FHWA-NJ-2007-011

Technical Solutions to Overcrowded Park and Ride Facilities

FINAL REPORT
May 2007

Submitted by

University Transportation Research Center – Region 2

Kyriacos C. Mouskos Ph.D.
Research Professor
The City College of New York, CUNY

Maria Boile Ph.D.
Associate Professor of Civil Engineering
Rutgers University, NJ

Neville Parker, Ph.D.
Professor of Civil Engineering
The City College of New York, CUNY

NJDOT Research Project Manager
Edward Kondrath

In cooperation with

New Jersey
Department of Transportation
Bureau of Research
And
U. S. Department of Transportation
Federal Highway Administration

DISCLAIMER STATEMENT

TECHNICAL REPORT
STANDARD TITLE PAGE

1. Report No. FHWA-NJ-2007-011	2.Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle FINAL REPORT Technical Solutions to Overcrowded Park and Ride Facilities		5. Report Date May 2007 6. Performing Organization Code
7. Author(s) Mouskos, Kyriacos C., PhD (CCNY), Maria Boile, PhD (Rutgers) and Neville Parker, PhD (CCNY)		8. Performing Organization Report No. RF 49777-19-03
9. Performing Organization Name and Address University Transportation Research Center – Region 2 The City College of New York New York, NY 10031		10. Work Unit No. 11. Contract or Grant No.
12. Sponsoring Agency Name and Address NJ Department of Transportation PO 600 Trenton, NJ 08625	FHWA US Department of Transportation Washington DC	13. Type of Report and Period Covered FINAL REPORT 01/01/2002- 10/01/2006 14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract
This report presents the results on potential techniques to more efficiently utilize existing park and ride technologies and plan for future changes to the park and ride facilities. It presents:
A summary of parking monitoring and parking guidance systems and recommendations. It includes a cost analysis using three technologies: magnetometer, video image processing and inductive loop detectors for a typical parking installation.
A prototype parking information and reservation system through the web and cell phone. It includes a parking reservation algorithm and solution methodology, a web-based parking reservation system and a cell-phone based parking reservation and information system. The establishment of a web and cell phone based parking information and reservation system is recommended as the main technology to efficiently allocate the parking spaces from overcrowded to underutilized park and ride facilities.
A prototype Park and Ride intermodal transportation planning model and a case study implementation. This model is recommended to be expanded as a Real-time traffic and park and ride forecasting system to enhance the operations and planning of park and ride facilities.

17. Key Words
Park and ride, parking monitoring, park and ride intermodal transportation planning, parking information, cellular parking information, parking reservation

18. Distribution Statement

19. Security Classif (of this report)	20. Security Classif. (of this page)	21. No of Pages	22. Price
Unclassified	Unclassified	236	

Form DOT F 1700.7 (8-69)

ACKNOWLEDGEMENTS

The author(s) wish to thank various members of the research team without whom this rewrite would not have been possible: The late Louis J. Pignataro Director of the Transportation Information and Decision Engineering (TIDE) Center at New Jersey Institute of Technology (NJIT) for the matching support and the TIDE researchers who contributed in this study: Dr. John Tavantzis (Professor, NJIT), Dr. Wu Sun (then Research Associate and currently with Citilabs USA Corp., San Francisco), Dr. David Bernstein (Professor, James Madison University), Dr. Edip Niver (Professor, NJIT), John Elvis (former Research Associate, NJIT). In addition, Dr. Kruno Peric (then Graduate Research Assistant at Rutgers University, now in Croatia), Mr. Saleh Buiyian (then Graduate Research Assistant at CCNY-CUNY) and Ms. Nadereh Moini (then Graduate Research Assistant at CCNY-CUNY and now a PhD Candidate at Rutgers University) contributed to the completion of this study.

Further we wish to thank Mr. William Piedra, Park and Rides Director of NJDOT and his colleagues who made this project possible with their assistance at all levels of the project.

The research team wishes to thank the NJDOT, the University Transportation Research Center for Region II, and the TIDE Center at NJIT for promoting and funding this project.

Special thanks go to Dr. Camille Kamga of the UTRC II for his administrative assistance throughout the duration of this project. Further we thank Ms. Alma Jefferson for her assistance in editing this document.

SUMMARY

This report summarizes the results of the work performed under the project *Technical Solutions to Overcrowded Park and Ride Facilities.* The New Jersey Department of Transportation (NJDOT) is continuing to improve its Park and Ride (P&R) program as the demand for new facilities increases or decreases due to various changes in the demographics and travel characteristics of a region in New Jersey. Currently the NJDOT operates a successful P&R program that covers over 80 P&R facilities over the state. However, some P&R facilities are overcrowded and some are underutilized**.** The NJDOT's goal is to maximize the utilization of the P&R facilities in order to reduce highway congestion and to provide mobility to people who cannot travel long distances with an automobile. The *goals of the research project* were to respond to the needs of the NJDOT relative to*:*

- Improving the operation and efficiency of the present P&R system.
- Identifying potential technological solutions that could address the issue of anticipated demand for P&R parking - overcrowding or underutilization of various facilities.

This project provides a review of potential technologies and makes recommendations on those that could contribute to an efficient management and operations of NJDOT's P&R facilities. The main technologies surveyed include: 1) Technologies to monitor in real time the parking space availability, 2) Technologies to provide P&R information to travelers, 3) Technologies to provide parking reservation to travelers, and 4) Development of a prototype intermodal transportation planning model that could be used to analyze various P&R spatial and operational configurations, including the impact of traveler information messages. These technologies are summarized next:

The principal elements of a comprehensive NJDOT P&R program may include:

1. An Integrated Statewide Parking Information and Reservation System (PIRS).
2. A P&R Planning, Management and Operations System for NJDOT.

Establishment of an NJDOT PIRS

Objective: Develop a real time monitoring of the parking space occupancy

Parking monitoring functionality - The use of one or more of parking space monitoring technologies is dictated by the functionality that is required by the parking operator. This functionality may include the following: 1) Parking space occupancy of the facility; 2) Parking space occupancy for each parking bay; 3) Parking space occupancy of each parking spot; 4) Vehicle license plate recognition; 5) Vehicle/Driver ID recognition; 6) Automated parking payment; 7) Automated parking gate opening; 8) Partial or 100% vehicle detection coverage; 9) Curb-parking monitoring capabilities; 10) Traveler information capabilities.

Reviewed parking space monitoring technologies - 1) Inductive Loop Detections Systems (ILDS), 2) Video Image Detection Systems (VIDS), 3) Dual Axis Magnetometers (DAM), and 4) Radio Frequency Identification (RFID) based detection systems. The simplest monitoring system consists of detectors being placed at the entrances and exits of each parking lot facility. Based on this limited study the SPVD-2 Dual Axis Magnetometer offers the most cost effective solution – It was estimated to cost near $5,000 per facility, based on one entrance and one exit without considering the associated cost of the communication system. Such a system may be implemented with or without entrance and exit gates.

- VIDS – VIDS could be used for either ingress/egress traffic flow estimation or for parking space occupancy monitoring in open space parking lots. The VIDS vehicle license plate recognition technology provides a universal solution since it combines vehicle ID and 100% vehicle coverage, which can be used for access, parking space occupancy estimation and parking fee payment.

- *RFID* - RFID technologies could be used to facilitate travelers that have already embedded such technology in their vehicles (e.g. the use of E-ZPass at the main airports in New York (Newark Liberty, John F. Kennedy and LaGuardia). RFID should be used in conjunction with another technology to produce estimates of the parking occupancy (e.g. ILDS, DAM or VIDS) since only a fraction of travelers have RFID transponders in their vehicles.

- *Cellular phone RFID* - The cell phone is by far the most promising and comprehensive technology that could be used for parking occupancy, parking and traveler information, and parking or other payments.

- *Teleparking cellular-based RFID* – This technology, developed by Mobipower Ltd, provides the most comprehensive system in terms of vehicle ID, automated payment, parking enforcement, curb-parking capabilities plus two-way cell-SMS parking or traveler information messages. The main disadvantages are: 1) It is a new technology that has not been implemented in the US; and 2) It requires a new mandate whereby all P&R users must install the Teleparking Unit (transponder) in their vehicles.

Objective: Provide real-time P&R and associated transit information to travelers

NJDOT-PIRS Communication System – Establish a communication system for the NJDOT-PIRS and integrate it with the NJDOT traffic operations centers (e.g. NJDOT's North and South traffic operations centers), the travelers and other agencies (e.g. the New Jersey Transit's and TRANSCOM's TRIPS123 traveler information systems).

NJDOT-PIRS Web site - Establish a Web-site for NJDOT's PIRS system that will provide real-time P&R information: parking occupancy and transit schedule. This web site should be integrated or federated with New Jersey Transit's (NJT) and the Transportation Coordinating Committee (TRANSCOM) Corporation's traveler information service (TRIPS123 – www.trips123.com). The web-based PRS system developed under this study could be one of the services provided by the NJDOT-PIRS web site.

NJDOT-PIRS Cell phone based traveler information service – Establish a cell phone based traveler information service that would incorporate traffic, transit and P&R information. It should be integrated with the NJDOT-PIRS web site and the TRIPS123 web site.

NJDOT-PIRS Parking Information and Guidance System (PGIS) – This report includes a review of various PGIS display technologies. NJDOT should consider the implementation of a PGIS system for a set of P&R facilities in order to reduce the time required to search for free parking spaces by directing travelers to parking lots that have free parking spaces while advertising at the same time the locations of P&R facilities thereby increasing the P&R demand.

Objective: Establish a PRS system for NJDOT's P&R facilities

NJDOT PIRS Parking Reservation System (PRS) – NJDOT may also consider the establishment of a dynamic PRS system for some or all P&R facilities. A PRS system may increase the demand for P&R facilities by eliminating the uncertainty of finding a free parking space upon arrival. A first call first serve system could be implemented that will provide assurance for some travelers that a parking space is available for them. Such a system is recommended to be accompanied with an associated parking payment system. As part of this study a PRS system was developed that could be used to support a cluster of P&R facilities based on the minimization of the system wide cost (parking cost plus the generalized travel cost from the travelers origin to the parking facility).

Web-based PRS system - As part of this study and in cooperation with the New Jersey Institute of Technology (NJIT) Transportation Information and Decision Engineering (TIDE) center, a web-based PRS system was also developed. A user enters his/her final destination (destination-based) or his origin (P&R type users) and the system allocates all users to specific parking lots while providing the associated shortest path from/to the parking lot to/from their office/home. This system can be integrated to the overall NJDOT-PIRS system.

NJDOT-PIRS cell phone based system – A prototype cell phone PIRS system was developed in cooperation with the NJIT TIDE center, the Mobility Parking Assistance Information Reservation System (MPAIRS), where travelers using a set of steps from their cell phone they can receive P&R information, make a reservation and receive routing directions. NJDOT through a partnership with the private sector could provide such a service given its relative low cost for implementation. The service can provide P&R information; initially P&R locations and transit service provided and later real-time parking occupancy and transit information, and parking reservation where applicable. The MPAIRS should also be integrated to the NJDOT-PIRS system. In a broader sense, MPAIRS could also be integrated to the regional TRIPS123 traveler information service and provide also traffic and transit information.

NJDOT P&R Planning, Management and Operations

NJDOT P&R Data Base Management System (PR-DBMS) – A new P&R facility database was developed as part of this study that includes the following elements: 1) P&R Facility Ownership, Management and History, 2) P&R Facility Infrastructure Characteristics, 3) P&R Historical Operational and Safety Database, 4) Transit Services Provided in the Vicinity of Each Facility, and 5) Literature Review on P&R Facilities.

NJDOT P&R Transportation Planning Model –A prototype **intermodal transportation planning model** has been developed as part of this study utilizing a static traffic assignment. The model is demonstrated for two case studies on that included the consolidation of a cluster of P&R facilities into one and the impact of

In the future, a Dynamic Traffic Assignment (DTA) could be developed that will improve the existing NJDOT models for the North and South Jersey. A calibrated model could be used to evaluate the location of P&R facilities, the impact of traveler information provided through various means including the Internet or variable message signs, and the location of parking guidance system signs (PGS) based on a cost – benefits analysis. In addition, it is envisioned that this model could be integrated to the North and South traffic control centers of the NJDOT to be used as an estimation and prediction system of the real time traffic and parking occupancy conditions.

The developed model has the capability – if fully developed and calibrated - to analyze travel patterns in an inter-modal network including P&R facilities. The model estimates changes in the network travel patterns that result from different information provided to travelers, alternative pricing and operating policies, changes in transit and park-and-ride systems and future increases in travel demand. A calibrated model has the potential to evaluate the location and capacity of an existing or new P&R facility.

In addition, a **parking equilibrium model** was also developed. The parking space pricing between parking facility owners and travelers has been formulated as an asymmetric spatial price equilibrium variational inequality (VI) problem. The parking facility owners and the travelers, who want to park at a specific geographic area, reach an equilibrium that is based on the functional form of the respective parking supply price and the user group demand price. No attempt was made in this study to identify the form of the supply and demand price functions. The supply, demand, and transaction cost are defined as functions of the corresponding supply parking spaces of all the competing parking facilities, user demand groups, and link flows, respectively. The necessary conditions to produce a unique solution are provided also. The study also includes solution algorithms that are based on the barrier method, which are demonstrated on small size problems.

NJDOT P&R parking payment and/or permit system for P&R - Establish a P&R parking payment and/or permit system for all the facilities to improve the financing of the P&R program and to further expand it throughout the state.

Integrate P&R PIRS with the NJDOT North and South Traffic Operation Centers - Each of these centers will be responsible for the *communication* and *parking space* *detection system* at each facility. The main additional functions that each traffic control center could incorporate are: A *P&R data processing system* that will include: 1) A *comprehensive P&R GIS system*; 2) A *parking space occupancy estimation and prediction algorithm*; 3) A *traffic flow estimation and prediction system for the transportation network under consideration*; 4) A *P&R-specific intermodal time-dependent shortest path algorithm that directs the travelers from their origin to their destination*; 5) A shortest path algorithm that directs the travelers to the parking facility of their choice from their origin. 6) *Integration or two-way communication with NJ Transit's web-based traveler information system and TRANSCOM's TRIPS123 traveler information system; 7) P&R parking pricing information for each facility*; 8) *A comprehensive P&R facility web site; 9) A Parking Guidance System (PGS)*; and 10) A *PRS system.*

Table of Contents

List of Figures

List of Tables

Technical Solutions to Overcrowded Park and Ride Facilities

INTRODUCTION

The New Jersey Department of Transportation (NJDOT) maintains in excess of 80 Park & Ride (P&R) facilities. The P&R supports commuters accessing carpools, vanpools and private carriers. An annual survey (visual observation) is conducted by the NJDOT Planning Department to determine usage and provide input for future planning. However, the information obtained from only one visual survey per year is inadequate. It does not provide substantial data to effectively monitor the parking occupancy per time period of the day, day of the week and special days. The utilization factors, at different P&R locations, are not consistent - some are underutilized while others are overutilized, which directly impacts the flow of traffic. The existing transportation-planning model used by the NJDOT, the North Jersey Transportation Planning Authority (NJTPA), and the planning model of the New Jersey Transit (NJT) do not have the capability to handle intermodal trips, as well as accurately model the dynamic conditions of traffic. At the present time, the management of Park & Rides is not centralized. Responsibilities for leases, maintenance, incident reporting, and planning cut across a number of operational areas.

The objectives of the Planning Department are to significantly maximize the utilization of P&R facilities to yield a reduction in highway congestion. Additionally, the focus is to provide mobility enhancements to travelers using automobiles.

The Planning Department's objectives are to obtain a technological solution to monitor usage. The system could be coupled with a motorist information system equipped to assist motorists select a location with open space.

The objectives of this research project were to identify and recommend technologies and strategies that would significantly enhance the utilization and management of the P&R facilities. This research focused on the main elements that could be incorporated into the development of a Statewide P&R Information and Reservation System (PIRS) and a P&R Management/Operations and Planning System. This report did not focus on the administration aspects of such a system.

A comprehensive P&R program for NJDOT is needed to improve the operation and efficiency of the present system and to provide a strategic plan for anticipated demand for parking. The principal elements of such a program may include:

- A *real-time monitoring and data warehousing of the parking occupancy* at each P&R facility per time period of the day, day of the week and special conditions. The monitoring system would be used for real-time parking information and reservation, as well as the establishment of historical databases of arrivals and departure at each P&R facility.

- A *real-time monitoring of the traffic flow conditions* at the transportation network.

- A *real-time transit monitoring system*. This will require a federation between NJDOT's P&R program, NJT and private transit operators. In addition, it will require the installation of a real-time location and communication system for the buses, vans, and trains.

- Establishment of a *data management system* for the P&R facilities. This system should be integrated to the NJDOT's overall data management system.

- A *communication system* between the monitoring system and the traffic operations centers (such as the NJDOT North and South traffic operations centers), the travelers, transit operators, traveler information providers and other agencies. The integration of this communication system with Transportation Operations Committee (TRANSCOM) Corporation's traveler information system TRIPS123 will be essential as well as with NJT traveler information service.

- A *real-time parking occupancy forecasting system* for the P&R facilities.

- A *real-time transit forecasting system* and its *federation* with NJDOT's envisioned PIRS system. NJDOT will require the integration of the bus and train transit monitoring system that is operated by NJT and some private companies.

- A *real-time traffic flow characteristics forecasting system*. This system would require the expansion of the NJDOT North and South transport operations centers to cover the entire state or at least the areas covered by the P&R program.

- A *real-time intermodal time-dependent shortest path algorithm* that could be used for real-time traveler information. This algorithm should be able to produce the shortest path for a traveler's Origin-Destination (OD) pair taking into consideration the predicted traffic conditions and the potential various modes such as auto only, transit only or intermodal.

- An intermodal *transportation-planning model* for existing and future Park & Ride facilities. The transportation-planning model will be used to evaluate the location and capacity of P&R facilities, and the location of parking guidance system signs (PGS) in the state based on cost – benefits analysis.

- A *parking reservation and payment system* at selected P&R facilities. Parking reservation is one of the means of reducing the frustration that usually arises from the search for a free parking space. Under a PRS system a traveler has the capability to reserve a parking space either via telephone or the Internet, as well as through a traditional short term or long-term space lease system. The latter is not discussed in this study, as it is well known and implemented by many organizations including the NJT at the majority of its P&R facilities. Three types of parking reservation systems may be considered, first come first serve, parking space allocation based on some global objective such as total user travel time, and hybrid systems that take into consideration both reservation and non-reservation travelers.

- A *P&R traffic operations center* that will incorporate the P&R facilities within its functional operations. The NJDOT North and South transportation operations centers could expand their functions by incorporating the envisioned PIRS. Each of these centers will be responsible for the communication and parking space detection system at each facility. The advantage of incorporating the functionality and operation of P&R facilities with the existing traffic control centers are the economies that will be achieved through the use of the knowledge of the transportation network that the personnel has accumulated. The NJDOT PIRS data processing system will include the above-mentioned models.

The main elements of an NJDOT's P&R Management/Operations and Planning may include:

- A *P&R Management/Administration System* that will incorporate all the entities within the NJDOT and NJT into a truly integrated system.

- A *Cost/Benefit Analysis Planning Model* for the Evaluation of P&R Facility Location and Parking Space Capacity.

- *P&R Data Management System (PR-DMS).* The main elements of the PR-DBMS are:

    - *P&R facility ownership, management and history*. The PR-DBMS should include: ownership and/or lease agreements, the name of the individual that maintains and operates it, the name and date when requested, the capital funding allocated and the associated operational and maintenance costs, including any parking fee structure and method of payment.

    - *P&R facility infrastructure characteristics*. This database should include the location, parking space capacity, various amenities such as bicycle stands, restrooms, showers, fencing, gated or non-gated, lighting features, Closed Circuit TV, parking space monitoring and communication system, posted transit schedules, area maps, Parking Guidance System, other.

    - *P&R historical operational and safety database*. This database will include the historical distributions of arrivals and departures, the safety record of the facility and the data from P&R related market research studies. A data storage procedure and a statistical model should be developed of the arrival and departure distributions for different types of travelers (bus, train, carpoolers and bicyclists). The safety record should include car thefts, carjacking attempts, vandalism and fatalities. The market research studies should include data on the distribution of people categories using the facility (wealth, age groups, male-female and OD matrices of the users).

    - *Transit services provided in the vicinity of each facility*. The database should include the bus and train schedules that each P&R facility serves, the P&R

facilities that could be considered as alternatives to the P&R (e.g. bus or train serving the same destination(s)).

- A *continuously updated literature review on P&R facilities* in NJ and around the world. It is envisioned that a continuously updated P&R state of the art review model could be established to aid the NJDOT, NJ Transit and researchers in taking more informed decisions on their P&R program. This model should concentrate on the best practices followed in New Jersey, neighboring states and significant developments around the world. The areas of interest are: parking space monitoring technologies, parking traveler information systems including parking guidance systems, parking reservation systems, parking payment systems, and any administration and management advances. Such a model could be implemented through a specially designed web site where several authorized organizations and researchers could directly enter any new developments in P&R around the world. A mechanism could be developed so that university researchers or consultants could be reimbursed annually or on a project-by-project basis for updating the current state of the art on P&R facilities. Alternatively, the web site may reside at a research center, which will then be responsible for its maintenance and continuous updating.

The report is organized as: Chapter 2 presents a literature review of parking space monitoring systems (supplemented in Appendix A). Chapter 3 presents a review of Parking Guidance and Information Systems (supplemented in Appendix B). Chapter 4 presents mathematical formulations and solution algorithms for Parking Reservation Systems, including prototypes using the web and cellular phone (supplemented in Appendices C, D and E). Chapter 5 presents the P&R planning models developed in this study (supplemented in Appendices F, G and H). The Conclusions are presented in Chapter 6 and References in Chapter 7.

PARKING SPACE MONITORING SYSTEMS

One of the main components of a P&R program is parking space monitoring. The functionality and capabilities of the parking space monitoring system is based on the objectives set by the corresponding P&R program: Long-term planning, Real-time parking space information, Vehicle identification, Queuing time estimation and prediction, and any combination, thereof. NJDOT envisions the establishment of an automated parking monitoring system to support its P&R management/operations, planning and traveler information services.

Real-time parking space availability can be determined at parking lots based on either data from a central parking system (the Parking service provider or Parking lot operator), or from automated counting systems. Automated counting systems can either be embedded into the infrastructure and/or into the vehicles.

The *parking space occupancy* is defined as the number of parking spaces occupied at time *t* at a parking facility.

The principal functions of parking space monitoring technologies are:

- *Count the number of vehicles entering and exiting the facility.* This methodology produces a continuous estimate of the parking facility's occupancy. Under this configuration they are installed at each entrance and exit gate of the parking lot. This is the cheapest form of implementation.

- *Count the number of vehicles entering and exiting each parking bay and each entrance and exit.* This system produces the parking occupancy for the entire facility and at each bay. The parking occupancy at each bay can be very valuable for large parking facilities where vehicles could be directed at parking bays with free parking spaces rather than trying to find them unassisted. Such a system would be most effective combined with a parking information system (e.g. Parking Guidance and Information System (PGIS)) that displays the parking bay information at strategic places within the parking facility. Alternatively, it might send the information to a web-site, a traveler's cellular phone or in-vehicle navigation unit.

- *Monitor the Parking Occupancy of Each Space.* This system provides a continuous status of each parking space that can further expand the functionality of a parking information system. Multi-story garages and very large parking lot systems could benefit the most out of such a system whereas it is not beneficial to small parking lots. In order to be effective it should also be integrated with a parking information system (e.g. PGIS) to direct vehicles to empty parking spaces, further reducing the time needed to search for a parking space. Any one of the pavement embedded systems or overhead technologies could be used to produce such parking space estimates. It is noted however that the cost is usually prohibitive for such systems excluding Video Image processing Systems (VIDS) that could cover a substantial area with a single camera. Even for VIDS the cost could still be a major concern. Vehicle ID/driver based technologies (see next item) may provide a more promising solution since they could be used for a variety of transportation, information and payment functions.

- *Identify Each Vehicle and/or Driver.* These systems are used to both estimate the parking occupancy at a facility and identify the vehicle entering the facility. The most traditional method is the use of a parking attendant that allows only authorized vehicles to enter the facility. However, many parking operators are increasingly relying on automated systems to provide this function, as follows: 1) ID magnetic cards are used at gates to manually enter and exit the facility. Wireless cards are also becoming popular that utilize short-range wireless communications to send the ID information to an antenna reader from the card; 2) VIDS are used to identify the license plate; 3) Vehicles and/or drivers equipped with transponders with unique IDs that are recognized by a reader located at the entrance and exit of each facility. A rather new implementation that also falls under this category is the use of a cellular phone that incorporates the driver's and/or vehicle's ID into a chip embedded into the cell phone. The advantage of the latter vehicle-ID based technologies is that they could be used for a variety of functions such as payment for parking, food at fast food restaurants, parking facility accessibility, traffic monitoring (vehicles as traffic probes), etc. The infrastructure cost for the implementation of such a system would be minimal, since most of the drivers are expected to own a cellular phone.

- *Open the gate at gated parking systems.* One of the functions of vehicle/driver ID systems is to open the gate to enter/exit a parking lot. This function could be achieved through a variety of technologies such as: Magnetic card readers installed at the gate, Wireless readers installed at the gate (smart cards, cellular phone, vehicle installed transponders), License plate recognition systems using video image processing, Any vehicle detection system (inductive loop detectors, radar detectors, etc.) that detects the presence of a vehicle and sends a signal to the gate controller to open the gate – these systems do not have any vehicle ID capability, and manual parking operator based systems where the parking attendant opens the gate.

- *Count the number of arrivals and departures per time period of the day.* In order to produce *estimates of the arrivals per time period of the day*, detectors should be placed at various places on the roadways that lead into to the parking facility. VIDS is the only technology that could be used to provide accurate results of the arrival rate as it can automatically track all vehicle trajectories – vehicles in the queue, upstream of the queue, and vehicles that have a different destination other than the parking lot. The *departure rate* is based on detectors installed in the vicinity of the exit gates. The departure rate may be affected by the traffic conditions of the roadways in the vicinity of the parking facility – if such a condition exists it will provide a biased estimate of the exit demand per time period of the day. In addition, it will create an incorrect estimate of the parking occupancy since some vehicles may be queued to leave the facility but they will not be counted as though they have already released their parking spaces.

PARKING SPACE DETECTION TECHNOLOGIES

The two major categories for traffic flow characteristics data gathering are pavement embedded and overhead type technologies. Pavement embedded technologies require closure of the roadway or affected parking area during installation and maintenance. Overhead type technologies require a structure to be mounted on, however, they are usually considered more effective since their maintenance is much less restrictive than embedded systems. Overhead systems could be maintained by a crew without restricting the operation of a parking or roadway facility.

Inductive Loop Detectors (ILDs)[(1)]

ILDs have been widely used – more than 40 years - for traffic flow characteristics monitoring, incident and presence detection systems and parking ingress and egress monitoring. The output of most current ILDs is a simple relay or semiconductor closure, signifying the presence or absence of a vehicle. The accuracy of such measurements is intimately related to the proper and uniform installation and calibration of loop detectors. In advanced detector processing systems, digitizing the detector output and feeding it to a microprocessor containing embedded signal processing algorithms can perform vehicle classification and fault detection. These algorithms match the detector output to stored signatures for specific vehicle types or fault conditions. The output from digital codes can be used to identify the type of vehicle detected or report detection faults to a central processing unit.

ILDs are capable of measuring the presence of a vehicle, traffic flow rate, vehicle-roadway occupancy, and vehicle speed. Vehicle speed is usually determined through the use of a pair of loops spaced at a short distance between each other.

ILDs are rather expensive to maintain. They are prone to elements such as water, when pavement cracks due to changes in the climate. The repair of an ILD requires unearthing the ILD, which is disruptive. Also, if the pavement must be resurfaced, new loop detectors have to be installed - Resurfacing at parking lots is not as frequent as on roadways, where the pavement is subjected to excessive loading from heavy trucks that further deteriorate the pavement. The installation and repair of ILDs may cause a reduction in the parking capacity that can be extensive. The duration varies from several hours to a few days. This may not be such a problem for parking facilities, since the maintenance can be completed during the non-operating hours (e.g. night) of the facility.

Commercial ILDs and Manufacturers

EDITraffic [(2)] is the ILD provider for Econolite, one of the largest companies providing vehicle detection solutions. EDITraffic develops 3 types of ILD systems: 1) Vehicle / Intersection Detectors; 2) System / Count Detectors; 3) Access Control Detectors. These are divided into 2 subclasses - shelf mount and rack mount.

A newly introduced system is the LMA Deflectometer series ILDs for access control. This system has the following new innovations: 1) 7-segment LED sensitivity meter; 2) Rear panel setup switches; 3) Separate color-coded status LEDs; 4) Advanced loop diagnostics; 5) 10 second "Call" output memory; 6) Sensitivity boost mode; 7) Non-volatile loop fault memory; 8) Delay and Extension output timing.

Non-Invasive Microloop

These are microloop [4, 5] sensors placed in a protective conduit below the road surface that convert changes in the vertical component of the earth's magnetic fields to changes in inductance. Its functionality is similar to the traditional ILDs. Since it is in a protected environment, the sensor can perform consistently regardless of the weather conditions. The conduit is typically installed using horizontal directional drilling across roadways or parking lot driveways.

Magnetometer Sensors

Magnetometers [4, 5] are based on small cylinders that contain a sensor coil that operates in a manner similar to inductive loops. When a vehicle passes over the cylinder probe, the ferrous material in the vehicle increases the density of the flux lines. It can be used in situations where loops are not feasible (e.g. bridge decks). The main types of magnetometers are as follows:

Single Axis Magnetometers (SAM)

The SAM is a sensor that can be buried on the ground with minimal disruption of traffic. Due to its small size, (10 x 10 x 10 inches), a 10-inch core drill or a Jackhammer can be used to make a hole in the pavement to bury the detector. Separate tunneling has to be constructed to protect the signal and power wires from the sensor to the data collection center.

SAMs only use the vertical axis and are prone to errors, such as the double detection of cars when the front and rear axle pass over the detector. Calibration is very important for the SAM. It uses the concentrated flux from the earth's magnetic field to calibrate itself. To concentrate the flux, a metal is used, which is prone to physical changes during the seasonal thermal changes, and thus requires manual recalibration several times a year.

Dual – Axis Magnetometers (DAM)

The DUA is a vast improvement over the SAM. SAM uses both the horizontal and the vertical axis to sense the arrival of a car accurately. The DAM can thus eliminate double counting of vehicles in 97% of cases Soulliard et.al [6]. The DAM does share the calibration problem present in SAM.

Improvement Over the DAM

Median Electronics (http://www.midians.com), a company working with the FHWA, created an improved version of the DAM called the Self–Powered Vehicle Detector (SPVD). This unit includes microcomputers to self calibrate, as compared to the flux calibration present in the old technology. The unit has a wireless transmitter capable of operating for four years with a single battery. Due to the small size of the SPVD, the installation is quick, when using an eight-inch core drill. Since the signal transmission medium is wireless, there is no need for a separate tunneling for conduits and wires. Since the signals are sent at a lower frequency (45 Mhz), the attenuation is minimal.

The current SPVD unit is called the SPVD-2 which is a very reliable unit measuring 6x6x6 inches. Installation is very simple. It supports wireless signal transmission and thus wirings are minimal. The unit currently has a “time out” configuration of 15 minutes; therefore, if a vehicle is present for more than 15 minutes, it will be ignored. However, this could be reconfigured to support its use for parking space occupancy monitoring. The signals are intercepted by receivers installed at the data collection center. Each receiver can support a maximum of 4 SPVD units.

Video Image Processing Detection System (VIDS)

Video Image Processing (VIP) technology has been in existence for approximately 20 years. VIP technology is currently in use for vehicle detection and license plate recognition. VIP can be used in a parking lot vehicle detection and identification system, where one or more video camera units are placed at strategic places in a parking lot. VIDS can be used to either identify the license plate of the vehicle entering/exiting a parking lot or to determine whether a parking space is occupied or not. License plate recognition is now a mature and accurate technology relative to parking space occupancy and vehicle ID determination since vehicles must slow down to a few mph or stop completely, at the entrance or exit of a parking lot. The data is fed to the central control unit using 230 Kbps over copper line infrastructure. The cameras sense the presence or absence of cars in each parking spot and report them to the control unit.

VIDS receive information from video cameras and use special algorithms to analyze the video image inputs of each video frame. A vehicle is detected based on the change in pixels between consecutive video frames over a specifically designated video frame area. The VIDS algorithm estimates the presence/absence of cars in each parking spot and reports them to the control unit. A basic system consists of: One or more image sensors (cameras) or other video source; a machine vision processor (MVP); and a supervisor computer.

The MVP is capable of simultaneously processing information from CCTV video image sensors. The video is analyzed at a rate of 25 or 30 frames per second. A single camera and processor can serve multiple lanes (parking spaces), but there is potential degradation by inclement weather. It requires significant processing power and a wide communication bandwidth. The data from the VIDS unit is fed to the central control unit using 230 Kbps over copper line infrastructure. The advances in wireless communications, including video compression technologies may soon overcome some of the current limitations on bandwidth availability, reducing the associated infrastructure costs inherent in wireline communication systems.

In parking lots, this technology could be used for:

- Vehicle counting at the entrances, exits and parking bays.

- Vehicle parking occupancy of a set of parking spaces – a camera installed high enough could cover a number of parking spaces in an open parking lot.

- VIP based license plate recognition.

- Vehicle trajectory tracking to determine accurate estimates of the arrival and departure rates – based on cameras installed at the roadways in the vicinity of the parking lot.

One of the latest implementations of VIDS is in license plate recognition that serves both to count vehicles and confirm the identity of a vehicle. The latter is a more comprehensive system that could be used for access to the facility (e.g. opening the gate) and automated parking fee payment.

The VIDS units in use now are fairly accurate, however, these systems are still in developmental stages, and problems of "occlusion" and "artifacts" such as rain, snow, and other moving objects are known to produce false signals [5, 9] – these problems are not so severe in parking lots.

A principal advantage of VIDS systems is that the corresponding video stream data can be stored and analyzed to further evaluate the accuracy of the corresponding VIP algorithm for the specific estimation of a traffic parameter. In contrast, all other technologies require either a manual traffic flow estimation study or a video feed to examine the corresponding traffic flow estimation accuracy. One of the VIDS technologies widely used for traffic flow estimation applications is the Autoscope™ system that is manufactured by Econolite.

The VIDS Autoscope™ system [9] is described in Appendix A.

VIDS Advantages

The main advantages of VIDS versus traditional detection systems are:

- Wide area detection produces direct estimates of traffic flow parameters such as density, space occupancy, queue lengths, vehicle trajectory tracking, number of stops, vehicle delay, link travel time, and link speed. Additional traffic/vehicle characteristics could be obtained automatically without additional cost such as: stopped vehicles, illegal vehicle movements, incident/crash, vehicle turning movements, vehicle trajectories, vehicle acceleration, deceleration, lane changing, vehicle characteristics, other.

- Detection can be visually verified in real time or off-line – other vehicle detection systems require an additional system to evaluate their performance. Machine vision can also be used for surveillance without additional cost.

- Year around installation and maintenance are possible without disturbing the traffic flow. It substantially reduces life cycle costs and increases detection flexibility.

- During construction and maintenance of the parking lot and the adjacent roadways, uninterrupted detection continues.

- Placing many virtual detectors within the camera's field of view significantly increases cost effectiveness.

- Virtual detector placement can be visually – input directly in the corresponding video frame - customized and optimized to fit the geometry of the situation and particular detection/surveillance needs.

- Virtual -detectors can be moved, added, or easily deleted, at no additional cost – an experienced video image processing professional could easily conduct these tasks within a few hours depending on the roadway coverage.

The above description for Autoscope is an excerpt from: The Emerging Technology for Advanced Traffic Surveillance Management and Control, Published September 1996, ITS International, P. G. Michalopoulos, http://www.imagesensing.com/ [(9)]

VIDS Potential Problem - Occlusion

When using the VIP techniques in parking spots, several errors can occur relative to the accurate number of vehicles recorded. Individual vehicles may be misrepresented as one complete unit, if two cars are parked close to one another, or one small car is very close to a large van – occlusion (larger vehicle covers partially or totally a smaller vehicle from the view of the camera). This is a major problem being faced by VIP systems, and can be corrected by using techniques such as zooming, developing better algorithms, and by using multiple Autoscope™ systems connected through a communications panel that is also developed by Econolite. The use of dynamic VIP that follows the movement of each vehicle can reduce the occlusion problem to a minimum – not yet developed commercially for parking lots.

Vehicle License Plate Recognition (LPR)

Another VIP technology gaining popularity in the field of Vehicle Control and Management is LPR. A video camera captures the license plate of a vehicle entering, leaving, or traveling through (see Figure 1). Then VIP technology is used to recognize the license plate number of the vehicle usually based on a preset state specific license plate format. For parking applications this technology can be used to:

- Identify authorized vehicles – based on license plate - at the entrance/exit to/from the parking lot. This information could be then forwarded to an automated gate controller to allow passage of the vehicle.

- Provide a continuous parking space estimation counting mechanism for the parking lots by placing cameras at all entrances and exits of a parking facility.

- Provide a continuous parking space estimation counting mechanism for each parking bay of the parking lot. Cameras could be placed at the entrances and exits of each parking bay to track the vehicles, as they move within the parking lot.

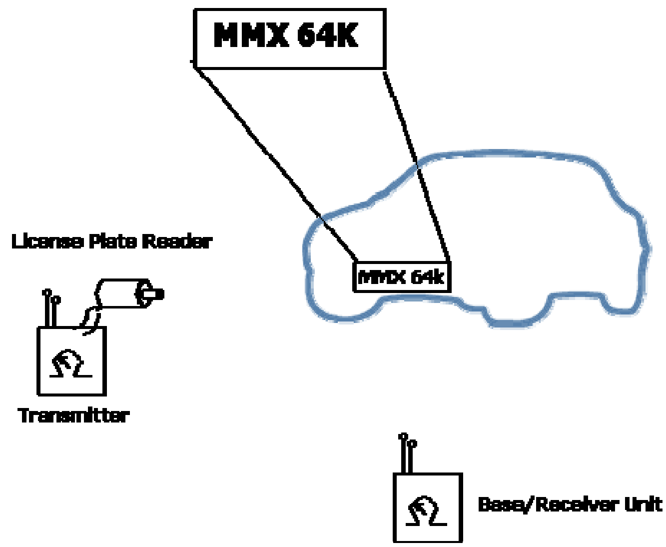


Figure 1. LPR – Parking Application

LPR Effectiveness / Precision

Earlier technologies suffered from problems of low recognition rates due to low-tech detection hardware and algorithms. With the improvements in sensing technologies, better algorithms, lighting, and license plate construction, a high rate of recognition is now obtained. The technology is license plate dependent and the camera, reader and algorithm, etc. has to be tweaked to suit the license plate of the specific location for accurate results.

LPR Parking Applications

The LPR technology due to its vehicle ID capabilities is applicable in parking systems where authorized access and/or payment is required. LPR can be used to detect authorized vehicles entering the facility-based o their license plate number and send the signal to the gate controller and/or the parking fee payment. Similarly, it could be used to open the exit gate when the patron leaves the facility. In parallel, the LPR could produce the ingress/egress flow rate and the time that the vehicle stayed in the facility. A further implementation would be the knowledge of presence of a certain vehicle in the parking lot. This could be accomplished through the installation of cameras at the entrance and exit of each parking bay of the parking lot.

The technology on LPR is further discussed in Appendix A.

Radio Frequency Identification (RFID)

RFID (*http://www.aimglobal.org/technologies/rfid/*) [11] first appeared in tracking and access applications during the 1980s. These wireless systems allow for non-contact reading and are effective in manufacturing and other hostile environments where bar code labels could not survive. RFID has established itself in a wide range of markets including automated vehicle identification (AVI) systems because of its ability to track moving objects. RFID is gaining popularity due to the fact that it is simple, cheap, and easy to maintain. RFID provides the benefit of vehicle identification in addition to vehicle presence detection.

RFID technologies are installed in the vehicle and contain information of the vehicle ID and/or location. The two main categories in this area can be divided into short range and long range wireless communication systems, respectively.

- *Short range wireless communication systems* send the information from a transponder installed in the vehicle to an antenna reader (usually within 100 ft) that is hardwired to a cable/telephone line/wireless communication system that sends vehicle ID info, time stamp, antenna reader ID to a data processing computer. An example of such a system that has been implemented in the Northeast-USA is the E-ZPass toll collection system and is currently being implemented as a parking payment system by the Port Authority of New York and New Jersey in the three main airports (JFK, Newark and LaGuardia).

- *Long-range wireless communication systems* include a vehicle based device that can either be permanently installed or be removable. It also contains a device ID that should include the vehicle ID. The vehicle ID and a time stamp are sent through a wireless communication medium (e.g. cellular network) to a central computer. Two types of devices are used in the industry: 1) An enhanced cellular phone, and 2) a specially designed device that utilizes cellular technology but sends and receives only data to/from the central computer.

Components

A typical RFID unit consists of 3 units:

- Transceiver – Sends and reads data from the vehicle tag.

- Transponder – Vehicle Tag with coded information for identification.

- Antenna – Emits and receives signals.

A transceiver is a unit that sends and receives signals through an antenna that is attached to it. The transceiver can be placed at the entrance of a parking lot, side of the road, or anywhere a vehicle needs to be identified or detected. The transceiver is connected to the antenna, which enables the transceiver to communicate with the transponder. Typical communication includes tag ID query signals, ID erasure and renewal etc. The third component, the transponder, is a programmable unit that is attached to the moving unit (e.g. vehicle). The transponder holds the vehicle ID, and can be reprogrammed on the fly using the transponder-antenna setup or internally from the control center. The type of data that can be stored is requirement dependent.

Types of Transponders

There are two types of transponders: Active and Passive.

An *active transponder* has internal power, either powered by inbuilt batteries or by the vehicle power supply. Active transponders provide more accuracy and detection/ identification range since they have the ability to transmit signals (when coupled with an internal antenna). They can also be programmed and may have memory capacity up to 1 MB. The trade off is greater size, greater cost, and a limited operational life (which may yield a maximum of 10 years, depending upon operating temperatures and battery type).

Passive transponders work with the limited amount of power they receive from the transceiver antenna. They are usually precoded with the vehicle ID information. Some of them are reprogrammable but they are not as flexible as the active ones, which can be reprogrammed through wireless communications. The advantages include absence of a power supply giving it unlimited life, low maintenance, and lightweight. The trade offs are: lower signal strength, higher signal strength is required for the transceiver antenna, and lesser detection/identification accuracy.

RFID Frequency Range

RFID systems are also distinguished by their corresponding frequency range. *Low-frequency* (30 KHz to 500 KHz) systems have short reading ranges and lower system costs. They are most commonly used in security access, asset tracking, and animal identification applications. *High-frequency* (850 MHz to 950 MHz and 2.4 GHz to 2.5 GHz) systems, offering long read ranges (greater than 90 feet) and high reading speeds, are used for such applications as railroad car tracking and automated toll collection. However, the higher performance of high-frequency RFID systems incurs higher system costs.

RFID Advantages

- Low cost, low maintenance and simple operation.
- Radio signals assure no contact, no line of sight operation.
- Radio signals penetrate through opaque structures.
- Detection is possible at high speeds.
- Active transponders are reprogrammable through wireless communications.

- Passive transponders have unlimited lifetime.

RFID-based Cellular Parking Technology

Research is currently being carried out for using cellular telephony technology to aid parking applications. The Global System for Mobile communication (GSM) [12] is a globally accepted standard for digital cellular communication. GSM is the name of a standardization group established in 1982 to create a common European mobile telephone standard that would formulate specifications for a pan-European mobile cellular radio system operating at 900 MHz.

One of the new technologies that utilize the GSM cellular technology is the one developed by Mobipower Ltd. that utilizes the cellular network to communicate with vehicles equipped with specially designed transponders that are installed in the vehicles.

RFID Cellular-based Technology - Mobipower Ltd.

The Mobipower Ltd (formerly Teleparking Inc. www.teleparking.com) system [13] utilizes current cellular infrastructure and integrates parking and cash collection into one unit.

A GSM transponder is installed inside the car and requires power (either internally powered or from the car battery). The vehicle ID is encoded into the transponder which also has a tiny inbuilt antenna that continually transmits GSM signals which can be picked up by a GSM transceiver to identify the vehicle and to provide current information such as parking time, time period of stay, departure time, etc. to a control center. Patrolling security officers could also be given hand-held versions of the transceivers for parking law enforcement purposes.

The GSM based parking system employed by the Teleparking System consists of 5 components: Tele-Parking Unit (TPU); Enforcement Unit (EU); Docking Charging Unit (DCU); Municipality / Parking Operator Control Terminal (MCT); Service Center. The Mobipower system is further described in Appendix A.

How the Tele-Parking System Works

The driver pulls into a parking space, and activates the Triffiq. Because this system has its own memory, it is not dependent on network availability and does not require airtime. Parking initialization is processed totally inside the vehicle, with no need for the driver to leave. The Triffiq displays the parking rates – these are compiled and stored into the Triffiq memory - and the maximum allowed time, while an intermittent beep is emitted to remind the driver that the system is in operation.

To end the parking transaction, the driver returns to vehicle and deactivates Triffiq. The actual parking charge is displayed, based on current municipal charging policies, and the data is transmitted to the CompuCenter. A monthly bill itemizes all parking transactions.

