N Entrances	EXPO (0.81)	54.7	39.4

Interpretation of Simulation Results

Reviewing the results of the simulations performed on the models of the base and improvement cases, it is apparent that the system of automated navigational signage results in a reduced average travel time for vehicles using the facility. The investigation described in this chapter results in an estimated 28% reduction in travel time within the parking facility for customers using the hypothetical transit station. The simulation was performed on an artificially small parking lot; the effect of an automated navigational sign system on a larger facility would likely be greater. This travel time is part of the time it would take a traveler to move from their automobile to the transit system during their commute. Therefore, the travel time is very important to the user in making their mode-choice decision. The transfer time can take on a perceived value of up to three times its actual duration, as described in the literature review. Travel times estimated through simulation indicate that the system of automated directional signs provide a significant benefit to travelers accessing this transit station by automobile.

While the simulation results give a positive indication of the proposed improvement's value, further consideration of the modeling and simulation efforts indicate that this may not be the best option. The limited influence of the two random components on the results of this solution indicates an important aspect of the operation of change-mode facilities serving daily commuters, such as those at transit stations. The high rate of arrivals during the morning peak period combined with the long duration of parking may reduce the benefits of a system of automated directional signs. The constraints described above eliminate the need for vehicles to circle the lot numerous times searching for parking during the base case. Some of the vehicles entering a transit station parking lot do circle the lot searching for the closest space. However, a simpler system might also address this problem, consisting of sign indicating when the lot is full. During a full implementation of the methodology recommended by this research, this observation would indicate the need for further investigation of the simpler alternative before the analyst makes a recommendation.

The characteristics described above also indicate that the automated directional signs might be more useful at change-mode facilities with a higher parking turnover. Facilities with low turnover may see additional benefit from such a system if the arrival and departure of vehicles occurs throughout the day. An example of such a change-mode facility is an airport parking facility. At these facilities available spaces can be located throughout the facility due to arrivals and departures spread throughout the day and parking duration ranging from hours to weeks.

It is important to note that the investigation into simulation presented in this report demonstrates the fundamental concepts of using computer modeling and simulation within the analysis methodology proposed by this project. The specific results obtained within this chapter should not be taken as a thorough evaluation of the ITS improvement analyzed. The simulation effort described here demonstrates the assessment of the value for one of many measurement criteria necessary to evaluate the various potential improvements to a transit station parking lot. The hypothetical nature of the lot under investigation mandated numerous assumptions that would require modification in actual practice.

Evaluation Matrix for Illustrative Example

Figure 10, on the following page, presents an evaluation matrix for the alternatives under consideration in this illustration. The simulation described above provides an estimate for the impact of an automated navigational sign system on the travel time. In actual practice, a more realistic simulation is necessary; the quantitative value is included here for illustration purposes. All the other cells in the matrix are qualitative estimates based on the improvement's characteristics. Values within the cells indicate the potential for improvement under each measurement criteria as compared with the base case. Complete simulation studies of each alternative improvement would allow quantitative estimates for a larger portion of the evaluation matrix, providing values for each of the measurement criteria for time and convenience. In this manner, simulation can allow a more detailed comparison of the candidate alternatives.

Figure 10. *Evaluation Matrix for Illustrative Example*

PERFORMANCE MEASURES/ MEASUREMENT CRITERIA	ALTERNATIVE IMPROVEMENTS									
	Automated Navigational Signs		*Numbered Spaces*		*DMS Availability Notification*		*Radio Availability Notification*		*Internet Availability Notification*	
TIME										
Parking Time	*29% decrease*	*1*	*decrease*	*2*	*no change*	*3*	*no change*	*3*	*no change*	*3*
Delay										
Maximum	*no change*	*1*	*increase*	*2*	*increase*	*5*	*increase*	*4*	*increase*	*3*
Average	*no change*	*1*	*increase*	*2*	*increase*	*5*	*increase*	*4*	*increase*	*3*
CONVENIENCE										
Queue Length										
Maximum	*no change*	*1*	*increase*	*2*	*increase*	*5*	*increase*	*4*	*increase*	*3*
Average	*no change*	*1*	*increase*	*2*	*increase*	*5*	*increase*	*4*	*increase*	*3*
LOT USAGE										
% Capacity	*increase*	*4*	*increase*	*5*	*increase*	*1*	*increase*	*2*	*increase*	*3*
Duration	*no change*	-	*no change*	-	*no change*	-	*no change*	-	*no change*	-
Turnover	*no change*	-	*no change*	-	*no change*	-	*no change*	-	*no change*	-
COST										
Agency Costs ($K)										
Capital for stand-alone	*$253 - $373*	*3*	*$20 - $40*	*2*	*$377 - $566*	*4*	*$21 - $28*	*1*	*$19 - $29*	*1*
O & M for stand-alone	*$14.5 - $21.8*	*3*	*$42 - $64*	*4*	*$12 - $18*	*2*	*$1.3 - $1.8*	*1*	*$46 - $57*	*4*
Capital for supplement	*$253 - $373*	*4*	*$20 - $40*	*3*	*$5.5 - $9*	*1*	*$21 - $28*	*2*	*$5.5 - $9*	*1*
O & M for supplement	*$14.5 - $21.8*	*2*	*$42 - $64*	*3*	*$1.1 - $2*	*1*	*$1.3 - $1.8*	*1*	*$1.1 - $2*	*1*

