PB2001-105351

Intelligent Transportation Systems Research and Development Fellowship Program at the Pennsylvania State University

Final Report

Prepared

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August 2000

REPRODUCED BY: NTIS
U.S. Department of Commerce
National Technical Information Service
Springfield, Virginia 22161

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
August 2000

3. REPORT TYPE AND DATES COVERED
Final Report

4. TITLE AND SUBTITLE
Intelligent Transportation Systems Research and Development Fellowship Program at the Pennsylvania State University

5. FUNDING NUMBERS

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Pennsylvania Transportation Institute
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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Mid-Atlantic Universities Transportation Center
The Pennsylvania State University
201 Transportation Research Building
University Park, PA 16802

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
III-0005

11. SUPPLEMENTARY NOTES
U.S. Department of Transportation
Pennsylvania Department of Transportation

12a. DISTRIBUTION/AVAILABILITY STATEMENT
National Technical Information Service (NTIS)
5285 Port Royal Road
Springfield, VA 22161
Telephone: (703) 487-4650

12b. DISTRIBUTION CODE
N/A

13. ABSTRACT *(Maximum 200 words)*

The objective of this project has been to provide the necessary resources for a program at Penn State in which faculty and students will create new ideas in the area of Intelligent Transportation Systems (ITS). This is an educational activity targeting graduate students at the Pennsylvania State University that as time progresses will be moved in practice. The project is renewed yearly and changes in the composition of the Transportation Operations Program at the Pennsylvania Transportation Institute at Penn State University will be reflected accordingly.

In addition, within this project a review of new needs in ITS research and development are performed at regular intervals and new directions incorporated on as needed basis. For the academic year 1998-1999 and 1999-2000 five fundamental areas of inquiry were defined and work in all areas was accomplished as planned. These specialty areas are: Network modeling and stochastic demand, traffic operations and machine vision, advanced public transportation systems, human factors issues, and commercial vehicle operations.

Moreover, a few considerations need to be made. First, the strategic directions of the research reported here are defined by the Center for Intelligent Transportation Systems (a center of excellence in the College of Engineering at Penn State), the Mid-Atlantic Universities Transportation Center (a US DOT funded consortium of universities with Penn State as the lead institution), and a variety of more applied research projects from State, Local, and Private entities. Funds from these projects are used as matching funds. The basic and fundamental research issues, however, are funded by private sources, the National Science Foundation, and seed funding from the Pennsylvania State University.

14. SUBJECT TERMS
ITS Fellowship Program at Penn State

15. NUMBER OF PAGES
13

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
None	None	None	N/A

Intelligent Transportation Systems Research and Development Fellowship Program at the Pennsylvania State University

PREFACE

The objective of this project has been to provide the necessary resources for a program at Penn State in which faculty and students will create new ideas in the area of Intelligent Transportation Systems (ITS). This is an educational activity targeting graduate students at the Pennsylvania State University that aims at developing new ideas and create the foundation for new methods, software, and hardware that as time progresses will be moved in practice. The project is renewed yearly and changes in the composition of the Transportation Operations Program at the Pennsylvania Transportation Institute at Penn State University will be reflected accordingly.

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TOPIC AREAS AND DELIVERABLES

1. Network Modeling & Stochastic Demand

Network modeling and traffic assignment become extremely complex when one considers fluctuations in the demand for travel. These fluctuations may be due to predictable temporal variation of demand, predictable user variation of demand, but also unpredictable factors. In addition, network modeling under ITS is needed in "real-time." This implies that a traffic control center and/or an emergency management center require traffic predictions in very short time as new information about the demand for travel becomes available. Within this topic, researchers at Penn State University will design new algorithms, methods, and software that advance the state-of-art in network modeling. Following is a brief report provided on Mr. Hao Tang's work in this area (supervising professor: Elise Miller-Hooks)

INTELLIGENT GOODS TRANSPORT

Objectives and Background

The advent and adoption of information technologies, such as Global Positioning Systems (GPS) and wireless communication, is changing less-than-truckload (LTL) trucking and package carrier operations as demand for direct deliveries rises rapidly. This research focuses on the development of real-time decision-making strategies for use in the intelligent transport of goods, where customers can request their delivery locations and time. The objective of this research is to develop the conceptual and methodological framework for making real-time en route vehicle routing decisions that exploit real-time information, coupled with historical data, leading to improved services. Specifically, we seek to answer the following questions.