The enforcement agent uses the eN-Force unit – carried by the parking enforcement officer - to verify the parking status of all Triffiq units within a radius of 10 meters (33 ft). If the maximum allowed time has elapsed, the enforcement agent may issue an electronic ticket. At the end of each day, data is downloaded from the eN-Force units via the DataDock to the municipality's RemoTerminal. The entire system is managed by the CompuCenter, which is operated by the national/regional Tele-Parking System Operator.

Mobipower has launched the Tele-Parking System in the cities of Gouda and Leiden in the Netherlands (known locally as the Triffiq system). Following the positive feedback from users, more cities are planning to launch the system. The Tele-Parking System has also been designated for an EU-funded trial in the City of Berlin, scheduled to be launched during 2003" (www.teleparking.com).

At parking lots, the technology could be used to automatically identify the vehicles entering/exiting a parking facility and open the gate, if there is one. The technology could be used for various applications such as: 1) Loading and Unloading payments, 2) Congestion charges, 3) Parking reservation, 4) Toll charges, 5) In-vehicle payments (fuel, car wash, fast food etc.), 6) Location Services (if the vehicle or the Triffiq is equipped with a GPS receiver).

Advantages

- System could be used for both curb-parking and parking lots.
- System does not require any infrastructure investment and could be deployed rather easily and fast.
- Wireless parking payment method.
- Wireless vehicle and traveler identification and access to the facility.
- System is flexible enough to handle a variety of parking alternatives, requiring mainly changing the software code. The parking operators could easily change their parking management by changing the code without any physical changes in the facility.
- Automated parking reporting at each facility: number of vehicles entering/exiting the facility, vehicle duration statistics.
- The technology could be used, as an anti-theft device since its location is known continuously.
- The unit could be used to receive traveler information including P&R occupancy information and bus/train scheduling and real-time arrivals and departures.

Disadvantages

- A rather new technology that has not been tested in the US,

- Each unit currently costs over $100.00 that may be viewed as too high by the travelers.

- Its effectiveness as a parking monitoring system requires 100% market penetration and it would be difficult to implement for all parking facilities. The NJDOT and NJ Transit would be required to establish a subscription-based system where only vehicles equipped with the Triffiq device could enter each facility. This, however, may discourage people to use the P&R program. Alternatively, each parking facility could have a designated area for authorized vehicles equipped with such a system. Further, NJDOT could split a number of P&R facilities into gated lots where only authorized vehicles could enter based on their RFID and/or license plate through the use of an LPR system, which was described earlier.

Cellular Phone Parking Space Monitoring and Information System

The use of cellular phone as a traveler information system is becoming very popular in the US, Europe and Japan. Specifically for PIRS systems, it could be used to:

- Receive real-time parking space availability at a parking lot.

- Receive routing information to a parking facility.

- Reserve a parking space.

- Obtain access to a parking facility. For gated facilities, a device would need to be placed at the entrances and exits of the facility that will communicate with the cell phone, identifying the proper ID and opening the gate. This could be easily implemented through the use of Bluetooth technology for short-range communications. For open parking lots the vehicle will be identified automatically again through Bluetooth technology.

- Receive transit schedule information serving a specific parking facility or facilities.

- Receive real-time transit arrival information at a parking facility.

- Receive parking facility amenities information such as bicycle stands, showers, telephones, safety features, etc.

- Pay for parking and for transit, as well as for other services. The cell phone is increasingly being used (especially in Europe and Japan) as an electronic purse.

The use of a cellular phone, as a location device is expected to become more popular as the emergency system E-911 system is implemented throughout the US. While this system is geared towards the identification of the callers under an emergency, it may also be used for the location of the caller at a parking facility. This is a significant advantage over other technologies since it does not require any additional infrastructure and the majority of the drivers already have a cellular phone in their possession. One disadvantage is that a few drivers may not carry a cell phone at the time they park their vehicle (either they may not own one or they may forget it).

The location of a driver using a cell phone currently is accurate enough to 200 yards which is sufficient for the identification of the location and P&R facility.

A comprehensive system using the cellular technology for parking information, reservation, and access to a facility would require the establishment of such a system throughout New Jersey. Such a system could be implemented initially as an ITS operational test involving the NJDOT, NJ Transit, a cellular service provider, consulting firms and research institutions.

Advantages

- Cellular phones are widely used.
- No substantial infrastructure investment needed. This could potentially become the cheapest form for parking space monitoring.
- Cell phone could be used for parking information, reservation and access to the parking facility.
- Cell phone could be used for parking payment through a wireless electronic transaction system requiring minimal interference from the user. The cell phone could be used in general for any credit type transaction.
- The cell phone could be used to request and receive traveler information including transit schedule and status, route planning, concierge services (location of restaurants, gas stations, etc), other.

Disadvantages

- New technology for parking information and reservation, requiring acceptance and use by the agencies and the travelers.
- Travelers will be required to send a message upon arrival at a parking facility to confirm that they are indeed parking at the facility. In addition they would need to send the vehicle license plate number to the parking operations center through their cell phones. This could be done automatically when all cell phones are equipped with GPS.
- Parking enforcement for unauthorized parking at non-gated parking facilities requires additional technology (VIDS, parking attendant, magnetic card, other).
- It requires a 100% cell phone usage. This could be remedied through the use of gated areas within the P&R facilities where only authorized vehicles could enter having a form of vehicle ID (RFID or VPR).

RFID - E-ZPass based Parking Space Monitoring System

The E-ZPass toll collection system (www.EZPass.com) has been installed at toll facilities in the NY/NJ/CT metropolitan area. The E-ZPass system could be used to estimate the number of vehicles entering and exiting a facility, provide access to the parking facility and be used as a payment system. An antenna reader would need to be installed at each entrance and exit of a facility.

The major components of the E-ZPass system are: E-ZPass tags (transponders) placed in a vehicle; Roadcheck™ 1 Basic Reader System (transceiver plus antenna) at each parking facility; Communication wireline or wireless; Data Processing Center (computers, software). The system is further described in Appendix A.

Advantages

- Easy tag ID identification and easy ingress/egress to/from the facility.
- Automated parking reporting at each facility: number of vehicles entering/exiting the facility, vehicle duration statistics.
- Proven technology with high accuracy rate.
- Technology is operational in the entire NY/NJ metropolitan area so a large percentage of people already have E-ZPass tags in their vehicles and a set up accounting system.

Disadvantages

- Each unit requires a deposit of $25. Although this is a rather modest amount, it may be viewed as a deterrent by some drivers.
- Drivers may view this as another device that invades their privacy.
- It requires the installation of a structure to mount the *Roadcheck™ Basic Reader*. This would add to the installation costs.
- Its effectiveness as a parking monitoring system requires 100% market penetration that it would be difficult to implement for all parking facilities. The NJDOT and NJ Transit would be required to establish a subscription-based system where only vehicles equipped with the E-ZPass tag device could enter each facility. This, however, may discourage people to use the P&R program. Alternatively, each parking facility could have an additional parking monitoring system to have full knowledge of the number of free parking spaces – as is the case at the Newark, LaGuardia and JFK airports in the NY/NJ metropolitan area where a hybrid system is in place.

Other Potential Parking Space Sensing Technologies

Listed below are a few of the most popular traffic flow characteristics monitoring technologies.

Active Infrared (Overhead Sensor) [4, 5]

This technology operates by directing a narrow beam of energy toward a background such as the surface of the roadway, at a specific pulse rate. A portion of the beam is directed back to the sensor and vehicles are detected by recognizing changes in the characteristics of the infrared beam. It directly measures vehicle speed but has potential degradation by obscurants in atmosphere and by inclement weather.

Passive Infrared (Overhead Sensor)

The passive infrared vehicle detection technology [4, 5] does not transmit energy itself but measures the amount of energy that is emitted by objects in the field of view. It has a greater viewing distance in fog than with visible wavelength sensors but is sensitive to heavy rain and snow.

Doppler Microwave (Overhead Sensor) [4,5]

The Doppler microwave detector transmits low-energy microwave radiation at a target area on the pavement and then analyzes the reflected data. The motion of a vehicle in the detection zone causes a shift in the frequency of the reflected signal. It operates well in inclement weather and directly measures vehicle speed; however, it cannot detect stopped vehicles or vehicles moving less than approximately 5 mph.

Microwave Radar (Overhead Sensor) [5, 7]

Electromagnetic energy is transmitted toward vehicles on the roadway. Traffic parameters are calculated by measuring the return signal. This technology performs well in all weather conditions, and has a high reliability. It measures the vehicle speed and detects stopped vehicles, but it requires a narrow beam antenna to confine footprint to a single lane in the forward-looking mode.

Passive Acoustic (Overhead Sensor) [5]

Vehicles are detected by using microphones, as well as a signal processing technology to identify sounds associated with vehicles. It is insensitive to weather conditions and provides day and night operation. This is a relatively new technology for traffic surveillance.

Ultrasonic (Overhead Sensor) [4, 5]

Electronic sound wave signals and a receiving unit are used to detect vehicles traveling in a traffic stream. It provides the basic traffic parameters. However, it is sensitive to environmental conditions and does not directly measure vehicle speed.

The above technologies should also be taken into consideration by the NJDOT as potential candidates for its envisioned P&R monitoring system. These technologies are continuously evolving and should be included in any future feasibility study.

The following section presents a sample pricing for three popular parking space technologies based on data obtained from three different vendors.

Sample Pricing of Three Parking Space Occupancy Technologies

In this comparative study on detector pricing for parking, the parking deck at the New Jersey Institute of Technology (NJIT) and the NJIT's student parking Open Lot have been taken into consideration. A preliminary feasibility study was conducted with implementation on the sensors in three ways:

- At the entrance and exit.
- At each level of the parking deck (to determine free spaces per floor).
- At each parking spot in each lot.

Prices are based on market rates (2003). The following companies were interviewed for each technology:

- Inductive Loop Detection Systems (ILDS): Amano Cincinnati, Roseland, NJ.
- Video Image Processing Detection System (VIDS): Econolite Control Products Inc., Anaheim, CA.
- Dual-axis Magnetometers: Midian Electronics, Tucson, AZ.

The pricing provided does not constitute bidding by any of the companies for a service to NJDOT. They are used here as a guideline to provide approximate estimations on the implementation of such systems. Implementation by the NJDOT may change the pricing based on the individual characteristics of each P&R facility, the economies of scale associated with a large number of parking facilities and the competitive bidding for such a contract by various vendors. It should be noted that other companies offer similar products that may have different pricing schemes.

<u>Parking Facilities</u>

NJIT Parking Deck: The Parking deck at NJIT is a parking facility consisting of eight floors of parking space capacity for 1,650 cars. There are two parallel entrances and two parallel exits. The entrances and exits are accessible through gates (installed and maintained by Amano, Cincinnati). There is currently an ILD at each entrance gate and exit that controls the opening and closing of the gates, respectively, while monitoring the number of arrivals and departures. There are no other detectors present either at the entrance or at any parking spot. This lot is accessible to the NJIT faculty, staff, and students, which use an authorized decal that is displayed at the vehicle's windshield. A limited number of visitors is also allowed to park subject to parking space availability at the time of their arrival.

Open Space NJIT Parking Lot: The student parking lot is a 300-car facility that has one entrance and one exit. At the entrance, an officer validates the entering vehicle.

However, the exit has an Amano gate and an inductive loop detector that detects on-coming vehicles and controls the opening and closing of the gate. There are currently no other sensors within the lot.

Access into each parking lot is achieved through a magnetic ID card and a reader that is installed at the entrance gate. The two ILDs, at the entrance gates simply act to count the number of vehicles entering the parking facility. On some occasions, they are also used to open the gate when the entrance to the parking lot is available to all visitors. The users do not have to swipe their magnetic ID card upon exiting the parking lot. The two ILDs installed just prior to the exit gates activate the gates upon the detection of a vehicle. The entering and exiting data are stored in a historical database maintained by NJIT.

Currently the system does not provide real time parking space occupancy for each parking lot. However, it has the necessary components to produce such estimates since all the parking lots at NJIT are connected with a wireline. It is further noted that such a system can only produce current parking space estimates for each parking lot. This could provide misleading information to the travelers relative to the parking deck, since the system does not take into consideration the arrival/departure patterns that are stochastic. A specially designed algorithm should be established that would take into consideration the real- time arrival and departure pattern so that a more accurate system could be developed. Such a system could aid the users in reducing their search for an empty parking space (e.g. go to other NJIT or privately owned parking lots).

<u>Installation Setups</u>

Setup Type 1: Detectors Only at the Entrance and Exit of Each Parking Facility

In this setup, a detector is required at the entrance and exit of each facility. This setup produces a vehicle counting system of the number of vehicles entering and exiting the facility. The parking system would enable the operator to use this information to produce an estimate of the current number of empty parking spaces at the parking lot.

The above estimate – simply based on the entering and exiting rates would not be accurate relative to a parking deck of eight floors or to large parking lots. There is a time delay for a vehicle to find an empty parking space upon entering the facility. At the same time other vehicle(s) are departing from their parked places. In cases where the arrival pattern is higher than the corresponding service rate of the entrance gates, a line forms at the roadway (Summit St.) outside the parking deck. This causes the departing vehicles to form a queue inside the parking deck in front of the exit gates since the exit service rate is reduced due to the entering queue that sometimes obscures the exit gates. Consequently, an estimate of the free parking spaces at the parking deck simply based on the entering service rate and the exiting service rate would be erroneous.

The corresponding pricing for the SPVD 2, VIDS and ILDS is summarized in Table 1.

Table 1. Setup 1 – Detectors Only at the Entrance and Exit of Each Parking Facility

SPVD 2	Price $	# Units	Battery (4 years)	Installation Cost $	Total Install	Total Cost
Magnetometer	395	6	40	200	1200	3610
Receiver	225	2	NA	300	600	1050
					Total	**4660**
VIDS						
Camera	5000	4	NA	500	2000	22000
Receiver	2000	2	NA	300	600	4600
					Total	**26600**
ILDS						
Loop	700	6	NA	800	4800	9000
Receiver	2500	2	NA	300	600	5600
					Total	**14600**

Setup Type 2: Detectors at the Entrance and Exit of Each Parking Facility and Two Detectors at Each Floor of the Parking Deck

This setup is an improved version of the first setup as it now provides an accounting system for each floor. This allows for an estimate of the number of vehicles entering and exiting each floor of the deck. This information could be combined with an information system at the entrance of the parking deck as well as on each floor that could inform the users of the current number of free parking spaces on each floor. This setup also has limitations since some users may be driving around looking for free spaces - this occurs at the NJIT parking deck. In addition, in some cases some drivers may simply opt to stop the vehicle while inside the parking deck and wait until a vehicle departs. The corresponding pricing is listed in Table 2.

Table 2. Setup 2 – At Entry/Exit and 2 detectors on each floor of the deck

SPVD 2	Price $	# Units	Battery (4 years)	Installation Cost $	Total Install	Total Cost
Magnetometer	395	22	240	200	4400	13330
Receiver	225	6	NA	300	1800	3150
					Total	**16480**
VIDS						
Camera	5000	20	NA	500	10000	110000
Receiver	2000	10	NA	300	3000	23000
					Total	**133000**
ILDS						
Loop	700	22	NA	800	17600	33000
Receiver	2500	10	NA	300	3000	28000
					Total	**61000**

Setup Type 3: Detectors at Entry/Exit and at every parking spot in both lots

This is a full coverage system where we can monitor the parking space occupancy of each space in real time. The corresponding pricing is listed in Table 3. The costs associated for such a system is prohibitively expensive; therefore, it is not recommended. In the case of VIDS, the capital cost for the cameras may drop dramatically over the next few years. Cameras could be less than $100. Such a change could make the use of cameras much more attractive, reducing the corresponding capital cost to $115,500. Such economies of scale could further be found for the other technologies due to more efficient manufacturing techniques and advancements in technology.

Table 3. Setup 3 – Detectors at Entry/Exit and at Every Parking Spot in Both lots

SPVD 2	**Price in $**	**# Units**	**Battery (4 years)**	**Installation Cost $**	**Total Install**	**Total Cost**
Magnetometer	395	1672	10032	200	334400	1004872
Receiver	225	419	NA	300	125700	219975
					Total	**1224847**
VIDS						
Camera	5000	66	NA	500	33000	363000
Receiver	2000	33	NA	300	9900	75900
					Total	**438,900**
ILDS						
Loop	700	1672	NA	800	1337600	2508000
Receiver	2500	419	NA	300	125700	1173200
					Total	**3,681,200**

The first set-up with detectors placed at the entrances and exits of P&R facilities provide the most cost effective alternative. The detector cost will be near $5,000 if the SPVD 2 technology is selected. A critical element in such a decision will be the corresponding costs associated with the communication system and the establishment of a P&R operations and information system.

Parking Payment Guidance Principles

These guiding principles (14) have been developed to assist the parking industry stakeholders as they develop and deploy electronic payment systems (EPS) that will increase operating efficiencies and offer greater convenience for the public. Electronic payment system technologies include but are not limited to smart card applications (including both contact and contactless technologies), automatic vehicle identification transponders, cellular communication systems, and the Internet.

The International Parking Institute (IPI) developed these principles to reduce overall technology costs, increase convenience for the public and ultimately optimize market penetration. Next these principles are quoted from IPI:

General

- Investment and participation in EPS for parking is voluntary.
- EPS parking applications provide system security and payment integrity.
- EPS parking applications have the potential to expand without compromising security.
- EPS parking applications have the capability to integrate with existing information and payment systems.
- EPS parking applications have the capability to accurately audit transactions.
- EPS parking applications have certified clearinghouse interface capability.
- The parking industry implements interoperable EPS systems throughout North America.

Smart Card Technology

- EPS smart card parking applications have the flexibility to support industry standards for multiple smart card schemes.
- EPS smart card parking applications support on- and off-street parking devices and operations.
- EPS smart card parking applications support multiple card issuers.

Privacy

- EPS parking applications provide reasonable expectation of privacy regarding access to and use of personal information. The parties must be reasonable in collecting data and protecting the confidentiality of that data.
- EPS parking application data access must be controlled and tracked; civil and criminal sanctions should be imposed for improper access, manipulation, or disclosure, as well as for knowledge of such actions by others.

Interoperability

- End users may obtain an EPS device from the operating agency or a compatible EPS device from an independent equipment vendor of the end user's choice.
- Parking agencies must work to establish business interoperability agreements among parking programs.

- The United States parking community works with the parking communities in Canada and Mexico to implement interoperable EPS systems throughout North America.

- The parking industry works to ensure that EPS systems for parking, where appropriate, are interoperable with other transportation related EPS systems (e.g., electronic toll systems, transit fare collection, etc.) that are in compliance with the National ITS Architecture.

- The parking industry works to ensure that EPS systems for parking, where appropriate, are interoperable with other electronic systems to encourage multi-functionality (e.g., retail applications, identification/access systems, campus cards, etc.).

Standards

The parking industry endorses the use of open standards and interoperability between systems in EPS parking applications.

Conclusions

This chapter presented a summary of some popular vehicle sensing technologies that could be used for parking applications, as well as some rather new technologies. This review concentrated mostly on the following technologies: 1) Inductive Loop Detections Systems (ILDS), 2) Video Image Detection Systems, 3) Dual Axis Magnetometers, and 4) Radio Frequency ID (RFID) based detection systems. The use of one or more of these technologies is dictated by the functionality that is required by the parking operator. This functionality may include the following:

- Parking space occupancy of the facility.

- Parking space occupancy for each parking bay.

- Parking space occupancy of each parking spot.

- Vehicle License Plate recognition.

- Vehicle/Driver ID recognition.

- Automated parking payment.

- Automated parking gate opening.

- 100% vehicle detection coverage.

- Curb-parking monitoring capabilities.

- Traveler information capabilities.

Table 4, below, offers a summary of the functionality of each technology. The letter x indicates that the technology can produce these estimates. The letter P indicates that the potential exists for such a measurement. The letter E indicates that the technology has the capability; however, this solution would be prohibitively expensive.

Table 4. Functionality of Parking Space Detection Systems

Technology	1	2	3	4	5	6	7	8	9	10
ILDS	x	x	E				x	x	P	
Dual Axis Magnetometers	x	x	E				x	x	P	
VIDS	x	x	P			x	x	x	P	
VIDS-License Plate Recognition	x	x	E	x		x	x	x		
RFID (Cellular phone)	P	P	P	P	x	x	x	P	P	x
RFID (Cell-based - Mobipower Ltd.)	P	x	x	x	x	x	x	P	x	x
RFID (e.g. E-ZPass based)	P				x	x	x	P		P

A parking space monitoring system would aid the NJDOT to support its short and long term goals for the P&R program through the provision of parking space utilization for all of its P&R facilities, and establish a real time Parking Information and Reservation System (PIRS). The primary concern for NJDOT is the capability to provide real time estimates of the parking space occupancy for each P&R facility, disseminate them to the existing users, and further attract other potential users.

One of the most useful informational enhancements to travelers is *the expected probability of finding a free parking space upon arrival at a specific parking lot*. Such information could aid in better utilization of the existing parking space availability and reduce congestion in the surrounding area through a reduction of unnecessary trips.

The simplest monitoring system is the one where detectors are placed at the entrances and exits of each parking lot facility. Based on this limited study the SPVD-2 Dual Axis Magnetometer offers the least expensive solution, which is less than $5,000 without the associated cost of the communication system and P&R operations/information center.

The VPR technology provides a universal solution since it combines both vehicles ID, as well as 100% vehicle coverage.

RFID based technologies cannot be used as a parking occupancy estimation system since they require 100% vehicle coverage. The NJDOT could divide some large P&R facilities to gated and non-gated sections. Vehicles equipped with authorized RFID devices would be allowed to park in the gated section while all other vehicles would park in the non-gated section. In addition, a traditional monitoring technology would need to be installed at the non-gated section to provide 100% coverage of the number of arrivals and departures.

The flexibility offered by the cellular-based RFID technology developed by the Mobipower Ltd. is unmatched by any of the technologies. It provides the most comprehensive system in terms of vehicle ID, automated payment, parking enforcement, as well as curb-parking capabilities. Furthermore, the TPU unit could be used to send real- time information to the users on parking space availability for specific P&R facilities of interest. The main disadvantages are: 1) It is a new technology that has not been implemented in the US and 2) It requires a new mandate so that all P&R users must install the TPU transponder in their vehicles.

The cellular phone is becoming a universal information and payment device. NJDOT could use such a technology to support a hybrid P&R monitoring system in conjunction with another technology that provides 100% of vehicle coverage. The cellular phone could be used to provide automated access to the facility, parking and transit payment, parking and transit information, route planning and other information either through web access, SMS, or e-mail service.

The cost analysis undertaken in this study is of limited use. The NJDOT should undertake a comprehensive feasibility study that would take into consideration the main functions that its P&R monitoring system should have. This feasibility study should further require that every cost analysis consider all P&R facilities and the associated costs of the necessary communication system (wireline, wireless, or hybrid).

PARKING GUIDANCE AND INFORMATION SYSTEMS (PGIS)

In order to reduce the problems associated with parking in the United States, many cities have continued to build more parking facilities. Meanwhile, cities in Europe, Germany, and Japan have used innovative methods, such as PGIS, to create a more efficient parking system without the need for building more facilities. Twenty years after the first PGIS was installed in Germany, two cities in the United States, Pittsburgh, Pennsylvania and St. Paul, Minnesota, determined that systems similar to those utilized in cities in other countries can be used in the US to solve the problem associated with parking. In the United States, these parking systems are often referred to as Advanced Parking Information (API) systems and have also been installed in San Jose, California and New York City.

Typically in Central Business Districts (CBD) of large urban areas, a significant amount of driver time is spent on looking for a parking space. Providing drivers with information on parking availability reduces their search time, the congestion in the impacted roadway network, as well as at the entrances of parking lots. In addition, the search for parking space availability increases the stress of the travelers. Furthermore, it has been found that the economic competitiveness of an area can be benefited by accurate parking space information. It is not uncommon for travelers to choose a specific area to do their business due to the availability of parking and parking information, and vise versa, to avoid a specific area due to the frustration associated with finding a parking space – if a good transit system is in not in place.

The P&R program could benefit by utilizing the deployment of an effective PGIS that would make travelers aware of P&R facilities, provide signage guidance to the facilities, transit related information, and parking space availability. The P&R facilities exhibit a spatial distribution that is different than CBDs, where the parking lots are usually concentrated in one geographical area. In contrast, P&R facilities are spaced throughout the transportation network near major arterials and highways. The implementation of a modern PGIS system for P&R facilities would require substantial investment to cover such a wide area. In the state of New Jersey, as the number of P&R facilities increases, it will soon be necessary to install PGIS signs at critical route decision locations along the main arterials, highways, freeways, and tollways.

The main function of a PGIS is to inform motorists of the location of parking facilities and the availability of free parking spaces, thereby reducing the time expended searching for parking lots and free parking spaces. The functionality of a PGIS system for P&R facilities could be expanded to include transit schedule information, which is an integral component of the P&R program. The directions to parking lot locations is usually accomplished through static signs where the availability of parking spaces is presented through electronic message signs located at downtown gateways and intermediary points closer to parking facilities and main destination venues. A single PGS can provide direction and free parking space information for one or more parking lots downstream of its location. By providing timely and accurate information, motorists are able to make more informed parking decisions, thus making their visit to downtown easier and ultimately leading to a better use of the existing parking supply. The use of PGIS systems for park and ride programs could have the following benefits:

Increase in Transit Ridership. The use of PGS would make auto travelers aware of both the location of a park and ride facility and the availability of free parking space(s), as well as bus or train routes that serve this facility. This “advertising” may potentially increase the transit ridership, by reducing the usual “fear of the unknown” related with the use of transit such as determining a bus/train stop, the train destination, the availability of a parking space, or the cost for parking.

Better Utilization of Parking/Park and Ride Facilities. Travelers will be informed of which P&R facilities have free parking spaces, and those that are full, thereby, reducing unnecessary trips for the travelers and directing them where they should go. Therefore, P&R facilities that normally have free spaces may obtain additional customers who would become aware of their availability.

Decrease in Roadway Congestion. The roadway network in the vicinity of the P&R facilities would observe a decrease in congestion since travelers would make more informed decisions regarding their choice of a P&R facility. Furthermore, the potential *conversion of some auto travelers to intermodal travelers* has the potential to decrease the congestion downstream on the corridor. Any reduction in roadway congestion would materialize only if an increase in the P&R customer base is coordinated with the preferential treatment of transit services. If some travelers move to intermodalism, there is the risk that other travelers may switch back to cars from transit, if they see that the congestion levels are down. Only if the transit service is viewed as a time saver and safe/stressless mode alternative will we see a real benefit. This could be accomplished through a set of potential transit priority systems such as High Occupancy Vehicle (HOV) lanes, Bus Rapid Transit (BRT), transit signal priority systems, transit related tax incentives, and premium transit ride quality.

Parma [(17)] explained the challenges and guidelines for implementing PGIS in the United States for daily downtown traffic. The challenges include: encouraging cooperation between public and private sectors, gaining funding to cover the cost of these systems, as well as overcoming the mentality of building more facilities when empty parking spaces are hard to find. In addition, awareness of these systems must be generated to provide another alternative to building more parking facilities. Most important, the motorists must be willing to accept the PGIS that is implemented, since they will be the determinants of whether a system is successful or not.

Khattak and Pollack [(18)] gave a detailed explanation on the features of the PGIS in the city of Nottingham in England. The Nottingham PGIS is a real-time parking information system, which was designed to alleviate congestion in the city center parking facilities. In this system, real-time information was disseminated through the radio, while historical information regarding parking locations was disseminated through newspaper advertisements and leaflets. Drivers in this city normally have the option of using multistory or surface car parks, park-and-ride facilities or a limited set of parking spaces at on-street parking. The broadcast parking information service provided a list of the congested car parks (queues and estimating queuing time), car parks with available spaces, occupancy levels at park-and-ride facilities and advice on what seemed to be the best course of action. The broadcast service, in this system, is available between 9 AM and 1 PM, at 20-30 minute intervals. The provision of a broadcast parking information service and the availability of parking (details of car parks and park-and-ride facilities) are advertised in newspaper, leaflets and on road signs. Also, the authors advised that there was potential in disseminating both the static and dynamic parking information, at a reasonable cost. A study on the effect of parking information on travelers' knowledge and behavior was conducted. The results indicated that drivers were more likely to have a greater knowledge of city center car parks, if they used several informational sources. Additionally, drivers were more inclined to use the relatively under-utilized P&R facilities, if they received parking information from newspaper advertisement or leaflets. The author concluded that overall it seemed reasonable to establish such information dissemination and monitoring systems for parking facilities in other urban areas. The authors further suggested that in order to support informed travel and activity participation decisions, parking information should be integrated with traffic and transit information.

Wright [(19)] showed the effects of the Advanced Parking Information (API) system used in St. Paul, Minnesota, which was one of the ITS projects. In this API system, 56 signs are used to inform drivers of the availability and location of parking facilities. Among them 46 are static to provide direction to parking lots and ramps near various event sites. A central computer controls data gathering and the information is sent to 10 electronic boards that provide real-time, updated information on the number of parking spaces available in each of 10 parking facilities tested in this project. This API system is used together with DIVERT, a traveler information service that notifies travelers on traffic delay due to incidents. NJDOT could use a similar system and integrate the PGIS system with its MAGIC ITS system for the North NJ area. Furthermore, the PGIS system could be integrated with TRANSCOM's forthcoming advanced traveler information service called TRIPS123.

Boyd et.al [(20)] reported the results of the ITS operational test on the effect of the Advanced Parking Information (API) system used in St. Paul, Minnesota. This was the initial operational test conducted in the United States. The focus was to demonstrate a real-time, event-based downtown parking information system. This test also demonstrated public-private partnerships with diverse interests between parking facility operators, equipment vendors, and federal, state, and local government agencies. The evaluation of this ITS operational test indicated that most operators and motorists responded positively to the system and requested its continuation and expansion. The authors concluded that after the system was debugged, it performed well, technically. The amount of traffic circulating in search of a parking space was significantly reduced. It provided a convenience to motorists and less congestion.

Orski [(21)] depicted the features of electronic parking information systems and also summarized the features of the API installed in St. Paul, Minnesota. The main features of these API systems included: ITS technologies to provide motorists with accurate, continuously updated information of parking occupancy, and PGS could be used to facilitate the access to parking garages in central business districts, surface parking lots on the periphery of downtown areas, P&R lots serving suburban commuter rail stations, satellite parking lots at airports, and parking areas surrounding sports and entertainment complexes. The API systems could be used independently as freestanding systems, or integrated into a more comprehensive Advanced Traffic Management/Traveler Information System (ATM/TIS). The author also explained the API systems architecture, which included the use of loop detectors in parking facilities, static directional signs, Variable Message Signs (VMS), and central computers. Communication between the three components can be accomplished using wireless links and/or hard wire.

Asakura et.al [(22)] studied the drivers' response to a new PGIS in the city of Mastuyama in Japan, using three questionnaire surveys on six chosen car parks that provided location, direction, and availability of parking spaces. The PGIS in Mastuyama uses three types of signboards. A driver traveling from the suburbs to the city center will find a *block signboard* located at the main entrance road of the city, which displays the availability of each of 6 sub areas of the concerned area on a schematic map with variable colored characters meaning Full, Congested, or Spaces. A *detailed colored area signboard* is located on a main street on the area and provides the direction and the availability information of car parks that could possibly be approached from the street. When a driver enters a sub area, he/she would find a *colored individual signboard* listing the names, availability, or the direction of individual car parks nearby. The study showed that although more than 80 percent of the drivers were aware of the PGIS, less than 20 percent of them actually utilized the information. The detailed area signboard, received better evaluation than the block signboard, whereas, the individual signboard received positive evaluation from most drivers.

Thompson et.al [(23)] explained various aspects of an integrated graphic database called PARKINFO - a central-city parking information system. The PARKINFO database system had been developed to assist with the evaluation and management of parking-related data. It combines data related to parking, traffic and land-use systems. It permits the interrogation of these data to be interactively performed, with the results presented dynamically in map or tabulated report form. Detailed maps and reports can be produced, allowing the evaluation and examination of the impacts of proposed developments, as well as traffic and parking policies. There are two types of data in this system: 1) data necessary for implementing traffic and parking models; and 2) data to enhance their usefulness as a general transportation-planning tool.

Noda et.al [(24)] experimented on the introduction of Route Guidance and Parking Information Systems in Toyota City, Japan. The projected impacts of this system were to shorten the time to travel to the parking lot, mitigate street congestion, and thus utilize parking space more effectively. The author stated that it was a good idea to use block-unit on signboard to show parking space availability (non-full parking lots). In addition, the parking space availability information provided through the car radio system was found to be very effective. The result of this experiment demonstrated that the most useful information was that of parking space availability. In addition, the car-radio scored very well, when the traffic was heavy since it provided traffic information and suggested faster routes.

Toyana [25] gave an overview of the current and future PGIS. These systems were designed such that the parking management center collects real-time vacancy information from parking facilities, estimates the utilization status of parking facilities on levels of blocks, zones and parking facilities, and the parking occupancy information is supplied to drivers on a real-time basis through guidance displays installed systematically on roads. Conventional static PGISs are based mainly on message board providing information that is common to all travelers. The new generation of PGIS will be linked with a comprehensive system, to enable continuous guidance information based on the capabilities of the communication system. This guidance could range from specific parking guidance information from a user's Origin to their Destination, universal parking lot guidance and parking space availability. In addition, a comprehensive system should include a data model for the collection of travelers parking information needs, experiences with the specific PGS system implemented and the performance of such a system. This data model should be part of a comprehensive transportation-planning model.

Kurogo et.al [26] and Thompson et.al [27] studied the impact of PGIS in the Shinjuku area, where the first PGS was implemented in Japan. Ideal conditions necessary for the introduction of a PGIS into a particular area were summarized, and the actual conditions of the Shinjuku area were discussed as compared with ideal conditions. The basic considerations of the Shinjuku area PGIS were described from conceptualization to construction, and its benefits were demonstrated from the results of surveys conducted before and after its introduction. The configuration of the system included: 1) information and guidance in multiple stages; 2) basic guidance route to each parking lot; 3) integration of parking lots into blocks; 4) image color assigned to each block; 5) guidance to the next non-full parking lot by entrance guide signs; 6) guide signs bearing names of individual parking lots; 7) easy-to-understand parking guide signs; 8) fulfillment of peak parking demand; 9) left-turn entry; 10) parking lot information through means other than guide signs; 11) prediction and control of parking demand; and 12) expandability of the system. Thompson conducted a questionnaire survey that included trip related queries such as: parking choice and use and perceptions of the PGIS. The results of this survey indicated that trip makers with higher frequencies, as well as short distances, were more likely to notice and understand the PGIS signboards. Infrequent trip makers, from further away, noticed the PGIS signboards were more likely to use (or follow) the information/guidance on the sign boards to influence their parking choice.

Sakai et.al [28] gave a detailed description on the main elements of the design of PGIS. It was stated that the most basic element of the design concept was to construct a complete PGIS from a system architecture, and equipment that could be flexibly adapted to changes in the number of parking lots, road networks, and traffic information gathering points with the growth of the city simply by changing partly the system program and data without modifying the devices substantially or replacing them. The author described the components of the system, which included: 1) system configuration; 2) information collecting including parking and congestion information; 3) information processing; and 4) provision of information. The results of a survey indicated that almost all drivers looked at the display signs and 70 percent of them used the displayed information when deciding on a parking lot, and 87 percent of the drivers confirmed the necessity of the PGI system.

Components of PGIS

A PGIS usually consists of four components Teng et.al [29]:

- A collection of roadside PGIS signs capable of displaying a limited set of static and/or variable messages.
- A vehicle counting mechanism, at parking facilities that can record the number of cars entering and leaving a facility and thus enable the calculation of occupancy of parking facilities.
- A control center that processes data on occupancy of parking facilities and controls the display of information on the variable message sign.
- A telecommunications network that facilitates the exchange of information between parking facilities, control center and variable message signs.

Appendix B provides sample static and dynamic PGIS signs as well as sample costs from two different systems. Further information can be found in Teng et.al[29]:

PGIS Communication System

The PGIS may employ the following communication media types to provide the required communications between all the components/subsystems that could be either one-way or two-way communication:

Wireline

For fixed-to-fixed communications requirements, the Traffic Management Subsystem can use leased or owned twisted wire pairs, coaxial cable, or fiber optic to gather information and to monitor and control Roadway Subsystem equipment packages (e.g., traffic surveillance sensors, traffic signals, changeable message signs, etc.). In other applications, it may be more advantageous to use terrestrial microwave links, spread spectrum radio, or an area radio network to provide communications between a Traffic Management Center and remote controllers. It should be noted that in some cases wireless communications technologies are used to provide fixed-to-fixed communications (e.g. TMC to VMS signs). In such cases, the architecture recognizes them as wireline communications media.

Wireless

There are two categories of wireless communication systems: Wide-area wireless (fixed-to-mobile) and short-range communications (fixed-to-mobile and mobile-to-mobile). The traffic reports disseminated over AM or FM radio is an example of one-way, wide-area wireless. A mobile traveler, who requests and receives current traffic information from an Information Service Provider, uses two-way, wide-area communications.

The short-range wireless communications focus on localized information. Applications include toll collection, parking fee collection, roadside safety inspections, credential checks, in-vehicle signing, intersection collision avoidance, and selected Automated Highway System (AHS) communications (e.g., safety checks, access authorization, and system status updates).

A schematic of a modern PGIS architecture is depicted in Figure 2. Such architecture could be considered by the NJDOT and further customized to include the specific functionality for the P&R program.

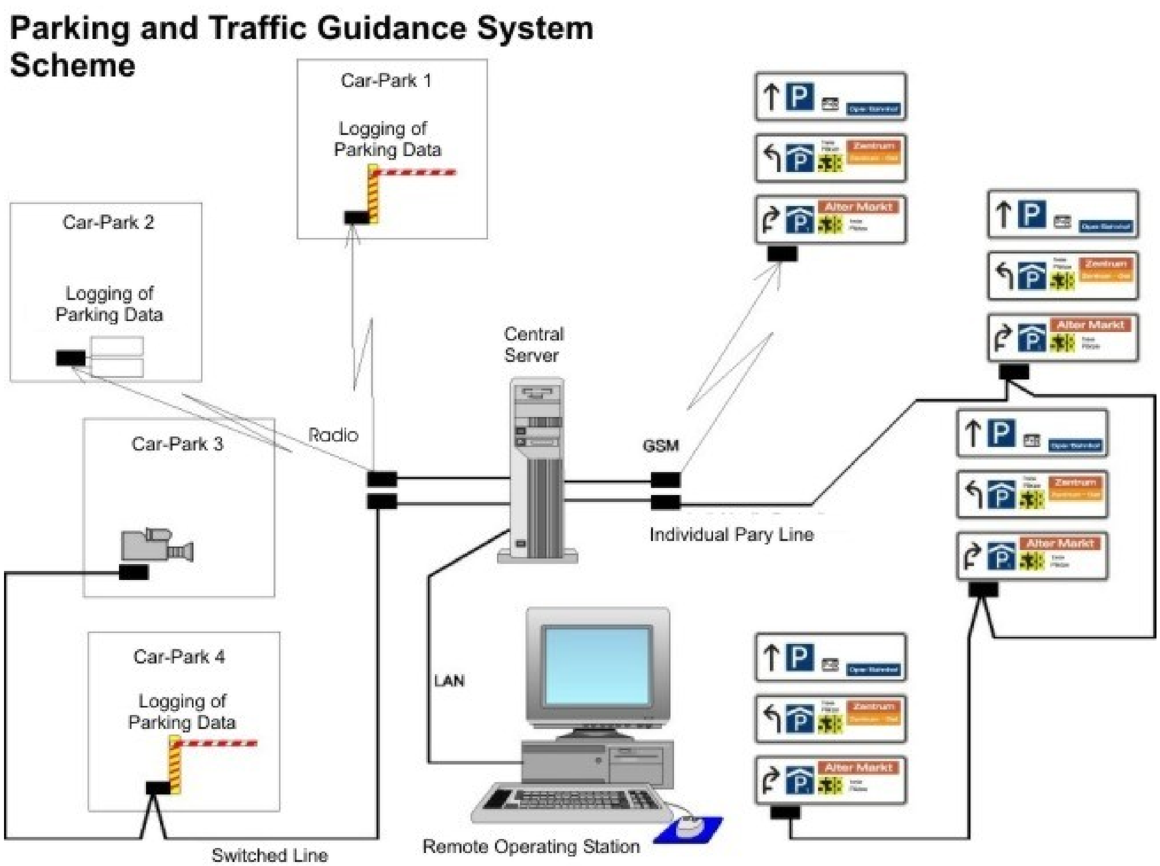


Figure 2. Schematic of a Parking Guidance System (source: Signalbau Huber Parking Management Control Centre - http://www.mtech-ag.de/englisch/main-e.htm)

Proposed Procedure for the Evaluation of the Location of PGIS Signs

In this section, a procedure is presented for the evaluation of the location of a PGS system using a transportation-planning model based on dynamic traffic assignment. The main function of a PGIS sign is to provide guidance and parking information from its location to one or more parking lots downstream. The principal feature that dictates its location is the path to each parking lot and the number of travelers destined to a specific set of parking lots. For downtown parking the parking lots are usually correlated with the final destination of the travelers. The P&R program differs significantly since the final destination of the travelers usually is several miles away and is directly related to the available transit service provided at each P&R facility. The analysis for downtown parking PGIS signs requires the use of a shortest path algorithm. For P&R facilities, an intermodal shortest path algorithm is necessary. Such an intermodal shortest path algorithm is embedded into a Dynamic Traffic Assignment (DTA) model the Visual Interactive System for Transport Algorithms (VISTA). VISTA also incorporates a traditional shortest path algorithm. VISTA was implemented as part of a research project by NJDOT to model the I-80 Intelligent Transportation Systems corridor (Chien et.al 2004). The principal characteristics of the intermodal shortest path algorithm are:

- The users specify their Origin, Destination and the desired departure or arrival time. The users also specify if they have to depart or arrive at a certain time.
- The transit schedule is known (e.g. buses and trains).
- The transit and parking fees are known.
- The system requires knowledge of the historical distributions of the travel times, along the links of the network, for each time period of the day. In addition, the value of time is needed to convert the travel time into dollar values. This produces a generalized cost function for each link.
- The VISTA intermodal shortest path algorithm then determines the best path based on the generalized cost - Origin to P&R facility using automobile, and from P&R facility to final destination using either bus or train. The algorithm is flexible enough to allow for the inclusion of walking to/from the transit stations and any additional transfers at various transit stations. Specifically for the P&R program, the algorithm considers only the transit stops and associated schedules that are in the vicinity of each P&R parking lot facility.
- A more comprehensive approach requires the implementation of the corresponding traffic assignment model. In this research, two models were implemented; 1) a static intermodal traffic assignment model and 2) the VISTA-DTA multi-modal/intermodal model in which the intermodal shortest path algorithm is embedded in it. Due to the limitations of this study, only the static model was deployed for the I-80 corridor as a prototype.

The principal functions of a PGIS system could include one or more of the following:

1. Provide guidance to travelers to specific parking lots through directional signs.
2. Provide parking space information.

3. Provide expected queuing time delay, at specific parking lots,

4. Provide transit information related to specific parking lots:

   - Bus and train schedule.

   - Expected bus/train arrival time.

To balance the costs for installing and operating a PGIS and the benefits to the travelers, a mix of dynamic and static messages is recommended. An incremental approach could be followed where dynamic signs are selected to be placed at the locations with the highest competition for parking. They will be most effective reducing congestion. The following Measures of Effectiveness (MOEs) could be used, as a guideline, for the selection of the locations of PGIS signs in an area:

- *Number of vehicle-miles traveled (VMT).* The VMT offer a measure of the total miles traveled, by all vehicles, due to the existence of the PGS at each specific location. The analyst could use this to provide estimates to the decision makers based on no-information and on PGS-based information. The analyst would then be able to evaluate various locations based on this MOE since different locations are expected to produce different estimates.

- *Total vehicle hours (VH).* Similar to the above VMT, the VH includes the travel time for each vehicle. This estimate could be estimated with the use of a dynamic traffic assignment model (DTA) and/or an operational system with an adequate traffic monitoring roadway system so that the path travel time delays could be estimated. The analysis should include: 1) the expected travel time to search for parking – No parking occupancy information available, 2) Expected travel time when a PGIS system is available. The analysis should consider whether a static or dynamic PGIS system is installed. Under the static system, the analysis should include the typical paths that the drivers follow by assuming that they do not have information on the parking occupancy, whereas, under a dynamic-based PGIS parking space occupancy is assumed to be known.

<u>Proposed Procedure</u>

- Estimate the historical parking space occupancy distribution, including arrivals and departures per time period of the day (15-minute recommended or less), for each parking facility of interest.

- Estimate the historical queuing time distribution per time period of the day and day of the week (15-minute recommended or less), for each parking facility of interest.

- Incorporate into the DTA simulator a module that will capture the traffic flow characteristics of vehicles entering and exiting each parking facility. This module will be based on the parking lot service rate, the parking lot arrival rate, the parking lot exit rate and the traffic flow characteristics of the roadway(s) in the vicinity of the entrances and exits of the facility. The new module will keep track of the parking occupancy of the facility without violating the capacity constraint.

- Conduct a market study for travelers destined to the geographical area of interest to estimate the OD matrix and the paths they follow from their origin to their destination. The people who park at the parking facilities are the best candidates for such a market study since they will be the ones that could benefit most from the establishment of a PGS system. Knowledge of the OD matrix and the associated paths will aid in the identification of the strategic locations of the PGS signs. The OD matrix and the path assignment could be embedded into a DTA model providing valuable calibration data.

- Identify all potential candidate PGS locations.