The numeric values within the cells of the evaluation matrix indicate an estimate of the rank of each alternative within each measurement criteria based on the characteristics of each improvement. Appendix C explains the reasons behind the measurement criteria estimates and ranks shown in the evaluation matrix. The costs used in the evaluation matrix are from the cost analysis of the candidate improvements described in Appendix A. The evaluation matrix contains two cost values for each alternative. The first cost represents the level of investment required for the improvement if no supporting systems exist in the area. Two of the alternatives are significantly less expensive if other ITS improvements to the transportation network exist. The DMS and Internet availability notification systems would benefit from the previous existence of roadside DMS signs and an Automated Traveler Information System (ATIS) respectively.

After developing an evaluation matrix, further discussion with the operator of the facility will help determine the significance of each performance measure considered in relation to the others. In this example, the lack of patrons using the current facility indicates the importance of the Lot Usage performance measure. While the Time and Convenience measures do represent significant deterrents to travelers choosing transit over an auto commute, the importance of these criteria will become greater as usage at the lot increases.

Based on the values presented in the evaluation matrix, an appropriate solution package for this facility would be a combination of the traveler information improvements. Depending on the presence of existing ITS improvements in the region, these improvements could be a relatively minor investment for the expected improvement in usage of the parking facility. If DMS signs are already present on the adjacent highway corridor, the DMS Availability Information system is a very attractive improvement. If DMS signs are unavailable, the combination of radio and internet improvements would be a logical choice. Addition of a sign indicating when the lot has reached capacity would also be a valuable part of a solution package for this facility, as mentioned in the investigation of simulation presented earlier.

In an actual implementation of the proposed methodology, the solution package recommended would rely on a more thorough analysis of each of the candidate improvements. In addition, the alternatives analysis procedure described within this step of the illustration should be iterated including consideration of the proposed solution package. This iteration would help validate the recommendation derived from reviewing the initial evaluation matrix.

Step 8: Monitor and Feedback

After implementation of the suggestions developed in the methodology, performance monitoring is important to assess the success of the improvements to the facility. In this case, the entry and exit counter required to implement the recommended improvements would greatly assist in this monitoring effort. The counter would allow archiving of daily counts of the usage at the lot. Periodic studies to assess the travel times and congestion experienced in the lot will provide valuable feedback regarding the performance of the improvements. This information will help indicate when additional improvements or expansion of the change-mode facility is necessary.

5. Conclusion

Effective intermodal passenger transportation systems will play an increasingly important role as the volume on urban roadways continues to increase. Change-mode parking facilities are already an important link in urban transportation networks, and improvements to these facilities can improve the operation of the complete urban travel system. Technologies developed through Intelligent Transportation Systems research provide additional means of improving the operation of these facilities. The methodology presented in this report encourages a thorough consideration of the numerous improvement alternatives available for a particular site, including those involving ITS technologies. This methodology stresses the importance of a systems analysis approach to generating and evaluating potential improvements, ensuring the thorough consideration of all viable candidates.

The example presented in this report illustrates the application of the analysis methodology to a transit station parking facility. This illustration provides a demonstration of appropriate techniques for completing each of the tasks required within the methodology. Within the evaluation task, the lack of quantitative estimates demonstrates the value of simulation or demonstration implementations of the various improvements assessing the potential performance of available improvements.