1. How can we accommodate en route changes in delivery time windows, delivery locations, and additional high priority shipments that were not available for pickup at the depot at the beginning of the day but should be delivered in this day?
2. What contingency plans should we make given that a driver becomes aware that (s)he cannot meet delivery deadlines for the day?

The problem of determining which vehicles should handle which packages and in what order these deliveries should take place given that one or more of the deliveries must be completed within a specified time-window is mathematically modeled as a vehicle routing problem with time windows (VRPTW). The single depot VRPTW requires the determination of the set of tours (i.e. route and schedule plans beginning and ending at the depot) that minimizes the total time (cost) to complete all deliveries such that each delivery location is served by exactly one vehicle and all time window, work hour, capacity and consistency constraints are met. The sub-problem of determining such a tour for a single vehicle is known as the traveling salesperson problem, or TSP, which is an NP-hard problem. Thus, exact solution to the TSP, and hence to the VRPTW, is computationally cumbersome. Since these problems have an enormous number of applications requiring solution to large size problems, many researchers and practitioners have focused on developing heuristic procedures for determining good, although probably not optimal, solutions to these problems.

Travel and delivery times (i.e. travel time between delivery locations and delivery time at each location) for the shipments are time-of-day dependent and are at best known *a priori* probabilistically. Through the course of the day, information about the roadway conditions, in terms of weather, construction and traffic, is revealed. Such information coupled with historical data can be used to better estimate future delivery times for the remaining part of the day, and therefore, to compute the probability that the remaining shipments can be delivered in the given time constraints. Additionally, suggestions for re-sequencing the remaining deliveries can be made. If the current or suggested schedule has a low probability of feasibility, contingency plans, including overtime, bumping a low priority shipment for delivery the next day, or passing one or more shipments to another vehicle, must be constructed.

This research seeks to develop the conceptual and methodological frameworks for autonomously addressing en route creation of contingency plans, acceptance or rejection of new loads, and dynamic re-sequencing of remaining deliveries in order to adjust to revealed conditions, to accommodate additional shipments, and to respond to en route changes in shipment priority levels or delivery locations.

Tasks

(1) Conduct literature review to investigate the potential use of existing methodologies for use in solving the problem posed in this research.
(2) Develop on-line optimization techniques, strategies and contingency plans to solve en route tour planning problems that exploit historical and real-time information concerning fleet performance, travel conditions and demand for service.
(3) Provide worst-case behavioral bounds on the performance of the techniques developed in Task (2). Similarly, evaluate the worst-case computational complexity of these techniques
(4) Test the procedures developed in Task (2) on small problem instances to illustrate the correctness and methodological steps of the procedure.
(5) Design and conduct a set of experiments to numerically test the heuristic procedures developed in Task (2). This will require implement in C++ of the heuristic procedures and an approach for determining exact solutions to small problems for use in comparing evaluating the heuristic solutions. Analyze the results of the experiments.

Findings

In Hao's literature review, he has identified two related problems: The Covering Tour Problem (CTP) and the Probabilistic Traveling Salesperson Problem (PTSP). In the CTP, all nodes must either be on the tour or must be within the specified distance from the tour (some nodes must be included in the tour). The solution is a feasible tour with the minimum length. In the PTSP, all nodes have some probability of requiring service. An a priori tour with the minimum expected length is selected, where the expected length depends on the probability that demand will exist at a particular node. En route, nodes that turn out to have zero demand are simply skipped. We extend these problem classes to introduce a new problem class we call the Probabilistic Covering Tour Problem (PCTP). The PCTP seeks the optimal *a priori* tour with minimum expected length such that all nodes representing points where service is required must be in the tour and the remaining nodes that represent points where service may be required with some known probability must be covered by the selected tour. Again, the expected length is a function of the probability of skipping a node whose demand turns out to be zero.