- Calibrate the DTA model based on the historical P&R parking occupancy distributions. Each P&R traveler is modeled as an intermodal trip that has to go through a P&R facility. Estimate the corresponding VMT and VHT for the network OD matrix and the corresponding P&R OD matrix. This is a person-based intermodal DTA model that has the following characteristics:

  - Persons are divided into auto only, transit only or intermodal travelers. Intermodal travelers are divided into those that follow the PGIS or not based on a percentage that is set initially as input by the analyst. The intermodal travelers follow a time-dependent shortest path algorithm that takes into consideration the location, P&R parking occupancy and the transit schedule that serves each P&R facility.

  - Drivers that do not follow the guidance of the PGS and they go to the P&R facility of choice (e.g. their original destination). These travelers have no information on the parking occupancy. The simulator will assign these P&R travelers based on their time-dependent shortest path for their specific OD pair. The dynamic traffic simulator will be allocating free parking spaces on a first come, first served basis. If a parking lot is full, it will then send the vehicle to the next available one closest to its final destination through a shortest path algorithm. The traffic simulator will continue until all vehicles are assigned to the various parking lots.

  - Drivers that follow the messages displayed at the PGSs. The DTA simulator will re-direct these travelers to the P&R facility that has free parking spaces once their vehicle passes through a PGS that displays a set of P&R facilities and the corresponding number of free parking spaces. If the P&R becomes full at the time of arrival then the simulator will send them to the next available P&R facility.

The analysis should consider various PGS and compliance percentage scenarios. A comparative analysis should consider the corresponding VHT and VMT and the number of P&R travelers that are exposed to PGS signs per scenario.

A more detailed and comprehensive approach is to develop an iterative procedure to identify the locations for the PGSs that produce the least VMT and VHT. *It is noted that when the potential number of PGS locations is large, it cannot be solved through an enumeration algorithm.* Such a problem falls under the general category of the network design problem that will require the development of an algorithm that will produce optimal or sub-optimal solutions to this problem. A DTA traffic simulator could be used to evaluate each potential PGIS scenario, subject to the enhancements mentioned earlier.

Recommendations

Establish a statewide PGIS system for parking lots in New Jersey including one specifically designed for P&R facilities. The principal components of such a proposed PGIS system could include:

- A New Jersey inspired architectural design for PGIS static and dynamic signs. This design should take into consideration the advantages and disadvantages of different types of designs in the US and abroad. The innovative roadway signage system deployed in the City of Newark could serve as a model for the static signs. Furthermore, it must serve both as an information sign as well as an advertisement for people to use P&R facilities. For example, it could have a sign indicating "P&R congestion busters" or a message that would make the travelers sensitive to the fact that they contribute to the reduction in congestion and be proud of it.

- A PGIS universal data model that would be based on a navigational GIS system for the roadway, which will incorporate all parking lots including the P&R facilities, PGIS sign locations, and transit schedules.

- A traffic monitoring system at each parking lot facility that would be used to estimate the parking occupancy at each facility in real time.

- A communication system between the parking lot facilities including the traffic monitoring system, the PGIS, the traveler information center, and the travelers.

- A traffic/parking operations and traveler information center that should have two-way communications with TRANSCOM's TRIPS123 traveler information system.

    - A parking occupancy estimation and forecasting algorithm for each parking facility.

    - A parking queuing time estimation and prediction algorithm at each parking lot.

    - A traffic flow estimation and prediction algorithm for the NJ highway system.

    - An off-line and real time optimal path estimation/prediction from each PGS sign to all associated parking lot facilities.

    - A PGIS sign optimal/sub-optimal location evaluation algorithm.

Establish a Simulation-based Dynamic Traffic Assignment (DTA) model for the P&R program of the NJDOT to estimate and predict the traffic conditions, and to evaluate the location of PGS systems. The VISTA software that was implemented on the I-80 corridor for NJDOT could be used, if it is integrated with the P&R program by incorporating all facilities into the model. The VISTA-DTA would be able to produce the paths of all the vehicles from their Origin to their Destination for each time period of the day and produce the corresponding VMT and VH for each case. Specifically, it could be used to emulate the behavior of the travelers and produce the corresponding path travel times of the vehicles from each PGS location to each parking lot destination. *The traffic simulator of VISTA called RouteSim would have to be modified to account for travelers going to a full parking lot, and then continuing the search until they find a free parking space.*

Develop an Iterative Procedure that will estimate the optimal or sub-optimal location of PGS signs for a geographical area. Under this procedure, each potential PGS system location would be evaluated based on the associated cost for implementation (capital, operations and maintenance costs) and the corresponding benefits based on the MOEs (VMT and VHT saved).

PARKING RESERVATION SYSTEMS (PRS)

One of the major causes of congestion and wasted travel time is the search for parking space. More people, especially in business districts, waste a substantial amount of time trying to find a parking space. They often drive around "in circles" until they find a parking space. This causes congestion because it adds more vehicles on the road, at that point in time, and people tend to drive much slower when searching for a spot. Furthermore, the search for parking causes frustration among the drivers and results in the loss of productivity. Methodologies that try to address this problem include the increase in parking capacity and the use of Parking Guidance and Information (PGI) systems, or the Advanced Parking Information Systems (API) [33…42] that are becoming popular in the US, Europe and Japan. PGIs or APIs aid the drivers in identifying the parking lot where they want to park and provide route guidance to the specific parking lot.

A rather new concept in the area of intelligent transportation systems is the development of Parking Reservation Systems (PRS) to aid travelers in securing a parking space either prior to or during their trip [34, 43, 44]. These systems differ from the standard weekly or monthly PRS systems as they are based on real-time operations. The principal characteristics of PRS are the following: The objective may consider either parking revenue maximization or user parking cost minimization or both, which can be formulated as a max-min type of problem. The user arrivals and departures may be considered random based on some underlying distribution that can be identified through studies of user parking behavior. The cost for parking includes the actual monetary value of the parking rate of a specific parking lot and usually a travel time cost to the final destination (e.g. office). Each parking lot has a finite capacity. Implementation of a PRS would require the establishment of parking reservation operations information centers, a communication system between the users and the PRS, real time monitoring of the current parking availability, and estimates of the anticipated demand. The anticipated demand could be estimated based on the number of people who reserved a space and the expected number of non-reserved arrivals during the next few time periods that could be based on historical arrival data. The users would be able to reserve a parking space and receive a response from the PRS through a variety of communication media such as telephone, fax, or the web.

Minderhoud, MM [34] presented the general aspects of dynamic parking reservation systems (DPRS) for city centers including operation, requirements, planning, characteristics, and effects. The system developed aimed at improving parking conditions and environmental qualities in city centers. In such a system, all available parking lots are subject to assignment according to individual parking demands that are dependent on the level of demand in time and space as well as on parking fares. In this paper, a simulation model of such a system was discussed, a key of which is a behavioral travel choice model of the random utility type describing the simultaneous choice of time, parking lot and mode of individual travelers.

The performance of the DPRS system was evaluated at a small town in the Netherlands and was shown with the specially designed simulation model. For the operation of this system, a substantial amount of data is necessary to offer actual and individual parking information to a potential user. Furthermore, since the demand for parking spaces is dynamic, it is important to know the duration, location and time period the travelers want to park in the city center, which is also the data needed by the system to set up an information and reservation for the users. The author concluded that since there was an extensive amount of information to be provided to the individual user, only a visual medium seemed suitable for this task.

In the DPRS system, the parking fee consisted of three parts: a rather high rate during the period a person arrives earlier than the expected arrival time, a normal rate over the expected parking duration time, and a relatively high rate during the period a person leaves later than the expected departure time. The procedure for of making a parking reservation was also explained in the paper: First, the person contacts the system giving personal parking demands; the system then checks the current parking space availability; if there is no capacity problems, the person receives a personal parking rate quote that is followed with a parking space confirmation; the traveler shows the confirmation number to the parking attendant and they receive a parking ticket. Finally, the person pays the parking fee before leaving the parking facility.

Mouskos et.al (2002) developed a universal parking reservation system where the main objective is to minimize the total travel time for all users that want to park in a specific geographical area or at various P&R facilities within the same geographical area. In the former, the parking cost includes the parking lot fee, and the walking cost to the users' destination (office, shopping, and restaurant). In the latter, it comprises of the shortest path cost to the park and ride facility and the associated parking fee. In addition, each traveler is required to specify his or her arrival and departure time period. This forms a binary integer linear programming problem that was solved with an Linear Programming software. It was also shown that the mathematical structure of the problem produces integer (binary) solutions. Furthermore, a stochastic formulation was presented by relaxing the exact arrival and departure time periods to probability distributions. This PRS system is described in detail in the following section.

Deterministic and Stochastic Parking Reservation System[2]

The problem addressed in this section assumes deterministic arrivals and departures, and that there is at least one parking lot with sufficient capacity to accommodate all the vehicles that arrive during one time interval. The time of the parking lot operation is discretized into small time periods. The smaller the time period, the more realistic the problem becomes as it represents the actual pattern of arrivals and departures. This problem falls under the category of the standard transportation assignment problem.

The problem can be formulated as a binary integer linear program.

[2] This model was developed by Drs. Mouskos (CCNY-CUNY), Bernstein (James Madison University) and Tavantzis (NJIT). The project is co-sponsored by the NJDOT, the TIDE center at NJIT, and the University Transportation Research Center for Region II at the City College of New York.

Let:

$$x_{ijk} = \begin{cases} 1 & \text{if } i\text{th car parks in parking lot } j \text{ at period } k \\ 0 & \text{otherwise} \end{cases}$$

$$y_{ijk} = \begin{cases} 1 & \text{if } i\text{th car that is parked in lot } j \text{ leaves at period } k \\ 0 & \text{otherwise} \end{cases}$$

Zj is the capacity of parking lot j,

c_{ijk} is the cost of vehicle i to park in parking lot j at period k,

Where:

$i = 1, \ldots\ldots, I$; I is the total number of cars,

$j = 1, \ldots\ldots, J$; J is the total number of parking lots,

$k = 1, \ldots\ldots, K$; K is the total number of time periods,

Objective Function: The objective function is to minimize the total system wide parking cost.

$$\min \sum_{ijk} c_{ijk} x_{ijk} \qquad (1)$$

Subject to:

Assignment Constraints: each vehicle i is assigned to parking lot j at period k, therefore one of the x_{ijk}*'s* becomes one and the remaining are assigned zero values.

$$\sum_{j} x_{ijk} = 1 \quad \text{for all } i, k \qquad (2)$$

Parking lot Capacity Constraints: the number of vehicles assigned to parking lot j at period k should be less than or equal to the number of available parking spaces in lot j.

For the first time period 1 (k=1) we assume there are no vehicles parked:

$$\sum_{i} x_{ij1} \le z_j \qquad (3)$$

For time period *k*, the number of new vehicles that can be assigned to parking lot *j* must be less or equal to the capacity of the lot minus the number of spaces occupied plus the number of spaces available due to vehicles that have left at period *k*:

$$\sum_i x_{ijk} \leq z_j - \sum_i \sum_{k'=1}^{k-1} x_{ijk'} + \sum_i \sum_{k'=1}^{k} y_{ijk'} \quad (4)$$

$$x_{ijk} = y_{ijl} \quad \text{where } l > k \quad (5)$$

Constraint (5) ensures that a vehicle *i* that is assigned to parking lot *j* at period *k*, is the same as the vehicle *i* that leaves from the same parking lot *j* at a later time period *l* that is pre-specified by vehicle *i*. Because of condition (5) the variables y_i are substituted in (4) and are no longer needed in the formulation.

Assumptions:

- The time period that vehicle *i* arrives and departs is known a priori.
- The parking capacity is fixed and known.
- A vehicle must arrive and depart at different time periods.
- We assume that there is sufficient parking capacity to accommodate all incoming vehicles at any time period. For example, one of the parking lots has sufficient capacity to accommodate all the vehicles at any time period, absorbing all the vehicles that are not assigned to the other parking lots.
- We assume the costs for parking include a fixed monetary value for each parking lot and a fixed travel cost (walking time) from the parking lot to the final destination that is user specific.

The solution characteristics of the above formulation are shown to produce binary (0 or 1) integer values. This mathematical formulation is expected to produce multiple solutions, which are based on the values of the objective function cost coefficients. Since some users are expected to be "penalized" more than others in any of these multiple solutions, it would be advantageous to obtain all the solutions and select the one that is most equitable. One way to achieve this is to select the solution with the least variance with respect to its corresponding mean cost for all the assigned vehicles.

Web-based PRS Developed

Under this research, a prototype web-based interactive parking reservation system has been developed to assist travelers in reserving a parking space, prior to their arrival at their destination through the Internet.

Two mathematical PRS formulations have been implemented that assume deterministic and stochastic arrivals and departures. Both mathematical formulations can be solved with commercially available linear programming solvers, such as CPLEX, which is the one used in this implementation. The present form of the Web-PRS is designed to handle both subscribers and non-subscribers. In this implementation, only the deterministic mathematical formulation has been demonstrated. The ILOG Concert Technology is used to integrate Java-based interfaces and C language based CPLEX solver. The system has a multi-tier structure with configuration information stored in a back-end XML file. The use of an XML configuration file increases the portability of the Web-PRS. The Dijkstra's shortest path algorithm is integrated into the system to search for shortest walking path from assigned parking lot to the user's destination building. The Web-PRS was demonstrated on a reasonably large parking system on the NJIT campus in Newark, NJ.

In the future, the system is expected to be integrated to a Geographic Information System (GIS). *It will* provide the users route planning information to the assigned parking lot, real-time information on the number of free parking spaces at each parking lot, parking costs for each parking lot and other pertinent information. In addition, the system will be designed so that any parking reservation algorithm may be easily implemented given that the corresponding solver can be easily integrated with the web-PRS interface.

Mobile Parking Assistance, Information and Reservation System (MPAIRS)

One of the most popular means for messaging is the use of a cellular phone. This is more prominent in Europe and Japan rather than in the United States, where users exchange SMS messages very frequently. It is, at the same time, one of the least expensive ways of sending pertinent traveler information to cell phone users since a substantial number of the population now have a cell phone. Although the information that can be sent is rather limited, it is still sufficient for a substantial number of applications, including parking information and reservation.

Under the MPAIRS system, a traveler has the capability of: 1) receiving parking free space information - the user specifies the parking lots of interest and sends the information to the server through an SMS message or e-mail, and 2) reserving a parking space using a Java enabled cellular phone - the user sends a request to the server by specifying the expected time period of arrival and departure, as well as their name. The MPAIRS is expected to be connected to a parking space monitoring system, at each parking lot, through a communication system that could be either wired or wireless.

MPAIRS allows two types of users, subscribers and non-subscribers:

Subscribers into the MPAIR system have their own personal profile. The profile consists of the credentials (name), parking preferences such as expected arrival and departure time per day, preferred parking lot, and the associated travel costs to each parking lot. If the subscriber travels to the same destination and time period of the day, then the system will return the reservation based on the user's profile. In other instances, the new destination and characteristics must be input at the time of the request.

Non-subscribers are required to enter the specific personal and parking related information.

The MPAIRS was implemented as a prototype for the NJIT parking lots utilizing historical data. The MPAIRS is discussed in more detail in Appendix E.

The proof that this mathematical problem produces integer solutions is presented in Appendix C. Appendix C also provides the corresponding formulation for stochastic arrivals and departures. In addition, Appendix D presents the Web-based PRS system developed in this study. Furthermore, Appendix E presents the cellular phone based PRS system MPAIRS.

Conclusions and Recommendations

The advancements in telecommunications and intelligent transportation systems have fostered the development of parking guidance and information systems in various countries around the world. In this study, an innovative solution to alleviate the time needed to search for parking is presented. A deterministic dynamic parking reservation system is formulated as an assignment binary integer linear program. Similarly a stochastic mathematical formulation is presented based on the arrival and departure distributions of each vehicle. It was shown that the constraint matrix is totally unimodular and the corresponding solution is binary. It is expected that based on the combination of the cost coefficients, a number of multiple solutions will be generated. Reasonably large problems have been solved using the CPLEX software providing confidence those problems can be solved in real-time.

Associated with the mathematical models developed for PRS, two implementation prototypes were also developed, a web-based PRS and a cellular phone based PRS, the MPAIRS. The web-PRS allows travelers to reserve a parking space at a parking lot through the web while the MPAIRS allows travelers to obtain information on parking space availability and/or make a parking reservation through cell phone commands.

A parking reservation system could be implemented for park and ride facilities by considering the travel time (cost) of each traveler from his/her origin (e.g. house) to the facilities that serve the bus or train routes that serve user destination (e.g. office). For this problem the following models could be employed:

First Model - First Come, First Served (segmented intermodal):

The cost of each traveler is a generalized cost of the shortest path from the user's origin to the P&R facilities that are served by buses and trains leading to his/her destination plus the parking cost only. A traveler is given information on the shortest path to a P&R facility and potentially two or more facilities and the user selects the one desired and reserves a parking space. The shortest path algorithm could be customized so that each traveler considers his or her own generalized cost function.

Second Model – First Come, First Served (integrated intermodal):

The cost of each traveler is a generalized intermodal cost from a user's origin to his/her final destination subject to the condition that the user parks at a P&R facility. This cost includes the travel time (cost) from the origin to the P&R facility, the parking cost, the transit cost and the transit travel time (cost) from the P&R facility to the final destination. This model has not been implemented for this study; however, it could be implemented through a modification of the intermodal shortest path algorithm that is embedded into the VISTA software. The model should take into consideration the parking lot capacity constraints and the corresponding discretization of time. This is the first model that we recommend for implementation since it takes into consideration both the P&R facility locations, transit schedules, and the corresponding parking and transit fees. The user has a more comprehensive approach in evaluating their OD path cost. In addition, a First Come, First Served parking reservation is more commonly accepted rather than the one presented in the preceding sections.

Third Model – System Wide Parking Reservation:

This is the same as the first model regarding the estimation of the generalized cost. However, now all travelers are assigned based on a system wide minimization of the generalized cost. This model can be solved by the models described in the preceding sections. A variation of this system could be a hybrid between the first model (FCFS) and the third model. Under such a system, the parking operator may impose higher parking fees for the FCFS users and less for all others. Furthermore, a more universal system could be produced that takes into consideration random arrivals at each P&R facility. The latter users may also be assigned a higher or lower fee based on the parking operator's parking policy for the corresponding time period of the day.

Fourth Model:

The fourth model is a more comprehensive model that incorporates the second model within the framework of a DTA. This model will take into consideration the travel choices of all travelers and all modes. It provides a more representative computation of the travel times of the vehicles, from their origin, to the P&R facilities and the corresponding travel time of the buses or trains to their final destination. The VISTA-DTA model implemented for the NJDOT on the I-80 corridor could be used to produce such a model as an off-line tool, without taking into consideration real-time traffic conditions.

Fifth Model:

This is a more comprehensive model integrating the third enhanced DTA model and real-time traffic conditions. Such a model will be feasible only if a comprehensive traffic surveillance system is installed on the NJDOT highway network. As a first step, TRANSCOM's traveler information system (TRIPS 123 – www.xcm.org) could be employed to produce a limited estimation of real-time traffic conditions for the part of the network that is covered by various types of detectors (e.g. TRANSMIT type, Inductive Loop Detectors, Microwave Radar Detectors, Video Image Processing Detectors etc.). The ultimate model would be able to produce in real-time the assignment of each P&R traveler from their origin to the destination, including the P&R facility where the user must park the vehicle, taking into consideration the existing and projected traffic conditions. The assignment of the users under this ultimate model could either be on a FCFS basis, minimizing some global cost or a hybrid model.

Implementation of the above mentioned models could be best accomplished through the New Jersey Transit's (NJT) traveler information web site, which will have to be enhanced to accommodate this added functionality. As such, it could also be available through the TRIPS 123 web site since NJT's web site is already linked to it. However, any implementation would require substantial funding for implementation. The NJDOT could undertake such leadership in cooperation with NJ Transit for implementing such a parking reservation program.

PARKING PLANNING MODELS

Parking planning models are an integral part of transportation planning models, as they are major trip generators. In a typical setting the vehicles arrive in P&R facilities during the morning peak period and they depart in the evening peak period. They can be distinguished in three major categories: 1) Parking lots that attract auto users where they walk to their final destination, 2) Parking lots that attract intermodal users (e.g. auto plus bus/train, bus plus train, auto plus auto (carpooling), bicycle plus bus/train, etc.) and 3) parking lots that attract both intermodal users and auto users. The last two cases fall under the category of P&R facilities. P&R facilities may attract the following type of travelers:

- P&R automobile single-occupancy users that park at the facility.
- P&R automobile two or more multiple occupancy users that park at the facility.
- P&R bicycle users that park at the facility.
- P&R bicycle users that take the bicycle with them in the transit vehicle (bus or train). These users do not affect the capacity of the P&R facility but they affect the transit vehicle capacity.
- P&R carpoolers where one or more drivers park at the facility and use a common automobile to go to their destination.
- P&R kiss and ride type of users. These users do not affect the capacity of the P&R facility but they affect the transit vehicle capacity.
- P&R walk and ride type of users. These users do not affect the capacity of the P&R facility but they affect the transit vehicle capacity.

Therefore, transportation planning models should be able to capture these types of route choices that users make, and consequently, predicting the demand distribution on the transportation network more accurately and providing a tool that can further evaluate the impact of the various types of parking lots on the transportation network. The establishment of an intermodal transport planning model that will be able to evaluate various infrastructure and operational improvements is essential given the increases in population that makes the sustainability of the auto-based transport system unsustainable. Such a model will aid the decision makers in the provision of an equitable and balanced transport system based on pedestrians, bicyclists, transit users, auto users, truck fleets, and intermodal users.

A comprehensive P&R-specific multi-modal/intermodal transportation-planning model should capture individual trips rather than the vehicle trips in order to be more comprehensive. Such a model would be able to:

- Predict the impact of a new parking lot or the removal of a parking lot based on the network flows and the modal distribution.

- Predict the impact of an increase/decrease in capacity of an existing parking lot based on the network flows and the modal distribution.

- Evaluate the impact of designing new bicycle facilities (to/from the parking lot(s)) on the modal distribution of traffic and the impact on the network flows.

- Evaluate the impact of new bus/train routes on the modal distribution and network flows in combination with existing or potential parking facilities.

- Evaluate the impact of traveler information such as traffic flow conditions, transit schedule information on traveler behavior.

In this study the following models have been developed:

- **A parking equilibrium mathematical formulation** that produces the parking supply price, the demand price for a group of users and the flows from each user group to each parking lot operating within the same geographical area (e.g. Central Business District, theater area, other),

- **A static intermodal planning model** for park and ride facilities that produces the modal distribution of traffic and the corresponding traffic assignment of each mode (bus or auto to the links of the network). In addition, the static intermodal planning model has been integrated within a general framework software called the Visual System for Transport Algorithms (VISTA) for the I-80 corridor in New Jersey (from I-287 to George Washington Bridge). Although the VISTA system already includes a person intermodal-planning dynamic model, it was not implemented in this study.

A summary of the models developed is presented in the next three sections.

Parking Equilibrium Problem

The parking equilibrium problem is the game played in a geographical area (e.g. the Central Business District (CBD)) between the parking facilities owners and the users who want to visit this area to conduct their personal and/or business functions. The parking facility owners place a price for parking (supply price) and the users set the price they are willing to pay (demand price). After a certain period of trade offs, usually the system reaches equilibrium, where the supply price for each parking facility equals the demand price of the user groups that have agreed to accept this price. The user groups, whose demand prices are lower than the supply prices, may elect not to park in this area. They would either use another parking facility further away from the designated geographical area; park on the street; visit the area through another transportation means (e.g. ride share, transit, bicycle, etc.), or avoid the area and go somewhere else to conduct their business and personal functions.

In reference to the P&R facilities, the main competition is expected to come from the private and state owned facilities using the associated parking prices that each will set. It is noted that NJDOT does not charge any parking fees for the majority of its facilities whereas private parking lots exist in the vicinity of train stations. In contrast, the NJ Transit charges parking fees at most of its P&R facilities, especially those that serve train stations. One could model such parking lot facilities with zero parking fees by placing a very small parking fee value and use the models that are described next.

This problem falls within the category of spatial price equilibrium mathematical formulation that is well addressed in [Nagurney, 1993]. In general, the problem involves a set of suppliers (parking lot owners) where each has its own supply price function, a set of users (parking lot customer groups) that are characterized by their specific demand price function, and the transaction (transportation, parking payment, vehicle arrival and departure to/from the parking lot) cost functions from each supply (parking lot) to each potential user group destination (office, restaurant, theater, retail shop, public building, etc.). Spatial price equilibrium problems are usually formulated as variational inequalities (VI).

The solution algorithms are usually problem specific and dictated by the size of the problem, as well as, the functional form of the supply, demand, and transportation cost functions (e.g. linear or nonlinear). In the parking equilibrium VI formulation, we assumed that the demand and supply price functions are linear. The feasible region is defined, naturally, by the positiveness of the variables (flow of users from each demand group to each of the candidate parking lots). The unique characteristics of this problem prompted the use of the barrier method to find feasible solutions. The barrier method provided a more transparent way of deploying a numerical method by providing at the same time, an analytical justification for its use. Although it has been applied to other nonlinear constrained problems, this is the first implementation to solve VI problems.

This chapter is presented as follows: First, the parking spatial price equilibrium problem is presented. Second, a background on the VI mathematical formulations for spatial price equilibrium problems is provided. Third, the implementation of the barrier function to solve the VI parking spatial price equilibrium problem, which is demonstrated on two case studies, is presented. Fourth, the main solution algorithms implemented to solve this problem are presented. Lastly, the main conclusions and future work are presented.

Parking Equilibrium Problem Definition

Assume that a geographical area has a set of m parking facilities (supply), n user groups that desire to visit this area, the parking facility price functions, the user group price functions and the transaction cost functions. The problem is to find the supply (number of parking spaces) for each parking facility, the demand (number of people who park at each parking facility) for each user group, the flow from each user group to each parking facility and the associated parking facility prices, user group prices, and transaction cost prices given that the system operates in equilibrium.

Parking Facility Price Functions

The parking facility price is a function of the number of parking spaces available at each facility, the number of spaces at other competing facilities, some fixed cost, a_0, that captures the operating, maintenance cost capital cost, and the time period of the day. The operating cost includes the human resources necessary to operate the facility such as parking guards, energy costs (lighting, heating, other) and any associated parking guidance or information system (PGS/PIS). The maintenance costs include: pavement maintenance (repaving, line striping, cleaning, etc.), structures (painting, resurfacing, other), the typical maintenance of the various fixtures (lights, bicycle stools, signs, parking gates, detectors (e.g. loop detectors), and the PGS/PIS). The capital cost includes the cost to build the facility, and the added elements such as entrance/exit gate(s), detectors, cost to install a parking guidance system, cost to implement a parking information system, other.

In this implementation, it is assumed that the parking lot price functions are linear and there is an influence to this price from other competing parking lots. The functional form of the parking lot price functions should be determined based on market studies for the specific area of interest. The functional form chosen for the parking lot price functions is,

$$\pi_i(s) = a_1 s_1 + a_2 s_2 + a_3 s_3 + ...a_i s_i ..... + a_m s_m + a_0, \text{ for } i = 1, 2, 3, ..., m$$

$\pi_i(s)$: The parking space supply price function for parking lot *i* as a function of the parking space supply of each competing parking lot,

a_o: The fixed term, a_0, represents the operating, maintenance and other fixed cost of each parking lot,

a_i: This coefficient represents the impact on the supply price of parking lot *m* of the number of parking spaces available at each parking lot,

s_i: The parking space supply variable for parking lot *i.*

For the parking space supply-price of parking lot *i*, the coefficient a_i is higher than all the other coefficients that correspond to the contribution of the number of parking spaces available from the other competing parking lots.

It is also noted that the contribution of each parking lot's parking space supply to the other parking lots parking space supply price is different. For example this interaction for parking lots *i* and *j* is asymmetric:

$$\frac{\partial \pi_i(s)}{\partial s_j} \neq \frac{\partial \pi_j(s)}{\partial s_i}, \text{ (asymmetric interaction)}$$

We note here that this asymmetric interaction is also assumed for the user group demand price function as well as the associated transaction cost functions.

User Group Demand Price Functions

Users are grouped together based on similar socio-economic characteristics that are represented in the functional form of each demand price function. The user group demand price functions are assumed to have a linear form that is a function of the various user groups that compete for parking in the same geographical area. The negative signs in the demand price function coefficients indicate that the higher the demand, the lower the demand price. The user group demand price functions in this implementation are assumed to have the following functional form:

$$\rho_j(d) = -b_1 d_1 - b_2 d_2 - b_3 d_3 - ..... - b_j d_j ..... - b_n d_n + b_0 .$$

$\rho_j(d)$: The demand price function for group *j* as a function of each user group's demand.

b_o: The fixed term, b_0, represents the maximum price that each user group is willing to pay for parking.

b_j: This coefficient represents the impact on the demand price of each user group.

d_j: The demand for user group *j.*

Transaction Cost Functions

The transaction cost functions for the parking problem may include the travel time (walking) from the parking lot to the user group's destination plus the parking lot cost, which is represented by the fixed term in the equation. The walking travel time usually is converted into cost based on the value of time. It may include other factors such as safety (the path from one destination to a parking lot may be classified as safe or non-safe and this can be captured into the corresponding transaction cost function). The coefficients are positive implying that the higher the number of users, the higher the corresponding transaction costs would be. This is usually attributed to the time required to park the car (e.g. arriving at the parking lot and trying to park, or if valet parking is used, the time required to leave the keys with the attendant that may cause some delay depending on the number of people waiting on line), and the time required to pay for parking (leaving the parking lot). It is also noted that these functions are assumed linear, however, in real situations they are expected to be nonlinear. The corresponding transaction functions are:

$$c_{ij}(Q) = e_{i1}Q_{i1} + e_{i2}Q_{i2} + e_{i3}Q_{i3} + ... + e_{in}Q_{in} + e_{i0}, \quad i = 1, 2, 3, ...,m$$

$c_{ij}(Q)$: The transaction cost to park at parking lot *i* and go to destination *j* as a function of the flow to each potential destination from parking lot *i*. For park and ride facilities this cost represents the travel time to go from the user's origin (e.g. house) to the park and ride facility.

Q_{ij} : The number of people that park at parking lot *i* and go to destination *j*. Here the destination *j* is synonymous to a user demand group. Therefore, two different demand groups may have the same physical destination but the demand subscript would be different.

e_{i0} : The fixed cost e_{i0} represents the walking time (for park and ride facilities it represents the travel cost from the users' origin to a specific park and ride facility) from parking lot *i* to the user's destination plus the fixed parking cost at parking lot *i.*

e_{ij} : The coefficient, e_{ij}, represents the "congestion" cost at the time of arrival and departure from the parking lot.

This implies that the price for parking at parking lot *j* is also now a function of the time period. The users can now be distributed at different time periods based on the corresponding demand price and transaction cost functions that are now based on the time period of the day. The corresponding demand price functions are:

$$\rho_{jk}(d) = -b_{11}d_{11} - b_{12}d_{12} ... - b_{1k}d_{1k} ... - b_{j1}d_{j1} ... - b_{jk}d_{jk} ... - b_{n1}d_{n1} ... - b_{nk}d_{jk} + b_0 .$$

Similarly, the transaction cost functions are based on the time period of the day and are given by:

$$c_{ijk}(Q) = e_{i11}Q_{i11} + e_{i22}Q_{i22} ... + e_{i2k}Q_{i2k} ... + e_{in1}Q_{in1} ... + e_{ink}Q_{ink} + e_{i0} .$$

The solution to this problem is the equilibrium parking supply and demand price for each parking lot and each user demand group, for each time period of the day, respectively. This also results in the corresponding flows for each user demand group to each parking lot, the transportation (transaction) costs, and the parking supply for each parking facility.

The formulation to the above problem is presented in Appendix F.

Conclusions and Recommendations

The parking space pricing between parking facility owners and travelers has been formulated as a spatial price equilibrium variational inequality problem. The parking facility owners and the travelers that desire to park at a specific geographic area reach an equilibrium that is based on the functional form of the respective parking supply price and the user group demand price. No attempt was made in this study to identify the form of the supply and demand price functions. The supply, demand, and transaction costs are defined as functions of the corresponding supply parking spaces of all the competing parking facilities, user demand groups, and link flows, respectively.

The contribution of the corresponding parking supply at each parking lot, number of users in each demand group, and the link flows to each other's parking supply price, user group demand price, and link flows are assumed to be asymmetric. Therefore, the corresponding VI mathematical problem for the parking spatial price equilibrium falls into the asymmetric category. The necessary conditions to produce a unique solution are shown.

An algorithm has been developed based on the barrier method that forces the solution to stay in the feasible region, which is the first implementation of this method to solve VI problems. A controlled N-R algorithm was implemented that forces the classical N-R sequence to stay within the boundaries of the feasible region. Two variations of the controlled N-R procedure were used. The first introduced a factor *beta* on the step size reducing it by a fraction. It was determined that a rather small value of *beta* is necessary (e.g. .0001) to force the N-R to stay in the feasible region. The other alternative forced the sequence to remain in the feasible region by returning to a point that is a feasible. This latter controlled N-R method performed very well for all tests conducted. It is recommended that the analyst allow a sufficient number of iterations so that, at each step, the feasible region is not violated.

For 10 dimensional problems, the controlled algorithm needed approximately 10-20 seconds of MATLAB CPU time to be executed. Comparatively, it needed about 120 to 200 seconds of CPU time to execute 50 dimensional problems.

The solution algorithm will be tested on large systems with many parking lots and customer groups. Furthermore, the algorithm developed will be compared to the diagonalization (relaxation) algorithm for large problems using the steepest descent method, as well as, other approaches. Generalize the problem where the supply price, demand price, and transaction cost functions are nonlinear. The parking lot supply price functions, the user group demand functions and the travel cost functions should be defined through market research analysis.

Intermodal Transportation Planning Model

This section presents a static intermodal-planning model that was developed for the New Jersey I80 transportation corridor and incorporated a set of the P&R facilities that are in the vicinity of the I80 Interstate Highway. This static model was based on the existing transportation-planning model currently used by the North Jersey Transportation Planning Authority (NJTPA) for North Jersey. The principal characteristics of this model are:

- The model considers the following person-trips: auto only, transit only, and intermodal (auto plus transit).

- It is assumed that a static Origin Destination (OD) matrix is known for all persons.

- The model assumes steady state conditions for the analysis period.
- All travelers have full information of the traffic conditions and they use the User Equilibrium (UE) traffic assignment principle to choose their OD paths.
- A set of link travel cost functions is known.
- The intermodal traffic assignment model produces the UE paths for all persons.

The main *deficiencies* of static intermodal planning models are:

- They cannot be used for congested conditions since the monotonicity of the link travel cost function is violated. (A function is monotone if it is either entirely nonincreasing or nondecreasing)
- It cannot model adequately the impact of traffic signal timing.
- It cannot model adequately link interactions.
- The traffic demand is dynamic in nature.

The second model is based on a simulation-based DTA that overcomes some of the deficiencies identified earlier such as:

- The OD matrix is dynamic. It is based on a discretization of the time into small intervals. This discretization is usually based on the traffic flow profile of traffic counts. Its accuracy depends on the availability of traffic counts on the network links, the spatial distribution of the locations of the traffic counts, and the aggregation of the traffic counts. The most frequent aggregation of the traffic counts is 15-minute time intervals. A smaller time interval such as 5 minutes would be much more preferable, as it will give a much better representation of the traffic flow dynamics and lead to a more representative DTA model.
- The traffic is modeled according to a traffic simulator that incorporates the proper geometry and traffic signal timing, which can model both, congested (oversaturated) and uncongested traffic conditions. The traffic simulator could be used at either the microscopic or mesoscopic level. At the microscopic level, it models the actual vehicle dynamics and driver instantaneous decisions, whereas, at the mesoscopic level vehicles follow the macroscopic relationships of the traffic flow theory (flow-speed-density) while each vehicle is monitored and modeled along its chosen OD path. Under microscopic modeling, traffic moves at a sub-second time interval that is user defined. Under the mesoscopic modeling traffic moves every few seconds, although it could be set also at the sub-second time interval.

The principal uses of the intermodal-planning model are:

- Evaluation of infrastructure changes. The intermodal planning model could be used to evaluate:

- Changes in the geometry of the roadways such as adding/deleting one lane, adding or deleting a new roadway/interchange.

- The location of a new P&R facility. The analyst can use the model to examine the impact one or more P&R facilities have on the roadway network, and the impact on the redistribution of the demand into auto-only, transit-only, and intermodal (auto plus transit – P&R users). One of the case studies developed for this research is the evaluation of the location of P&R facilities on the I80 corridor.

- Evaluation of the impact of traveler information to travelers. In this research we present an implementation of the static model in a case study involving the impact of pre-trip information through the use of Variable Message Signs (VMS) on car users' propensity to park at P&R facilities and then use transit to complete the remaining part of their trip.

- Estimation and prediction of traffic flow characteristics through integration of the DTA-based intermodal model with the traffic surveillance system of the underlying transportation network. A specific use of this capability for the P&R users is real-time estimation and prediction of the shortest path for each OD pair.

Literature Search on Travel Behavior Models

Impact of Traveler Information on Traveler Behavior Models

In this section, five models (Models 1 to 5) are reviewed that could be used to predict the impact of pre-trip information on travelers' behavior. The extent to which travel behavior can be affected by the provision of information depends on what information is provided, when and where it is provided, and how it is provided. The higher the position in the travelers' decision making chain at which information is provided, the larger the number of decisions of travel behavior could be influenced. It is well known that traffic forecasting is not as reliable in urban/suburban settings that experience a high variability in traffic flow characteristics, that usually stem from incidents due to accidents, daily construction, weather conditions and special events. The impact of these incidents is not known to all travelers and result in unpredictable traffic conditions. This variability in traffic conditions make pre-trip planning a challenge for many travelers.

Several papers were attempted to formulate this problem. In DeCea, Cabrera and Florian [60] presented several approaches to formulate network equilibrium models with combined modes. In that paper, a combined mode auto-metro is selected to be representative of mode combinations, for analyzing combined mode trips called intermodal trips in network equilibrium models. An intermodal trip is defined as the combined trip of at least two modes of transport such as: auto plus bus, auto plus train, bus plus train, van plus train, other. When such trips occur, there are two main modeling issues that arise:

- First, is the *modeling of the choice of the intermodal mode type*; how is the choice among pure mode trips and intermodal mode trips represented and what behavioral assumptions govern the route choice for intermodal mode trips?

- Second, is the *modeling of the choice of transfer nodes*; how is the transfer node represented and what behavioral assumptions govern the route choice from origins to transfer nodes, and from transfer nodes to destinations.

Depending on the modeling approach selected for the representation of mode, transfer node and route choices, authors have identified three types of models:

- In the first model, the choice of the intermodal mode and the transfer node point is part of the network route choice model only. The main assumption is that the network is subject to congestion effects and that the Wardrop's user optimal principle governs the route choice – *under steady state conditions, for each OD pair all used paths will experience the same travel cost and all unused paths will have a cost that is either equal to or higher than the used paths cost*. Thus, for a specific OD pair, travelers use an intermodal mode path if its generalized path cost equals that of all the other used paths (intermodal or single mode (e.g. auto or transit)). Since it is assumed that the OD matrix is known, this problem is defined as a *fixed demand intermodal network equilibrium model*.

- In the second model the intermodal mode is modeled as a pure mode. Travelers choose between modes according to the mode function and then, once the mode is chosen, they choose routes on distinct sub-networks, corresponding to "pure" and "intermodal" modes. A Logit-based model is assumed which gives a proportion of trips taken by each mode according to the formula:

$$G_w^{k}(U_w) = \exp-(\alpha^k - \beta_1 U_w^{k}) / \sum_{k'} \exp-(\alpha^k \quad \beta_1 U_w^k) \qquad (1)$$

Where:

- Uwk is the user's perception of the generalized cost of traveling between origin and destination by mode k that corresponds to a user optimal route choice of the network;

- {Uw} is the vector of generalized costs for all modes present; and

- αk', β1 are parameters that are calibrated by using mode choice data.

The denominator in (1), contains the sum over all the modes available for an O-D pair *w*, which are indexed *k'*. The models in this paper assume that the intermodal mode alternative is not relevant when the transit (metro) mode is available for travel between O-D pair *w*. The choice of transfer nodes, in this model, is a direct consequence of the paths that are generated during the computation of the bimodal network equilibrium model and the assignment of the resulting car-transit O-D trips matrix to the corresponding combined mode paths. While this model accounts for the different perceptions the travelers make on the pure and intermodal modes in a mode choice model, the transfer node choice of the combined mode trips is modeled as part of the route mechanism. Hence, the different attributes of the transfer facilities may not be considered explicitly and this model has the limitation that the transfer choice is handled by a simplistic behavioral assumption.

- The third model is an extension of the second model that incorporates explicitly, in the demand sub-model, the transfer choice for intermodal mode trips. The number of intermodal mode trips between OD pair *w* by transfer node *t* is determined by introducing an additional Logit model G_2:

$$G_{w,t}^{k}(U_{w}^{c}) = \exp - (\alpha_{t}^{c} - \beta_2 U_{w,t}^{c}) / \sum_{t\sim} \exp - (\alpha_{t\sim}^{c} - \beta_2 U_{w,t\sim}^{c}) \qquad (2)$$

Where:

- $U_{w,t}^{c}$ represents the user's perception of the generalized travel cost for combined mode *c* via transfer node *t*, assuming a user optimal route choice on the car and transit networks;

- $\{U_{w}^{c}\}$ is the vector of generalized travel cost perceptions for the combined mode via all transfer nodes *t*; and

- $\alpha_{t\sim}^{c}, \beta_2$ are parameters that are calibrated on the observed data, in order to adjust the model to observed behavior with respect to the choice process represented by demand model.

In Boile, Spasovic and Bladikas [(61)] a methodological framework for analyzing the effects of various policies on network flow pattern and associated travel costs in intermodal network were presented. The model produces the equilibrium flows over an intermodal network that minimizes user costs, total travel cost of each policy, rail service and parking capacity additions needed to accommodate rail ridership increase.

The approach adopted in this model, formulates the commuters' choice of auto or rail transit within the demand side of the model formulation via a binomial logit model, which splits the total demand between auto and transit. Then, within transit, the choice between pure transit (walk-to-rail) and intermodal (auto-to-rail) trips is treated as a least cost routing problem.

The above-mentioned models assume that all travelers have perfect information on the traffic conditions and they consistently make route choices based on the utility functions mentioned above. However, traffic conditions are rarely known to all travelers due to the dynamic nature of traffic and the presence of incidents whose impact is difficult to estimate and consequently extremely difficult to be estimated by the travelers. In the majority of cases, a percentage of travelers will choose to change their route in real-time where another percentage will stay on the originally planned route.

Given traffic information, the travelers choose their routes based on the relevance of the information provided for their own OD trips, the reliability of the information provided, and the users' personal characteristics and preferences. In reference to the Park and Ride type of drivers, the most important information are: 1) What is the probability of finding a free parking space upon arrival at the P&R facility, 2) What is the expected waiting time for the next bus or train that services his/her final destination, 3) What is the estimate/prediction of the intermodal path travel time for his/her specific OD pair and the associated auto only and transit only estimates.

Japan and the Netherlands have adapted and tested Advanced Traveler Information Systems (ATIS). The results of these studies can be found in Krann(62) and Thompson(63), respectively. These studies have not been reviewed in detail, as the user characteristics and preferences are widely different from those in the US. Their use is, therefore, limited in the methodology used rather that the corresponding outcomes of the studies. Mathematical and computer simulation models have been widely used in route and mode choice behavior due to the limitations in obtaining real life data.

Transportation simulation models have been used to model the travelers' behavior. Several studies such as Adler, Recker and McNally(64) ,Balmforth et.al(65) , Bonsall and Parry(66) , Bonsall, et.al(67) , Chen and Mahmassani(68) , Koutsopoulos et.al(69), Koutsopoulos et.al (70) , Vaughn (71) have shown that transportation simulators could offer very powerful tools in analyzing travelers route choice under traveler information. Computer simulators are used to:

- Simulate real-world decision-making environments, and to record the behavior of human subjects interacting with this simulated environment;
- Aid in calibrating models of the decision-making behavior; and
- Permit simulations of decision-making behavior in a large variety of contexts.

Computer simulation models typically consist of two components (72):

- A dynamic driver simulation model.
- A traffic simulation model.

The driver simulation model captures the drivers' behavioral, preferential and cognition characteristics' effect on their route and mode choice decisions. The capabilities of such models are based on (62):

- The manner in which a real world situation can be simulated.
- The manner by which physical elements of the real world that play an active role in the choice process are represented.

The output from these traveler simulation models forms the input to the traffic simulation models, which are used to estimate the assignment of the travelers on the network based on their specific OD paths. The analysts can then perform statistical analyses to produce the corresponding traffic flow characteristics (traffic flow, travel time) at the link, OD path, sub-network or network level. These models could then be used as emulators of real-time traffic conditions to evaluate the route choices of the travelers under a simulated environment.

As stated earlier, the route choice behavior depends on the information provided, as this affects the cognitive process of the driver. Thus, it is important to understand the informational needs of the traveler, its accumulation and how, why and when s/he implements the information accumulated. The general approach suggests that travel is defined in three stages (see Figure 3): pre-trip planning, en-route assessment and adjustment, and post-trip evaluation. The first two stages involve direct decision making in real-time. The third stage is a longer-term evaluation of past trip-making success creating the link between past performance and future impression that shapes the traveler behavior over time. Studies have shown that the reliability of the information presented is one of the most important factors to affect the compliancy behavior of the driver (71, 72).