Many of the potential improvements to change-mode parking facilities are recently developed technologies. Consequently, there is little knowledge about the performance of these systems after implementation. Computer simulation is a promising tool for evaluating the impacts of improvements before implementation. This is especially true for systems where there is no previous experience to use as a basis for decisions. Simulations can provide quantitative estimates of the impacts various alternatives will have on the operation of a parking facility. Within the analysis methodology, simulation can establish values for the performance of various alternative improvements. The simulation effort completed during this project demonstrated that modeling and simulation is useful in establishing values for these measurement criteria. Effort expended in modeling the operation of a facility can also yield valuable observations regarding the performance of candidate alternatives. These observations might suggest the inclusion of other improvement alternatives during iteration of the methodology. Computer simulation provides a valuable support tool when carrying out the methodology developed during this research project.

Directions for Future Research

Reviewing the research performed during this project indicates several promising directions for future research. Three potential areas for future research could build upon the research conducted during this project:

- expanding simulation capabilities to incorporate additional performance measures and improvement alternatives, developing a robust support tool for analyzing improvements to parking facilities
- conducting implementation studies of the potential ITS improvements to parking facilities, enabling a more realistic evaluation of the performance of each alternative and its relevant costs
- determining the affect of improvements to change-mode facilities on mode choice decisions through incorporation of expected performance improvements into mode-choice models that account for transfer delay

Research in these areas will provide improved support for making informed decisions regarding improvements to change-mode parking facilities. The improved analysis possible after this additional research would increase the effectiveness of the methodology recommended in this report.

An investigation into simulation techniques to estimate other performance measures and improvement alternatives would greatly assist engineers in carrying out the methodology. The techniques described in this report provide rough estimates of transfer time values for one possible improvement; similar techniques could be developed to estimate values for other performance measures and other possible improvements. Research could reveal promising techniques for simulation to reveal queues that occur within a parking facility, walking distances required of travelers, even the delay experienced within the lot due to pedestrians and other vehicles. Modification of the techniques used in the example case could create models representing other possible improvements to change-mode facilities.

Achieving results for each of these performance measures would require varying levels of effort. Modeling of some of the vehicle queues within a parking facility may be possible through modifications to the model described in this report. More advanced work could incorporate techniques from existing traffic simulations to represent vehicle interaction. Pedestrian walking distances and their interaction with vehicles would require a model representing the entire change-mode facility, including arrival by the first mode, transfer through the facility and departure via the second mode.

Implementation of the ITS improvements discussed in this report would determine the impact of the systems on the operation of the parking facilities. Actual implementation of the systems would identify unforeseen costs and implementation hurdles. Implementation under the appropriate conditions would aid in identifying a realistic expectation of benefits from the systems. In-depth simulation studies could also develop better estimates of the performance of the untried improvements. After implementation of some of the candidate technologies, the simulations could be modified to assess the affect of varying local conditions on the performance of an improvement. Such a simulation tool could develop into a software package that would automate much of the evaluation process described in this report.

Incorporating expected improvements in the operation of change-mode facilities into demand models that account for the travel delay experienced in changing modes would allow estimation of the effect of any improvements on the larger network. Simulation and implementation studies can provide values for the potential improvements in the operation of the facilities. A model simulating the impact of improvements to change-mode facilities on the transportation networks they serve would provide valuable information to assist in the design of more efficient intermodal urban transportation systems.

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Appendix A: Cost Estimates for Potential Improvements

The cost estimates presented in Table 4 of this report have evolved from careful consideration of the required components of each potential improvement. Wherever possible, estimates for each component of each improvement are derived from data within the ITS Deployment Analysis System published developed by Cambridge Systematics in 1998 (IDAS, 1998). Table A-1 contains relevant values from the IDAS system, used as a basis for cost estimates in this study. This appendix describes the development of cost estimates for each of the improvements mentioned in Table 4 from the data shown here and assumptions made regarding the costs of other components. In actual implementation, the analysis methodology would require a more detailed estimate of the costs of particular improvements, most likely through interviews with product vendors. In practice, the inclusion of a net present worth calculation over an appropriate planning horizon would facilitate the comparison of improvement costs.