Hao has formulated the integer programming formulation for the PCTP. He has developed several heuristic solution approaches for solving this problem. He has identified the worst-case computational complexity of these approaches and is currently focusing on developing behavioral bounds for these procedures and on implementing the procedures in C++. Once implementation is complete, the numerical experiments will be designed and completed. Hao has begun implementation of an exact procedure for solving the PCTP through complete enumeration (Task (6)) and has illustrated the heuristic approaches on a single example problem. The next step is to extend one or more of these heuristics for use where the demand sites have associated time-windows in which deliveries must be fulfilled.

MATCHING FUNDS: Penn State University provided approximately $50,000 in start-up funds to Dr. Elise Miller-Hooks for the majority of hardware and software in the OPTIPATH laboratory located at the Pennsylvania Transportation Institute at PennState University. In Work Order 23 salaries and tuition are provided for Hao Tang a Ph.D. student in the Department of Civil and Environmental Engineering.

2. *TRAFFIC OPERATIONS AND MACHINE VISION*

One promising method in data collection using ITS technologies is the use of video cameras. This method allows to observe and classify vehicle/driver behavior with unprecedented detail. However, the use of video images needs to be studied in more depth to identify optimal ways this information can be used. In this topic researchers at Penn State will experiment with video images from intersections and highway segments to identify the best use of video cameras in traffic operations. In addition, the combination of different instruments and associated software and hardware will also be explored.

Activities in ATLAS

In this area the ATLAS laboratory continued to be equipped with a variety of instruments and tools. In addition, portable units for ITS evaluations were also purchased, tested, and became operational for analysis. Work in this area is proceeding with the definition of performance measures in ITS evaluations.

MATCHING FUNDS: The Pennsylvania Turnpike Commission provided approximately $160,000 in a project to evaluate the Phase III Adavnced Traveler Information System currently designed the FRHarris with Pi Dr. Goulias and Co-PI Dr. Elefteriadou. In Work Order 23 and for this task funds were expended for equipment and a few months of wage payroll salaries for the graduate students working on the project.

Matching project: January 2000-December 2000. "Pennsylvania Turnpike Commission Advanced Traveler's Information System (ATIS) Phase III, Independent Evaluation." Subcontract with Frederick Harris, Inc. $160,000

3. ADVANCED PUBLIC TRANSPORTATION SYSTEMS

Public transportation may be one of the areas that can benefit the most from ITS technologies. In this topic Penn State researchers will create a model for a transportation system that is appropriate for small urban and rural areas. Then a test bed for technologies and methods will be created with ultimate objective to maximize ridership and minimize operating costs for transit agencies. Within the task the researchers will conduct user surveys, analyze the data, and design systems to accommodate their needs.

Research in Perceptions

In this area two key products have been the papers by Goulias, Tae-Gyu Kim, and Sandy Koza. Following we provide the abstracts of related papers.

Paper Title: Multilevel random effects analysis of modal use constraints and perceptions on public transportation using data from Germany by Konstadinos G. Goulias

Abstract

Multilevel random coefficient regression models account for hierarchical levels in survey data (e.g., trip, individual, household, place of residence), control for the effects of explanatory variables, and provide estimates of the random variation contributed by each level. The nonlinear regression models in this paper use data from a series of interviews in Germany to analyse true and perceived constraints and dislikes of travellers. The presence or absence, for each trip, of these constraints and dispositions are explained using social and economic characteristics of the trip maker, place of residence, household resources, trip characteristics, and random effects at the trip, person, household and city of residence levels. Regression coefficients and components of variance are estimated using a Markov chain Monte Carlo method with the Metropolis-Hastings algorithm. The estimated models show that heterogeneity emerges from person characteristics (e.g., age, gender, employment), household characteristics (e.g., car ownership), experience of circumstances as people execute a given activity schedule in a day (e.g., trip purposes, day-of-the-week, distance to a destination), and experience/attitude based on each mode chosen. As expected, however, heterogeneity is also due to a variety of unobserved factors reflected in the level specific random effects. In addition, the household variance contribution is similar in size to the a person's variance contribution and larger than the city of residence contribution.