Static User Equilibrium Intermodal Model Developed in this Study

In this study, we concentrated on the development of an intermodal-planning model that captures the route choice characteristics of P&R users, as well as auto and transit (bus or train) users. In addition, we further developed a sub-model that takes into consideration the impact of P&R messages displayed on Variable Message Signs (VMS) in choosing a P&R facility. Whereas, there is substantial literature on the impact of pre-trip and en-route information on route choice behavior, there is limited research on models that can represent P&R intermodal types of users.

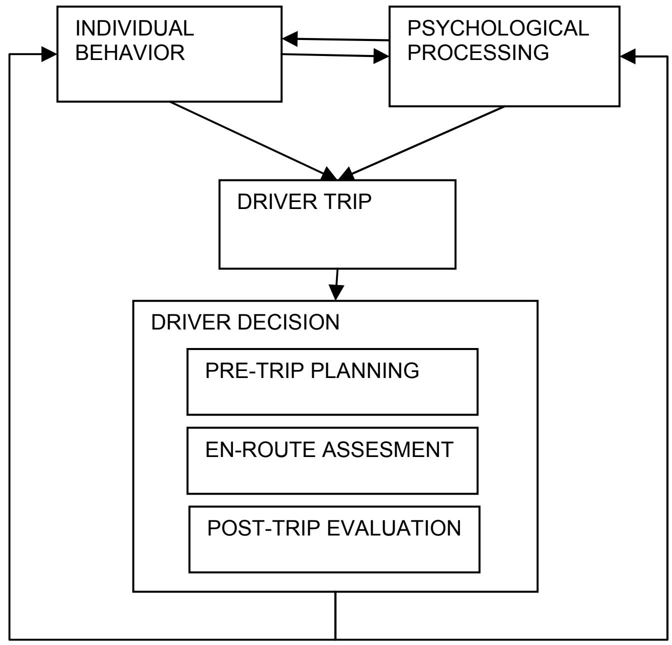


Figure 3. General schema for driver behavior model

First we present the three steps involved in assessing the impact of parking and transit information on mode choice.

Step 1. Determining the Variables that are Relevant to Mode Choice

This step includes the personal data set, and the travel characteristics that influence the driver's mode choice decision. This can be initially compiled through literature review of previous work in this area. The main data that are used to model the travelers' route and mode choice behavior are: Age, Sex, Income group, Occupation, Work schedule, Tolerance to late arrival at work, Preferred arrival time at work, More than one work location?, Use carpool?, Number of cars owned, and Average travel time.

The travel characteristics of the driver that affect route and mode choice are: Trip purpose, Origin and destination, Receive traffic information, Response to recurring congestion, Expected delay on usual routes [62], Travel time on alternate routes [62], Perceived congestion level on alternate routes [62], Information sources [62], and Reliability of information obtained.

Step 2. Data Collection Methodologies used in travelers' route and mode choice models

The main methodologies used to obtain information for route choice models are:

- SP survey.

- RP survey.
- Computer simulation models.

Surveys of stated preference and revealed preference towards congestion and ATIS have a response rate of 40% to 60% in the US.

Step 3. Route and Mode Choice Model Development

Once the data is collected, a model can be developed to represent the real life decision process in choosing mode and route for a specific OD pair. Then, the effect of the variables considered in the model on choice can be analyzed.

A summary of the models presented in the literature of route and mode choice are presented in Appendix G.

Network Development

The network used for the implementation of the intermodal traffic assignment model that was part of this project was an extraction of the I-80 corridor in North New Jersey. The development of the transportation network data model required a substantial effort, because of its size and incompleteness of the data available. The data model development consisted of:

- Road network development.
- Bus Routes.
- P&R facilities.
- Rail Network.
- Demand nodes.
- Intermodal capabilities.

Road Network Development

Data Sources

We have received road network data from three sources: 1) Transportation planning data from the North Jersey Transportation Planning Authority (NJTPA) (green in Figure 4) and from the corresponding software that was developed for the North Jersey transportation planning model; 2) GIS data that was already integrated within the TransCAD software (black in Figure 4); 3) NJDOT GIS data; 4) NJDOT Straight-line diagram data.

Data Model Issues

There are two main issues regarding the road network data:

1. *The level of detail of the topology/geography.* Bus routes cover not only major highways but also local roads. In order to represent the bus service realistically, the bus routes, bus stops and the associated bus schedule had to be included in the network. The geography of the NJTPA data was not detailed enough, so the bus routes had to be inserted into the network that was built in the TransCAD software. From Figure 4, it can be observed that the TransCAD data provide much more detail than the corresponding NJTPA data, which is a highly aggregated network.

2. *The availability of the data for the attributes of the links that is necessary for the analysis.* The main link attributes that are necessary for the static traffic assignment and mode choice are the speed limits and the capacities of the links. The data built in TransCAD did not have any of these link attributes where the NJTPA data as well as the NJDOT straight-line diagrams had those attributes. Since the NJTPA network was too aggregated for this implementation and in some cases containing errors, for new links that had to be added into the network or modified, the corresponding link attributes had to be found and embedded into the new network database.

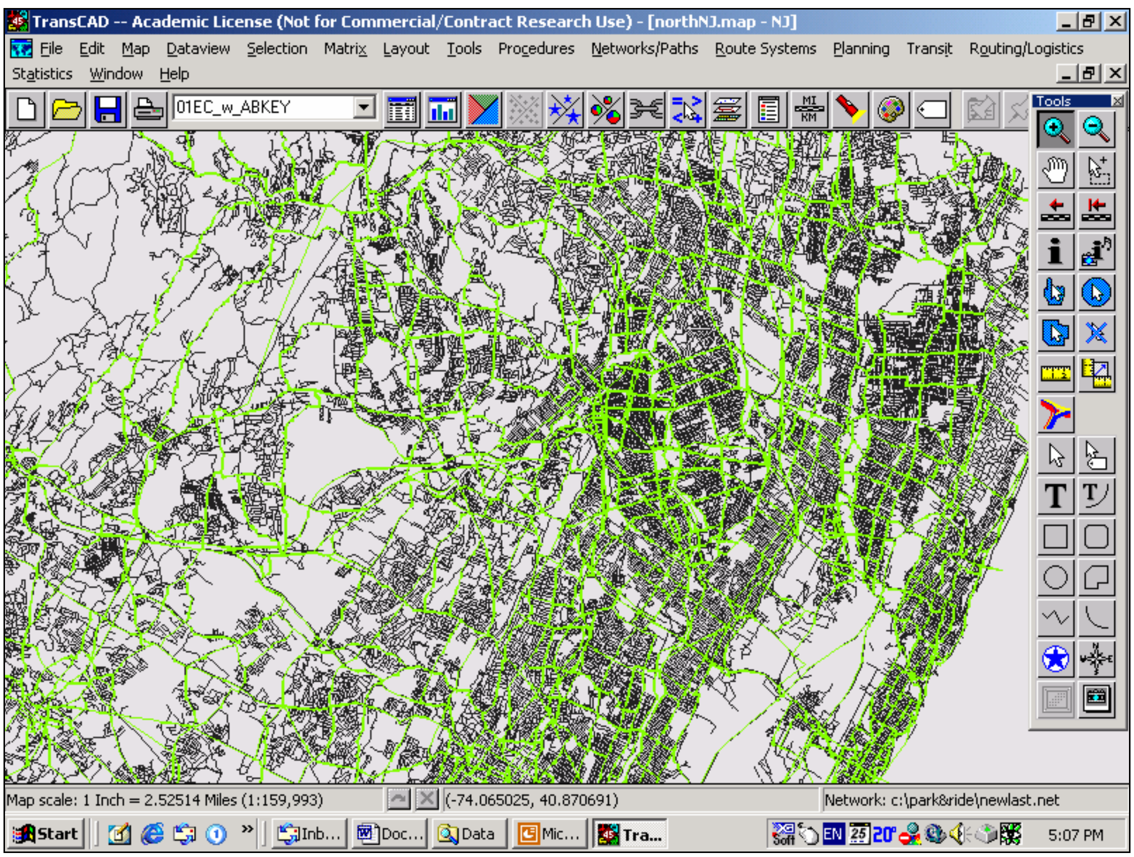


Figure 4. GIS of the Test Network

Data Model Development

Network Connectivity

The level of detail possessed by the TransCAD built-in data was determined to be too detailed for the implementation of a prototype intermodal traffic assignment model. The inclusion of these local streets into the model would have needed the corresponding link and node attributes that were not readily available and would have required substantial data retrieval and integration effort. Furthermore, the computational requirements for such a detailed network would have been tremendous and beyond the scope and funding of this project.

Instead an aggregated TransCAD network data model was developed by creating buffers around major highways and around bus routes (pink color, Figure 5). This approach resulted in an aggregated network (Figure 6 – green lines show the buffers created) that incorporated the bus routes and major highways.

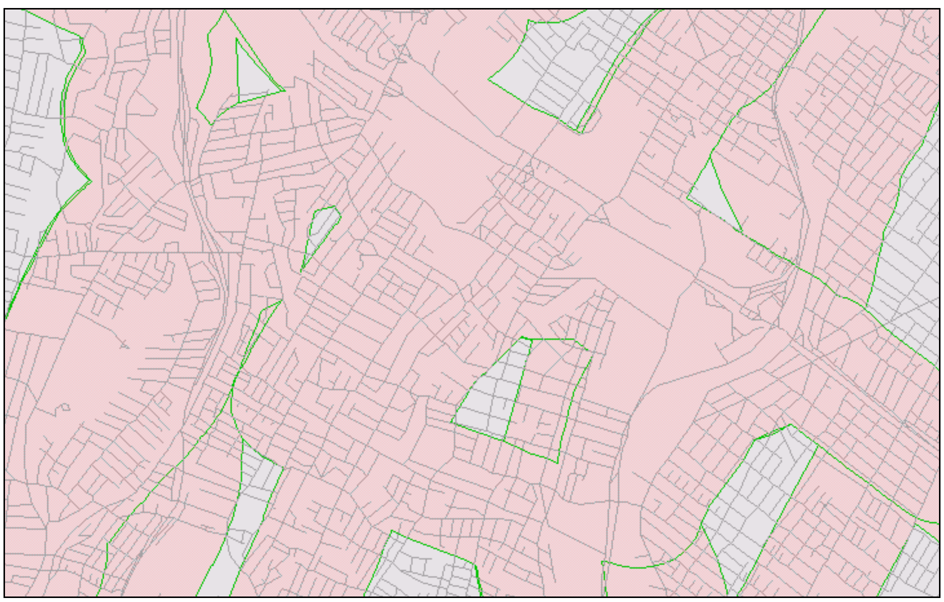


Figure 5. Aggregated TRANSCAD network

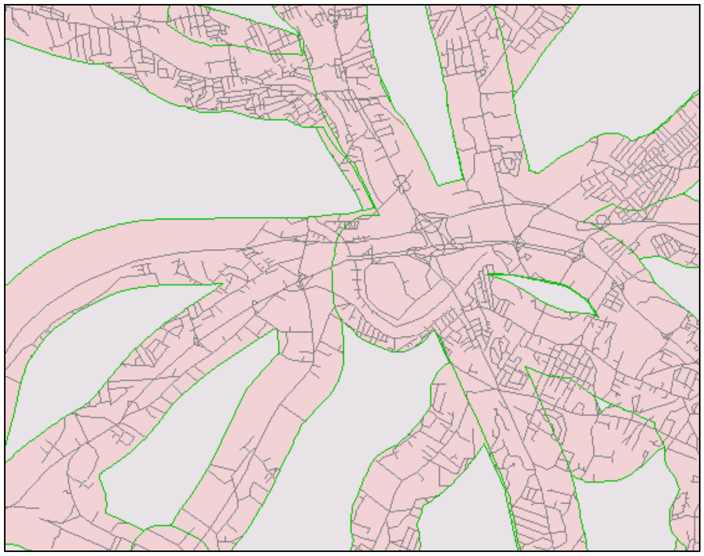


Figure 6. Further-Aggregated TRANSCAD network

This network had to go under some further "cleaning" since it contained parts of local streets. Also, it was important (for operational model) that all exiting ramps are kept in order to allow traffic to go out. The final editing resulted in the network depicted in Figure 7.

Figure 7. Finalized Aggregated Network

Another challenge in building the network data model was network connectivity. The geography of the NJTPA network had many missing links that were affecting the connectivity of the model network, which are necessary for routing applications that are embedded into the traffic assignment model. For example, a big segment of the I80 was missing. This segment was incorporated by using the TransCAD network. Also, some geography was not correct and those links had to be corrected. For example, the ends of two neighboring links were not connected and they had to be joined. As part of this effort, approximately 1200 link segments and their associated attributes were incorporated manually into the original NJTPA network. The link attributes (speed limit and capacity) were retrieved from the NJDOT straight-line diagrams data. Figure 8 depicts the links (red color) that were either added or modified in the link database.

Figure 8. Link segments that were added to achieve network connectivity

Bus Routes

The criteria followed for inclusion of the bus routes into the network were:

1. Bus route services the I80 corridor.
2. Interconnects with Morristown and/or Boonton Rail line.
3. Has at least one P&R facility along its route.

The bus routes were retrieved from the NJ Transit's website (Figure 9). We emphasize here that NJ Transit has bought the GIS database for New Jersey from Navigational Technologies, Inc. that is more up to date for navigational applications. In addition, they incorporated their bus and train routes and associated schedules into their GIS database. The drawing was not to scale that made our task more difficult; therefore, the street names were used to provide the main orientation. Also, the way the TransCAD network database is constructed is not suitable for precisely entering long bus routes. This was primarily due to the fact that the roadway between adjacent intersections is comprised of many segments where each one of them had to be selected and integrated into the new database manually. All together 32 bus routes were entered into the aggregated GIS database for this project (Figure 10).

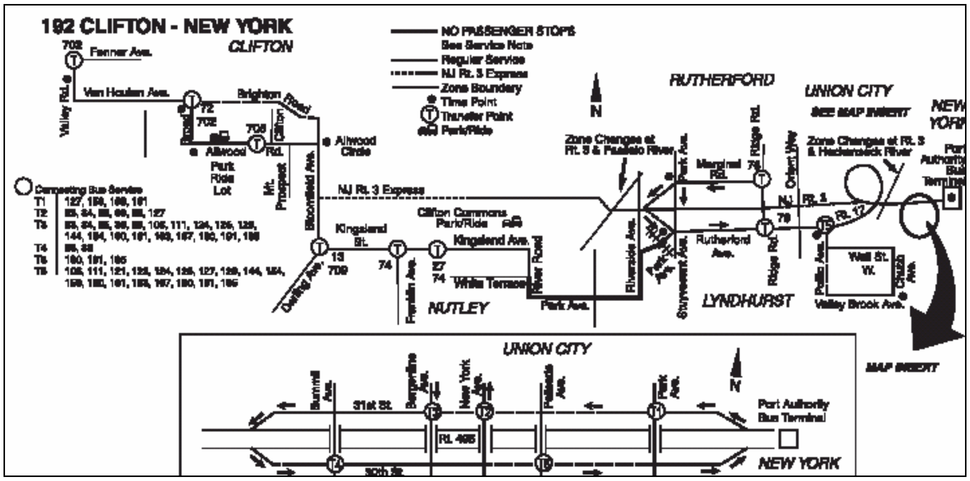


Figure 9. Sample bus route 192 Clifton-New York

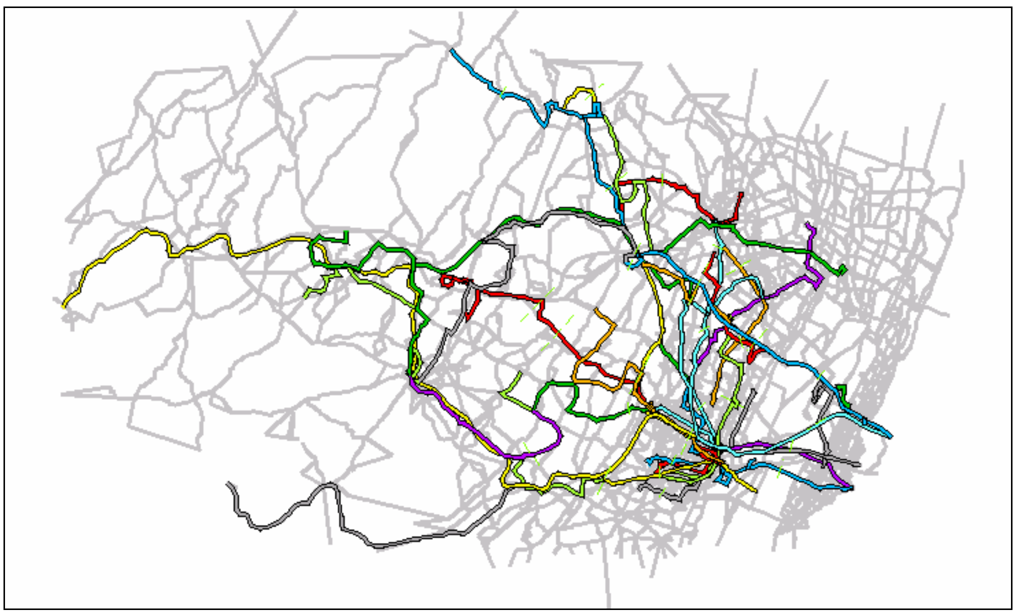


Figure 10. Bus routes included in the network model

The bus stop stations were also retrieved from the NJ Transit's website. We note here that this database is incomplete because the posted bus stations on the bus schedules, as well as the web site, contain only a partial list of the actual bus stops. The locations of the bus stops, along a bus route, were determined by the corresponding street names listed in the web site, and the bus schedules. Landmark locations, not having an exact address, were harder to locate in GIS. The resulting GIS bus stop locations are shown in Figure 11.

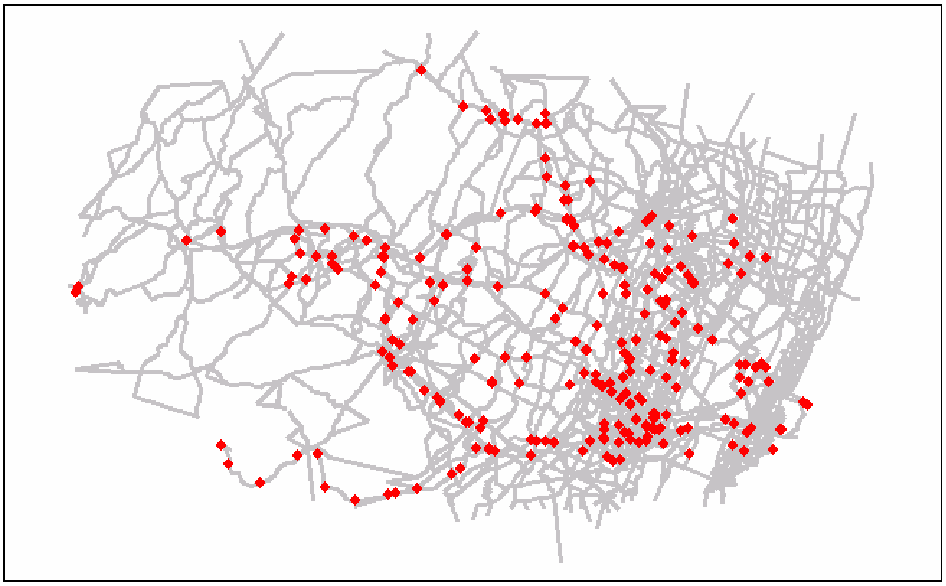


Figure 11. Bus Stops included into the network model

P&R Facilities

The data for P&R locations was received from the NJDOT database. The locations were described by addresses. Some of the addresses were precise enough, so they were geocoded (located by GIS), immediately. However, more than 60% of the P&R facilities could not be located easily requiring substantial manual work.

Atlantic City Service Area	7/25/2000	Garden State Pa	41.4	4 miles north of Atlantic City Expressway. Can also acı
Atlantic City Expressway Intercept	8/1/2000	Atlantic city expr	4	Adjoining Atlantic City Expressway information center
Atlantic City Bus Terminal	8/1/2000	Atlantic City Exp		Ohio and Artic Avenue (station at michigan and atlantic)
Montvale Railroad Station	7/24/2000	N/A		Railroad Ave/Grand Ave
Route 17 Park & Ride	8/16/2000		17.6	Route 17 South
Walnut Place	8/16/2000			Walnut Street & Franklin Ave
Franklin Lakes VFW 5702 Park & I	8/7/2000			Pulis Ave & Franklin Ave
Hillsdale Railroad Station	8/2/2000			Washington Ave
Park Ridge Park & Ride	8/2/2000			Hawthorne & Park Ave
Park Avenue Park & Ride	8/2/2000			Broadway & Park Ave
Harrington Park Park & Ride	8/14/2000			La Roche Ave & Elm St.
Ramsey Railroad Station	7/31/2000			Main Street & Maple Street
Montvale Park & Ride	7/24/2000	Garden State Pa		Located on center median, between GSP North and adjı
Cottage Place	8/16/2000			Cottage Street & Franklin Avenue
River Edge Rail Road Station	8/21/2000			River Edge at Rail Road Station
Oradell Town Green	8/16/2000			Oradell Ave & Maple St.
Emerson Park & Ride Lot	8/14/2000			East Emerson Ave
Oradell Park & Ride	8/16/2000			Oradell Ave & Church St.
Woodcliff Lake Railroad Station	8/2/2000			Broadway Ave
Veldran Avenue Commuter Parking	4/10/2002		0	Municipal Building on Oradell Avenue
Rutherford Railroad Station Park &	8/29/2000			Erie Avenue & Park Ave
Wyckoff Baptist Church Park & Ric	8/7/2000			Russell Ave & Wyckoff Ave

Figure 12. Sample P&R Database

That was the case for the P&R facility marked in Figure 12. It gives the landmark, but not the exact location. In order to find the exact address, we first searched the web, found the exact address and then embedded it manually into the GIS database. Also, there were problems regarding different road street (road) names in the software database and the data provided by the NJDOT. Overall, we had problems with the locations of more than 50 P&R locations that required extra effort for integrating them into the data model.

A total of 81 P&R facilities were located in the study area in North Jersey, which are depicted in Figure 13. We note though, that this is not a complete set of all the P&R facilities in the area.

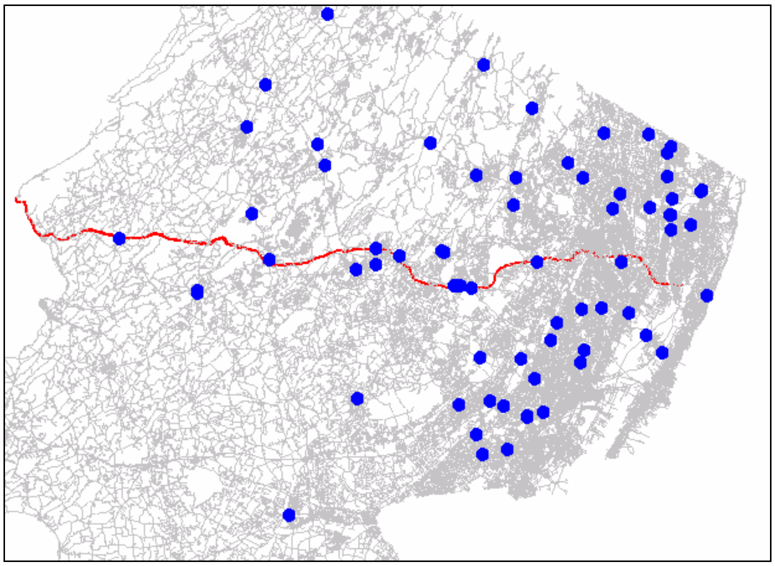


Figure 13. P&R Facilities in North Jersey

Rail Network

The main NJ Transit rail lines operating in North Jersey are presented in Figure 14. They included stations that are on the Boonton and Morristown Rail lines (see Figure 14). The NJ Transit rail lines that were built in the TransCAD GIS database were selected and imported into the new data model. The exact locations of the rail stations were retrieved from the NJ Transit's web site and integrated into the data model utilizing the geocoding capabilities of TransCAD (Figure 15).

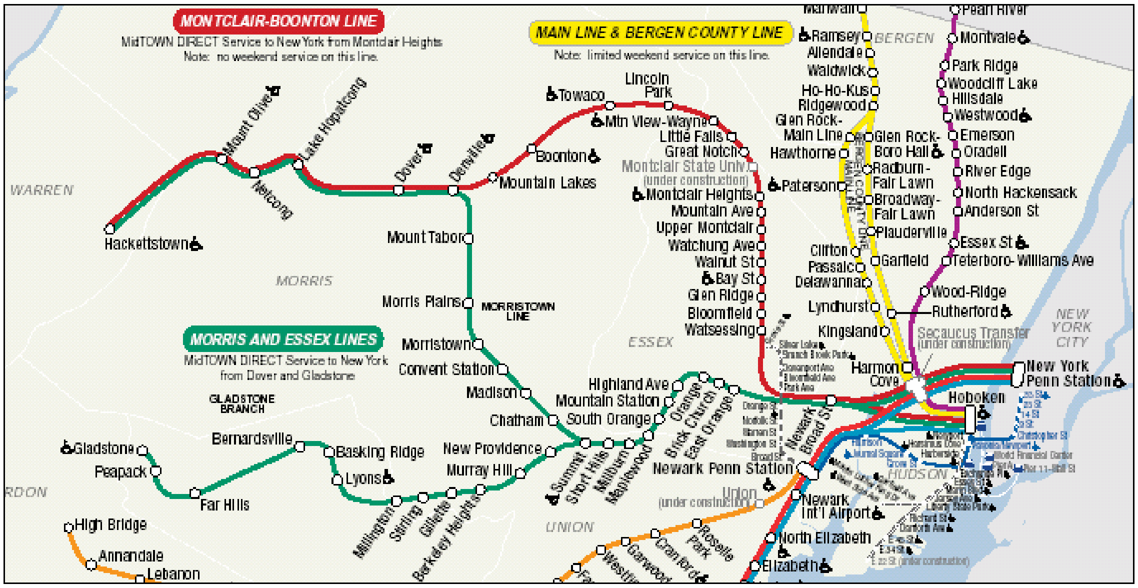


Figure 14. NJ Transit rail lines in North Jersey

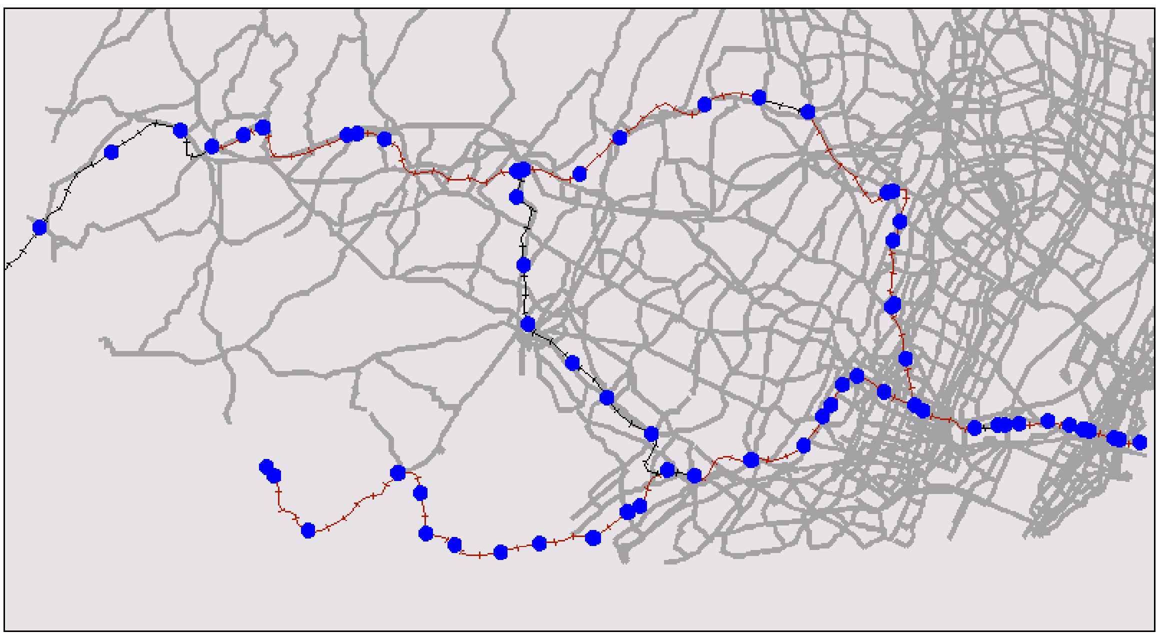


Figure 15. Rail line Stations integrated into the network model

Demand Data

The original NJTPA transportation-planning model was enhanced to include additional demand nodes. These new demand nodes have been created as centroids of census tracts that cover the wider area of the network. Those nodes were then connected to road layer so the demand could be assigned to paths (Figure 16), as needed, by the traffic assignment model.

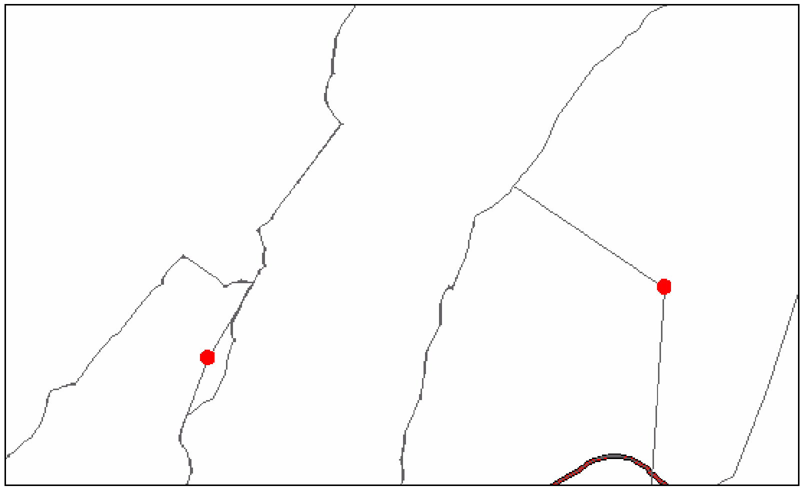


Figure 16. Sample new demand nodes embedded into the network model

The traffic demand that was built in the NJTPA transportation-planning model for North Jersey was used to estimate an OD matrix utilizing TransCAD's *OD Estimation feature* that was based on the User Equilibrium travel behavior principle. The OD estimation procedure utilizes TRANSACD's traffic assignment procedure to match observed historical traffic counts. This procedure resulted in an updated static OD matrix (ODs displayed in Figure 17) that was then used as the basis of the new intermodal traffic assignment model for the network under investigation.

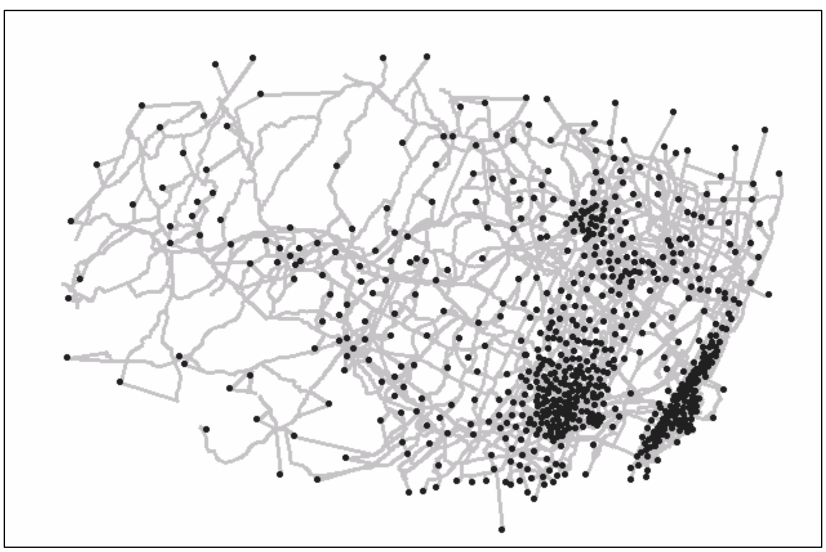


Figure 17. OD nodes in the network model

Intermodal Capabilities

One of the major contributions of this research was the incorporation of the intermodal P&R users (auto plus bus or auto plus train). In order to be able to model these intermodal paths, the P&R feature had to be incorporated into the model. These P&R nodes were connected to the road line layer using the TransCAD option *Connect* and they became a part of the underlying node layer of the road line layer. In order to activate the P&R feature of TransCAD, the P&R facilities were first selected, second the transit network was created, and third the *P&R* option was selected that set them as P&R transit stations.

When the TransCAD *Multiple* S*hortest Paths* feature is used, the software produces the shortest path (including the path travel time) from each user's origin to the P&R facility of interest.

The *Mode Split* module of TransCAD was executed and applied to the OD matrix to estimate the demand for each mode and OD pair. From this output, the corresponding demand for each P&R facility was estimated.

The *Traffic Assignment* module is based on the User Equilibrium principle and produces the OD path for each type of user such as auto only, bus only, walk plus bus/train, auto plus bus/train and walk plus bus plus train.

The analytical model and case studies developed is presented next.

Intermodal Transportation Planning Model Developed and Case Studies

The model developed takes into consideration the intermodal characteristics of the network, and the associated intermodal paths. In order to predict the demand for those paths and P&R facilities, the model had to include drive access to public transit. This is not the only means to access public transit. However, since there are similarities among the alternatives (walk and drive access to the public transit) and because the assumption of independence is violated, the multinomial logit model could not be applied. Alternatives available in our network are indicated in the following chart (Figure 18).

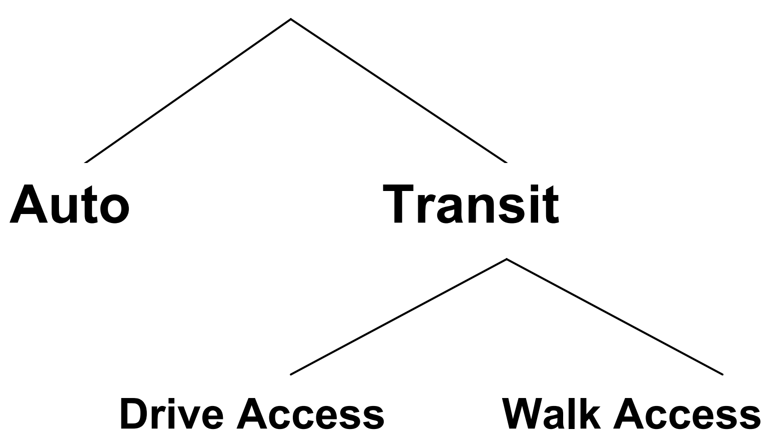


Figure 18. Nested Choice Model (NLM)

The Nested Logit Model (NLM) relaxes the assumption of independence and it is the one implemented in this study. The utilities for different modes in NLM are shown in the following equations.

$$Utility\_of\_Auto = \beta_{\log sum} * \ln(e^{Utility\_of\_Auto}) \quad (1)$$

$$Utility\_of\_Transit = \beta_{\log sum} * \ln(e^{Utility\_of\_Walk\_Access} + e^{Utility\_of\_Drive\_Acces}) \quad (2)$$

$$\beta_{\log sum} = 1 \quad (3)$$

Since in Auto option - there is just one option - the function **ln** does not have any impact, while it has in the Transit option. There was no data for β_{logsum}, so for simplicity, it is assumed to be 1.

The relevant parameters and the coefficients are taken from Model 5 in the literature search, proposed by the Guan and Nishii. The variables and coefficients are shown in Table 5.

Table 5. NLM Parameters – Model 5

Explanatory Variable	**Value**
Alternative peculiar dummy	0.4937
Parking cost subsidies	0.4809
Commuting Time	-0.0406
Cost	-0.0003

Further, those explanatory variables and coefficients for different alternatives were applied to our network. The alternative *peculiar dummy* can be treated as a constant in a utility function, once the alternative is chosen. Parking cost subsidies are calculated as a waived parking cost in that area. For example, if the parking cost for a whole day of parking is $5, then the user of a P&R facility has free parking and the charge is waived. This is reasonable, because in most P&R facilities in NJ, parking is free or waived, if the ticket for public transit is purchased. The Commuting Time for the transit option was calculated as a sum of the Access_Time (Walk or Drive Access) and Travel_time. Travel_time consisted of Transfer_times, Wait_time, In_Vehicle_Time and Egress_time. Transfer Time was not included since realistic data could not be obtained. The Commuting Time in Auto option was calculated as a free flow time from origin to destination. The Cost for the Transit option was calculated as a fare price for the shortest transit path. The Cost in the Auto option was calculated as a parking price at the destination. The following equations represent our model. In the next chapters these values of the coefficients represent the base case of utility functions:

*Utility_of_Transit_Walk_Access =0.4937-0.0406*Travel_Time-0.0003*Cost(Fare)*
*0.0406*Walk_Time* (3)

*Utility_of_Transit_Drive_Access =0.4937-0.0406*Travel_Time-0.0003*Cc* (4) -
*0.0406*Drive_Time+0.4809*Parking_Cost_Subsidies*

*Utility_of_Auto = 0.4937-0.0406*Drive_Time -0.0003* Cost(Parking)*

The marginal probabilities of Auto and Transit were calculated using the logit probability equation from the NLM option, based on the utilities as specified earlier in this section. When these probabilities were applied to the OD matrix, the total demand between each OD pair was estimated for each of the three modes (auto, transit with walk access and transit with drive access).

Sensitivity Analysis

There were several types of pre-trip information that had to be examined. Sensitivity analysis was used and several scenarios developed in order to determine the impact of various types of pre-trip information. The results of all scenarios were then compared to the results of the base scenario that formed the basis to determine which type of information had the biggest impact.

Scenarios 1&2-Testing the Impact of Pre-trip Information on Parking Availability

The impact of Information on parking availability on commuters was represented by increasing parking the corresponding subsidies coefficient in the model. This factor increased the propensity to use P&R facilities due to the reduction of the uncertainty relative to knowledge on the availability of parking.

In Scenario 1 the coefficient was increased by 25% and in Scenario 2 it was increased by 50%. The exact values of coefficients are shown in Table 6.

Table 6. Parking Subsidies Coefficients

	Parking subsidies coefficient		
Scenario 1	0.4809	--->	0.601125
Scenario 2	0.4809	--->	0.721350

Scenarios 3&4-Testing the impact of pre-trip information on highway congestion

This impact was modeled by increasing the coefficients for the corresponding Commuting Time coefficient in the auto and the transit_drive_access utility function, respectively. The information about highway congestion was simulated by giving more negative weight to the auto commuting time, thereby encouraging commuters to use public transit. This could most likely occur if travelers were provided with such information. In Scenario 3 the coefficient's absolute value was increased by 25% and in Scenario 4 it was increased by 50%, respectively. The values of the coefficients in those scenarios are shown in Table 7. The increasing of this coefficient, both for auto travel time from origin to destination and simultaneously the corresponding coefficient for drive_access_to_transit may not be true, since highway congestion stimulates commuters to use public transit. Also, it is true that highway congestion creates problems accessing P&R facilities – if it exists in the network surrounding the P&R facilities. Further, highway congestion may also impact the travel time of the corresponding bus routes that serve the P&R facilities.

In order to test the impact of this kind of pre-trip information, another sub-scenario was created (Scenario 3a and 4a) in which the highway congestion does not have impact on the drive_access alternative. In these scenarios, only the coefficient for auto travel time has been increased.

Table 7. Auto Travel Time Coefficients

	Auto TT coefficient		
Scenario 3 & 3a	-0.0406	--->	-0.05075
Scenario 4 & 4a	-0.0406	--->	-0.06090

Scenarios 5&6-Testing the Impact of Pre-trip Information on Transit Arrivals

Together with parking availability and highway congestion, the uncertainty about transit arrivals makes commuters reluctant to use P&R facilities, and transit in general. If commuters were relieved of that uncertainty, they would have been more prone to use public transit. This was represented in the model by setting the Commuting Time coefficient for transit travel time less negative. This resulted in an increase of the corresponding the transit utility. In Scenario 5, the coefficient for transit travel time was multiplied by 0.75. In Scenario 6, the coefficient for transit travel time was multiplied by 0.50. The coefficients used for these scenarios are listed in Table 8.

In Scenarios 5 and 6 the Transit Share grew to 10.72% and 12.25%, respectively. The associated Transit increase was 15.10% and 31.53%, respectively. The corresponding number of P&R ride users grew 15.52% in Scenario 5 and 32.36% in Scenario 6.

Table 8. IVTT Coefficient

	IVTT coefficient		
Scenario 5	-0.0406	--->	-0.03045
Scenario 6	-0.0406	--->	-0.02030

Results

The main MOEs for the intermodal transportation planning model developed in this study are: P&R share, transit share and the total number of P&R users in the network. These MOEs are obtained by executing the Mode Choice modulus in TransCAD and then analyzing the data. This analysis contains of exporting matrices for each mode into a table and performing a statistics analysis, which gives a summation of the total demand for each mode. When the total number of users for each mode is obtained, the corresponding mode splits can be estimated as well.

This model also provides the number of users for each P&R facility as: joining the two tables from transit skims (origin-parking matrix and origin to origin parking matrix) and aggregating the data per P&R node. This results in the estimation of the total demand (Figure 19) for each P&R facility.

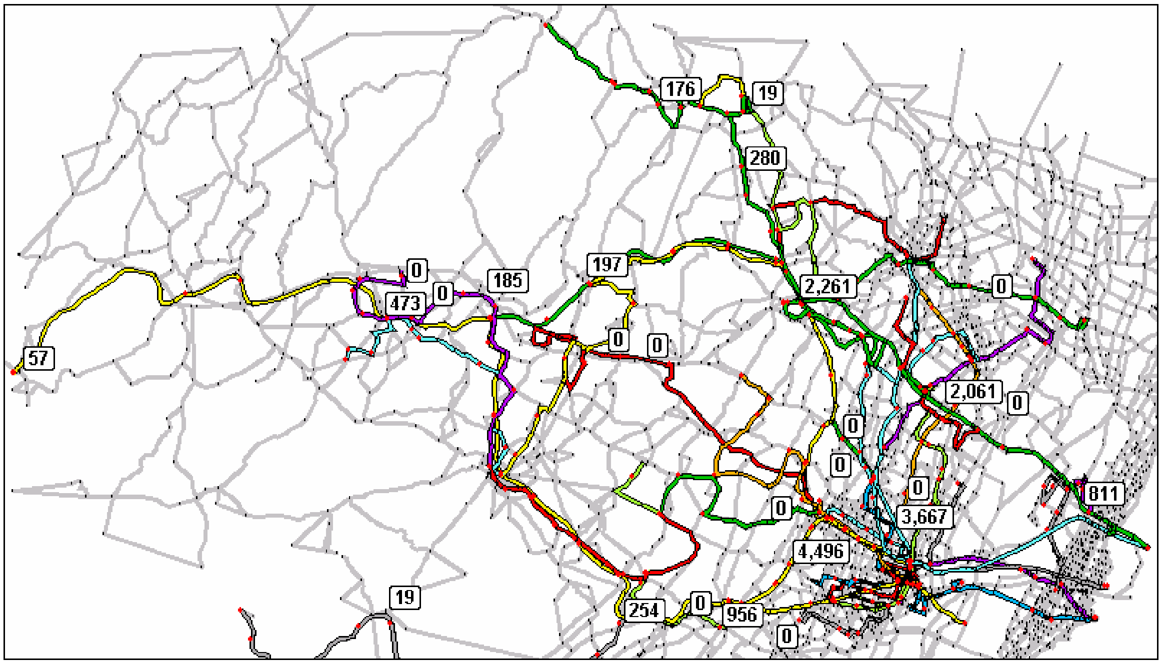


Figure 19. Total Demand for P&R facilities

The initial results from the intermodal model resulted in higher estimates of P&R users at each facility. This is due to a TransCAD limitation on limiting the capacity of each P&R facility. As a reminder, each P&R facility is represented as a node within the network from where intermodal users are “forced” to pass by. The effect of this limitation was reduced by decreasing the capacity on the links leading to the P&R and leaving just one access link to each facility open. However, the negative effect could not be completely removed. This limitation creates more problems. For example, if there are three P&R facilities that are very close to each other, the software will send all users to the most the favorable one, leaving the two neighboring facilities empty, which in reality is not correct. Since the nodes do not have the capacity restrictions, this is expected to occur (see Figure 20).

These limitations can be overcome through the use of am intermodal DTA model which is not based on link functions but on a traffic simulator. Each P&R facility will be modeled as a sink/source node where vehicles enter and leave based on the model. The traffic simulator will allocate vehicles into a P&R facility up to capacity.

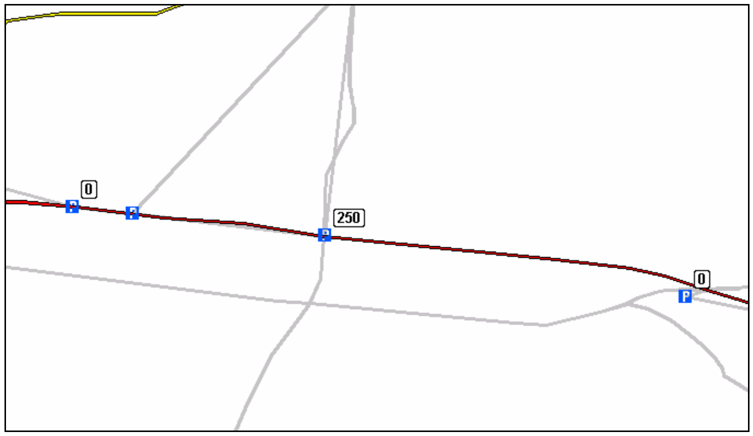


Figure 20. Sample estimated demand at P&R facility

Results of the Sensitivity Analysis

The Transit Modal Split share increased 9.83% in Scenario 1 and 10.24% in Scenario 2; an increase from 9.31% to 9.83% and 10.24% in Scenario 1 and Scenario 2, respectively. The number of P&R users increased 7.86% in Scenario 1 and 14.20% in Scenario 2.