Table A-1. *IDAS cost estimates for relevant ITS technologies.*

	Costs*				Useful Life
	Capital ($K)		*O & M ($K/yr.)*		*(yrs.)*
Component	*Low*	*High*	*Low*	*High*	
Loop Detectors (pair)	5	8	0.5	0.8	5
ISP Service Fee			0.12	0.18	
Roadside DMS Sign	80	120	4	6	20
DMS Sign Tower	100	150	0	0	20
Wireline to Roadside Message Sign	6	9	0	0	20
Highway Advisory Radio	16	20	0.8	1	20
Electronic Toll Reader	2	5	0.2	0.5	10
Electronic Toll Collection Software	5	10	0	0	10
Electronic Toll Collection Structure	10	15	0	0	20
Hardware for Traffic Information Dissemination	5	10	0.25	0.5	5
Software for Traffic Information Dissemination	18	22	0.9	1.1	5
Labor for Traffic Information Dissemination	0	0	90	110	0
DS0 Communication Line (56Kbps capacity)	0.5	1	0.6	1.2	20
Software for Dynamic Electronic Tolls	22.5	27.5	1.125	1.375	5
Integration for Dynamic Electronic Tolls	90	110	4.5	5.5	20
Toll Administration Hardware	10	15	1	1.5	5
Toll Administration Software	40	80	4	8	10

Cost values from IDAS Build 1, 1998 by Cambridge Systematics, Inc.
* All values in thousands of 1995 U.S. Dollars

The remaining tables in this appendix show the details of the cost estimates for each potential improvement with a dollar figure shown in Table 2. Amounts shown in the tables are adapted from the IDAS values or based on an educated estimate of the possible cost of a particular component. IDAS does not include some technologies of an appropriate size for installation in parking facilities. For these technologies, most notably DMS signs, the cost estimate for installation within a parking facility is a fraction of the value given in IDAS for implementation on a larger scale. While the dollar values computed for these potential improvements do not represent a detailed estimate of the costs associated with implementing a particular improvement, the values do aid in determining the level of investment required.

Alternative/Components	Costs				Quantity	Comments
	Capital ($K)		*O & M ($K/yr.)*			
	Low	*High*	*Low*	*High*		
Automated Directional Signs						
Base Costs						
Hardware for Parking Information Dissemination	5	10	0.25	0.5		cost based on traffic info. hardware
Software for Parking Information Dissemination	18	22	0.9	1.1		cost based on traffic info. software
Total Base Costs	*23*	*32*	*1.15*	*1.6*		
Variable Costs						
Entry/Exit Loop Detectors (pair)	5	8	0.5	0.8	1 per entry/exit	
Entry DMS Sign	20	30	1	1.5	1 per entry/exit	cost is 25% of roadside sign
Wireline to DMS Signs	1.5	2.25	0	0	1 per sign	cost is 25% of roadside value
Cost per Entry/Exit	*26.5*	*40.25*	*1.5*	*2.3*		
Aisle DMS Signs	20	30	1	1.5	1 per parking aisle	cost is 25% of roadside sign
Aisle Loop Detectors (pair)	5	8	0.5	0.8	1 per parking aisle	
Wireline to DMS Signs	4	5	0.2	0.25	1 per sign	cost is 25% of roadside value
Cost per Parking Aisle	*29*	*43*	*1.7*	*2.55*		
Numbered Parking Spaces						
Base Costs						
Signage/ Pavement Marking	5	10				
Enforcement			40	60		
Total Base Costs	*5*	*10*	*40*	*60*		
Variable Costs						
Ticket Dispenser	5	15	1	2	1 per entry/exit	
Hardware/Software	10	15	1	2	1 per entry/exit	
Cost per Entry/Exit	*15*	*30*	*2*	*4*		
Preferential Parking						
Enforcement			40	60		
Total Cost			*40*	*60*		