Paper Title: An Analysis of the Resident Component in PennPlan's Public Involvement Survey: Survey Overview and Item Non-Response Selectivity Issues by Koza, Kim, and Goulias

Abstract

As part of the public involvement initiative undertaken for Pennsylvania's new long-range transportation plan (PennPlan) an attitudinal survey was administered to a sample of residents in the State. The purpose of this paper is to summarize a selection of survey issues and an in-depth analysis of the survey questions. Information is provided on: a) the purpose of the survey, its components, and underlying themes; b) the administration of the survey and its advantages and disadvantages and possible solutions to improve the administration process; and c) an in-depth analysis of the grades and importance ratings assigned to various aspects of the existing transportation system. This last issue receives particular importance in the paper.

To compensate for the high number of non-responses and the systematic response for the grades and importance ratings, the analysis was done in two steps. The first step was done using sample selectivity to determine if systematic patterns existed between the residents who did and did not assign grades and importance ratings to certain aspects of the existing transportation system as functions of personal and residence characteristics. The results of this step were then used to "adjust" the coefficients in an ordered probit regression model that explains resident grades and importance ratings for the valid responses. By doing this, the models can account for the systematic non-response and yield models of responses based on which unbiased inferences can be made.

MATCHING FUNDS: The Pennsylvania Department of Transportation provided approximately a total of 874,000 in three projects on PennPlan in which a long range plan for Pennsylvania has been created. Work Order 23 provided salaries and tuition for M.S.. and Ph.D. students to work on theoretical and practical issues on human perceptions, opinions, attitudes, and values. Work in this subject will continue until the completion of the current MAUTC agreement. Dr. Goulias is the PI of all three projects on PennPlan.

Matching Projects:

July 2000-July 2001. "Phase III-Pennplan." Pennsylvania Department of Transportation. $125,000.

June 1998-July 2000. Statewide Transportation Planning Public Involvement Program (Penn Plan)." Pennsylvania Department of Transportation. $649,604

January 1998-July 1998. "Transportation Operations Partnership Work Order 17: "Statewide

Transportation Planning Public Involvement Program Preparation Study (PennPlan Prepare)." Pennsylvania Department of Transportation. $105,078.

4. Human Factors' Considerations

Human factor issues (including traveler and shipper behavior issues) have been identified to be of paramount importance for the success of ITS technologies. They have also been identified as the key to technology acceptance by potential users. In this topic researchers at Penn State studied these factors focusing on information system design, information retrieval, and use. For example, new designs have been developed, better understanding of behavioral issues has been achieved, and statistically rigorous assessments were made and published. The design implications on transportation system performance have also been emphasized. Based on a variety of project findings papers and reports are currently under preparation and they will be submitted as they are finalized. These activities include a review of ITS evaluation projects, design of surveys for measuring attitudes and perceptions, and data analysis methods for measurement and forecasting. A sample of two papers follows.

Paper Title: Use of Traveler Information in the Puget Sound Region: A Preliminary Multivariate Analysis by Viswanathan, Goulias, and Jovanis

Abstract

Recent developments in information technologies, providing new ways to disseminate and use information, may help alleviate congestion, reduce user cost and time, and enhance safety. This influence of technology use, however, is mediated by telecommunication and information technology ownership and use. This paper uses a multivariate probit model specification to determine how the above parameters influence traveler decision making when confronted with information about traffic problems before making a trip <u>to</u> work/school, enroute <u>to or from</u> work/school, before making a trip <u>from</u> work/school. The paper addresses the key relationship between telecommunication and information technology ownership and use with travel decisions when information about traffic problems is available. Data from the Puget Sound region for 1997 are used in the analysis. The results suggest technology ownership and use influence travel decision making in different ways for each stage of travel, i.e., before leaving home, en-route, and returning home.