In Scenarios 3 and 4 the number of Transit users increased by 0.65% in Scenario 3 and 1.45% in Scenario 4; the Transit share in the Modal Split was 9.37% in Scenario 3 and 9.45% in Scenario 4. The number of P&R users decreased by 1.15% and 2.25% in Scenario 3 and 4, respectively. In Scenarios 3a and 4a P&R usage increased by 4.74% and 9.68%, respectively. Correspondingly, in these scenarios the Transit ridership increased by 4.61% and 9.39%.

In Scenarios 5 and 6 the Transit Share grew to 10.72% and 12.25%, respectively. Transit increase was 15.10% and 31.53%. The number of P&R users grew 15.52% in Scenario 5 and 32.36% in Scenario 6. The results are depicted in Figure 21.

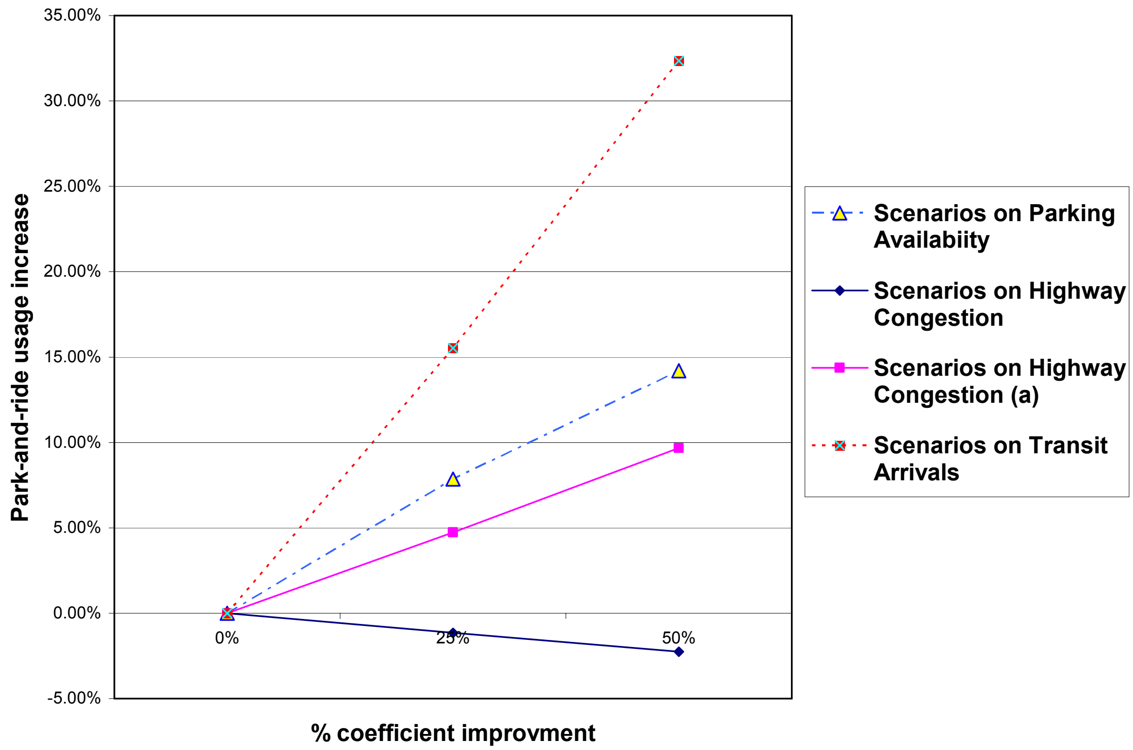


Figure 21. P&R increase in usage vs. % Coefficient improvement

Case Studies

This section describes possible uses for the P&R demand model using two case studies. The first study indicates the effect of changing location of a P&R facility, and its implications on transit ridership, P&R usage, and the overall highway network. The second study examines the impact of merging several P&R facilities into one using the same categories.

Case study 1- Changing P&R location

One of the potential uses of this intermodal-planning model is measuring the effect of changing the location of P&R facilities.

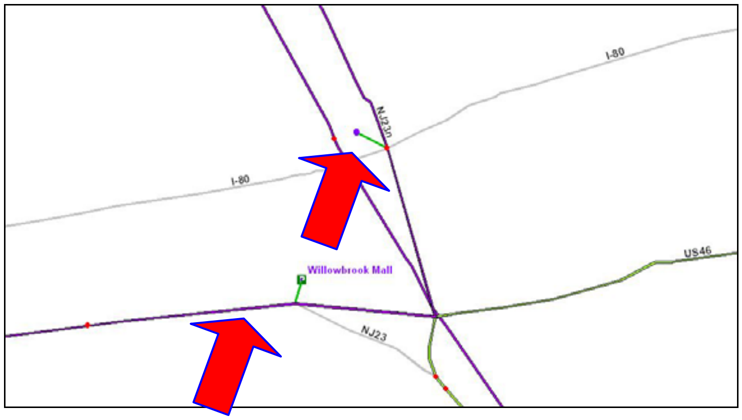


Figure 22. Evaluating the impact of changing the location of P&R facilities

The P&R facility at Willowbrook Mall was moved further north on NJ Route 23 (Figure 22). Based on the results from the model, this action resulted in a reduction of 427 P&R (3.9%) users from the original Willowbrook Mall location. Correspondingly, the total number of transit users dropped from 16828 to 16236 or a 3.52% reduction. The total travel time on the network increased 31 hours. The total traveled miles on highway for auto users increased by 3,784 miles. The average total travel time for P&R users increased from 18.26 minutes to 18.53 minutes. This study demonstrates that the current position in the Willowbrook Mall is more favorable than the location further north. This result is used for illustrating the methodology rather than the results of a well calibrated model. It should be used as a guidance for establishing such an operational intermodal model rather than as an actual result.

Case study 2- Changing P&R location

One of the major planning studies that are usually undertaken by DOTs and transit agencies is the examination of a potential consolidation of various P&R facilities within a geographical area to one facility. These cases include underutilization at some of the facilities, the presence of rail service in the area serving the same destination(s) as the corresponding bus services, cost cuts, or other reasons. In this case study, the twelve mostly underutilized P&R facilities were merged into one (Dover Bus Terminal). These P&R facilities are shown in Figure 23.

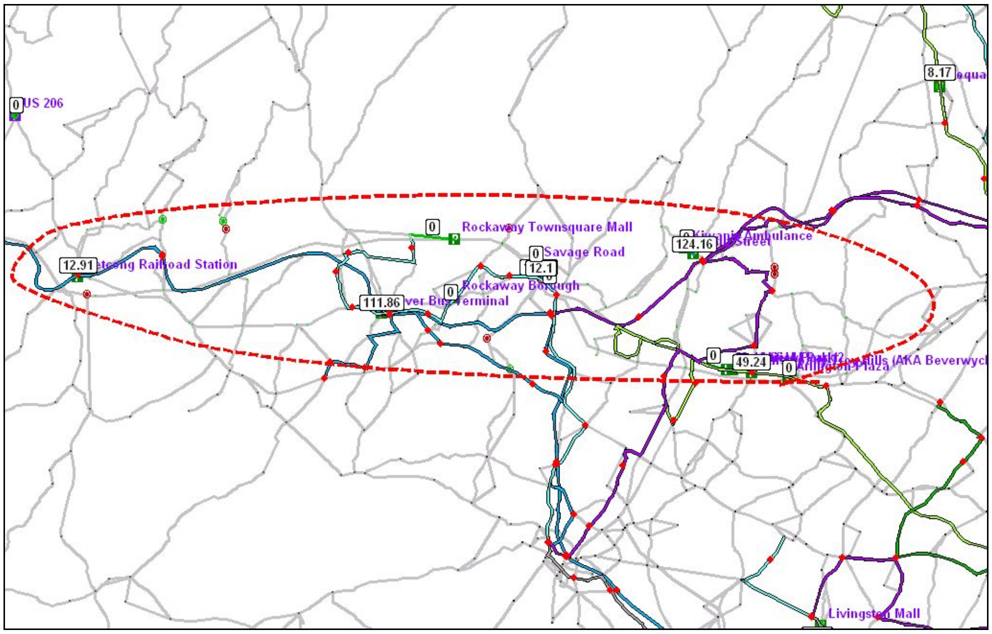


Figure 23. Sample Grouping of P&R facilities

The result of this consolidation is a decrease in the total P&R demand from 10,915 down to 10,442, and an increase of the total travel time on the highway network by 64 hours and the total vehicle miles traveled by 3,961 miles. The average total commuting time for P&R users across the network increased from 18.26 minutes to 18.70 minutes. That increase in travel time is due to the OD spatial characteristics and the corresponding OD matrix. The effects of this action on the network were negative. In view of the model results and considering only the travel time implications, this action would not be recommended if travel time is the main parameter for such a consolidation. Table 9 summarizes the results of the case studies.

Table 9. Summary of the Case Studies

Case Study	Number of commuters by mode			Transit Total	Average P&R commute time (min)	Total Travel Time on Network (hours)
	Auto	Intermodal	Pure Transit			
Base	776058	10915	5914	16828	18.26	115,793
Case 1	776619	10488	5779	16267	18.53	115,824
Case 2	776650	10442	5794	16236	18.70	115,857

As indicated from the table, the more P&R users we have, the lower is the total travel time of the transportation network.

Again, it has to be mentioned that the utility parameters were taken from literature and they are not really applicable here. These case studies are for demonstration purposes only. For a more applicable model, a market survey has to be conducted and actual parameters obtained.

Summary and Conclusions

In this report, an extensive literature review relative to the impact of pre-trip information on commuters' travel pattern has been conducted. One of these models was chosen and implemented into the North Jersey intermodal network, through the use of the TransCAD software.

One of the main characteristics of the intermodal model developed in this study is that it accounts for auto, transit, intermodal users (auto plus bus and auto plus train) and the impact of pre-trip information on intermodal network. The results of the modal split showed significant increases in transit and P&R usage, as an impact of having accurate information before the trip has been started.

It is noted that the model results were based on a calibrated model obtained from the literature. Therefore, the results of the implemented model were not intended to capture the actual travel behavior characteristics for the North Jersey model developed but they were used to demonstrate the potential use of the model. A more accurate planning model must be calibrated based on the results of a market survey in the corresponding area of interest. In addition, a simulation-based intermodal DTA model will reduce the deficiencies inherent in the static traffic assignment by modeling properly the traffic flow propagation through freeways as well as signalized roadway systems while accounting for the time dimension. Furthermore, the operational tools needed for such a model will need to be developed.

<u>The work that has been presented in the previous sections may be summarized as follows:</u>

- A thorough literature review on models describing the impact of information on drivers' decisions has been presented.
- Four major groups of models have been presented: models with pre-trip information, models with en-route information, models with transit information and models describing the impact of parking information.
- A model that describes the usage of a P&R system that could help reduce highway congestion was chosen, adjusted, and implemented in our study.
- An intermodal network model including highways, bus and rail routes and P&R facilities has been created using data from NJTPA, NJ Transit and Tiger data.
- An OD matrix for the above network, based on data from the NJTPA model, has been developed.
- The model has been calibrated by adjusting the coefficients so that the total P&R demand from the model fits the total real usage of the P&R.
- The impact of various types of information to travel patterns has been modeled by adjusting the value of the parameters in the model.

- Possible usage of this decision tool has been described using several hypothetical scenarios and by observing the effect of the decisions made.

The model presented a methodology for analyzing travel patterns in an inter-modal network including P&R facilities. An operational model if implemented could be used to produce estimates in: changes in the network travel patterns that result from different information provided to travelers, alternative pricing and operating policies, changes in transit and P&R systems, and the future increase in travel demand.

Recommendations

- Perform a market survey in order to obtain real data and calibrate the model. This is necessary because the preferences of the travelers in a specific corridor must be obtained for every model. Those data would be statistically analyzed and parameters estimated accordingly.

- Establish an simulation-based intermodal DTA model that would incorporate all P&R facilities, which would be more accurate and suitable for real time implementation. This DTA based model should be further integrated with the NJDOT traffic control centers of North and South such that it can be continuously calibrated utilizing the existing traffic surveillance systems of the state. Such a model will then be used not only for the P&R program but also as a general real-time traffic forecasting tool and an off-line transportation planning model.

- The model could be interfaced with existing state and regional planning tools and provide the capability of inter-modal network analysis, evaluation of P&R pricing policies and operation schemes, the impact of information on traveler's decision, and its effect on the network patterns.

REFERENCES

1. Sreedevi, I. and J. Black, “ITS Decision, Inductive Loop Detectors, Last update: 02/01/01 URL: http://www-path.eecs.berkeley.edu/~leap/ TM/Incident_Manage/ Detection/loopdet.html

2. The EDITraffic Website, URL: http://www.editraffic.com/products/detectors/index.htm

3. ITS Amano Cincinnati Inc.

4. Carvell J.D., Jr., K. Balke, J. Ullman, K. Fitzpatrick, L. Nowlin, and C. Brehmer; Freeway Management Handbook, Report No. FHWA-SA-97-064.

5. Klein, L.A. Vehicle Detector Technologies for Traffic Management Applications, Part 1 http://www.itsonline.com/detect_pt1.html andhttp://www.fhwa.dot.gov/ohim/tvtw/vdstits.pdf.

6. Soulliard, C. J and M. C. Soulliard, “Vehicle Detection goes Wireless,” IMSA Journal Feature Article, Jan/Feb 2002.

7. Electronic Integrated Systems Inc., Remote Traffic Monitoring System (RTMS), <http://www.rtms-by-eis.com>

8. Voicebit Communication Solution Professionals, Finland, URL: http://www.voicebit.fi/

9. Image Sensing Systems, Inc. http://www.imagesensing.com/.

10. Hofman, Y. "License Plate Recognition - A Tutorial ", URL: http://www.licenseplaterecognition.com/, Copyright Hi-Tech Solutions. R&D Manager.

11. *The Association for Automatic Identification and Data Capture Technologies URL: http://www.aimglobal.org/technologies/rfid/.*

12. GSM - Global System for Mobile Communication, URL: http://www.iec.org/online/tutorials/gsm/

13. Mobipower Ltd., Teleparking Systems, URL: http://www.teleparking.com/, The Baran group.

14. E-Squared Engineering, Guiding Principles for Electronic Payment Systems, URL: http://www.e-squared.org/parking_(eps).htm

15. European Union Road Federation (ERF) Parking Projects, URL: www.erf.be/projects/pr_EPARKING.htm

16. Aculab Website – Digital Network Access. URL: www.aculab.com

17. Parma, KD, Challenge and Guidelines for Implementing Advanced Parking Information Systems in the United States for Daily Downtown Traffic, Aug 1996.

18. Khattak, A. and Polak, J, Effect of Parking Information on Travelers' Knowledge and Behavior, Transportation, Jan 1993.

19. Wright, JL, ITS Projects in St. Paul: DIVERT and Advanced Parking Information System, ITE Journal, Vol. 66, Sep, 1996.

20. Boyd, SJ and Rylander, GF, Advanced Parking Information System-Operational Test, Intelligent Transportation Conference, April, 1996.

21. Orski, CK, Electronic Parking Information Systems, Parking, Jun, 1996.

22. Asakura, Y; Kashiwadani, M; Nishii, K and Furuya, H, Driver's Response to Parking Information System: Empirical Study in Matsutama City, Intelligent Transport Systems World Congress, Nov. 1995.

23. Thompson, RG and Collins, EC, Parkinfo: A Central City Parking Information System, Traffic Engineering and Control, Vol. 34, No. 10, Oct. 1993.

24. Noda, K; Ogino, H and Kurimoto, Y, Experiment on Introduction of Route Guidance and Parking Information Systems in Toyota, 4TH World Congress on Intelligent Transport Systems, Oct, 1997.

25. Toyama, Y, Parking Guidance Systems (PGS) in Japan: How They Are and How They Will Be, 2ND World Congress on Intelligent Transport Systems, Nov, 1995;

26. Kurogo, H; Takada, K; Miyamoto, S and Yamaguchi, T, Concept of A Parking Guidance System and Its Effects in the Shinjuku Area----Construction and Performance of System, 2ND World Congress on Intelligent Transport System, Nov, 1995.

27. Thompson, RG; Takada, K, Kobayakawa, S and Miyamoto, S, The Demand for the Shinjuku Dynamic Parking Guidance and Information System, 2ND World Congress on Intelligent Transport System, Nov, 1995;

28. Sakai, A; Sugimoto, T; Goto, K and Okuda, T, Parking Guidance and Information Systems, *2ND World Congress on Intelligent Transport System,* Nov, 1995.

29. Teng, H., J. Falccochio, Parking Guidance Systems, Urban ITS Center Polytechnic University Final Report to NYCDOT, July 2002

30. Web site: http://www.ci.san-jose.ca.us/cty_clk/10_24_00docs2/6e8.htm

31. Polak J. W., I. C. Hilton, K.W. Axhausen, and W. Young; Parking Guidance and Information Systems: Performance and Capability; Traffic Engineering + Control, Volume 31, Number 10, pp. 519-524, October 1990.

32. Web site:http://www.ci.san-jose.ca.us/cty_clk/10_24_00docs2/6e8.htm

33. Web site:www.dksassociates.com/ITE-2001-PGS-paper.pdf

34. Minderhoud, MM and Bovy, PHL, A Dynamic Parking Reservation System (DPRS) for City Centers, Intelligent Transportation Conference, Oct, 1996.

35. Khatak, A. and Polak, J, Effect of Parking Information on Travelers' Knowledge and Behavior, Transportation, Jan, 1993,

36. Wright, JL, ITS Projects in St. Paul: DIVERT and Advanced Parking Information System, ITE Journal, Vol. 66, Sep, 1996,

37. Asakura, Y, Kashiwadani, M; Nishii, K and Furuya, H., Driver's Response to Parking Information System: Empirical Study in Matsutama City, Intelligent Transport Systems 2nd World Congress, Nov, 1995, Yokohama, Japan,

38. Thompson, RG and Collins, EC, Parkinfo: A Central City Parking Information System, Traffic Engineering and Control, Vol. 34, No. 10, Oct, 1993,

39. Noda, K; Ogino, H and Kurimoto, Y, Experiment on Introduction of Route Guidance and Parking Information Systems in Toyota, 4TH World Congress on Intelligent Transport Systems, Oct, 1997,

40. Toyama, Y, Parking Guidance Systems (PGS) in Japan: How They Are and How They Will Be, Intelligent Transport Systems 2nd World Congress, Nov, 1995, Yokohama, Japan,

41. Kurogo, H; Takada, K; Miyamoto, S and Yamaguchi, T, Concept of A Parking Guidance System and Its Effects in the Shinjuku Area-Construction and Performance of System, Intelligent Transport Systems 2nd World Congress, Nov, 1995, Yokohama, Japan,

42. Sakai, A; Sugimoto, T; GOTO, K and Okuda, T, Parking Guidance and Information Systems, Intelligent Transport Systems 2nd World Congress, Nov, 1995, Yokohama, Japan,

43. Mouskos, K.C., D. Bernstein, and J. Tavantzis, "A Deterministic and Stochastic Mathematical Formulation for a Parking Reservation System with Fixed Costs," Transportation Research Board CD ROM Proceedings, Washington DC, January 2002.

44. Mouskos K.C., J. Tavantzis, D. Bernstein, and A. Sansil, "A Deterministic Mathematical Formulation of a Parking Reservation System," IEEE Melecon 2000 Proceedings, Limassol-Cyprus, May 2000.

45. Papadimitriou, C. and K. Steiglitz, Combinatorial Optimization: Algorithms and Complexity, Prentice Hall, NJ, 1982.

46. Chandrasekaran, R., Total Unimodularity of Matrices, SIAM J. Appl. Math, Vol 17, No. 6, pp. 1032-1034, 1969.

47. Hoffman, A.J. and J.B. Kruskal, Integral Boundary Points of Convex Polyhedra, Linear Inequalities and Related Systems, Princeton University Press, Princeton, pp. 223-246, 1956.

48. Mouskos, K. C., Bernstein, D., and Tavantzis, J. Mathematical Formulation of Deterministic and Stochastic Parking Reservation Systems (PRS) with Fixed Costs. Submitted for Publication to the Transportation Research - Part C Journal, 2002.

49. Fowler, M. and Scott, K. UML Distilled: a brief guide to the standard object modeling language. Addison-Wesley, 2000.

50. Java Servlet API Specification Version 2.3. September 2001, Sun Microsystems, Inc.

51. Ayers, D., H. Bergsten, M. Bogovich, J. Diamond, M. Ferris, M. Fleury, a. Halberstadt, P. Houle, P. Mohseni, A. Patzer, R. Philips, S. Li, K. Vedati, m. Wilcox and S. Zeiger. Professional Java Server Programming. Wrox Press Ltd., 2000.

52. XML Schema. http://www.w3.org/XML/Schema. Accessed July 25, 2002.

53. ILOG CPLEX. http://www.ilog.com/products/cplex/index.cfm. Accessed July 25, 2002.

54. ACME Java. http://www.acme.com/java/. Accessed on July 25, 2002.

55. Porter, T. and T. Duff. Compositing Digital Images. Computer Graphics Volume 18, Number 3 July 1984 pp 253-259.

56. Blending Images, URL: http://developer.java.sun.com/developer/JDCTechTips/2002/tt0618.html#tip2. Accessed July 25, 2002.

57. Nagurney, A. (1993), Network Economics-A Variational Inequality Approach, Kluver Academic Publishers, Norwell, Massachusetts, USA.

58. Strang, G. (1988), Linear Algebra and Applications 3rd edition, Harcourt Brace Jovanovich, Inc., Orlando, Florida.

59. Vanderbei, R.J. (2001), Linear Programming-Foundations and Extensions 2nd edition, Kluver Academic Publishers, Norwell, Massachusetts, USA.

60. De Cea, E.F.J., Florian, M., Cabrera, E., Network Equilibrium Models with Combined Modes, Transportation Science, Vol. 28,No. 3, August 1994.

61. Boile,M.P., Spasovic, L.N., Bladikas, K., *Modeling Intermodal Auto-Rail Commuter Networks*, Transportation Research Record 1516.

62. Krann, M, et al. *Evaluating network wide effect of VMS's in the Netherlands.* Nov 1998.

63. Thompson, R.G., et al. *Understanding the demand for access information.* Transportation Research Part C.1998. Vol 6 Issue 4.p 231-245.

64. Adler, J.L, et al. *A conflict model and interactive simulator (FASTCARS) for predicting en-route driver behavior in response to real–time traffic condition information.* 1993. Transportation 20. p 83-106.

65. Balmforth, P.W.A., Bonsall, P.W., and Palmer, I.A., PARKIT-a Parking Choice Simulator. Working Paper, Institute for Transport Studies, University of leeds, England, 1997

66. Bonsall, P.W., and Parry, T., Using an Interactive Route Choice Simulator to Investigate Drivers' Compliance with Route Guidance Advice, Transportation Research record 1306, p 59-68, 1991.

67. Bonsall, P.W., Firmion, P.E., Anderson, M.,E., Palmer, I.A., Balmforth, P.J.A., Validating VLADIMIR: Can Results of a Route Choice Simulator Be Trusted?, Proceedings of the 4th International Conference on Survey Methods in Transport, University of Leeds, UK, 1996.

68. Chen, P.S., Mahmassani, H.S., Dynamic Interactive Simulator for Studying Commuter Behavior Under Real-Time Traffic Information Supply Strategies, Transportation Research Record 1413, p 91-107, 1994.

69. Koutsopoulos, H.N., et al. *A driving simulator and its application for modeling route choice in the presence of information*

70. Koutsopoulos, H.N., Polydoropoulou, A. and Ben-Akiva, M.Travel Simulators for Data Collection on Driver Behavior in the Presence of Information, Transportation Research Part 3C, No 3, p 143-159.1994.

71. Vaughn, K.M., Abdel-Aty, M.A., Kitamura, R., Jovanis, P.P., Yang, H., Kroll, N.E., Post, R.B. and Oppy, B., Experimental Analysis and Modelling of Sequential Route Choice Behavior Under ATIS in a Simplistic Traffic Network, Transportation research Record 1408.

72. Dia, H. *Modeling the impact of advanced traveler information system using Intelligent Agents.* Road and Transport Research journal. September 1999. Vol 8, No. 3.

73. Mahmassani, H.S., Chen, P.S., Srinivasan, K.K. *Effect of Information Quality on Compliance Behavior of Commuters under Real-Time traffic information.* Transportation Research Record. 1676.

74. Mahmassani, H.S., Liu, Y. Dynamics of commuting behavior under advanced traveler information system. 1999. Transportation Research Part C. p.91-107.

75. Khattak, A., Polydoropoulou, A., Ben-Akiva, M., Modeling Revealed and Stated Pre-trip Travel Response to Advanced Travel Information Systems, Transportation Research Board 1537.

76. Ben-Akiva, M., Kayasi, I., Polydoropoulou, A., Koutsopoulos, H., Whitworth, P. Design of an Integrated Data Collection Program to Support Modeling for User Response to ATIS Services. Proceedings, 1994 IVHS America First Annual Meeting.

77. Khattak, A.,Schofer, J., Koppelman, F. Effect of Traffic Reports on Commuters' Route and Departure Time Changes. Journal of Advanced Tyransportation , Vol. 29, No. 2, 1995.

78. Ben-Akiva, M., de Palma, A., Kaysi, I. Dynamic Network Models and Driver Information Systems. Transportation Research Part A, Vol 25, No 5, 1991.

79. Schofer, J., Khattak, A., Koppelman, F. Behavioral Issues in the Design and Evaluation of Advanced Traveler Information Systems. Transportation Research Part C, Vol 1, No 2, 1993.

80. Bradley, M.A., Daly, A.J. (Hague Consulting Group). Estimation of Logit Choice Models Using Mixed Stated Preference and Revealed Preference Information. Proceedings of the 6th International Conference on Travel Behavior, Quebec, Canada, 1991.

81. Polak, J., Jones, P., The acquisition of pre-trip information: A stated preference approach, Transportation 20. p 179-198, 1993.

82. Jou, R.-C., Modelling the impact of pre-trip information on commuter departure time and route choice. Transportation Research Part B. Vol 35.p 887-902. 2001.

83. Fujiwara, A., Sugie, Y., Zhang, J., A Survey and Analysis Method to Evaluate Influence of Pre-trip Information on Commuter's Travel Choice Behaviour. Traffic and transportation studies: proceedings of the ICTTS 2000.p. 754-761.

84. Guan, H., Nishii, K., A Modeling Method for Estimating the P&BR Demand. *Proceedings of the Conference on Traffic and Transportation Studies, ICTTS 2000. ASCE, Reston, VA, USA, p 378-383*

85. Dia, H. *A conceptual framework for modeling dynamic driver behavior using intelligent agents.* Proceedings of the 6th International Conference on Application

of Advanced Technologies in Transportation Engineering. 28-30 June 2000. Singapore.

86. Ben-Akiva, and Bolduc, D. Multinomial Probit with Logit Kernel and a General Parametric Specification of the Covariance Structure. Working paper, Department of Economics, Massachusetts Institute of technology, Cambridge, 1996.

87. Brownstone, D., Train, K. Forecasting New-Product penetration with Flexible Substitution Patterns. Working paper. Department of Economics, University of California, Irvine, 1996.

88. Bhat, C., Recent Methodological Advances Relevant to Activity and Travel Behavior Analysis. International Association of Travel Behavior Research Conference, Austin, Texas, 1997.

89. Polydoropoulou, A., Ben-Akiva, M., Khattak, A., Lauprete, G. *Commuters' Normal and Shift Decisions in Unexpected Congestion: En Route Responses to Advanced Traveler Information Systems Volume 2.* California PATH Research Report. University of California, Berkeley. July 1996.

90. Mahmassani, H.S., Jayakrishnan, R., System Performance and user response under real-time information in congested traffic corridor. Transportation Research 25 (5), p 293-307, 1991.

91. Abdel-Aty, M., Kitamura, R., Jovanis, P.P. *Investigating effect of Advanced Traveler Information on Commuter Tendency to use transit.* Transportation Research Record. 1550.

92. Hester, A. E., Fisher, D.L., Collura, J. *Drivers' Parking Decisions: Advanced Parking Management Systems*. Journal of Transportation Engineering, Vol. 128, No. 1, January 1, 2002.

93. Thompson, R., Richardson, A. A parking search strategy. Proceedings of 7th World Conference on Transport Research, Vol 1: Travel behavior, UK, 1996.

94. Khattak, A. Behavioral Impacts of Recurring and Incident Congestion and Response to Advanced Traveler Information Systems in the Bay Area. California PATH Working-Paper, UCB-ITS-PWP-93-12. California PATH, 1993.

95. S. Chien, K.C. Mouskos, and A. Ziliaskopoulos, "Development of a DTA/Simulation Model for the NJDOT I-80 ITS Priority Corridor," Final Report, July 2005, New Jersey Institute of Technology.

96. Abdelghany, K.F., A.F. Abdelghany, H.S. Mahmassani, and A.S. Abdelfatah. 2001. Evaluating Bus Preemption Strategies at Signalized Intersections Using a Multi-modal Dynamic Network Assignment-Simulation Methodology. 80th Annual Meeting of the Transportation Research Board, 2001. Pre-print CD ROM.

97. Abdelghany, K.F. and H.S. Mahmassani. 2001. Dynamic trip assignment-simulation model for inter-modal transportation networks. Transportation Research Record 1771: 52-60.

98. Agrawal, B.B., S.T. Waller and A.K. Ziliaskopoulos. 2002. A Modeling Approach for Transit Signal Preemption. On the 81st Annual Meeting of the Transportation Research Board, 2002, Pre-print CD ROM.

99. Ben-Akiva, M., H.N. Koutsopoulos and A. Mukudan. 1994. A dynamic traffic model system for ATMS/ATIS operations. IVHS Journal 2 (1): 1-19.

100. Daganzo, C.F. 1994. The cell transmission model : a dynamic representation of highway traffic consistent with the hydrodynamic theory. Transportation Research 28B (4): 269-287.

101. Los Alamos National Laboratory. 2002. TRANSIMS: Transportation Analysis Simulation System, Version: TRANSIMS - 3.0. Vol. 3, Modules. Report no. LA-UR-00-1725. Los Alamos. Available at http://transims.tsasa.lanl.gov/TRANSIMS_3-0_docs.html. Date last accessed: 1 November 2002.

102. Mahmassani, H.S., S. Peeta, T.Y. Hu and A.K. Ziliaskopoulos. 1993. DTA with multiple user classes for real-time ATIS/ATMS applications. In Proceedings of the Advanced Traffic Management Conference, St. Petersburg, Florida. Washington D.C.: Federal Highway Administration.

103. Mahmassani, H.S. 2001. Dynamic network traffic assignment and simulation methodology for advanced system management applications. Networks and Spatial Economics 1: 267-92.

104. Peeta, S. and A.K. Ziliaskopoulos. 2001. Foundations of DTA: The past, the present and the future. Networks and Spatial Economics 1 (3/4): 233-65.

105. Van Aerde, M., B. Hellinga, M. Baker and H. Rakha. 1996. INTEGRATION: An Overview of Traffic Simulation Features. Paper presented at the Annual Meeting of the Transportation Research Board, Washington, D.C., January 1996. Available at http://www.civil.uwaterloo.ca/bhelling/Publications/TRB%201996%20Integration%20Features.pdf. Date last accessed: 30 September 2002.

106. Ziliaskopoulos, A.K. 2000. A linear programming model for the single destination system optimum DTA problem. Transportation Science 34 (1): 37-49.

107. Ziliaskopoulos, A.K. and H.S. Mahmassani. 1993. Time-dependent, shortest path algorithm for real-time intelligent vehicle highway systems applications. Transportation Research Record 1408: 94-100.

108. Ziliaskopoulos, A.K. and S.T. Waller. 2000. An internet based geographic information system that integrates data, models and users for transportation applications. Transportation Research 8C (1): 427-44.

APPENDIX A PARKING MONITORING TECHNOLOGIES

ILDS System Description

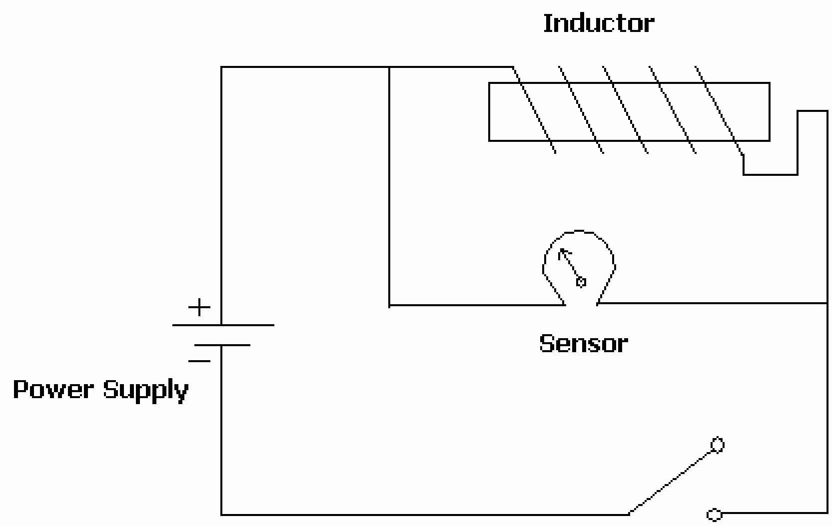


Figure 24. Principle of Operation - Inductive Loop Detector

ILDs operate on the principle of inductance (Figure 24), the property of a wire or circuit element to "induce" currents in isolated but adjacent conductive media. The principal components of an ILD detector are one or more turns of insulated wire buried in a shallow cutout in the roadway, a lead-in cable that runs from a roadside pull box to the controller, and an electronics unit located in the controller cabinet. The wire loop is excited with a signal ranging in frequency from 10 kHz to 200 kHz and functions as an inductive element in conjunction with the electronics unit. When a vehicle stops on or passes over the loop, its inductance is decreased. The decreased inductance increases the oscillation frequency and causes the electronics unit to send a pulse to the controller, indicating the presence or passage of a vehicle. An algorithm is used to translate this change in the magnetic field into a vehicle detection or a more precisely axle detection.

ILDs need extensive pavement sawing depending on the application (usually 6X6 ft) and opening of a 1 ft deep to bury the loop. For most conventional installations, when the inductance or frequency changes a preset threshold in the actuate detector electronics, this indicates that a vehicle has been detected. Further, extensive heavily protected wiring is required to send the signals from the loop to the data collection center. Many factors determine loop inductance, such as wire size, wire length, the number of turns, lead length, and insulation.

VIDS - Autoscope™

The Autoscope™ system [9] is one of the first VIDS technologies that have primarily been implemented on roadway systems for the estimation of vehicular traffic flow, vehicle presence, roadway occupancy, vehicle classification, and queue length. The Autoscope™, manufactured and marketed by the Econolite / Traffic Control Equipment, is a very reliable product and can be used in parking reservation systems. Figure 25 presents a typical installation of VIDS for a parking space monitoring application.

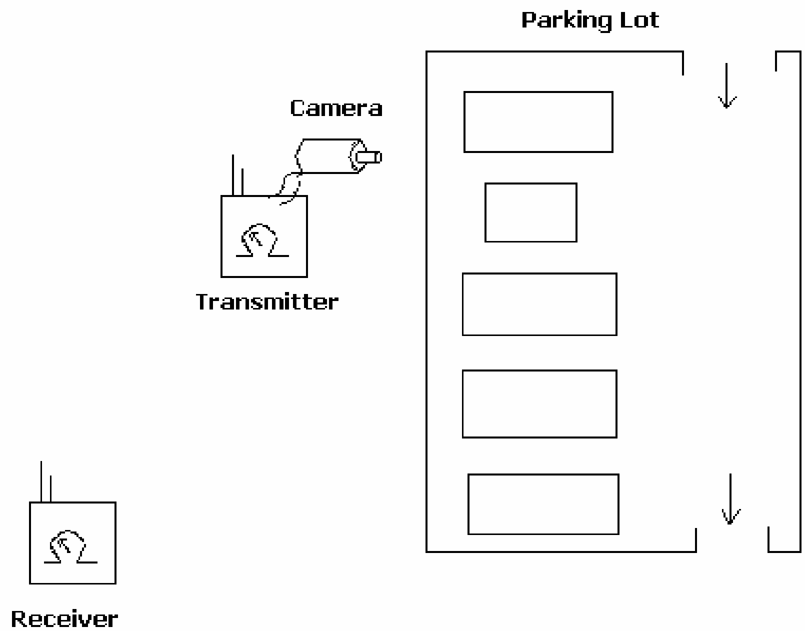


Figure 25. VIDS Implementation – Parking Application

Machine Vision Processor

The main unit of the Autoscope™ Traffic Sensing System is a real-time Machine Vision Processor (MVP). The MVP hosts the traffic measurement software and executes these at 30 frames per second. The Video Interface Module (VIM) consists of video input and output to the external world. Input to the MVP is analog video from multiple cameras in standard format EIA-RS170 or CCIR. An image processor that digitizes and formats the data for digital processing then processes the video. A processor based on Intel X86 chip family processes the data and extracts traffic parameters.

The MVP communicates the extracted traffic parameters to the local controller/hub and also to the Traffic Management Center (TMC). It receives local controller phase input and outputs traffic parameters measurement in formats standard for national and international controllers. Its output to TMC includes both video and data. The data consists of the measured traffic parameters. A non-volatile flash memory is available in the MVP for collecting interface traffic measurement records for transmittal to the TMC.

Vehicle Detection and Tracking

Before performing any of the traffic parameter measurements, the Autoscope™ MVP first performs necessary detection and tracking of the vehicles in its Field-of-View (FOV). A three dimensional (x, y, time) filtering method first estimates the background image. The filtering method adapts to expected variation in background intensity due to variation in ambient illumination. The intensity variation model includes sources such as solar illumination variation due to passing clouds, diurnal transition, and nocturnal illumination. Image intensity different from the estimated background intensity is thresholded and combined with edge images. Two sets of edge images are computed, based on spatial gradient and a temporal gradient. Thresholded background and edge images are logically combined to detect objects. Following the detection, the objects are then tracked. Two alternative methods of tracking are employed: symbolic tracking and numeric signature tracking. In signature tracking a set of intensity and geometry based signature features are extracted for each detected object. These features are correlated in the next frame to update the location of the objects in the new frame. Next, the signatures are updated to accommodate for the changes in range, perspective, and occlusion. These updated signatures are used in the next frame for correlation and the process continues.

In symbolic tracking, objects are independently detected in each frame. A symbolic correspondence is made between the sets of objects detected in the frame pair. A time-sequenced trajectory of each matched object provides a track of the object. Each of the two tracking methods produces better results under different conditions. The various required spatio-temporal parameters, such as deceleration, density, and others are then measured from these detected and tracked objects.

Loop Emulation

Most existing traffic control devices are designed for receiving and operating on output from inductive loop sensors. It is important that a video traffic sensor be compatible with such traffic control devices and provides output data, as if it came from a loop sensor. This set of measurements is called Loop Emulation (LE) measurements. To obtain LE measurements, an operator identifies a cell in the image where loop emulation is desired. Although the MVP processes the whole image, the object detection and traffic measurement output is reported only in the desired cell identified by the operator. Some evaluators view these measurements due to the appearance of the reporting cells on a display monitor.

The LE measurement software in the MVP includes the following parameters:

- Demand Presence - Presence of a vehicle at the reporting cell.
- Directional Presence - Presence of a vehicle approaching from a selected direction.
- Volume - Number of vehicles detected during the time interval.

- Time Occupancy - Percent of time a reporting cell is occupied by vehicles.
- Flow Rate - Vehicles per hour, per lane.
- Time Headway - Average time interval between vehicles.

System Architecture

The MVP is the central key element in this architecture. Each MVP receives input video from several camera units. It also receives phase information from the local traffic controller. One set of outputs also goes to the local traffic controller/hub. A second set of outputs goes to a communication server called ScopeServer. The ScopeServer is Windows/NT based software that is intended to reside on a desktop traffic management PC, at the Traffic Management Center. ScopeServer communicates to the MVP over RS232 / RS422 data path and RS170 video path. The ScopeServer can communicate with one MVP over direct point-to-point communication, or it can communicate with several MVPs over multi-drop communication channel. The data communication is TCP/IP compatible. It is also compatible with the emerging National Transportation Communication for ITS Protocol (NTCIP). Jet Propulsion Laboratory, under guidance from the NTCIP Steering Group, has developed a set of object definitions for advanced traffic imaging sensors.

The communication link between the MVPs, in the field, and the ScopeServer, at the Traffic Management Center, can be any one of the following: Plain Old Telephone System (POTS) through Dial Up Modem; Dedicated T1 line; ISDN; Twisted Pair; Optical Fiber; Wireless Cellular; Spread Spectrum; Point-to-Point Dedicated Channel Wireless.

At the Traffic Management Center, ScopeServer allows communication to other client computers over a local area network using TCP/IP protocol. It enables a traffic engineer, at the center, to access MVP data from his/her own desktop PC, without leaving the office or workstation. However, ScopeServer provides the flexibility for a user to use the ScopeServer platform computer for client application operation as well. In addition to the ScopeServer interface, client applications such as data analysis, traffic monitoring, video management, and others can reside on the ScopeServer platform.

Sensor Operation

Before the sensing systems can commence operation, the camera units must be installed at the appropriate height and location relative to the roadways. This is accomplished through proper site engineering, which is outside the scope of this paper.

Once the cameras and the MVP are interconnected, the MVP must be "set-up" to begin the operation. The objective of the set-up is to instruct the MVP of the required measurements. A personal computer (PC) with Windows operating system is used to set up the MVP. The set-up can be accomplished at the field site with either a portable or a laptop PC. The set-up can also take place, e remotely, from the Traffic Management Center using a desktop PC. A user-friendly graphical user interface referred to as a Supervisor which includes a menu of traffic parameters, is used by the traffic engineer to set up the MVP. The menu is the familiar mouse-driven point-and-click type. The graphical user interface allows geographic coding of the measurements.

At the Traffic Management Center, a desktop PC is used to open communication with the MVP. This is accomplished with the Windows based communication server tool called ScopeServer, described earlier. The ScopeServer allows a traffic engineer to open direct communication with one MVP or multi-drop communication with several desired MVPs. Using the open communication through ScopeServer, the user can access the data accumulated in the flash memory of the MVP. Alternatively, the user can access continuous live measurements from the MVP polled at the desired interval. The measurements are provided in a format convenient for the traffic engineer to display using the desired spreadsheet format. This data is quite voluminous. To expedite the interpretation of the data, a graphical tool, Autoscope™ Grapher (ASGrapher), displays the data in the user's desired medium such as pie charts, bar charts, or graphs. Most importantly, the measurements can then be then used in advanced traffic control logic residing at the Traffic Management Center. In addition, information based on the measurements can be sent to the traveler, if desired.

The Traffic Alarm Monitor application uses several variables collected through the ScopeServer and compared with normally occurring statistics. Thus, it automatically monitors traffic conditions and alerts the operator when the safety and/or congestion conditions reach an alarming level. This alarm can then be sent using NTCIP protocol to the Variable Message Sign upstream of the alarm location.

License Plate Recognition (LPR) Technology

The basis of this technology (Hofman [10]) is that the license plates, which are issued by the Division of Motor Vehicles (DMV) for all vehicles, are consistent in size, shape, etc. This can be used as an identifier for each vehicle by reading the data on individual license plates. The reader is generally a wall or floor mounted Infrared Illuminator and a camera unit. The infrared illuminator emits infrared rays onto the front/back of the car and illuminates the license plate. The camera then takes a digital picture of the license plate, which is then sent to the Control Unit, where it is processed for information. The picture is scanned, and fed to the image processing code, where the vehicle is identified and compared with the database of authorized users. After authentication of the user/vehicle, the signal is given to the gate controller to open or close.

LPR Image Processing

"The image of the front side of the car, shown in a typical format, is composed of 256 gray levels ranging from black (gray level 0) to white (gray level 255). For a typical format there are 768 X 288 pixels, or about 0.2 Million elements. This vast amount of information is processed by the recognition software in order to automatically locate and read the plate. The initial image starts from the raw data and then repeatedly zooms up (with factor x2) until the pixel level. The computer processing needs to work on the global information (the entire image) for detecting the plate, then zoom into the data in order to handle the small details and finally extract the registration data. The end result of the recognition process is a string. This transformation of the image data into a result string is actually a very large compression of the original raw data (1:31600!). " Excerpt from "License Plate Recognition - A Tutorial ", http://www.licenseplaterecognition.com/, Copyright Hi-Tech Solutions. Written by Y. Hofman, R&D Manager [10]

LPR System Elements

The system consists of the following basic units:

- **Camera(s)** - that photograph the images of the car (front or rear side).
- **Illumination** - a controlled light that can brighten up the plate, and allow day and night operation. In most cases the illumination is Infra-Red (IR) that is invisible to the driver.
- **Frame Grabber** - an interface board between the camera and the PC, allows the software to read the image information
- **Computer** - normally a PC running Windows or Linux. It runs the LPR application that controls the system, reads the images, analyzes and identifies the plate, and interfaces with other applications and systems.
- **Software** - the application and the recognition package. Usually the recognition package is supplied as a DLL (Dynamic Link Library).
- **Hardware** - various input/output boards used to interface the external world (such as control boards and networking boards).
- **Database** - the events are recorded on a local database or transmitted over the network. The data includes the recognition results and (optionally) the vehicle or driver-face image file **"** Hofman [10]**.**

RFID – Mobipower Ltd

The main components of the Mobipower Ltd are described next.