Alternative/Components	Costs				Quantity	Comments
	Capital ($K)		O & M ($K/yr.)			
	Low	High	Low	High		
Variable Parking Pricing						
Base Costs						
Software for Variable Parking Pricing	22.5	27.5	1.125	1.375		based on Dynamic Electronic Tolls
Integration for Variable Parking Pricing	90	110	4.5	5.5		based on Dynamic Electronic Tolls
Fee Administration Hardware	10	15	1	1.5		based on Toll Administration Hardware
Fee Administration Software	40	80	4	8		based on Toll Administration Software
Total Base Costs	*162.5*	*232.5*	*10.625*	*16.375*		
Variable Costs						
Electronic Toll Reader	2	5	0.2	0.5	1 per entry/exit	
Electronic Toll Collection Software	5	10	0	0	1 per entry/exit	
Electronic Toll Collection Structure	10	15	0	0	1 per entry/exit	
Cost per Entry/Exit	*17*	*30*	*0.2*	*0.5*		
DMS Availability Notification						
Variable Costs						
Entry/Exit Loop Detectors (pair)	5	8	0.5	0.8	1 per entry/exit	
Cost per Entry/Exit	*5*	*8*	*0.5*	*0.8*		
Roadside DMS Sign	80	120	4	6	1 per sign	
DMS Sign Tower	100	150	0	0	1 per sign	
Wireline to Roadside Message Sign	6	9	0	0	1 per sign	
Cost per Roadside DMS Sign	*186*	*279*	*4*	*6*		
With existing DMS signs						
DS0 Communication Line (56Kbps capacity)	0.5	1	0.6	1.2		to TMC for existing DMS Signs
Base Cost with existing DMS Signs	*0.5*	*1*	*0.6*	*1.2*		
Radio Availability Notification						
Base Costs						
Highway Advisory Radio	16	20	0.8	1		
Total Base Costs	*16*	*20*	*0.8*	*1*		
Variable Costs						
Entry/Exit Loop Detectors (pair)	5	8	0.5	0.8	1 per entry/exit	
Cost per Entry/Exit	*5*	*8*	*0.5*	*0.8*		

Alternative/Components	Costs				Quantity	Comments
	Capital ($K)		O & M ($K/yr.)			
	Low	High	Low	High		
<u>Internet Availability Notification</u>						
Base Costs						
DS0 Communication Line (56Kbps capacity)	0.5	1	0.6	1.2		to TMC for existing ATIS
Total Base Costs w/ Existing ATIS	*0.5*	*1*	*0.6*	*1.2*		
Hardware for Parking Information Dissemination	5	10	0.25	0.5		
Software for Parking Information Dissemination	9	11	0.45	0.55		50% of areawide traffic ATIS value
Labor for Parking Information Dissemination	0	0	45	55		50% of areawide traffic ATIS value
ISP Service Fee			0.12	0.18		
Total Base Costs w/o Existing ATIS	*14*	*21*	*45.82*	*56.23*		
Variable Costs						
Entry/Exit Loop Detectors (pair)	5	8	0.5	0.8	1 per entry/exit	
Cost per Entry/Exit	*5*	*8*	*0.5*	*0.8*		
<u>Fee Prepayment</u>						
Base Costs						
Fee Administration Hardware	10	15	1	1.5		based on Toll Administration Hardware
Fee Administration Software	40	80	4	8		based on Toll Administration Software
Total Base Costs	*50*	*95*	*5*	*9.5*		
Variable Costs						
Electronic Toll Reader	2	5	0.2	0.5	1 per entry/exit	
Electronic Toll Collection Software	5	10	0	0	1 per entry/exit	
Electronic Toll Collection Structure	10	15	0	0	1 per entry/exit	
Cost per Entry/Exit	*17*	*30*	*0.2*	*0.5*		
<u>Advanced Reservation System</u>						
Enforcement			40	60		
Total Cost			*40*	*60*		