Paper Title: Travel Behavior Implications of Information and Communications Technology (ICT) in the Puget Sound Region by Viswanathan and Goulias

Abstract

The explosive growth of Information and Communications Technologies (ICT) has given rise to new paradigms in the manner in which business is conducted and also in the manner in which people conduct their everyday affairs. This new dimension has the potential to affect travel behavior in direct and indirect ways and for this it is important to study these effects, e.g., for their possible policy implications for transportation planning. In this paper a multivariate multilevel analysis is presented using data from the Puget Sound Region. ICT usage impacts on travel behavior are examined in terms of activity and travel time expenditures in a day. Model formulation in the study accounts for day-to-day variation, controls for the close relationship between activity participation and travel, and incorporates the contextual influence of households on individual behavior. This is accomplished using observed and unobserved heterogeneity regression model components.

The findings in this study indicate that Internet usage at home and workplace is associated with a reduction in travel times. To the contrary, mobile technology usage is associated with significantly higher travel times. However, high levels of person-to-person variance of this effect shows there may be groups of people that use the technology in radically different ways and most likely conflicting (e.g., one group uses mobile technology to consolidate trips and the other to reach activity opportunities that require longer travel times). In terms of activity participation none of the technologies appears to be a significant contributor to the difference in behavior among technology users and non-users.

MATCHING FUNDS: The Pennsylvania Department of Transportation provided approximately a total of 50,000 in a project on ITS planning in which key ITS issues were explored. In addition the Puget Sound Regional Council provided data of $150,000 value and CITranS provided $5,000. Work Order

23 provided salaries and tuition for M.S.. and Ph.D. students to work on statistical analysis techniques. The PI of all projects is Goulias.

Matching Projects:

March 1999-July 2000. "University-based Research, Education and Technology Transfer Program, Work Order 26: Updating Pennsylvania's Intelligent Transportation Systems (ITS) Strategic Plan." Pennsylvania Department of Transportation. $50,000.

5. COMMERCIAL VEHICLE OPERATIONS

The factors affecting commercial vehicle operations (CVO) have received little attention. As a result our understanding on the impact ITS technologies may have on CVO is limited. In fact, major initiatives exist at the federal level attempting to close this gap. In this topic researchers at Penn State designed a research activity that aims at identifying the factors affecting CVO and the strategies to improve CVO in Pennsylvania. Two areas of emphasis in this topic were developed. The first is teleshopping because it represents the best case study impacting passenger and good movement as described below. The second is CVO and safety.

Paper Title: A Framework for the Analysis of Grocery Teleshopping by Marker and Goulias

Abstract

Household replenishment and consumer direct, two closely related and developing forms of teleshopping emerging as strategies within the broader field of Supply Chain Management, could have an impact upon grocery shopping trip making behavior and commercial development. In concept, household replenishment and consumer direct simply refer to businesses delivering groceries to households through various means. Such systems have the potential to change household activity behavior, resulting in numerous potential changes throughout the transportation network. An effort is made to examine the relevant issues concerning the implementation of household replenishment and consumer direct and analyze their potential impact upon transportation systems planning. A conceptual framework for modeling changes in business and household behavior is also offered in this paper.

MATCHING FUNDS: The Pennsylvania Department of Transportation provided approximately a total of 300,000 in a project on CVO and ITS safety in which presciptive procedures are prepared in partnership with ATAF and other Universities in the Northeastern US.. In addition a Weiss year-long fellowship was provided to John Marker, Jr. and CITranS provided partial funding for Dr. Goulias in the amount of $50,000 (sabbatical leave salary and travel). Work Order 23 provided salaries and tuition for M.S.. and Ph.D. students. The PI of the projects is Goulias.

Matching projects: Weiss Fellowship, CITranS, PennState sabbatical leave.

June 1998-January 2001. I-95 Corridor Coalition Field Operation Test #10: Coordinated Safety Management Project Plan. $300,000.