Tele-Parking Unit (TPU)

The TPU (Triffiq) is a transponder, cellular-based in-vehicle device, which is easily self-mounted by the driver in his vehicle, and which is used to initiate, record, store, and transmit -- via wireless infrastructure (GSM SMS cellular service) -- the various events of a parking transaction; including the start and end of the transaction and a violation notice, if received. The TPU contains the vehicle's registration information, make and color, various permits the driver owns, and relevant parking data such as city and zone information, as well as rates needed by the driver to complete a parking transaction. The unit provides a visual display for the driver, and a blinking light facing the exterior of the vehicle, for the enforcement agent. The TPU communicates with the Enforcement Unit using Bluetooth technology (a computing and telecommunications industry specification that defines how mobile phones, computers, and personal digital assistants (PDA's) interface with each other using a short-range wireless connection) and enables the enforcement agent to verify parking status from a distance.

Enforcement Unit (EU)

This is a small hand-held unit, the size of a TV remote control, carried by the enforcement agent and is used to verify the parking status of TPU users. The EU communicates with the TPUs via Bluetooth technology to perform two-phase interrogations. The first phase activates TPUs within a radius of approximately 10 meters (33 feet). Once activated, TPUs will blink either at a slow or fast rate. Slow meaning valid parking and fast indicating a parking violation. This phase provides all the information needed to the EU to evaluate the cars in the selected area. The second phase is an individual interrogation performed on a peer-to-peer basis after the agent selects the vehicle to be interrogated. Individual interrogation is necessary since a violation must be absolutely confirmed before a ticket is issued, and it is this second interrogation that leaves the violation notice in the TPU. The EU is equipped with a Global Position System (GPS) unit to automatically add geographic location to the ticket.

Since the EU can be used to interrogate TPUs from a distance, enforcement agents need not stop at each vehicle for visual verification of parking status and can concentrate on suspected violators only. At the end of the day, the EU is inserted into the Docking Charging Unit to download the day's activities from the device's log. With the aid of the internal GPS unit, each record identifies the exact location of the event so that supervisors may monitor and track their agents' activities for an entire workday.

Docking Charging Unit (DCU)

This is a cradle-like docking device used to download the EU's data to the municipality or parking operator's computer. The downloaded information is used for comparing the enforcement day's activity, to information stored in the Service Center database for data integrity checks, and for monitoring agents' on-street activities. The DCU is also used to recharge the EU's batteries.

Municipality / Parking Operator Control Terminal (MCT)

This is a remote terminal that is installed at the municipality (or parking operator) premises that provides reliable online control of the system. The municipality (or a private parking operator who performs the parking function and administration on behalf of the municipality, or as part of his own private parking business) can use this terminal to monitor the parking activities in its region: follow load, compare transactions with enforcement agents' daily activities (to confirm continued full reliability of the system), and above all retain complete monitoring and control of parking revenues. The MCT also enables flexibility for changing parking policies, as needed, from one single control point.

Service Center

An unattended nationwide computer center, maintained by the TPS Operator, that stores subscriber data and all other parking information such as city location, rates, zones, etc. in its data base. The Service Center receives parking events from the TPUs and compiles them into parking transactions. The Service Center also updates TPUs with the information needed for in-car processing; processes billing information, and sends periodic invoices to TPS subscribers; adds and updates subscriber information; and compiles and produces various reports for the municipalities and other parking operators.

E-ZPass-based Parking System

E-ZPass Tag (transponder)

The E-ZPass tag is a vehicle's electronic identification device. Physically it consists of an antenna and electronic circuitry designed to carry out the transaction for paying tolls. The E-ZPass system uses this tag for identification and payment transactions. The RSTs through the use of a short-range antenna system radiate interrogation pulses continuously to "wake up" the tags mounted in the vehicles. As a tag equipped vehicle approaches the capture zone of the RST, it responds back to the interrogation pulse by transmitting specific data to the RST including its identification data, ID. The tag transmits data at 500 kbps in the 915 MHz band. The tag ID data are sent to the E-ZPass operations center that matches the tag ID to a valid E-ZPass account. The E-ZPass data processing system then deducts the appropriate toll amount from the user's account. If the system detects that the account does not have any money in it, it immediately sends back a message to the user notifying him/her of the specific situation such that he/she can resolve the problem, as soon as possible.

In a similar fashion, the E-ZPass system is now installed at the Newark and JFK airports allowing E-ZPass users to utilize their account also for airport parking. Similarly, the E-ZPass system could be used by the NJDOT as a parking permit/payment system at its P&R facilities.

Roadcheck™ Basic Reader System

Roadcheck™ Basic Reader System: Installed at the RST, the *Roadcheck™ Basic Reader* is an autonomous stationary unit linked through a wireline to a computer at the data processing center. The reader system consists of: Antenna(s): single/multi lane or side fire; CPU Board; RF Control Board; Communication Boards Power Module.

APPENDIX B. PGIS SAMPLE SIGNS AND COSTS

PGIS Display System

Directional signing to parking facilities forms the most important direct interface with road users. Current information is communicated between the PGIS system and the drivers through display panels. Available display technologies are: Light Emitting Diode (LED) displays, Liquid-Crystal Displays (LCD) and flip-flops (plastic chip technology) or prism signs [27].

The design of a parking sign system involves the determination of the types, messages, and locations of signs to be used. The main types of PGS signs [27] are:

- Dynamic signs.
- Static signs.

Static signs offer information on the location of parking lots by directing drivers through the use of directional arrows. This information is of limited use in areas where parking lot capacity is fully utilized for some parking lots. In contrast, PGIS that incorporate dynamic signs through variable messages are more useful as they direct travelers to parking lots with free parking spaces. Static signs are substantially cheaper as they only require a pole with some directional signs on them. However, dynamic signs require a traffic surveillance system, a communication system, a variable message sign system and a computer either at a central location (centralized system) for all PGS signs or a system of computers that control a number of PGS signs (de-centralized system).

Static PGS Signs

A typical set of static signs is illustrated in Figure 26 [29]:

- Map sign on boundary roadways (Map signs).
- Static sign on the internal roadways (Internal signs).
- Static signs in front of parking facilities (Front signs).

Map Signs

The sign shown in Figure 26 is a map sign, which is used to show the zone code of parking facilities in Downtown Flushing and the locations of those parking facilities participating in the system. Map signs are also called “advance signs.” Thus, they are placed at least one block before the VMS at the periphery of the pilot area.

The map sign consists of two segments. On the top, the “P” sign is displayed. Adjacent to that is a title including “Downtown Flushing PGS” and “Parking Guidance System.” The lower part includes the map of downtown Flushing with a different orientation for each location. All of the parking facilities are highlighted on the map and only the names of the participating facilities are displayed.

Static Internal Signs

Static internal signs are the continuation of the dynamic signs, and they consist of (Figure 27):

- A big circular P.
- Some panels showing parking information for related parking facilities.

The parking information on each panel contains:

- Name of a parking facility.
- Arrows directing the driver to the indicated off-street parking facility.
- Colors illustrating the zone the indicated parking facility belongs to.

These panels are the same as those displayed on VMS. Note that the number of panels on each sign may be different and is determined by the location from which a different number of parking facilities can be accessed. In addition, as shown in Figure 27(b), a sign may not have a facility's name when there is a limitation of pavement space to accommodate a larger sign. Furthermore, the names of non-participant facilities are to be shown in the signs that are closest to the corresponding facility.

Front Signs

Figure 28, presents a Front Sign that is required in front of each parking facility. By doing so, the signage of parking information system can be standardized. On the top of the sign, it includes the "P" sign. Underneath it includes a panel that depicts the name of the facility with the background zonal color.

Figure 26. Map Signs with Different Orientations - Teng et.al [29]

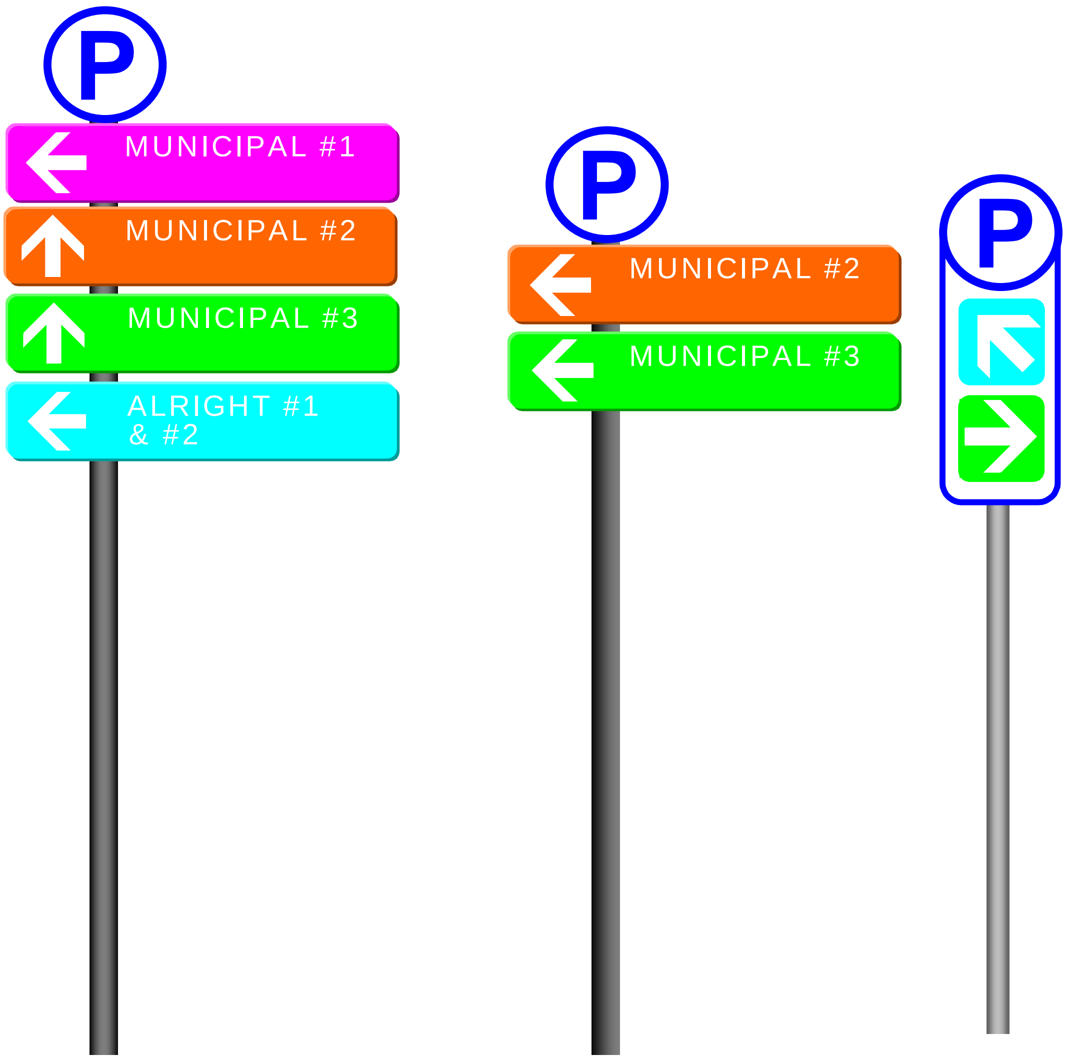


Figure 27. Static Internal Signs - Teng et.al [29]

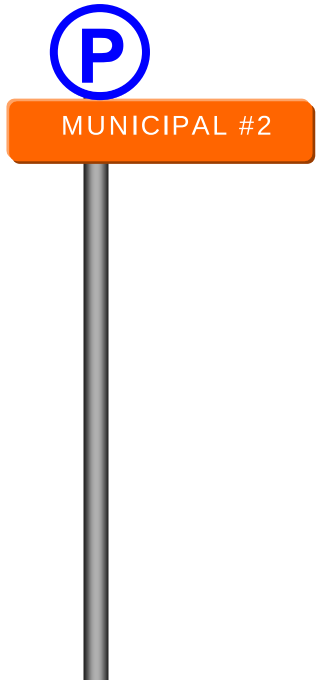


Figure 28. Static Signs - Front Sign - Teng et.al [29]

Dynamic PGIS Signs

The dynamic message roadside display, shown in Figure 29, consists of:

- A big circular P sign on the top, indicating the relevance of the sign to parking.
- “Available Spaces” next to P that shows the number of available parking spaces.
- Several compartments, which are representing an off-street parking facility participates in the system.

Only parking facilities that can be reached directly from a location are shown on the dynamic sign. As shown in Figure 29, more than one parking facility such as the sign “Alright 1 and 2”, may be combined together in one compartment if they are in the same zone, have the same ownership, and are in close proximity to each other.

The parking availability indication in the dynamic signs could be displayed as: number of available spaces, % FULL, OPEN, CLOSED, FULL, AVAILABLE, etc. depending on the individual parking agency choices. Figure 30, shows an example of a static sign in Helsinki, Finland and Figure 31, an example of a map sign in Toyoda City, Japan.

Figure 29. A Dynamic Roadside Display - Teng et.al [29]

Figure 30. Parking guidance system in Helsinki

Figure 31. Provision of information on parking lots (on Internet screen) in Toyota City, Japan

PGIS Sample Costs

As a part of this review, two cost examples were referenced for implementing a PGIS: San Jose, California [30] and Shea Stadium in New York City [29].

<u>San Jose, CA Parking Guidance System</u>

The City of San Jose awarded DKS and two sub-consultants, Kimley-Horn Associates and Wilbur Smith Associates, a feasibility study for the implementation of a downtown PGS system in November 1999 [30]. In September 2000, the City of San Jose

Department of Streets and Traffic in cooperation with the Redevelopment Agency staff completed an evaluation of the feasibility and concept plan of a PGS for downtown San Jose. Design of the first phase began in late 2000 and continued through 2001. Construction and implementation was scheduled to begin in late 2001 and extended to mid-2002. The cost estimation for the proposed PGS in San Jose California is presented in Table 10.

Table 10. Cost Estimate for PGS System in Downtown San Jose, CA [30]

Item description	Unit Cost
Dynamic Message Signs	$7,000.00
7' * 8' LED Full Matrix Sign	$150,000.00
Full Matrix Sign	$20,000.00
Static Guide Signs	$800.00
Garage Connection	$10,000.00
DMS Connection	$5,000.00
Electrical Service Connection	$10,000.00
Conduit	$25.00
Twisted Pair Cable	$2.00
Garage Data Controller	$8,000.00
Central Computer	$25,000.00
Central Software	$50,000.00
Central Com. Modifications	$25,000.00
Design and Testing	
Detailed Design	%20(Capital Cost)
Contingency	25%
Testing	15%
Operations and Maintenance	
Spare parts	5%
Maintenance Support (Year 1)	$50,000.00

Shea Stadium's (Queens, NY) Parking Guidance System

The Shea Stadium is the baseball ground for the Mets that is located on the Northern side of the Flushing Meadows Corona Park, south of Flushing Bay in the Borough of Queens. Currently, no parking information system exists for the Shea Stadium. This creates problems during the baseball season. In addition, parking areas around the Shea Stadium act as P&R facilities for those driving to the area and then using transit to get to work (e.g. NY City). There are several parking facilities surrounding the stadium and nearby facilities (National Tennis Center, New York Hall of Science and Technology, Queens Museum of Art, Queens Zoo/Wildlife Center, and picnic areas and playgrounds).

The main problem in the Shea Stadium area arises at the entrances and exits of the various parking facilities. Currently the NYPD facilitates the traffic circulation at various intersections and locations in the area. As part of an effort to reduce the burden on the NYPD and to provide parking information to the motorists and to further promote the P&R program, a PGS system was proposed. This PGS system is envisioned to alleviate some of the congestion associated with parking that is further exacerbated during baseball games and the tennis US Open. The cost estimation for a PGS in the area around the Shea Stadium is given in Table 11 [29].

Table 11. Cost Estimate for PGS System at the Shea Stadium, NY [29].

Item description	**Unit Cost**
CCTV	$27,000.00
Remote Traffic Microwave Sensor	$5,000.00
Loop detector & Entrance Gate Counter	$6,000.00
Computer Work station	$3,000.00
Electronic Variable Message Signs(VMS)	$80,000.00
Installation of Electronic VMS	$15,000.00
Portable VMS	$30,000.00
Static sign/Trailblazer	$1,000.00
Traffic Management Center Terminations	$50,000.00
System Software Development	$75,000.00
Conduit & Fiber Optic (linear feet)	$20.00
Conduit & Fiber Optic (per unit)	$30,000.00
T-1 line	$2,000.00
Modem, etc	$25,000.00
Design and Testing	
Planning & Design	$100,000.00
Operations and Maintenance	
Training, Documentation, Staffing, etc.	$100,000.00
Miscellaneous	$50,000.00

APPENDIX C. PARKING RESERVATION SYSTEMS (PRS)

This appendix provides an example of the deterministic PRS formulation, a proof that the solutions of this mathematical formulation are integer and the formulation of the corresponding stochastic problem.

Deterministic PRS Example

For illustration purposes we consider a trivial example with 4 vehicles, 3 parking lots, and 3 time periods. Vehicles 1 and 2 arrive in time period 1. Vehicles 3 and 4 arrive in time interval 2. Vehicle 2 departs during time period 2 and vehicles 1, 3 and 4 depart in time period 3. We further assume that there is an associated cost matrix (cij) where *i* = 1, …,4 and *j* = 1, …,3,

$$C = \left(c_{ij}\right) = \begin{pmatrix} 1\,2\,3 \\ 2\,2\,4 \\ 3\,2\,3 \\ 1\,3\,3 \end{pmatrix}$$

and the corresponding parking capacities are:

z_j where j = 1, 2, 3

(z_j) = (1, 2, 5)

The mathematical formulation for this example is presented below:

$$\begin{aligned} Min(C) = 1x_{111} + 2x_{121} + 3x_{131} + 2x_{211} + 2x_{221} + \\ 4x_{231} + 3x_{312} + 2x_{322} + 3x_{332} + 1x_{412} + 3x_{422} + 3x_{432} \end{aligned}$$

Subject to:

$x_{ijk} = (1 \text{ or } 0);$ binary variables

$$x_{111} + x_{121} + x_{131} = 1$$
$$x_{211} + x_{221} + x_{231} = 1$$

$$x_{111} + x_{211} \leq 1$$
$$x_{121} + x_{221} \leq 2$$
$$x_{131} + x_{231} \leq 5$$

$$x_{312} + x_{322} + x_{332} = 1$$
$$x_{412} + x_{422} + x_{432} = 1$$

Since vehicle 2 has departed the corresponding capacity constraints are as follows:

$$x_{111} + x_{312} + x_{412} \leq 1$$
$$x_{121} + x_{322} + x_{422} \leq 2$$
$$x_{131} + x_{332} + x_{432} \leq 5$$

For time period 3, no vehicles arrive therefore no assignment constraints exist. Consequently, since all vehicles depart at time period 3, then no capacity constraints are necessary. The optimal solution to this example yields a total parking cost (min C = 7 cost units), with the following vehicle assignments:

$$x_{121} = x_{221} = x_{322} = x_{412} = 1$$

As an example, x_{412} = 1 means that vehicle 4 is assigned to parking lot 1 at time period 2. Another optimal solution is the following:

$$x_{121} = x_{211} = x_{322} = x_{412} = 1$$

Vehicle 2 is assigned to parking lot 1 instead of parking lot 2, as in the previous optimal solution. It is noted that the cost for vehicle 2 to park either at parking lot 1 or 2 is the same. Since the simplex algorithm always finds solutions at the vertices, the solutions generated are guaranteed to be integer. In general, this mathematical formulation is expected to yield multiple optimal solutions subject to the different combinations of the objective function coefficients. In such cases, the solution to be generated can be chosen arbitrarily or according to some rules that the parking system operator decides.

Deterministic PRS Integer Solution Proof

In order to prove that the above mathematical formulation has an integer solution, we have to show that the constraint matrix is totally unimodular [45, 46, 47]. The PRS Integer Linear Problem (PRSILP) is transformed into an equality constrained problem by introducing a set of slack variables s_i where *i = 1, ….,6 are all* ≥ 0. We then express the constraint conditions as a system of linear algebraic equations of the form $Ax = b$, where A is a 10×18 matrix.

$$
\left|\begin{array}{cccccccccccc|cccccc}
1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\hline
1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\
\hline
0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
\hline
1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\
0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 1
\end{array}\right|
\left|\begin{array}{c}
x_{111} \\ x_{121} \\ x_{131} \\ x_{211} \\ x_{221} \\ x_{231} \\ x_{312} \\ x_{322} \\ x_{332} \\ x_{412} \\ x_{422} \\ x_{432} \\ s_1 \\ s_2 \\ s_3 \\ s_4 \\ s_5 \\ s_6
\end{array}\right|
=
\left|\begin{array}{c}
1 \\ 1 \\ z_1 \\ z_2 \\ z_3 \\ 1 \\ 1 \\ z_1 \\ z_2 \\ z_3
\end{array}\right|
$$

The above matrix is manipulated through row operations and transformed into the following equivalent system:

$$
\left|\begin{array}{cccccccccccc|cccccc}
1&1&1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&1&1&1&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&1&1&1&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&1&1&1&0&0&0&0&0&0\\
\hline
1&0&0&1&0&0&0&0&0&0&0&0&1&0&0&0&0&0\\
0&1&0&0&1&0&0&0&0&0&0&0&0&1&0&0&0&0\\
0&0&1&0&0&1&0&0&0&0&0&0&0&0&1&0&0&0\\
\hline
1&0&0&0&0&0&1&0&0&1&0&0&0&0&0&1&0&0\\
0&1&0&0&0&0&0&1&0&0&1&0&0&0&0&0&1&0\\
0&0&1&0&0&0&0&0&1&0&0&1&0&0&0&0&0&1
\end{array}\right|
\left|\begin{array}{c}
x_{111}\\ x_{121}\\ x_{131}\\ x_{211}\\ x_{221}\\ x_{231}\\ x_{312}\\ x_{322}\\ x_{332}\\ x_{412}\\ x_{422}\\ x_{432}\\ s_1\\ s_2\\ s_3\\ s_4\\ s_5\\ s_6
\end{array}\right|
=
\left|\begin{array}{c}
1\\ 1\\ 1\\ 1\\ z_1\\ z_2\\ z_3\\ z_1\\ z_2\\ z_3
\end{array}\right|
$$

Since the total objective function cost C is a linear functional, the minimum occurs on the vertices, edges, or faces of the polytope $\{x | Ax = b\}$. The vertices are obtained by setting 8 out of the 18 variables to zero and solving for the remaining 10 variables. In order to show that this problem is well posed, we must show that the components of the vertices of the polytope are nonnegative integers. This is equivalent to showing A is totally unimodular (TUM), i.e. every square nonsingular sub-matrix *B* of *A* of maximal rank has determinant equal to $\pm$ 1. Then by Cramer's rule, the nonzero variables *x* can be expressed as $x = \frac{AdjBb}{\det B}$ (45). Then the *x* is integer valued. Note, the constraint matrix A is of the form,

$$
\left[\begin{array}{cccccccccccc|c}
1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \\
0 & 0 & 0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0_{4x6} \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 0 & 0 & 0 & \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & \\
\hline
 & & & & & * & & & & & & & I_{6x6}
\end{array}\right]
\left[\begin{array}{c}
x_{111} \\ x_{121} \\ x_{131} \\ x_{211} \\ x_{221} \\ x_{231} \\ x_{312} \\ x_{322} \\ x_{332} \\ x_{412} \\ x_{422} \\ x_{432} \\ s_1 \\ s_2 \\ s_3 \\ s_4 \\ s_5 \\ s_6
\end{array}\right]
=
\left[\begin{array}{c}
1 \\ 1 \\ 1 \\ 1 \\ z_1 \\ z_2 \\ z_3 \\ z_1 \\ z_2 \\ z_3
\end{array}\right]
$$

Case 1. The parking lot capacities z_k are large, indicating that all slack variables are $>$ 0. We must find all 10×10 nonsingular matrices and show their determinants are equal to $\pm$ 1. However, it is easier to notice that all these constraints can be dropped out of the constraint matrix, yielding a constraint matrix that contains only the upper left part. Then this part can be shown to have a network form by adding all the rows and thus creating two entries per column. Therefore it is guaranteed to yield integer solutions. These integer solutions are also constrained to be binary due to the assignment equality constraints that have a value of 1.

Case 2. At least one of the slack variables is zero (implying that the corresponding parking lot is full). As an example we assume that $s_1=0$, implying that parking lot 1 is full. We can then eliminate the 13^{th} column, yielding the following configuration:

$$
\left|\begin{array}{ccc:ccc:ccc:ccc|c}
1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \\
0 & 0 & 0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0_{5x5} \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 0 & 0 & 0 & \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & \\
\hline
1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \\
\hdashline
\multicolumn{12}{c:}{*} & I_{5x5}
\end{array}\right|
\left|\begin{array}{c}
x_{111} \\ x_{121} \\ x_{131} \\ x_{211} \\ x_{221} \\ x_{231} \\ x_{312} \\ x_{322} \\ x_{332} \\ x_{412} \\ x_{422} \\ x_{432} \\ s_2 \\ s_3 \\ s_4 \\ s_5 \\ s_6
\end{array}\right|
=
\left|\begin{array}{c}
1 \\ 1 \\ 1 \\ 1 \\ z_1 \\ z_2 \\ z_3 \\ z_1 \\ z_2 \\ z_3
\end{array}\right|
$$

In this case we need to choose 5 columns from the upper left matrix (the upper left matrix is comprised of the four blocks, which are delineated with dotted lines in the above diagram). It can be shown that if a block is omitted entirely from the solution then the corresponding determinant is zero, implying an infeasible solution. It can also be shown that if only one column is chosen from each block then the corresponding matrix will have a $\pm$ 1 determinant.

Finally, taking all combinations, we find that nonsingular matrices have determinant $\pm$ 1. In case more than one slack variable is zero a similar procedure is followed that may be shown to yield similar results. In combination with the assignment constraints that force the *x* to have values less than one, then it can be concluded that the solution to this integer linear program (LP) will yield binary solutions.

The problem can be generalized to *I* cars, *J* parking lots and *K* time intervals, yielding

$$\min \sum_{i,j,k} c_{ijk} x_{ijk}$$

$$\text{subject to } Ax = b$$

Where, after rearranging the rows we have:

$$
\begin{bmatrix}
1\ldots1 & 0\ldots0 & 0\ldots0 & 0\ldots0 & \\
0\ldots0 & 1\ldots1 & \ldots & \ldots & \\
\ldots & 0\ldots0 & \ldots & \ldots & \\
\ldots & \ldots & \ldots & \ldots & 0_{Ix(JxK)} \\
\ldots & \ldots & \ldots & \ldots & \\
\ldots & \ldots & \ldots & \ldots & \\
0\ldots0 & 0\ldots0 & 0\ldots0 & 1\ldots1 & \\
\hline
 & * & & & I_{(JxK)x(JxK)}
\end{bmatrix}
\begin{bmatrix}
x_{111} \\ x_{121} \\ . \\ . \\ . \\ . \\ . \\ . \\ . \\ . \\ . \\ . \\ . \\ x_{IJK} \\ s_1 \\ s_2 \\ . \\ . \\ s_J
\end{bmatrix}
=
\begin{bmatrix}
1 \\ . \\ . \\ 1_I \\ z_1 \\ z_2 \\ . \\ . \\ z_J \\ . \\ . \\ . \\ . \\ . \\ z_1 \\ z_2 \\ . \\ . \\ z_J
\end{bmatrix}
$$

Similarly in order to show that the problem is well posed, we need to show that the constraint matrix *A* is TUM, which can be accomplished in a similar manner.

PRS Stochastic Model Formulation

The assumption that each vehicle arrives and departs during a pre-specified time period is now relaxed. Each vehicle is assumed to arrive/depart according to a probabilistic arrival/departure distribution that is specific to each vehicle. It is further assumed that for each vehicle, the expected arrival time period is known a priori, and the arrival and departure distributions are further apart such that there is no overlap. Each driver arrives and departs with a probability distribution $f_a(t)$ and $f_d(t)$, respectively with no overlap.

Let

$$p_{ij} = \int_{t_{j-1}}^{t_j} f_a(t)dt$$

$$q_{ik} = \int_{t_{k-1}}^{t_k} f_d(t)dt$$

Where:

p_{ij} = probability that driver *i* arrives at the *jth* time period and

q_{ik} = probability that driver *i* departs at the *kth* time period and $j < k$

Note that $\sum_j p_{ij} = 1$ and $\sum_k q_{ik} = 1$

Example: Two vehicles are subscribers to the PRS system.

- Vehicle-1 is expected to arrive at periods 1and 2 with probabilities p_{11} and p_{12}, respectively. The corresponding expected departure probabilities for vehicle-1are q_{14}, q_{15} and q_{16} assuming that it may depart during time periods 4, 5 and 6, respectively. Then we have $p_{11} + p_{12} = 1$ and $q_{14} + q_{15} + q_{16} = 1$ for the arrival and departure probability distributions of vehicle-1, respectively.

- Vehicle-2 is expected to arrive at periods 2 and 3 with probabilities p_{22} and p_{23}, respectively. The corresponding expected departure probabilities for vehicle-2 are q_{24}, and q_{25} assuming that it may depart during time periods 4, and 5 respectively. Then we have $p_{22} + p_{23} = 1$ and $q_{24} + q_{25} = 1$ for the arrival and departure probability distributions of vehicle-2, respectively.

Combining these scenarios we have a total of 10 probabilities of occurrence, two of which are:

- *Occurrence 1:* Vehicle-1 arrives at period 1 and leaves at time period 5*;* the corresponding probability of occurrence is $p_{11}\, q_{15}$.

- *Occurrence 2:* Vehicle-1 arrives at period 2 and leaves at time period 5; the corresponding probability of occurrence is $p_{12}\, q_{15}$.

Similarly we can identify all 10 possibilities. One way to approach this problem is to minimize the expected total cost *E(c)* that leads to the following linear programming formulation.

$$\min E(c) = \sum_{\text{all possible scenarios}} \left\{ \left(\sum_{ijk} c_{ijk} x_{ijk} \right) (\text{joint probability of occurence}) \right\}$$

$$\text{Subject to}: \sum_{\text{j}} x_{ijk} = 1 \text{ for each scenario, each car } i \text{ and time period } k$$

$(\text{\# of cars in the parking lot}) + (\text{\# of cars assigned}) - (\text{\# of cars that are leaving}) \leq z_j$ for each parking lot j.

The above mathematical problem is very similar to the deterministic one described earlier. The principal difficulty arises from the large number of constraints that are generated and the corresponding objective function. Therefore, as the number of vehicles increase, the problem size increases exponentially. Both formulations can be shown to produce integer solutions since it can be proven that the corresponding constraint matrices are totally unimodular. Test runs of the deterministic mathematical formulation using the CPLEX software indicated that randomly generated problems with 10000 vehicles, 12 time periods and 10 parking lots can be solved within 20 seconds of clock time. These results give us confidence that the problem can be solved in real-time and hence it could be part of an on-line parking reservation system. Although the probabilistic mathematical formulation is expected to yield a much larger objective function due to the number of variables, it can reasonably be concluded that also for that case reasonable execution times can be obtained. The above mathematical formulations are expected to yield multiple solutions that are based on the similarities in the cost coefficients of the variables in the objective function. The system operator may want to solve the problem as many times as possible and select the best solution according to his/her criteria.

APPENDIX D. WEB-BASED PRS

This appendix presents the PRS mark-up language developed and an example for the Web-PRS system using the NJIT parking facilities.

Web-based Parking Reservation System[3]

A web-based parking reservation system was implemented by integrating the deterministic PRS algorithm described in the preceding section with the TIDE center's web server. The principal characteristics of this system are described in the following section. Also included is a case study developed for the NJIT campus area.

An associated model could work as well for a geographic area involving a number of P&R facilities. The principal difference would be the estimation of the cost coefficients in the objective function. This cost would include the shortest path travel time from each user's origin to each P&R facility of interest and the associated parking fee.

Model Solver

The linear programming solver ILOG CPLEX is used to solve the deterministic model. The ILOG CPLEX delivers high-performance, robust, flexible optimizers for solving linear, mixed-integer and quadratic programming problems in mission-critical resource allocation applications [(53)].

ILOG CPLEX Suite consists of the following components:

- CPLEX Simplex Optimizers
- CPLEX Mixed Integer Optimizer
- CPLEX Barrier Optimizer

CPLEX accepts the following methods of representing a mathematical programming problem:

- A text file, using CPLEX LP Format or industry standard MPS format
- ILOG Concert Technology, using modeling objects and algebraic expressions in C++ or Java
- Sparse Matrix representation, using matrix indices

The Web-PRS uses CPLEX Simplex Optimizer as its solver, and its mathematical programming model is represented as a CPLEXModeler object, a Java-Based ILOG Concert Technology modeling object.

---

[3] This system was developed by Dr. Wu Sun (PB Consult, formerly researcher at the TIDE center) with assistance from Drs. K. Mouskos (CCNY-CUNY and TIDE center), D. Bernstein (James Madison University and TIDE) and J. Tavantzis (NJIT and TIDE).

The ILOG Concert Technology for the Java platform is a class library offering an API with modeling facilities that can be used to embed CPLEX optimizers in a java application. The Concert Technology classes for CPLEX are implemented using Java Native Interfaces (JNI). On Windows system, this library is called cplex75.dll [53].

To use the CPLEX Java interfaces, ilog.concert.* and ilog.cplex.* packages need to be imported into the application. The first task is to create an IloCplex object. The Interface functions for doing so are defined by the Concert Technology interface IloModeler and its extension IloMPModeler. In the CPLEXModeler object of Web-PRS, methods objGenerator(), assignmentConstraintsGenerator(), and capacityConstraintsGenerator() are designed for constructing objective function, assignment constraints and capacity constraints, respectively. After a model has been created, the IloCplex object is ready to solve the model. Invoking the optimizer is as simple as calling method solve(). Method solve() returns a Boolean indicating whether the optimization succeeded in finding a solution. More precise information about the outcome may be obtained by calling: IlogCplex.getStatus(). The objective value of that solution can be queried using method: Double lbjval=cplex.getObjValue(). Solution values for all the decision variables may be queried by calling: Double [] xval=cplex.getValues ().

System Design

The Web-PRS was designed using UML, a modeling language for OO analysis and design. By highlighting important details in a concise and clear fashion, UML helps to achieve better communication and OO analysis [49]. The major UML techniques used in the Web-PRS are use cases, class diagrams, sequence diagrams, and state diagrams. To limit the length of this paper, use cases have been omitted in this paper.

The Web-PRS is designed for two types of users, subscribers and non-subscribers. Subscribers are registered users and their information is stored in configuration XML files. Non-subscribers are users not registered with the Web-PRS. Non-subscriber information, including parking patterns, is collected on a one-time basis for temporary use. The major functionality of Web-PRS is to provide subscribers and non-subscribers an interactive tool for making parking reservations online. The user specifies the time period of arrival and departure. The system then assigns a parking space to them, either directly on the screen, or through a notification to their e-mail account or both. Furthermore, the system produces the shortest walking path from the assigned parking lot to the user’s desired destination.

Architecture

The Web-PRS is a multi-tier system, including front end JSPs (JavaServer Pages), Servlet controller, CPLEX handler, and XML (Extensible Markup Languages) files. The front-end JSPs provide a group of interfaces to collect user-entered information. The Servlet controller is used to control page transitions and pass data between front end and CPLEX handler and XML files. The CPLEX handler is a wrapper of an ILOG Concert Technology-Based Java object used to represent and solve the parking reservation model. The system configuration files are written as XML files and store subscriber information, parking facility information, and model parameters of the PRS. Using XML files to store system configuration files increases the portability of the Web-PRS.

Class Diagrams

A class diagram describes the types of objects in the system and the various kinds of static relationships that exist among them. There are two principal kinds of static relationships, subtype and association. Associations represent relationships between instances of classes. Class diagrams also show the attributes and operations of a class and the constraints that apply to the way objects are connected [(49)]. Web-PRS consists of three major classes: FrontEndController, PRSMetaDataHome, and CPLEXHandler.

FrontEndController

A *FrontEndController* object contains a vector of SubscriberRequest objects, a vector of NonSubscriberRequest objects, a vector of Login objects, a PRSMetaDataHome object, a User Data object, and a PRSImageResult object. The PRSMetaHome object is instantiated during FrontEndController initialization. When FrontEndController detects that a user request is complete, it instantiates a CPLEXHandler object, which will be used to represent and solve the parking reservation model. The parking assignment result is delivered to the user in three formats, online text result, online graphic result, and result via Email. The graphic result is a graphics interchange format (GIF) file stored on the server's hard disk. The FrontEndController class diagram is presented in Figure 32.

A *SubscriberRequest* object contains an individual subscriber's request, such as name, arrival time, departure time, office addresses etc. A NonSubscriberRequest contains similar information for non-subscribers. A UserData object is a collection of information of users already in the study parking facilities, including user ID assigned when a user request comes in, user in time, and user out time. For the current Web-PRS, it is assumed that in addition to users that come in later, there are already a fixed number of users in the parking facility. The in times and out times of these users are randomly generated.

A *PRSImageResult* object handles the generation of a GIF file. It blends two images together, one image is a map of the study site, and the other image is a path representing the shortest walking distance from the assigned parking lot to users' office building. The study site map is loaded in the application, and converted to an off-screen Image object. The shortest path image is created in the application using network configuration and shortest path information.

CPLEXHandler

A CPLEXHandler is instantiated in FrontEndController. In a CPLEXHandler object three main Java objects are instantiated, they are CPLEXModeler, SPHandler, and EmailHandler. CPLEXHandler class diagram is presented in Figure 33.

A *CPLEXModeler* object contains methods to construct a mathematical model in a format that can be solved using ILOG CPLEX. EmailHandler object handles sending parking assignments as an email message to users. The Web-PRS runs Dijkstra's shortest path algorithm to find the shortest path from assigned parking lot to user's destination. In Web-PRS, a Dijkstra object is used to implement the shortest path algorithm. The SPHandler object is a wrapper of the Dijkstra object. Each office building or parking lot is represented as a node, and is implemented as a Java object NetNode. CheckedNodeSet and NotCheckedNodeSet are two node sets composed of a vector of NetNode objects, representing checked nodes and non-checked nodes respectively.

PRSMetaDataHome

A PRSMetaDataHome object contains Web-PRS system configuration data. A PRSMetaDataHome object has several Java object data members, including a vector of MetaDropDownMenu objects, a vector of MetaParkingLot objects, a MetaParameters object, a MetaNetwork object, and a vector of MetaSubscriber objects. A MetaParameters object includes a MetaDistribution object. A MetaNetwork object is composed of a number of MetaArc objects. A MetDropDownMenu object contains the content of a drop down menu on JSPs. Using MetaDropDownMenu objects on a JSP can avoid hard-coding of item names in a menu, and enforce unity of menus used on different JSPs. PRSMetaDataHome class diagram is presented in Figure 34.

Sequence Diagram

Interaction diagrams are models that describe how groups of objects collaborate in some behavior [49]. Sequence diagrams are one of two major types of interaction diagrams.

The FrontEndController converts user entered information to SubscriberRequest and NonSubscriberRequest objects, and then pass them, together with system configuration information stored in PRSMetaDataHome object, to CPLEXHandler. SubscriberRequest and NonSubscriberRequest objects contain user requests collected from front-end JSPs. A sequence diagram is presented in 6.

State Diagram

State diagrams describe all of the possible states that a particular object can get into and how the object's state changes, as a result of events that reach the object. State diagrams are drawn for a single class to show the lifetime behavior of a single object [49].

The FrontEndController is loaded (instantiated and have its init() called) on the startup of the Web-PRS, using a load-on-startup tag in the web.xml configuration file of Web-PRS.

The content of this tag is assigned a value 0, indicting FrontEndController has the top loading priority. The JSP/Servlet container must guarantee that the servlets marked with lower integers are loaded before servlets marked with higher integers [50].

A servlet is only loaded once initially and then services requests in multiple servlet container threads [51]. The initialization of a servlet is done in the init() method of the servlet. Before requests are serviced, it is recommended that certain operations, such as loading persistent data, need to be included in servlet initialization. The initialization of the FrontEndController includes loading the Web-PRS configuration XML file and instantiating a PRSMetaDataHome object.

Each time a JSP request comes in, the name of the JSP page is passed in to FrontEndController, and an action takes place accordingly. The action could be simply a transition from one page to another page, or, it could be a more complicated process of generating a SubscriberRequest object, a NonSubscriberRequest object, or a Login object using information wrapped in the JSP request. SubscriberRequest and NonSubscriberRequest are exclusive to each other. In no circumstance, for the same user, will these two exist at the same time. The major function performed in the Login object is to validate whether a user name and password pair match. For a Web-PRS user, parking reservation results are generated in a CPLEXHandler object, and can only be generated after both a Login object and a SubscriberRequest or a NonSubscriberRequest object have already existed. Since the FrondEndController is multithreaded and JSP requests from different users may intermix, session ID of each JSP request is used as the key in matching user objects, namely Login, SubscriberRequest and NonSubscriberRequest objects. These three types of objects are stored in three corresponding vectors, which are checked by the readyToCreateResult() method to see if parking reservation results should be generated for the user represented by a given session ID. The state diagram of the FrontEndController is presented in Figure 35.

Miscellaneous Issues

Image Blending

To generate a graphic parking reservation result, two images need to be blended together. The first image, a study site map is loaded and converted to an off-screen Image object in the application. The second image, a shortest path off-screen image, is created in the application.

A straightforward way of creating an Image object is by using a java.awt.image.MemoryImageSource object and creating an Image object for it with java.awt.Toolkit's createImage(ImageProducer) method [51]. However, in order to take advantage of the high-level AWT (Abstract Windowing Toolkit) graphic methods, a Frame object is created and then connected to AWT toolkit by calling its addNotify() method [51]. This Frame object can be used to obtain an off-screen image with full AWT support.

The Java 2D API provides support for the blending of multiple images through what are known as Porter-Duff rules [55]. The rules describe how to combine the contents of multiple images when one image is drawn on top of the other. Within the Java 2D API, the blending rules are supported by the `AlphaComposite` class. The class provides twelve constants, one for each rule [56].

Finally, the blended off-screen Image object is encoded as a binary stream in GIF format, which is understood by the browser. A free encoder package, Acme.JPM.Encoders.GifEncoder [54], is available on the Internet. Using this package, it takes only a few lines of code to save an Image object to the hard drive as a GIF file.

Send Parking Reservation Results via Email

In order to provide email functionality programmatically, we need to use JavaMail APIs. A transport is Sun's term for a service that has the capability to send messages to its destinations, and a store is a service to retrieve messages delivered to a mailbox through other user's transports [51]. The widely used transport protocol is the Simple Mail Transfer Protocol (SMTP), and the widely used store protocols are Post Office Protocol 3 (POP3) and Internet Message Access Protocol (IMAP). JavaMail APIs provides communication using these protocols. It is necessary to include both JavaMail API implementation and JavaBean Activation Framework (JAF) in the Web-Inf/lib directory, because JavaMail Messages depend on JAF. In the test example of Web-PRS, SMTP mail host of Web-PRS is set to mailhost.njit.edu.

System Data Structure

There are five types of configuration data in Web-PRS, the subscriber data, drop down menu data, parking lot data, network data, and system parameters. Each registered subscriber has a profile in the system, containing information from the subscriber's arrival and departure patterns to other personal information such as user name, password, address, etc.. Drop down menu data contains the contents of drop down menus on JSPs. Parking lot data describes the capacity, cost, and other information of all the study parking lots in the system. The configurations of the end network are described by the network data. System parameters critical to a Web-PRS include the type of the parking reservation model on which the Web-PRS is based, the type of shortest path algorithm which is used to calculate the path from the assigned parking lot to the destination, and the statistical distribution types of user arrival and departure times when the parking reservation model is stochastic.

Due to its hierarchical, easily processed, easily read, and stylable nature, XML is quickly becoming the standard of data interchange on the Internet. A configuration XML file, named as Parking Reservation Markup Language, is used in the Web-PRS to store all the above-mentioned five data types.

Parking Reservation Markup Language (PRML)

PRML, an XML application, is designed to specify the data format for exchange of parking reservation system information over the Internet. A sample PRML is presented in the next section with element descriptions attached. For simplicity reasons, the inner most elements are not closed. Elements enclosed in brackets are optional repetitive elements.

<webprsconfig>	root element
<subscribers>	encloses all subscribers of Web-PRS
<subscriber>	encloses one subscriber
<name>	subscriber name
<password>	password used to access Web-PRS
<email>	subscriber Email
<tel>	subscriber telephone number
<homeaddress>	subscriber home address
<officeaddress>	subscriber office address
<arrivaltime>	subscriber arrival time
<departuretime>	subscriber departure time
<age>	subscriber age
<gender>	subscriber gender
<income>	subscriber annual income
<costtopay>	parking cost subscriber willing to pay
</subscriber>	
[<subscriber>..	
...	
<subscriber>..	
]	
</subscribers>	
<menus>	encloses all drop down menus
<menu>	encloses one drop down menu
<name>	drop down menu name
<noofitems>	number of items in the menu

<item> encloses one item in the menu

[<item>..

...

<item>..

]

</menu>

[<menu>..

...

<menu>..

]

</menus>

<lots> encloses all parking lots

<lot> encloses one parking lot

<number> parking lot number

<capacity> parking lot capacity

<cost> parking cost in the lot

</lot>

[

<lot>..

...

<lot>..