Appendix B: Calculation of Travel Times within Example Lot

Quantitative Modeling of Example Change-Mode Parking Facility Travel Times

Assumptions

	mph	ft/s
Travel Speed	5	7.333333333
	seconds	
Parking Movement Time	3	

Dimensions

	feet
Aisle Width	22
Stall depth	20
Stall width	8

Real System

Origin	*Destination*	*Aisle Widths*	*Stall Lengths*	*Stall Widths*	*Other (ft)*	*Parking?*	*Travel Time (s)*	*Travel Time (min)*
Entrance	Aisle 1 Choice	2	3		60		22.36	0.37
Aisle 1 Choice	Space 10	0.25				1	3.75	0.06
Aisle 1 Choice	Space 11	0.25		1		1	4.84	0.08
Aisle 1 Choice	Space 12	0.25		2		1	5.93	0.10
Aisle 1 Choice	Space 13	0.25		3		1	7.02	0.12
Aisle 1 Choice	Space 14	0.25		4		1	8.11	0.14
Aisle 1 Choice	Aisle 2 Choice	0.75	2	5			13.16	0.22
Aisle 2 Choice	Space 20	0.25		4		1	8.11	0.14
Aisle 2 Choice	Space 21	0.25		3		1	7.02	0.12
Aisle 2 Choice	Space 22	0.25		2		1	5.93	0.10
Aisle 2 Choice	Space 23	0.25		1		1	4.84	0.08
Aisle 2 Choice	Space 24	0.25				1	3.75	0.06
Aisle 2 Choice	Space 25	0.25		4		1	8.11	0.14
Aisle 2 Choice	Space 26	0.25		3		1	7.02	0.12
Aisle 2 Choice	Space 27	0.25		2		1	5.93	0.10
Aisle 2 Choice	Space 28	0.25		1		1	4.84	0.08
Aisle 2 Choice	Space 29	0.25				1	3.75	0.06
Aisle 2 Choice	Leave Choice	0.5		5			6.95	0.12
Leave Choice	Aisle 1 Choice	0.5	2				6.95	0.12
Leave Choice	Exit	1			60		11.18	0.19
Space 10	Exit	1.5	2		60	1	21.14	0.35
Space 11	Exit	1.5	2	1	60	1	22.23	0.37
Space 12	Exit	1.5	2	2	60	1	23.32	0.39
Space 13	Exit	1.5	2	3	60	1	24.41	0.41
Space 14	Exit	1.5	2	4	60	1	25.50	0.43
Space 20	Exit	0.5			60	1	12.68	0.21
Space 21	Exit	0.5		1	60	1	13.77	0.23
Space 22	Exit	0.5		2	60	1	14.86	0.25
Space 23	Exit	0.5		3	60	1	15.95	0.27
Space 24	Exit	0.5		4	60	1	17.05	0.28
Space 25	Exit	0.5			60	1	12.68	0.21
Space 26	Exit	0.5		1	60	1	13.77	0.23
Space 27	Exit	0.5		2	60	1	14.86	0.25
Space 28	Exit	0.5		3	60	1	15.95	0.27
Space 29	Exit	0.5		4	60	1	17.05	0.28

Automated System

Origin	*Destination*	*Aisle Widths*	*Stall Lengths*	*Stall Widths*	*Other (ft)*	*Parking?*	*Travel Time*	*Travel Time (min)*
Entrance	Assignment Station	0.75			60		10.43	0.17
Assignment Station	Space 10	1.25	3			1	14.93	0.25
Assignment Station	Space 11	1.25	3	1		1	16.02	0.27
Assignment Station	Space 12	1.25	3	2		1	17.11	0.29
Assignment Station	Space 13	1.25	3	3		1	18.20	0.30
Assignment Station	Space 14	1.25	3	4		1	19.30	0.32
Assignment Station	Space 20	0.25	1			1	6.48	0.11
Assignment Station	Space 21	0.25	1	1		1	7.57	0.13
Assignment Station	Space 22	0.25	1	2		1	8.66	0.14
Assignment Station	Space 23	0.25	1	3		1	9.75	0.16
Assignment Station	Space 24	0.25	1	4		1	10.84	0.18
Assignment Station	Space 25	0.25	1			1	6.48	0.11
Assignment Station	Space 26	0.25	1	1		1	7.57	0.13
Assignment Station	Space 27	0.25	1	2		1	8.66	0.14
Assignment Station	Space 28	0.25	1	3		1	9.75	0.16
Assignment Station	Space 29	0.25	1	4		1	10.84	0.18
Assignment Station	Exit	1	1		60		13.91	0.23
Space 10	Exit	1.5	2		60	1	21.14	0.35
Space 11	Exit	1.5	2	1	60	1	22.23	0.37
Space 12	Exit	1.5	2	2	60	1	23.32	0.39
Space 13	Exit	1.5	2	3	60	1	24.41	0.41
Space 14	Exit	1.5	2	4	60	1	25.50	0.43
Space 20	Exit	0.5			60	1	12.68	0.21
Space 21	Exit	0.5		1	60	1	13.77	0.23
Space 22	Exit	0.5		2	60	1	14.86	0.25
Space 23	Exit	0.5		3	60	1	15.95	0.27
Space 24	Exit	0.5		4	60	1	17.05	0.28
Space 25	Exit	0.5			60	1	12.68	0.21
Space 26	Exit	0.5		1	60	1	13.77	0.23
Space 27	Exit	0.5		2	60	1	14.86	0.25
Space 28	Exit	0.5		3	60	1	15.95	0.27
Space 29	Exit	0.5		4	60	1	17.05	0.28

Appendix C: Rationale for Sample Evaluation Matrix Values

This appendix describes the rationale behind the qualitative values presented in the evaluation matrix of Figure 10. The discussion describes the characteristics of each improvement that led to the entries displayed in the matrix. Each section of this appendix describes the values for a particular measurement criteria, including the reasoning behind the ranks representing the relative performance of the alternative improvements.