]

</lots>

<network> encloses a parking network

<nodes> encloses all nodes in the network

```
        <node>                          encloses a node in the network
            <number>                    node number
            <x>                         x coordinate of this node
            <y>                         y coordinate of this node
        </node>
        [
        <node>..
        ...
        <node>..
        ]
    </nodes>
    <arcs>                              encloses all arcs in the network
        <arc>                           encloses an arc in the network
            <staringnode>               arc starting node
            <endingnode>                arc ending node
            <length>                    arc length
        </arc>
        [
         <arc>..
         ...
        <arc>..
        ]
    </arcs>
</network>
<modelparameters>                       encloses Web-PRS parameters
```

<type>	parking reservation system type
<distribution>	arrival and departure distributions
<arrival>	arrival distribution
<departure>	departure distribution
</distribution>	
<spalgorithm>	shortest path algorithm type
</modelparameters>	
</webprsconfig>	

PRML Schema

The grammar of PRML is governed by an XML Schema, which is recommended by W3C (world wide web consortium) [52]. The Schema of PRML is presented as following:

```
<?xml version="1.0"?>

<xs:schema xmlns:xs="http://www.w3.org/2001/XMLSchema">

<xs:element name= "webprsconfig" type= "webprsconfigtype"/>

<xs:comlexType name= "webprsconfigtype">

        <xs:all>

                <xs:element name= "subscribers" type= "subscriberstype"/>

                <xs:element name= "menus" type= "menustype"/>

                <xs:element name= "lots" type= "lotstype"/>

                <xs:element name= "network" type= "networktype"/>

                <xs:element name= "modelparameters" type= "modelparameterstype"/>

        </xs:all>

</xs:complexType>

<xs:comlexType name= "subscriberstype">

        <xs:sequence>
```

```
                <xs:element name= “subscriber” type= “subscribertype” maxOccurs=
“unbounded”/>

        </xs:sequence>

</xs:complexType>

<xs:comlexType name= “menustype”>

        <xs:sequence>

                <xs:element name= “menu” type= “menutype” maxOccurs=
“unbounded”/>

        </xs:sequence>

</xs:complexType>

<xs:comlexType name= “lotstype”>

        <xs:sequence>

                <xs:element name= “lot” type= “lottype” maxOccurs= “unbounded”/>

        </xs:sequence>

</xs:complexType>

<xs:comlexType name= “networktype”>

        <xs:sequence>

                <xs:element name= “node” type= “nodetype” maxOccurs= “unbounded”/>

                <xs:element name= “arc” type= “arctype” maxOccurs= “unbounded”/>

        </xs:sequence>

</xs:complexType>

<xs:comlexType name= “parameterstype”>

        <xs:all>

                <xs:element name= “type”>

                        <xs:simpleType>

                                <xs:restriction base= “xs:String”>
```

```
                        <xs:enumeration value= “det”/>
                        <xs:enumeration value= “sto”/>
                        <xs:enumeration value= “dyn”/>
                    </xs:restriction>
                </xs:simpleType>
            </xs:element>
            <xs:element name= “distribution” type= “distributiontype”/>
            <xs:element name= “spaalgorithm”>
                <xs:simpleType>
                    <xs:restriction base= “xs:String”>
                        <xs:enumeration value= “sp1”/>
                        <xs:enumeration value= “sp2”/>
                        <xs:enumeration value= “sp3”/>
                    </xs:restriction>
                </xs:simpleType>
            </xs:element>
        </xs:all>
    </xs:complexType>
    <xs:comlexType name= “subscribertype”>
        <xs:all>
            <xs:element name= “name”>
                <xs:simpleType>
                    <xs:restriction base= “xs:String”>
                        <xs:minLength value= “5”/>
                        <xs:maxLength value= “8”/>
```

```
                                        <xs:pattern value= “[a-zA-Z0-9]”/>
                              </xs:restriction>
                    </xs:simpleType>
          </xs:element>
     </xs:all>
</xs:complexType>
<xs:comlexType name= “menutype”>
     <xs:sequence>
          <xs:element name= “name” type= “xs:String”/>
          <xs:element name= “noofitems” type= “xs:integer”/>
          <xs:element name= “item” type= “xs:String” maxOccurs= “unbounded”/>
     </xs:sequence>
</xs:complexType>
<xs:comlexType name= “lottype”>
     <xs:sequence>
          <xs:element name= “number” type= “xs:String”/>
          <xs:element name= “capacity” type= “xs:integer”/>
          <xs:element name= “cost” type= “xs:decimal”/>
     </xs:sequence>
</xs:complexType>
<xs:comlexType name= “nodetype”>
     <xs:sequence>
          <xs:element name= “number” type= “xs:String”/>
          <xs:element name= “x” type= “xs:integer”/>
          <xs:element name= “y” type= “xs:integer” />
```

```
        </xs:sequence>
</xs:complexType>
<xs:comlexType name= “arctype”>
        <xs:sequence>
                <xs:element name= “startingnode” type= “xs:String”/>
                <xs:element name= “endingnode” type= “xs:String”/>
                <xs:element name= “length” type= “xs:decimal” />
        </xs:sequence>
</xs:complexType>
<xs:comlexType name= “distributiontype”>
        <xs:sequence>
                <xs:element name= “arrival” type= “arrivaldeparturetype”/>
                <xs:element name= “departure” type= “arrivaldeparturetype”/>
        </xs:sequence>
</xs:complexType>
<xs:simpleType name= “arrivaldeparturetype”>
        <xs:restriction base= “xs:String”>
                <xs:enumeration value= “norm”/>
                <xs:enumeration value= “other”/>
        </xs:restriction>
</xs:simpleType>
```

Example

This system has been tested on parking facilities on the campus of New Jersey Institute of Technology (NJIT), Newark, New Jersey. The study parking lots include the parking deck and parking lots 1, 2, 3, 5, 7, 12, and 16. All major intersections and buildings on the campus are represented as nodes in a network, and a Dijkstra’s shortest path algorithm is run on the network. A subscriber logged in with his/her default profile information, and the Web-PRS produces both a text and a graphic result that includes:

arrival time, departure time, assigned parking lot number, and shortest walking path and distance from assigned parking lot to his/her office building. The result is sent to the subscriber via both Internet and Email. This example contains a reasonably large problem with 500 randomly generated users in the parking lots, and an additional user added from Web-PRS user interfaces. The operation time of the parking lots are divided into 12 time periods. The text parking reservation result is presented in Figure 36, and the graphic result is presented in Figure 37.

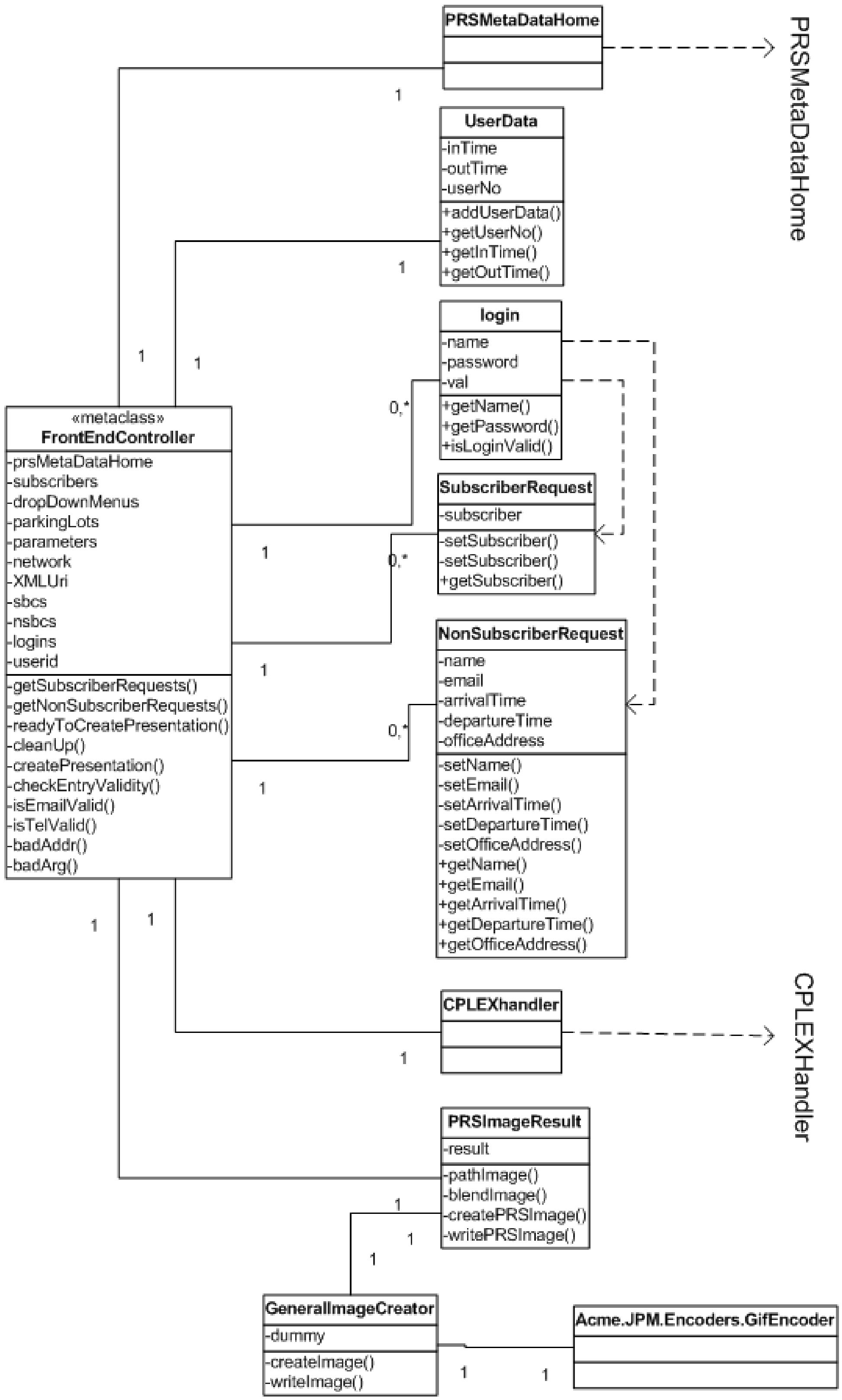


Figure 32. FrontEndController Class Diagram

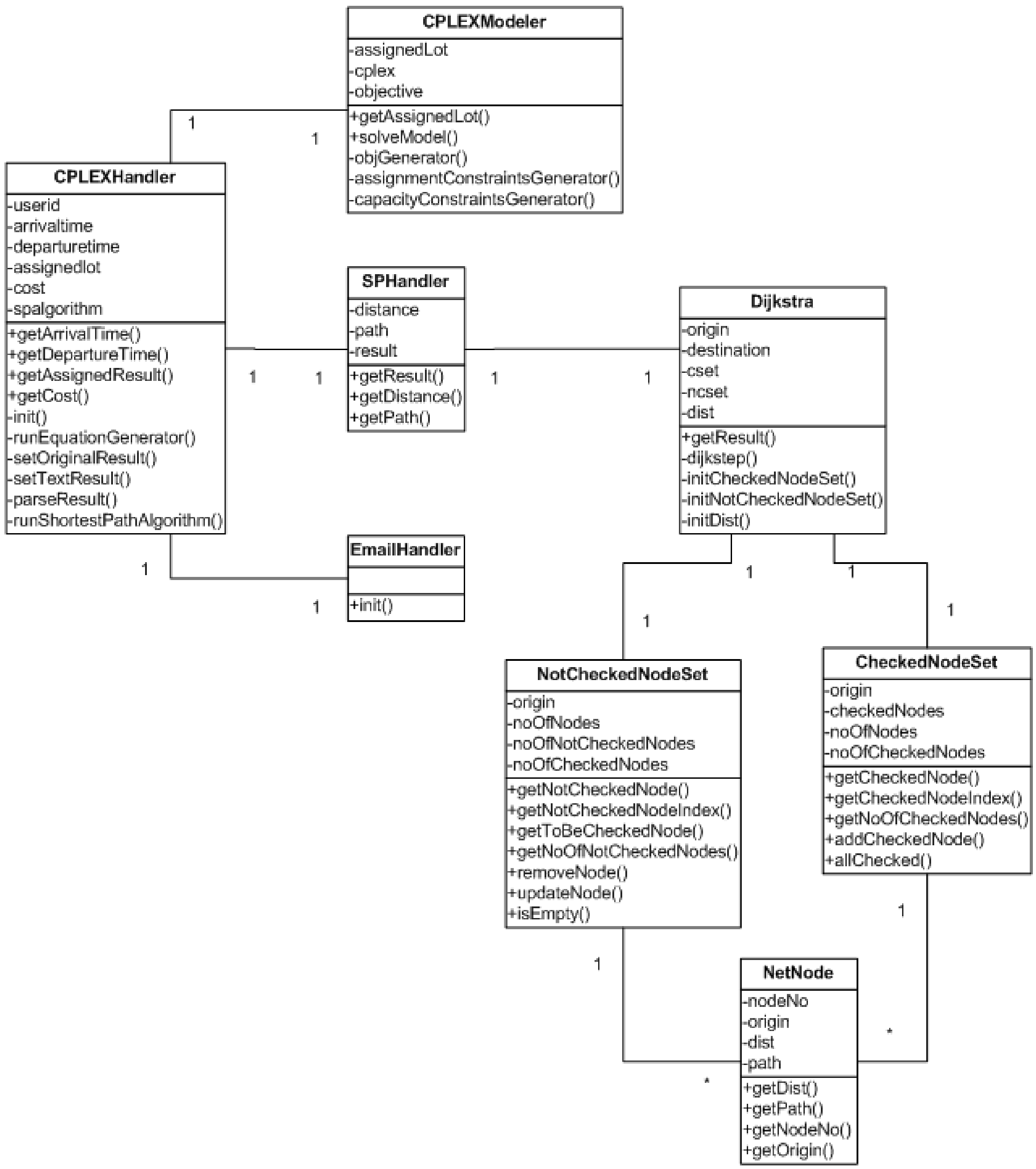


Figure 33. CPLEXHandler Class Diagram

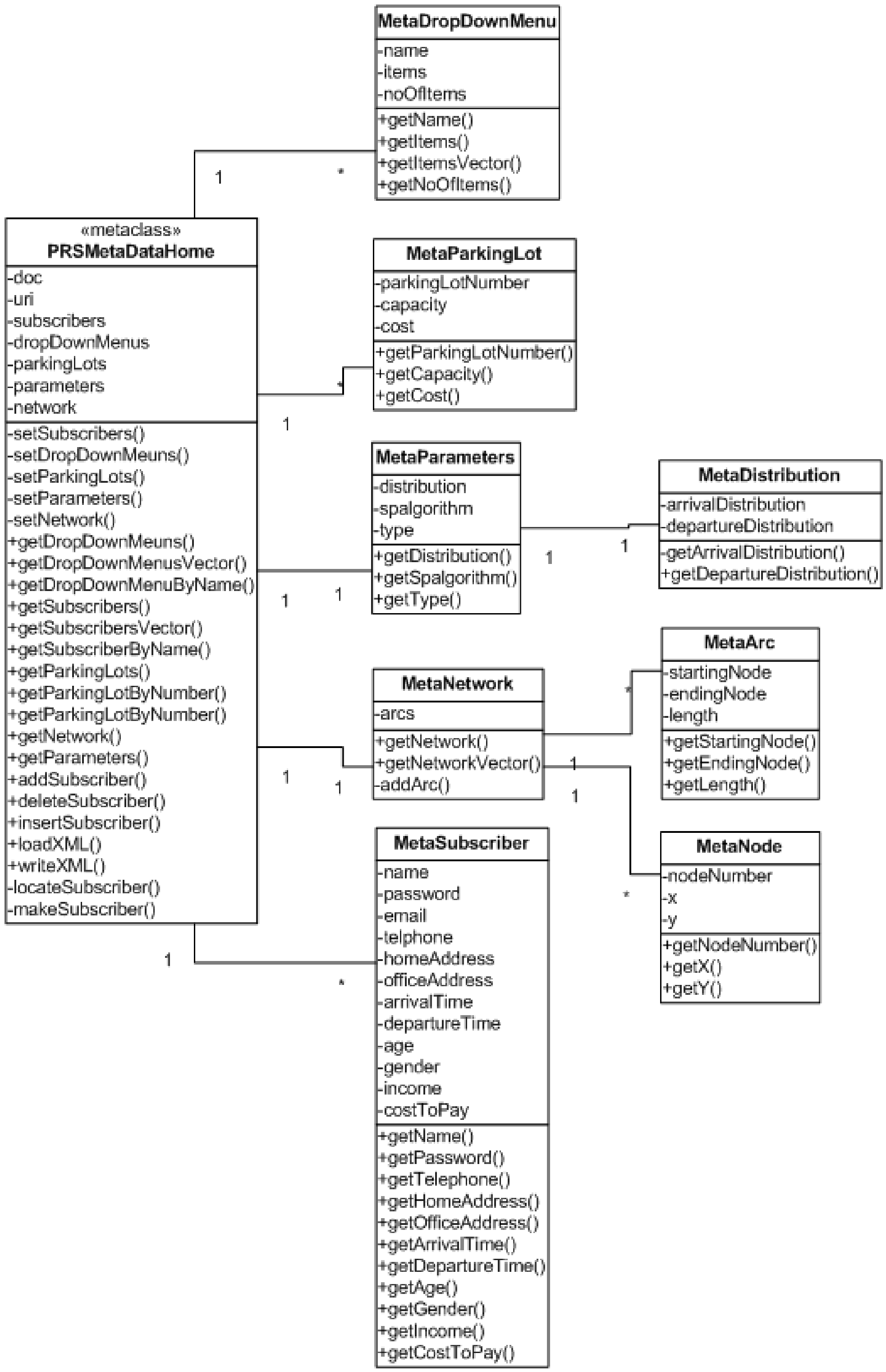


Figure 34. PRSMetaDataHome Class Diagram

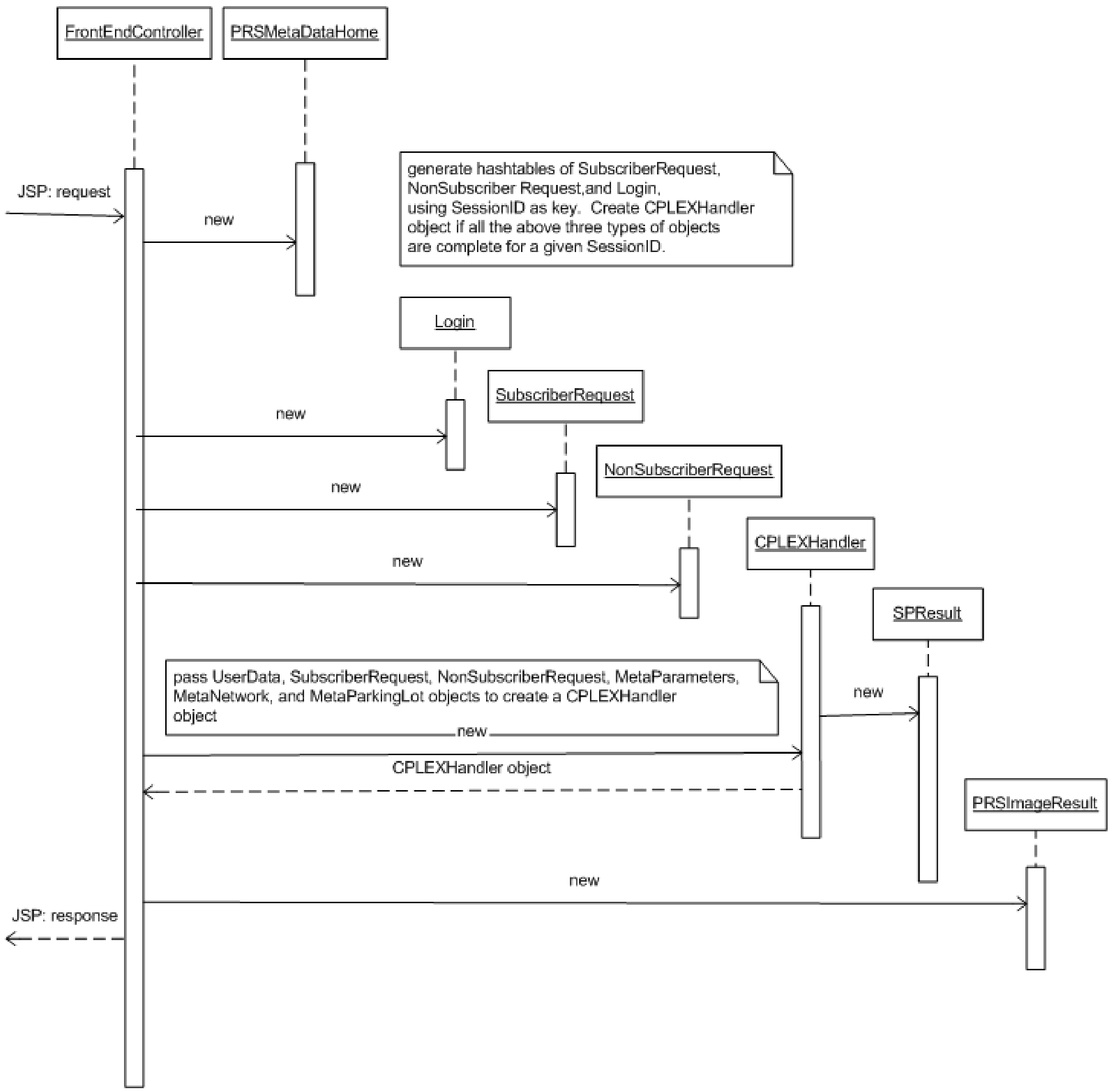


Figure 35. Web-PRS Sequence Diagram

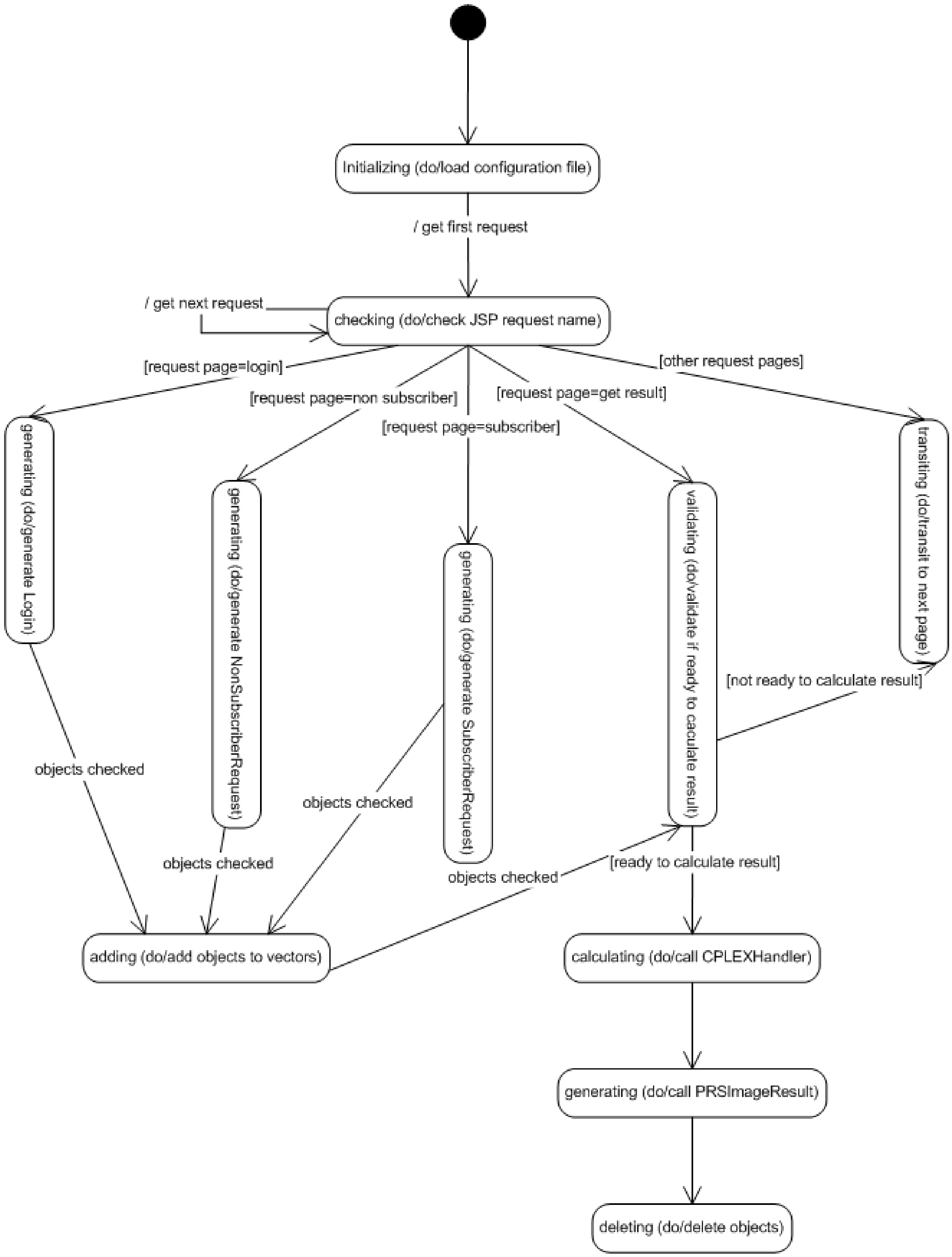


Figure 36. Web-PRS State Diagram

Wu, your parking assignment:

Arrive at: 8:00 am-9:00 am

Departure at: 5:00 pm-6:00 pm

Assigned parking lot: lot 12

Walking distance from the parking lot to your office is: 330.0m.

Please follow the direction below to your destination:

Figure 37. Parking Assignment Result-Text

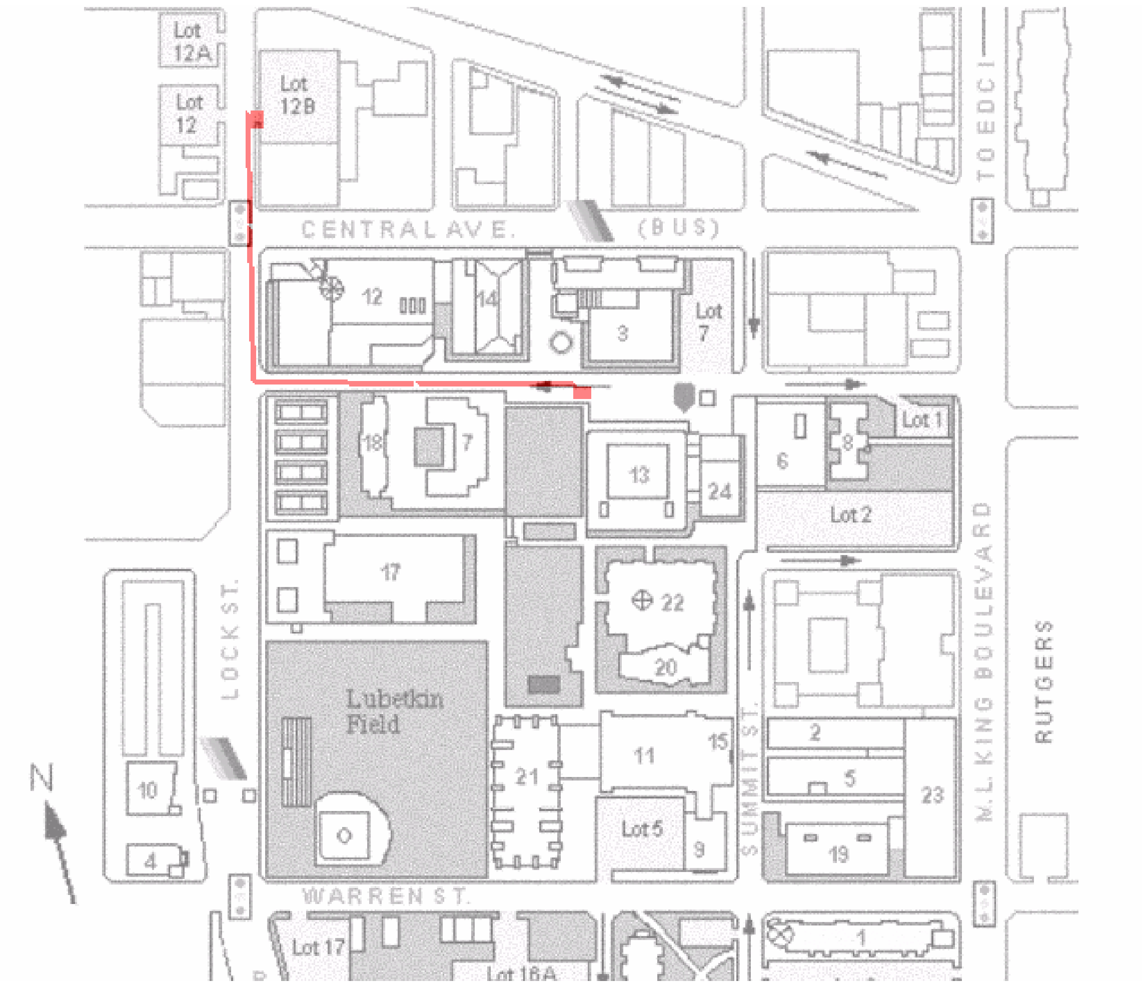


Figure 38. Parking Assignment Result-Graphic

APPENDIX E. MOBILE PARKING ASSISTANCE INFORMATION AND RESERVATION SYSTEM (MPAIRS)

One of the most popular means for messaging is the use of a cellular phone. This is more prominent in Europe and Japan rather than in the United States, where users exchange SMS messages very frequently. It is, at the same time, one of the least expensive ways of sending pertinent traveler information to cell phone users since a substantial number of the population now have a cell phone. Although the information that can be sent is rather limited, it is still sufficient for a substantial number of applications, including parking information and reservation. The specific application addressed in this study is the capability of receiving parking free space information and reserving a parking space.

MPAIRS Components[4]

The principal components of the envisioned MPAIRS are:

Parking Space Detection System

The parking space detection system would be comprised with detectors either at the entrances and exits of each parking lot, at each parking space corridor, detectors at each parking space, transponders in each vehicle, or area wide parking space technologies such as video image processing. Some of these technologies were outlined in Chapter 2.

Parking Communication System

The main components of the MPAIR system include:

- Communication between the parking detection system and the parking operations system.
- Communication between the parking operations systems and the travelers.
- A Parking Operations System.
- Parking Reservation System.
- Parking Space Information System.
- Parking Payment System.

---

[4] This research study was accomplished with the cooperation of the Transportation Information and Decision Engineering Center (TIDE) at NJIT. It was developed by Dr. Wu Sun with assistance from Dr. Mouskos (CCNY-CUNY) and Dr. Bernstein (James Madison University).

The MPAIR System is expected to be connected to a parking space monitoring system, at each parking lot, through a communication system that could be either wired or wireless.

<u>Objectives</u>

The developed cell-based PIRS system was limited to the following applications:

- Get real time-parking information using a cell phone. The user specifies the parking lots of interest and sends the information to the server through an SMS message or e-mail.

- Make parking reservation using a cell phone. The user sends a request to the server by specifying the expected time period of arrival and departure, as well as their name.

MPAIRS Users

- *Cell phone users who are MPAIRS subscribers.*

  Subscribers into the MPAIR system have their own personal profile. The profile consists of the credentials (name), parking preferences such as expected arrival and departure time per day, preferred parking lot, and the associated travel costs to each parking lot. If the subscriber travels to the same destination and time period of the day, then the system will return the reservation based on the user's profile. In other instances, the new destination and characteristics must be input at the time of the request.

- *Other Cell Phone Users.*

  Other cellular users will be required to enter the specific personal and parking related information.

- *Any Other Users Randomly Arriving at Parking Garages.*

  The MPAIR system is envisioned to include a parking forecasting system for people not desiring to reserve a parking space. They simply arrive and leave the facility. The parking forecasting system would be based on both reservation and non-reservation arrivals to first estimate the current parking space availability at each parking lot and then to predict the future expected number of free spaces.

Payment methods for these two types of users (1 and 2) are different. It is noted that the parking payment is not part of the current MPAIRS system, although, it is expected to be included in a future commercial system.

Facilities:

- Parking Garages.

- Swapcard-based Parking Garage Gates.

Computer System:

- Application server (MPAIRS server).
- Swap card machine (a swap card simulator is developed for now).
- Java-Enabled Mobile phones.
- Network connection between swap card machine and application server.
- Wireless network connection between cell phones and application server.

How It Works

Types 1 and 2 Users:

- Use cell phone to start MPAIRS.
- Check if parking spots available.
- Parking info of each garage sent to cell phones.
- Make reservation on cell phone.
- Swap card at garage gate, door opens and vehicle enters garage.
- Vehicle at exit, swap card, gate opens and vehicle exits.

Type 3 Users:

- Vehicle arrives at the garage entrance, swap card, door opens and vehicle enters garage.
- Vehicle at exit, swap card, gate opens and vehicle exits.

Status of a Parking Spot:

- Taken; parking space is occupied.
- Reserved; parking space is reserved for a traveler who is expected to arrive during time period x.
- Available; parking space is free for everyone.

Transition of Parking Spot Status:

- When a type 1 or 2 user makes a reservation, an available spot changes from "Available" to "Reserved";

- When a user swaps card at entrance. If swap card ID matches a user on the reservation list, a spot changes from "Reserved" to "Taken". If swap card ID doesn't match a user on the reservation list and the garage is not full, a spot changes from "Available" to "Taken". Otherwise, if the garage is full, the gate will not open;

- When a user exits, swapping his/her card at the exit gate, a spot status changes from "Taken" to "Available".

Status of a Parking Garage (lot):

- Full: if taken spots+reserved spots = capacity

- Not-full: if taken spots+reserved spots < capacity

MPAIR System Architecture

MPAIRS is a typical client/server application (see Figure 39). On the server side, a Java Servlet running on Apache Tomcat 4.1 container. The server processes the requests from its clients, sends the corresponding response back to its clients, and connects to the database that also resides on the server machine. The database stores user registration and reservation information.

There are two types of clients on the client side, mobile phones and swap-card machines. Mobile phone clients collect user-entered information and send corresponding requests to the server. Swap-card machine clients collect information collected from swap card and send it to the server. A wireless application developed on J2ME platform is installed on mobile phones. A record store acting like a mini database is created on cell phones, which is used to store the cell phone number. A J2SE application is installed on swap card machines (we created a swap card simulator on a desktop).

Communications between cell phones and the server is established via HTTP wireless connection. Communications between swap machines and the server is established via a regular HTTP connection.

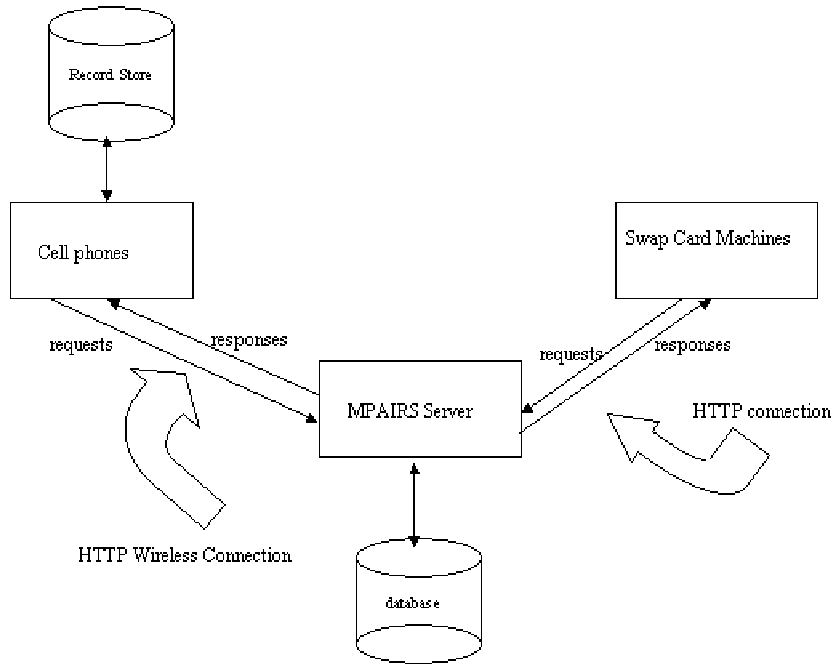


Figure 39. MPAIRS System Architecture

The User Interface between the Cell Phone and the MPAIRS is depicted in Figure 40. The UML diagram is depicted in Figures 41 and 42.

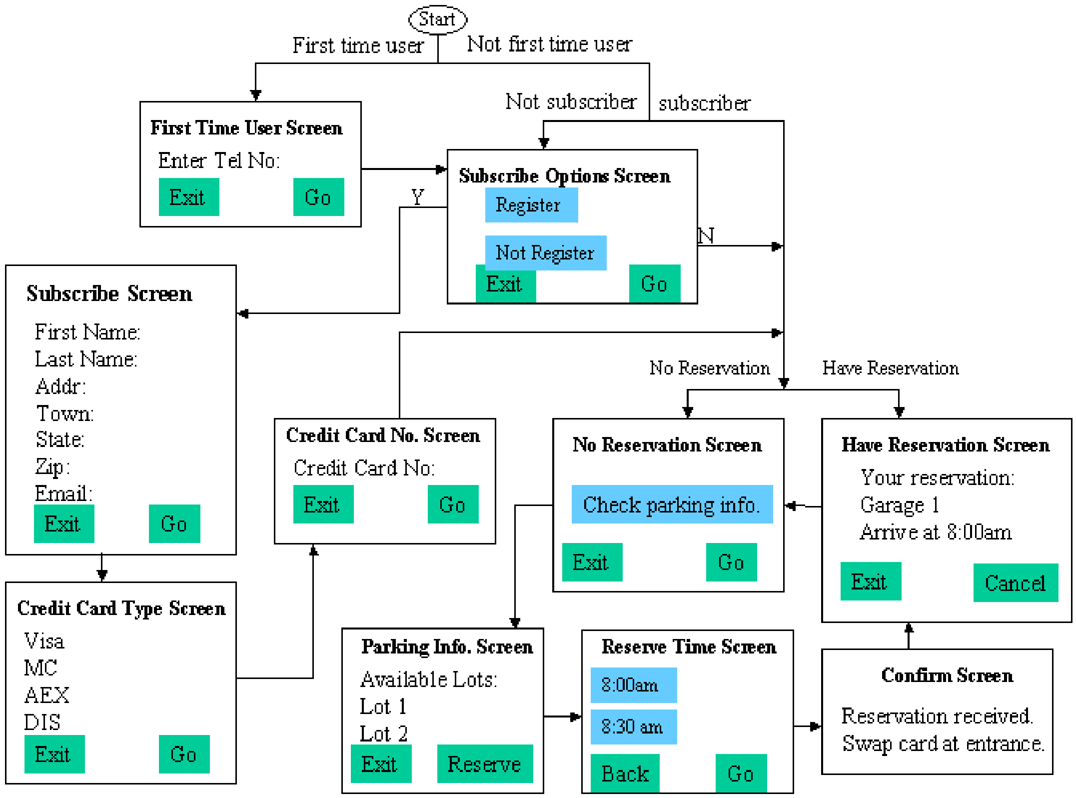


Figure 40. User Interface with the MPAIRS

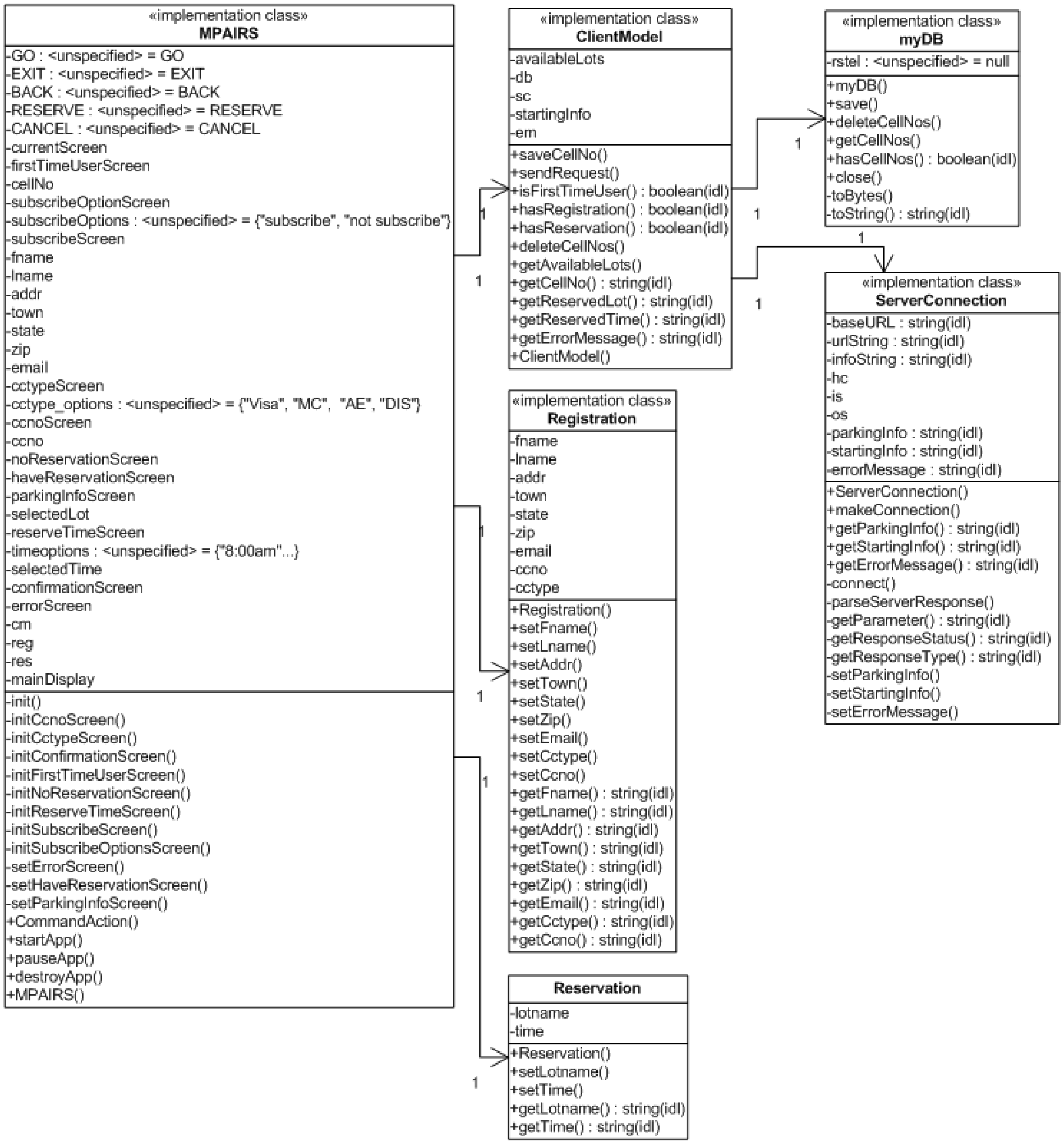


Figure 41. MPAIRS Sequence Diagram

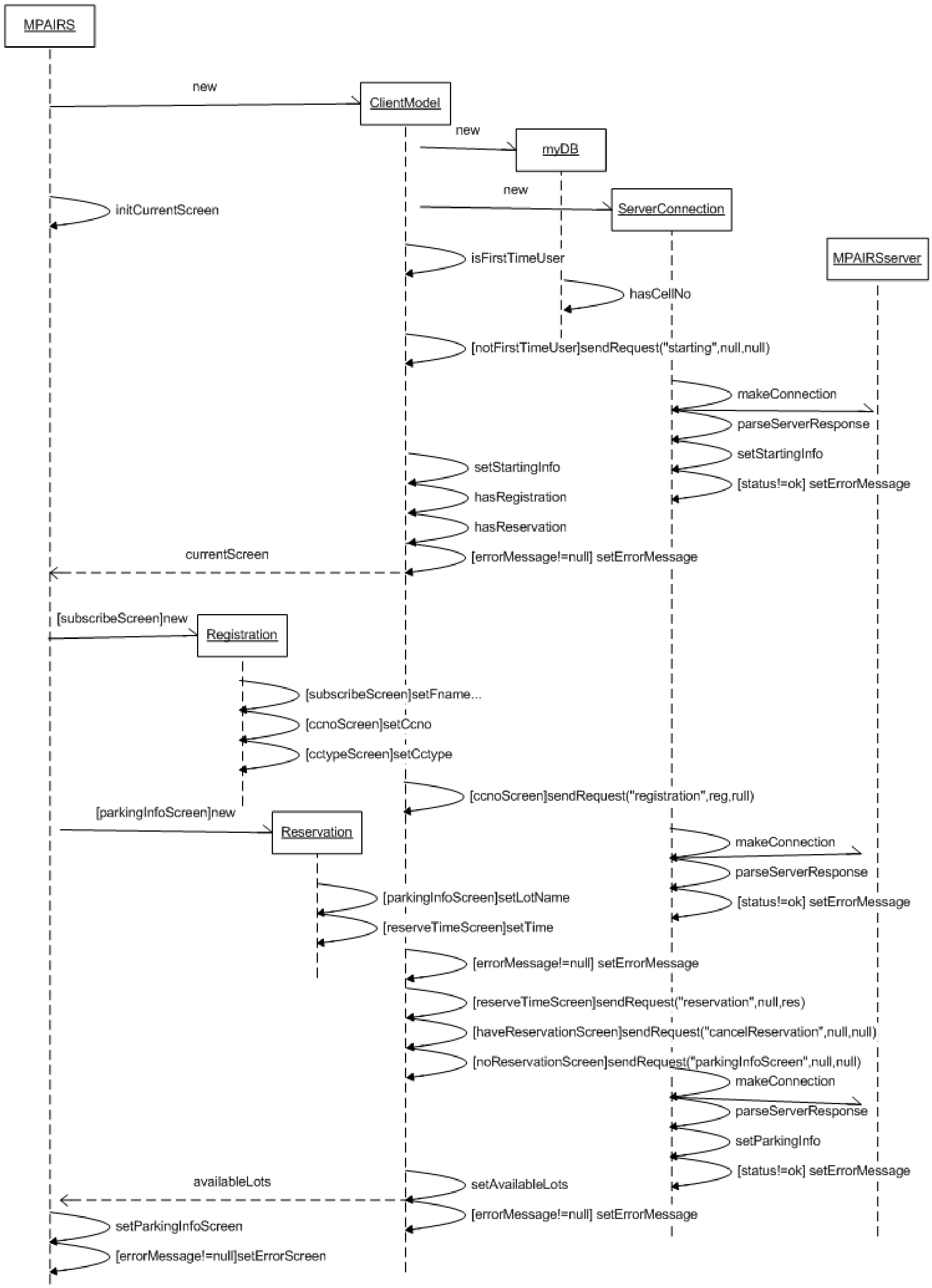


Figure 42. MPAIRS Sequence Diagram

APPENDIX F. VI FORMULATION OF THE PARKING SPATIAL EQUILIBRIUM PROBLEM

This appendix provides the VI formulation, solution algorithms and sample examples for the parking spatial equilibrium problem.