Parking Time

The values entered for parking time indicate "no change" or a "decrease" in the travel time within the lot. The simulation described in Chapter 4 provides the reason for the quantitative value provided for the Automated Navigational Sign System. The ability of such a system to lead travelers directly to the next available space means it should provide the greatest improvement under this criterion. A system involving numbered parking spaces and a ticket dispenser assigning patrons to an appropriate available space would provide a similar benefit, but direct travelers to the spaces via a space numbering system indicated via permanent lot signage. This technique would provide the second largest decrease in travel time by providing the same service to travelers, but adding the delay of stopping to receive tickets and return tickets upon exit. Additional delays would be caused by travelers that did not return their ticket upon exit or who parked in a space other than the one assigned to them. These reasons explain the difference in performance rank between the navigational sign system and the assignment of numbered spaces.

The three other alternatives under consideration do not show the potential to affect travel time within the lot when compared to the base case. These traveler information systems are likely to attract additional travelers to the lot by making them aware of the facility, however, they do not provide information within the facility to assist travelers in parking more quickly. Consequently, the traveler information systems should cause no change in the travel time experienced by travelers.

Delay

The values determined for the delay to vehicles within the lot estimate the effect of each alternative on the maximum and average values of delay. Determination of differences between these two criteria would require detailed examination of the alternatives, through either implementation or simulation. The qualitative values presented in the matrix represent the capability of the alternative to handle an increase in the volume of vehicles using the facility. The navigational signs and numbered spaces accommodate this increase in volume without significant increases in congestion by directing vehicles to available spaces. The traveler information systems do not accommodate this demand and congestion is likely to develop. The navigational sign system provides direction without delaying vehicles at the entrance and exit to the lot, while the numbered spaces require this delay. This results in the ranking shown in the matrix.

The ranks for the traveler information systems, third through fifth in this category, stem from the likely increase in demand caused by these improvements. Behavioral studies would provide a better indication of the reaction of drivers to these systems, however the rankings in this matrix derive from the number of travelers each system has the potential to reach. The dynamic message sign system could conceivably reach every driver on the adjacent highway as they pass by the sign on the highway. Radio notification would reach those parties who tune the radio to the designated stations, a considerably smaller number than those reading a DMS sign. Internet notification would only reach those who check the appropriate website prior to leaving home, likely to be a low portion of the population. In addition, the perceived reliability of the internet information may be low due to the potential for the lot to fill during the time required to travel to the lot. These differences between the three traveler information systems result in the ranking displayed in the figure.

Queue Length

The maximum and average queue length criteria were also treated as one measure for this qualitative analysis. The considerations in determining the relative ranking of each of alternative followed the same logic as the decisions for the delay caused by each alternative. An additional contribution to the high ranking of the navigational systems in these criteria is that, when implemented alone these improvements are not likely to attract additional patrons. While the traveler information systems increase awareness of the facility, the navigational systems do not. Consequently, the facility is not likely to experience significant queues under the navigational improvements, while the congestion would likely increase under the traveler information systems.

Percentage of Capacity Used

The percentage of capacity used is predicted to increase for each of the possible improvements. The greatest increases are likely to arise from the traveler information systems, ranked based on their potential to reach the greatest number of travelers. Small increases are likely in response to improved operation of the facility with the navigational systems. The lower ranking of the numbered space system stems from the inconvenience caused by the ticket dispensers.

Duration and Turnover

None of the systems considered in this illustrative example is likely to affect the duration of parking at the facility or the turnover of vehicles using the lot. These characteristics are due to the facility's function in serving daily commuters and few of the possible alterations to the lot could affect these characteristics.

Cost

The costs listed in the table stem from the cost analysis discussed in Appendix A of this report. Entries in the matrix are the result of calculations using the unit costs discussed in Appendix A and the characteristics of the hypothetical lot presented in Chapter 4. Two sets of rankings listed in the matrix indicate the significant reduction in the cost of the DMS notification system when a DMS system is already in use along the adjacent corridor. If such a system exists, the DMS notification system would be relatively inexpensive to install and operate. Without an existing DMS system, the costs of this alternative become very high, assuming the need for installation of two roadside DMS signs. An analogous situation occurs regarding the Internet notification system and the presence or absence of an existing automated traveler information system (ATIS).