The spatial price equilibrium problem can be formulated as a VI in the case where the feasible region *K* is convex and compact subset of R^n. If *F* is a vector function on *K*, then x* in *K* satisfies the VI if $F(x^*) \cdot (x - x^*) \geq 0$ for all *x* in *K.* This is equivalent to:

If *x** is in the interior of *K* (Figure 43) then *F(x*) = 0*, otherwise if *x** is on the boundary of *K*, then *F(x*)* is perpendicular to the boundary of *K* at *x** and *F(x*)* points inward (see Figure 44). In rare cases, *F(x*)* could be equal to zero even though *x** is on the boundary.

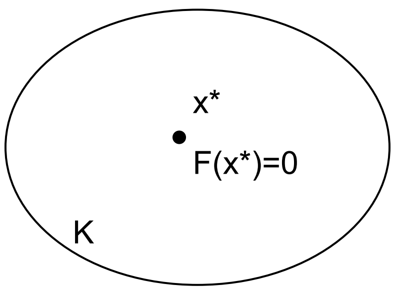


Figure 43. Interior Solution

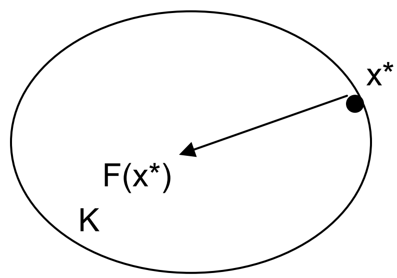


Figure 44. Solution at the Boundary

The existence of a solution to the VI formulation where *F* is continuous, *K* is convex and compact in R^n is based on fixed-point theory. A map $P \circ (I - \gamma F)$ is constructed from the set *K* onto itself, where *P* is the orthogonal projection operator on the boundary of the feasible region *K* and γ is any positive number greater than zero. From analysis we know that such a map has a fixed point (Nagurney, 1993 [(57)]). Finding a solution to this VI problem is equivalent to finding a fixed point $P(x^* - \gamma F(x^*)) = x^*$ on *K*.

In the implementation of the parking spatial price equilibrium problem the feasible region is R_+^n, the non-negative orthant of R^n. *F* is assumed to be of the form $F(x) = Mx + b$ where *M* is a positive definite matrix not necessarily symmetric (Note that given that M is positive definite implies F is strongly monotone). It is shown that for a number *R* sufficiently large, there is no solution to the VI outside $B_R \cap R_+^n$, where B_R is the closed ball of radius *R.* This restricted region $B_R \cap R_+^n$ is now convex and compact.

Proof. Consider $x_R \in R_+^n$, $\|x_R\| = R$, then for $x \in B_R \cap R_+^n$,

$$F(x_R) \cdot (x - x_R) = (Mx_R + b) \cdot (x - x_R) = -x_R^T M x_R + x^T M x_R + b \cdot (x - x_R) < 0,$$

for large *R* since $x_R^T M x_R$ is positive definite and dominates the remaining terms (see Figure 45). We therefore cannot possibly have a solution x* to the VI since $\|x_R\| \geq R$.

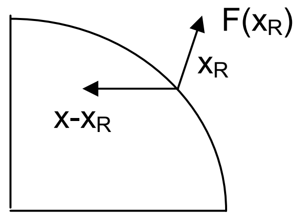


Figure 45. Feasible Region $B_R \cap R_+^2$

Since $B_R \cap R_+^n$ is convex and compact we have a solution to the VI problem using fixed point theory as previously described.

Uniqueness. As for uniqueness, suppose x_1^*, x_2^* are two solutions which satisfy

$F(x_1^*)\cdot(x - x_1^*) \geq 0$ and $F(x_2^*)\cdot(x - x_2^*) \geq 0$, respectively for all $x \in B_R \cap R_+^n$. Choose $x = x_2^*, \text{and } x = x_1^*$ in the first and second inequalities, respectively. Adding the inequalities we obtain

$$(F(x_1^*) - (F(x_2^*))\cdot(x_2^* - x_1^*) \geq 0, \quad \text{or}$$
$$(F(x_1^*) - (F(x_2^*))\cdot(x_1^* - x_2^*) \leq 0.$$

On substituting $F(x) = Mx + b$ we have

$$M(x_1^* - x_2^*)\cdot(x_1^* - x_2^*) = (x_1^* - x_2^*)^T M(x_1^* - x_2^*) \leq 0.$$

Since M is positive definite $x_1^* - x_2^* = 0$ or $x_1^* = x_2^*$. We therefore have uniqueness.

To determine whether *M* is positive definite, since *M* is not necessarily symmetric, we observe that

$$x^T Mx = x^T M_s x$$

where $M_s = \dfrac{M + M^T}{2}$, the symmetric part of *M.* A necessary and sufficient condition for *M* to be positive definite is that all eigenvalues of M_s are positive (Strang, 1988[58]). We will apply this property in the examples to follow.

Solution Algorithm – The Barrier Method

As pointed out previously, the solution to the VI complementarity problem lies on one of the coordinate planes and the vector field *F* at that point is perpendicular to the coordinate plane. For very small dimensions the problem could be solved algebraically. However, as the dimension field increases the problem becomes intractable to solve. Therefore, other methodologies are needed to direct the search towards a feasible VI solution. The barrier method (Vanderbei, 2001 [(58]) is one of the more widely used methodologies employed to solve similar types of problems and it is used here. A description of the barrier method follows.

We will first describe the implementation to the symmetric case followed by the asymmetric case. For $F(x) = (F_1(x), \ldots\ldots, F_n(x)),$ where $x = (x_1, \ldots\ldots, x_n)$, the symmetric case is defined generally as

$$\frac{\partial F_i}{\partial x_j} = \frac{\partial F_j}{\partial x_i}.$$

This implies that for $F(x) = Mx + b$, *M* is symmetric. Because of the symmetry we can find a potential function ϕ such that $F = \nabla\phi.$ In this specific case $\phi = \frac{1}{2}x^T Mx + x^T b$, which is a quadratic form and has a minimum. However, the minimum may not be in the feasible region. Adding a barrier to ϕ forces the minimum to be relocated within the feasible region. The new function is

$$\phi_B(x;\mu) = \phi(x) - \mu\left(\sum_{i=1}^{n} \ln x_i\right).$$

As $\mu \to 0$ the $\min\phi_B(x;\mu) \to x^*$, which is the solution to the VI problem. This can be seen since the minimum of ϕ_B, is found to satisfy $\nabla\phi_B = 0$, or

$$\nabla\phi_B(x;\mu) = \nabla\phi(x) - \mu\left(\frac{1}{x_1}, \ldots\ldots\ldots, \frac{1}{x_n}\right)^T = 0.$$ Component wise we have

$$(\nabla\phi(x))_i - \frac{\mu}{x_i} = 0 \text{ or } x_i(\nabla\phi(x))_i - \mu = 0 \text{ for i} = 1, \ldots\ldots, \text{n}.$$

And as $\mu \to 0$ we have $x_i(\nabla\phi(x))_i = 0$, the Kuhn-Tucker conditions, which states that either $x_i = 0$ or $(\nabla\phi)_i = 0.$

Asymmetric Case. The asymmetric case is defined generally as

$$\frac{\partial F_i}{\partial x_j} \neq \frac{\partial F_j}{\partial x_i},$$ implying that *M* is asymmetric.

Decomposing M into the symmetric and skew-symmetric parts $M = M_s + M_{sk}$,

where $M_s = \frac{M + M^T}{2}$ and $M_{sk} = \frac{M - M^T}{2}$, respectively

Now $F(x)$, can be expressed as, $F(x) = (M_s + M_{sk})x + b = M_s x + (M_{sk} x + b)$.

We can think of F as being almost symmetric with the exception of the term $M_{sk} x + b$. We will define the following sequence $\{x^n\}$, following the general iterative scheme described in [Nagurney, 1993] however implementing the barrier method. Consider

$$g(x^n, x^{n-1}) = M_s x^n + (M_{sk} x^{n-1} + b).$$

Note that for $g(x, y) = M_s x + M_{sk} y + b$, then (i) $g(x, x) = F(x)$ and (ii) $\nabla_x g = M_s$ is symmetric and positive definite (Nagurney, 1993 [57]).

Since M_s is symmetric, the potential ϕ of g as a function of x^n is given by

$$\phi(x^n, x^{n-1}) = \frac{1}{2}(x^n)^T M_s x^n + x^{n^T}(M_{sk} x^{n-1} + b)$$

and satisfies the condition $g = \nabla \phi$, where the gradient is taken with respect to x^n.

Similarly, as before, the barrier is added

$$\phi_B(x^n, x^{n-1}; \mu) = \phi(x^n, x^{n-1}) - \mu(\sum_{i=1}^{n} \ln x_i^n).$$

For a fixed μ and x^{n-1}, x^n is found, which minimizes ϕ_B. The sequence $\{x^n\}$ thus obtained will converge to some limit x_μ. As in the symmetric case, x_μ will satisfy

$$(\nabla \phi(x_\mu))_i - \mu \frac{1}{(x_\mu)_i} = 0 \text{ for } i = 1, \ldots\ldots, n \,.$$

The above convergence is not obvious for a general F, however in this special case, where

$g(x^n, x^{n-1}) = M_s x^n + (M_{sk} x^{n-1} + b)$, the minimization condition is that

$$M_s x^n + (M_{sk} x^{n-1} + b) - \mu\left(\frac{1}{x_1^n}, \ldots\ldots\ldots, \frac{1}{x_n^n}\right)^T = 0 \,.$$

We will show that for small μ, the conditions for the convergence of the sequence $\{x^n\}$, we require that $\|M_s^{-1}M_{sk}\| < 1$.

Proof. We have for two successive iterations

$$M_s x^n + (M_{sk} x^{n-1} + b) - \mu(\frac{1}{x_1^n}, \ldots\ldots, \frac{1}{x_n^n})^T = 0 ,$$

$$M_s x^{n-1} + (M_{sk} x^{n-2} + b) - \mu(\frac{1}{x_1^{n-1}}, \ldots\ldots, \frac{1}{x_n^{n-1}})^T = 0 .$$

Subtracting the second term from the first term

$$M_s (x^n - x^{n-1}) + M_{sk} (x^{n-1} - x^{n-2}) - \mu(\frac{1}{x_1^n} - \frac{1}{x_1^{n-1}}, \ldots\ldots, \frac{1}{x_n^n} - \frac{1}{x_n^{n-1}})^T = 0 \text{, or}$$

$$M_s (x^n - x^{n-1}) + \mu(\frac{x_1^n - x_1^{n-1}}{x_1^n x_1^{n-1}}, \ldots\ldots, \frac{x_n^n - x_n^{n-1}}{x_n^n x_n^{n-1}})^T = -M_{sk} (x^{n-1} - x^{n-2}) \text{, or}$$

$$(M_s + \mu D)(x^n - x^{n-1}) = -M_{sk} (x^{n-1} - x^{n-2}) ,$$

where D is the diagonal matrix with entries, $d_{ii} = \frac{1}{x_i^n x_i^{n-1}}$.

Since M_s is diagonally dominant and all the diagonal elements of D are positive (μ is also positive) then $M_s + \mu D$ will be even more diagonally dominant. It is well known that a diagonally dominant matrix has an inverse [Strang, 1988]. Taking the inverse, we have

$$x^n - x^{n-1} = -(M_s + \mu D)^{-1} M_{sk} (x^{n-1} - x^{n-2}) .$$

Taking the norm of both sides and using properties of norms,

$$\|x^n - x^{n-1}\| \le \|(M_s + \mu D)^{-1} M_{sk}\| \|x^{n-1} - x^{n-2}\| .$$

Convergence follows if $\|(M_s + \mu D)^{-1} M_{sk}\| \le c < 1$, where c is a constant. For μ small we require $\|M_s{}^{-1} M_{sk}\| < 1$.

Numerical Algorithms

We solved the problem $M_s x^n + (M_{sk} x^{n-1} + b) - \mu(\frac{1}{x_1^n},......., \frac{1}{x_n^n})^T = 0$ using the Newton method iteratively and the sequence converged to the solution. We could have used the diagonalization method which solves, $Dx^n + (M - D)x^{n-1} + b - \mu(\frac{1}{x_1^n},......., \frac{1}{x_n^n})^T = 0$.

Where the diagonal matrix D is given by $D = (m_{ii})$ is expected to produce the same results.

The solution methodology followed is:

- Determine whether the x_0, the zero of *F,* is in the feasible region, R_+^n.
- If this is the case, then the VI solution x^* is x_0.
- Otherwise, x^* is at the boundary of R_+^n.
- Decompose *M* into the symmetric part M_S and the skew symmetric part M_{SK}. Simply, $M_S = (M + M^T)/2$ and $M_{SK} = (M - M^T)/2$, where M^T is the transpose of *M.* We further need that the M_S to be positive definite and dominant over M_{SK}.
- Then $F(x) = Mx + b = M_S x + M_{SK} x + b$.
- Define a function *g* (Nagurney, 1993) $g(x;y) = M_S x + M_{SK} y + b$. The potential of ϕ of *g* (as a function of x only, y considered as a parameter) is given by $\phi(x,y) = \frac{1}{2} x^T M_S x + x^T (M_{SK} y + b)$. Note that $\nabla\phi = g$.

Since we are constrained to find a solution in the positive quadrant of R^n we remove the constraint by adding a barrier $\mu(\sum_{i=1}^{n} \ln x_i)$ to $\phi(x;y)$ obtaining, for small μ,

$$\phi_B(x,y) = \phi(x;y) - \mu(\sum_{i=1}^{n} \ln x_i) \text{ or in totality,}$$

$$\phi_B(x,y) = x^T M_S x + x^T (M_{SK} y + b) - \mu(\sum_{i=1}^{n} \ln x_i).$$

We note that since M_S is positive definite and dominant over M_{SK}, $\phi_B(x;y)$ has a minimum for every *y*. We must now seek a sequence $\{x^n\}$ such that for $y = x^{n-1}$, $\phi_B(x;y)$ has a minimum at x^n. By requiring $\left\| M_s^{-1} M_{sk} \right\| < 1$ for small μ (see Bernstein et.al., 2003), the sequence $\{x^n\}$ will converge to x^*, the solution to the original VI problem. In the first paper (Bernstein et.al. 2003) the N-R algorithm was used to find the minimum point x^n, for each x^{n-1}, of ϕ_B by solving $\nabla \phi_B(x^n; x^{n-1}) = 0$.

The difficulty with the N-R method is to find a proper initial starting point that will ensure convergence to a feasible solution. We experimented with several variations of the line search method, however, it was found to be relatively slow in converging to the solution. In order to maintain feasibility, we controlled the step size of the N-R method. The various algorithms used are outlined below.

The Barrier Solution Algorithm

The general steps for the barrier method are outlined first.

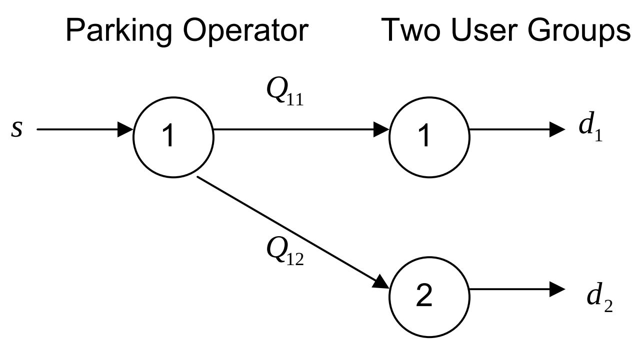
3. *Step 1.* Choose a small μ. Select an initial point $x^0 \in R_+^n$.

4. *Step 2.* Determine x^1 that minimizes $\phi_B(x, x^0; \mu)$.

5. *Step 3.* Repeat step 2 to find a sequence of points and then terminate when a tolerance is reached.

6. *Step 4.* Check the final result to see if the limit is on one of the coordinate planes and that *F* evaluated at that point is perpendicular to that coordinate plane.

Two-dimensional Problem



s: parking space supply of parking lot 1

Q1j: flow from parking lot 1 to destination of user's group *j*

Supply Price Function: $\pi_1 = s + 2$

Where, $s = Q_{11} + Q_{12}, d_1 = Q_{11}, d_2 = Q_{12}$

Equilibrium Principle: If the supplier's price is greater than the *jth* demand price,

$\pi_1 > \rho_j$, there is **no transaction**, and $Q_{1j} = 0$ (no flow; no customers of user group *j* will park at parking lot 1). Otherwise,

$\pi_1 = \rho_j$, and there is a **transaction,** and $Q_{1j} > 0$ (flow; customers of user group *j* will park at parking lot 1).

For this example there are four possibilities:

- $Q_{11} > 0, Q_{12} > 0$ There are flows for both 1 and 2
- $Q_{11} = 0, Q_{12} > 0$ There is a flow to 2 only
- $Q_{11} > 0, Q_{12} = 0$ There is a flow to 1 only
- $Q_{11} = 0, Q_{12} = 0$ There is no flow either to 1 or 2

The feasible region is $R_+^2 = \{Q_{11} \geq 0, Q_{12} \geq 0\}$, the first quadrant.

Case 1.

Demand Price Functions:

- User group 1: $\rho_1(d) = -3d_1 - 0d_2 + 6$,
- User group 2: $\rho_2(d) = -d_1 - 2d_2 + 8$.

The difference between the supply and the demand prices is

$$F(Q) = (\pi_1 - \rho_1, \pi_1 - \rho_2) = (4Q_{11} + Q_{12} - 4, 2Q_{11} + 3Q_{12} - 6)$$

Solving for *F(Q)* = 0, we find Q^* = (Q_{11}, Q_{12}) = (.6, 1.6), an interior point of R_+^2. This means that there is a 0.6 flow to destination 1 (user group 1), and 1.6 flow to destination 2 (user group 2) from parking lot one, respectively.

The parking supply is the sum of the flows, *s* = 2.2, and the corresponding supply price is $\pi_1 = 4.2$. Similarly, the corresponding demand prices (to have an equilibrium) have the same value as π_1 and are $\rho_1 = 4.2$ and $\rho_2 = 4.2$, respectively.

Case 2. Same as before except we assign different marginal demands.

User group 1 demand price function: $\rho_1(d) = -3d_1 - 0d_2 + 9$,

User group 2 demand price function: $\rho_2(d) = -d_1 - 2d_2 + 3$.

Now, $F(Q) = (4Q_{11} + Q_{12} - 7, 2Q_{11} + 3Q_{12} - 1)$.

Solution. Solving for *F(Q)* = 0 we find Q = (0, -1) which is outside the feasible region R_+^2. In this case we observe that *Q** = (7/4, 0) is on the boundary of the feasible region that corresponds to *F(Q*)* = (0, 5/2). The vector *F(Q*)* is perpendicular to the Q_{11} axis and points into the feasible region. Now the supply price is π_1 = 15/4 and the demand prices for groups 1 and 2 are $\rho_1 = 15/4, \rho_2 = 5/4$, respectively. There is flow from user group 1 to parking lot one, $\pi_1 = \rho_1$ and no flow from user group 2, $\pi_1 > \rho_2$.

Implementation of the barrier method

The above result will be shown numerically by implementing the barrier method.

We have that *F(Q)* = *MQ* + *b* where $M = \begin{pmatrix} 4 & 1 \\ 2 & 3 \end{pmatrix}$ and $b = -\begin{pmatrix} 7 \\ 1 \end{pmatrix}$. Note that *M* is asymmetric. The symmetric part of *M* is $M_s = \begin{pmatrix} 4 & 3/2 \\ 3/2 & 3 \end{pmatrix}$ and the skew-symmetric part of *M* is $M_{sk} = \begin{pmatrix} 0 & -1/2 \\ 1/2 & 0 \end{pmatrix}$. The matrix *M* is positive definite since $x^T M x = x^T M_s x$, and the eigenvalues of M_s are positive, $\lambda = (7 \pm \sqrt{10})/2$.

Define the following sequence $\{Q^n\}$ as

$$g(Q^n, Q^{n-1}) = (4Q_{11}^n + 3/2Q_{12}^n + (-1/2Q_{12}^{n-1} - 7),\ \ 3/2Q_{11}^n + 3Q_{12}^n + (1/2Q_{11}^{n-1} - 1)).$$

The potential ϕ of *g* satisfying $g = \nabla\phi$ as a function of Q^n is

$$\phi = 2(Q_{11}^n)^2 + 3/2Q_{11}^n Q_{12}^n + 3/2(Q_{12}^n)^2 - Q_{11}^n(1/2Q_{12}^{n-1} + 7) + Q_{12}^n(1/2Q_{11}^{n-1} - 1).$$

We add a barrier function to ϕ, where μ is small and positive,

$$\phi_B = \phi - \mu(\ln Q_{11}^n + \ln Q_{12}^n).$$

The minimum of ϕ_B is found iteratively for fixed Q^{n-1} and μ as,

$$\begin{aligned} &4Q_{11}^n + 3/2Q_{12}^n + (-1/2Q_{12}^{n-1} - 7) - \mu/Q_{11}^n = 0, \\ &3/2Q_{11}^n + 3Q_{12}^n + (1/2Q_{11}^{n-1} - 1) - \mu/Q_{12}^n = 0. \end{aligned}$$

Since the leading term is diagonally dominant, we can solve for Q^n for a fixed Q^{n-1} and μ, using Newton's method. We now show that the sequence $\{Q^n\}$ converges. We use the property the norm property of matrices, $\|A\| = \sqrt{\lambda_{\max}(A^T A)}$, where $\lambda_{\max}$ is the maximum eigenvalues of $A^T A$ [Strang, 1988]. Using this formula, we evaluate numerically the norm of $M_s^{-1} M_{sk}$ to be .2606, which is less than one.

The solution to the nonlinear equations is shown in Table 12 for different μ. Note that for μ =.0001, we have the solution Q^* of the VI problem.Table 12. Summary of solutions based on μ.

μ	Q_{11}	Q_{12}
.1000	1.7547	.0381
.0100	1.7504	.0039
.0010	1.7501	.0004
.0001	1.7500	.0000

The software MATLAB v6.1 was used to implement the barrier method, using the Newton-Raphson method to solve the set of nonlinear equations. The diagonalization method was also implemented using MATLAB and yielded identical results.

Four-dimensional Problem

We implement the barrier method to the spatial price equilibrium sample problem presented in [Nagurney, 1993]. This problem has two suppliers (parking facilities) and two demands (user groups). The corresponding supply price, demand price, and transaction cost functions are given below.

$$\pi_1(s) = 5s_1 + s_2 + 2,$$

$$\pi_2(s) = s_1 + 2s_2 + 3.$$

The user group demand price functions are:

$$\rho_1(d) = -2d_1 - d_2 + 28.75,$$

$$\rho_2(d) = -d_1 - 4d_2 + 41.$$

The corresponding transaction functions are:

$$c_{11}(Q) = Q_{11} + .5Q_{12} + 1,$$

$$c_{12}(Q) = 2Q_{12} + Q_{22} + 1.5,$$

$$c_{21}(Q) = 2Q_{11} + 3Q_{21} + 15,$$

$$c_{22}(Q) = Q_{12} + 2Q_{22} + 10.$$

Flow conservation constraints:

Supply:

$$s_1 = Q_{11} + Q_{12}$$

$$s_2 = Q_{21} + Q_{22}$$

Demand:

$$d_1 = Q_{11} + Q_{21}$$

$$d_2 = Q_{12} + Q_{22}$$

The feasible region is R_+^4. The difference function *F(Q)* is $F(Q) = MQ + b$, where:

$$M = \begin{pmatrix} 8 & 6.5 & 3 & 2 \\ 6 & 11 & 2 & 6 \\ 5 & 2 & 7 & 3 \\ 2 & 6 & 3 & 8 \end{pmatrix} \quad \text{and} \quad b = -\begin{pmatrix} 25.75 \\ 37.50 \\ 10.75 \\ 28.00 \end{pmatrix}.$$

The zero of *F(Q)* is (2.5899, 0.6761, -1.8022, 3.0213) which is outside the feasible region R_+^4. We expect the solution to be on one of the coordinate planes. Here,

$$M_s = \begin{pmatrix} 8 & 6.25 & 4 & 2 \\ 6.25 & 11 & 2 & 6 \\ 4 & 2 & 7 & 3 \\ 2 & 6 & 3 & 8 \end{pmatrix} \quad \text{and} \quad M_{sk} = \begin{pmatrix} 0 & .25 & -1 & 0 \\ -.25 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix}.$$

The eigenvalues of M_s are all positive, λ_1, λ_2, λ_3, and λ_4, equal to .7839, 5.6300, 6.6755, and 20.9105, respectively, which makes *M* to be positive definite, implying existence and uniqueness.

As before, construct the sequence $\{Q^n\}$, the potential ϕ, and the potential with the barrier added, ϕ_B, where

$$\phi_B = \phi - \mu(\ln Q_{11}^n + \ln Q_{12}^n + \ln Q_{21}^n + \ln Q_{22}^n)$$

Step 1. Decompose *F(Q)* into a symmetric part, which is a function of Q^n and a non symmetric part which is a function of Q^{n-1}.

Step 2. The potential ϕ of $F (\nabla\phi = F)$ as a function of Q^n is found since we have symmetry

Step 3. We add a barrier function to ϕ, where μ is small and positive.

$$\phi_B = \phi - \mu(\ln Q_{11}^n + \ln Q_{12}^n + \ln Q_{21}^n + \ln Q_{22}^n)$$

The minimum of ϕ_B satisfies the equation,

$$M_s Q^n + (M_{sk} Q^{n-1} + b) - \mu(\frac{1}{Q_1^n},......., \frac{1}{Q_n^n})^T = 0.$$

Iterating, we have convergence since $\|M_s^{-1} M_{sk}\| = .8387$, which is less than one.

The limit of the minimum of ϕ_B is given in Table 13 for various values of μ. As μ goes to zero we observe that the limit the VI solution, Q^* = *(1.5, 1.5, 0, 2),* given in [Nagurney, 1993]. The solution Q^* is on the coordinate plane $Q_{21} = 0$ and $F(Q^*) = (0, 0, 5.75, 0)$ is perpendicular to the plane.

Table 13. Summary of solutions based on μ.

μ	Q_{11}	Q_{12}	Q_{21}	Q_{22}	s_1	s_2	d_1	d_2
.1000	1.4976	1.5067	.0171	1.9954	3.0043	2.0125	1.5147	3.5021
.0100	1.4997	1.5002	.0017	1.9995	3.0009	2.0012	1.5014	3.5007
.0010	1.5000	1.5000	.0002	2.0000	3.0000	2.0002	1.5002	3.5000
.0001	1.5000	1.5000	.0000	2.0000	3.0000	2.0000	1.5000	3.5000

Table 14. Summary of solutions based on μ.

μ	c_{11}	c_{12}	c_{21}	c_{22}	π_1	π_2	ρ_1	ρ_2
.1000	3.2510	6.5088	18.0465	15.4975	19.0340	10.0293	22.2185	25.4769
.0100	3.2503	6.5019	18.0045	15.5002	19.0057	10.0033	22.2465	25.4958
.0010	3.2500	6.5000	18.0006	15.5000	19.0002	10.0004	22.2496	25.4998
.0001	3.2500	6.5000	18.0000	15.5000	19.0000	10.0000	22.2500	25.5000

Using Newton's method the results summarized in Tables 13 and 14 were obtained. Next we present the controlled N-R barrier method.

Controlled N-R barrier method

Step 1. Choose a small μ *(e.g., .01, .001, .0001)*. Select an initial point $x^0 \in R_+^n$ with relatively large magnitude away from the boundary.

Step 2. Determine x^n which minimizes $\phi_B(x, x^{n-1})$, i.e. $\nabla\phi_B(x^n, x^{n-1}) = 0$, for each x^{n-1} using the controlled N-R algorithm, such that the step size is smaller than the actual step. Using this methodology, it reduces the risk of violating the feasible region.

Step 3. Repeat step 2 to find a sequence of points and then terminate when a tolerance is reached.

Step 4. Check the final result to see if the limit is on one of the coordinate planes and that *F* evaluated at that point is positive and is perpendicular to that coordinate plane, i.e. $F(x^*)x^* = 0$.

Numerical Algorithms

We solve $\nabla \phi_B(x^n, x^{n-1}) = 0$ recursively for x^n, from the previous value, x^{n-1}. Since $\nabla \phi_B(x^{n+1}, x^{n-1}) = \nabla \phi_B(x^n, x^{n-1}) + H_{\phi_B}(x^n, x^{n-1})(x^{n+1} - x^n) + ...$, where H_{ϕ_B} is the Hessian of ϕ_B.

The n-dimensional N-R algorithm is obtained from the above by solving for x^{n+1} when the left side of the above equality is set equal to zero, and by omitting the higher order terms of the series, yielding,

$$x^{n+1} = x^n - H^{-1}{}_{\phi_B}(x^n, x^{n-1}) \nabla \phi_B(x^{n+1}, x^{n-1}).$$

The n-dimensional Controlled N-R (CN-R) algorithm is

$$x^{n+1} = x^n - \beta\, H^{-1}{}_{\phi_B}(x^n, x^{n-1}) \nabla \phi_B(x^{n+1}, x^{n-1});$$

where β is chosen to be a number $0 < \beta \le 1$.

Recalling that in our application,

$$\phi_B(x, y) = x^T M_S x + x^T (M_{SK} y + b) - \mu(\sum_{i=1}^{n} \ln x_i).$$

Taking the gradient of ϕ_B,

$$\nabla \phi_B(x, y) = M_s x + (M_{sk} y + b) - \mu(\frac{1}{x_1^n}, ..., \frac{1}{x_n^n})^T$$

$$\text{and } H_{\phi_B}(x, y) = M_s + \mu \begin{pmatrix} \frac{1}{x_1^2} ....0 \\ 0 .... \frac{1}{x_n^2} \end{pmatrix}.$$

In this controlled step, the analyst can further ensure feasibility by going back to the feasible region, using as a basis the previous feasible solution and multiplying it by a positive factor (we used a factor of 2 in this implementation). This methodology forces the N-R method to visit other regions until convergence is achieved.

Line Search Methods

Since ϕ_B is convex we start with initial points x_0 of the sequence with large magnitude and set $x_1 = x_0$. How large? Large so that $\nabla \phi_B(x_1, x_0)$ points “away” from the origin. This gives us a direction *u*,

$$u = \frac{\nabla \phi_B(x_1, x_0)}{\left\| \nabla \phi_B(x_1, x_0) \right\|}$$

We now seek to find $\lambda \geq 0$, which will minimize ϕ_B on the line $x^1 - \lambda u$, that is $\min_{\lambda \geq 0} \phi_B(x^1 - \lambda u, x^0)$. This is equivalent to finding the critical point of ϕ_B as a function of λ or

$$\frac{d\phi_B(x^1 - \lambda u, x^0)}{d\lambda} = 0 ,$$

To obtain this critical λ we can either use the bisection algorithm (costly) or the N-R algorithm or use a hybrid where we find the initial solution(s) using the bisection, followed by the N-R, which is faster.

The N-R algorithm on λ is,

$$\lambda^{n+1} = \lambda^n - \frac{d\phi_B(x^1 - \lambda u, x^0)}{d\lambda} / \frac{d^2\phi_B(x^1 - \lambda u, x^0)}{d\lambda^2}$$

Where by the chain rule for differentiation,

$$\frac{d\phi_B(x^1 - \lambda u, x^0)}{d\lambda} = \nabla \phi_B(x^1 - \lambda u, x^0).(-u) \text{ , and}$$

$$\frac{d^2\phi_B(x^1 - \lambda u, x^0)}{d\lambda^2} = u^T H_{\phi_B}(x^1 - \lambda u, x^0)u ,$$

where H_{ϕ_B} is the Hessian of ϕ_B .

Computational Experiments

<u>Example 1. Four dimensional problem</u>

We implemented the barrier method to the spatial price equilibrium sample problem as presented in (Nagurney, 1993 [57]). This problem has two suppliers (parking facilities) and two demands (user groups). The feasible region is R_+^4. Here we represent the flows *x* with the capital letter Q as used in the introduction. The function *F(Q)* is $F(Q) = MQ + b$, where:

$$M = \begin{pmatrix} 8 & 6.5 & 3 & 2 \\ 6 & 11 & 2 & 6 \\ 5 & 2 & 7 & 3 \\ 2 & 6 & 3 & 8 \end{pmatrix} \quad \text{and} \quad b = -\begin{pmatrix} 25.75 \\ 37.50 \\ 10.75 \\ 28.00 \end{pmatrix}.$$

The zero of *F(Q)* is (2.5899, 0.6761, -1.8022, 3.0213) which is outside the feasible region R_+^4. We expect the solution to be on one of the coordinate planes. Here,

$$M_s = \begin{pmatrix} 8 & 6.25 & 4 & 2 \\ 6.25 & 11 & 2 & 6 \\ 4 & 2 & 7 & 3 \\ 2 & 6 & 3 & 8 \end{pmatrix} \quad \text{and} \quad M_{sk} = \begin{pmatrix} 0 & .25 & -1 & 0 \\ -.25 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix}.$$

The eigenvalues of M_s are all positive, λ_1, λ_2, λ_3, and λ_4, equal to .7839, 5.6300, 6.6755, and 20.9105, respectively, which makes M_s as well as *M* positive definite, implying existence and uniqueness. Iterating, we have convergence of the sequence since $\left\| M_s^{-1} M_{sk} \right\| = .8387$ (Bernstein et.al. 2003), which is less than one. The limit of the minimum of ϕ_B is given in Table 15 and 16 for various values of μ. As μ goes to zero we observe that the limit the VI solution, $Q^* = (1.5, 1.5, 0, 2)$, given in (Nagurney, 1993 [(57)]). The solution Q^* is on the coordinate plane $Q_{21} = 0$ and $F(Q^*) = (0, 0, 5.75, 0)$ is perpendicular to the plane.

Table 15. Summary of solutions based on μ.

μ	Q_{11}	Q_{12}	Q_{21}	Q_{22}	s_1	s_2	d_1	d_2
.1000	1.4976	1.5067	.0171	1.9954	3.0043	2.0125	1.5147	3.5021
.0100	1.4997	1.5002	.0017	1.9995	3.0009	2.0012	1.5014	3.5007
.0010	1.5000	1.5000	.0002	2.0000	3.0000	2.0002	1.5002	3.5000
.0001	1.5000	1.5000	.0000	2.0000	3.0000	2.0000	1.5000	3.5000

Table 16. Summary of solutions based on μ.

μ	c_{11}	C_{12}	c_{21}	c_{22}	π_1	π_2	ρ_1	ρ_2
.1000	3.2510	6.5088	18.0465	15.4975	19.0340	10.0293	22.2185	25.4769
.0100	3.2503	6.5019	18.0045	15.5002	19.0057	10.0033	22.2465	25.4958
.0010	3.2500	6.5000	18.0006	15.5000	19.0002	10.0004	22.2496	25.4998
.0001	3.2500	6.5000	18.0000	15.5000	19.0000	10.0000	22.2500	25.5000

Using the N-R method the results summarized in Tables 15 and 16 were obtained. It is noted that the regular N-R method violated the feasible region given different starting solutions. It is therefore recommended that the controlled N-R methods be used to ensure that the solution converges at the boundary of the feasible region for problems where the zero solution to the problem falls within the infeasible region.

Computational experiments with randomly generated inputs

In order to test the controlled versions of the N-R algorithm for large dimensional problems, the entries of *M* and *b* are generated randomly, using a uniform distribution between a lower and upper bound. In order to ensure that *M* of *F(Q)* is positive definite, we had to ensure that *M* is diagonally dominant by raising the corresponding lower and upper bound for the diagonal terms of *M*. For each trial we test the positive definiteness of *M* and whether the zero of F(Q) is outside the feasible region since M and b are randomly generated. Since at each run we will get different generated M and b, we must save them in the memory.

Example 2. Ten dimensional problems

In this example we have five parking lots and two demand groups. The results are summarized in Tables 17 and 18. The value of μ is taken to be 0.0001.

The CPU time for the 10 dimensional problems using a Dell dimension computer with a Pentium 3, 800 MHz processor and the MATLAB software was 13 seconds CPU time. Correspondingly for a 50 dimensional problem, it required about 138 seconds CPU time. The use of a faster computer and software such as CPLEX would decrease the CPU time substantially.

Table 17. Example 2.1, 10 dimensional problem and corresponding solution

F(Q)		M										Q*		b	Qo	λ
0.0000		31.2765	7.1276	4.0842	7.6786	6.7030	5.4497	5.4888	6.3730	4.8312	6.7325	0.6948		41.6928	0.7000	10.3159
0.0001		2.2256	47.5222	3.9827	9.4728	3.6568	2.9316	9.3948	6.4326	10.8787	3.0295	0.1594		32.5119	0.1557	16.3914
0.0000		9.5536	3.9056	31.1083	4.6843	7.4476	10.4646	8.5251	4.9234	4.5974	5.2891	0.4324		38.2491	0.4506	21.9689
0.0000		3.2669	6.7702	3.7773	37.6222	6.3479	10.9011	7.3224	3.0454	4.6471	2.5961	0.6537		41.2240	0.6713	27.0431
0.0000	=	3.1507	9.4184	6.7456	9.5664	55.2817	10.4551	10.4513	2.7061	3.9618	8.4850	0.2609		41.2048	0.2687	29.8504
1.0439		10.8310	3.4859	7.4215	10.5876	9.6865	19.4846	7.8942	4.8401	4.0836	7.9261	0.0000	+	31.8744	-0.0805	33.1175
0.0000		3.5205	6.1165	9.9168	6.0599	8.3145	9.0326	25.7449	4.4473	6.8500	8.0229	1.0425		44.7814	1.0584	39.3154
0.0000		10.8626	9.8559	2.5778	6.9738	10.8428	2.6763	10.8700	29.6077	4.2206	10.4828	0.4670		44.8776	0.4595	44.1998
0.0001		4.4368	2.2213	6.1440	9.7907	6.0590	7.4111	8.4994	8.5398	58.7936	5.0283	0.1159		34.5105	0.1192	52.8142
0.0001		6.1818	7.9568	8.6181	0.2175	5.6386	4.1790	4.3695	8.5617	0.9352	38.5882	0.1534		33.1806	0.1511	100.0132

Table 18. Example 2.2, 10 dimensional problem and corresponding solution

F(Q)		M										Q*		b	Qo	λ
0.0000		20.9378	3.5481	10.8843	10.7172	4.8211	5.6989	2.1675	5.1423	6.2673	9.0509	0.4880		-43.2528	0.5626	1.8259
0.6716		6.3406	19.8465	7.4684	2.5755	10.8319	8.8613	9.5256	5.1728	4.6775	4.2655	0.0000		-34.3953	-0.1269	4.2831
0.0000		10.6151	2.8073	16.4851	6.7792	2.0596	7.3590	3.4993	2.1902	3.5628	9.0411	0.3265		-34.7161	0.4395	5.2786
0.0000		9.4965	5.2646	4.5159	15.2358	7.7660	5.8325	4.4682	5.5766	3.1056	9.6761	0.6517		-42.2156	0.4108	8.9849
0.0000	=	2.3336	7.4168	8.4261	4.6952	17.7408	7.4968	10.9565	2.2205	9.9957	5.1736	0.7982		-37.1219	1.1735	9.7815
0.0000		6.8923	6.9737	10.2765	2.6281	2.0374	13.6658	8.8026	10.0460	3.0121	10.3554	1.1272	+	-43.8752	0.8265	10.9978
0.0001		3.8824	3.8473	6.2397	5.5521	5.9634	5.1098	16.7952	9.4396	8.2882	9.7421	0.1237		-36.4360	0.1103	13.6432
0.0000		9.3548	3.6715	5.4760	9.3229	4.1650	3.4637	7.2774	12.5448	7.8527	8.2046	0.8756		-38.2988	1.1178	16.8526
5.5878		6.2989	8.5914	8.2296	7.8278	7.9461	6.3647	8.1184	9.5292	17.2731	6.2226	0.0000		-33.2640	-0.5047	23.0583
0.0000		4.5856	3.0411	4.8167	3.7083	3.3244	3.8949	3.0542	5.9990	10.5471	18.3003	0.8235		-33.9727	1.0545	74.1195

- λ : eigenvalues for matrix M_s, the symmetric matrix of M;
- Q_o: The zero value of *F(Q)* falls into the infeasible region (e.g. Example 2.1 - *Q(6)* is negative; Example 2.2 – Q(2) and Q(9) are negative);
- μ = .00001; A small μ is recommended to produce values closer to the solution. It is noted however that if μ = 0, the solution will be in thrown into the infeasible region.
- *F(Q*)Q** = 9.8889e-005 (Example 2.1) and 9.9618e-005 (Example 2.2); This indicates that the sequence converges towards the boundary of the feasible region and that *F(Q*)* is perpendicular to the vector from zero to *Q**.
- *beta* = .0001; This is the value for the controlled N-R approach. We found out that a rather small value of *beta* will almost certainly guarantee that the sequence remains in the feasible region.

APPENDIX G. LITERATURE REVIEW ON ROUTE AND MODE CHOICE MODELS

Modeling the impact of pre-trip information on drivers' behavior in Route-Choice.

Model 1

In the study of Khattak, et.al [75], the goal was to explore how travelers react to unexpected congestion and how they might respond to ATIS. Travelers' departure times, routes and mode choice selections were examined through a survey of Bay Area auto commuters. The impact of various factors such as sources of information, trip characteristics and route attributes on travelers' response to unexpected congestions were investigated. A stated preference approach was used to determine the effect of future ATIS technologies to pre-trip response. The multinomial logit model was used to develop a combined stated preference and revealed preference model.

Based on earlier work, Ben-Akiva, et.al [76], Khattak, Schofer, Koppelman [77], Ben-Akiva and Bolduc [78] and Schofer et.al [79], an ATIS behavioral framework can be summarized as follows:

- In urban transportation systems incident bottlenecks are prevalent. Through electronic sources or direct observation travelers receive information and in light of their knowledge they interpret the information. This interpretation translates into a perception of travel time and delay. Perceptions, restrictions, and individual characteristics create a preference for certain modes, routes and departure times. This preference is also subject to previously acquired knowledge and on thresholds of the main parameters. Observable alternatives that have outcomes are results of these preferences. If those outcomes are satisfying, they will probably be repeated, creating a commuter pattern.

Various aspects of travel information influence travelers' decisions. Processing of information depends on its content, presentation style, if it is static, dynamic or predictive, and whether it is qualitative or quantatitive. The perception of delay and the quality of information is especially important under incident related congestion. Many aspects of event-related information impact travelers' decisions. When travelers approach or reach their expectation tresholds, the travelers' decisions are reviewed. Travelers have a set of restrictions that partly influence their patterns. For example, this restriction could be arrival to work before start time. Any diversion from the preffered arrival time would probably be onerous.

In the study conducted, mail back questionnaires were distributed to peak-hour commuters crossing the Golden Gate Bridge, San Fransisco [94] . The questionnaire contained questions regarding normal travel patterns, pre-trip response, willlingness to change travel patterns and personal information. Travelers were asked to recall the time when they became aware of unexpected congestion and whether they modified their travel patterns. This study specifically concentrated on travelers who became aware of unexpected congestion on their home to work trip.

The uniqueness of this study is the estimation of the ATIS response model that combines data from two sources: revealed preference (RP) and stated preference (SP) data.

The utility maximized by each traveler in RP context is defined by:

$$U_{RP} = V_{RP} + \varepsilon \quad (3)$$

- V_{RP} is the systematic utility function influencing RP decisions.
- ε is the random utility component influencing RP decisions.

The utility maximized by each traveler in SP context is defined by:

$$U_{SP} = V_{SP} + \gamma \quad (4)$$

- V_{SP} is the systematic utility function influencing SP decisions.
- γ is the random utility component influencing SP decisions.

It is assumed that the non-measured components of the RP utility (ε) and the SP utilities (γ) are independently and identically Gumbell distributed, and the level of noise in the data sources is represented by the variance of ε and v. We define μ^2 to be the ratio of the variances:

$$\mu^2 = \text{var}(\varepsilon) / \text{var}(\gamma) \quad (5)$$

and therefore the SP utilities can be scaled by μ

$$\mu \, U_{SP} = \gamma V_{SP} + \mu\gamma, \quad (6)$$

so that the random variable (μ γ) has a variance equal to that in the RP utility (ε). It is possible to use both RP and SP observations in a logit estimation procedure that requires equal variance across observations. However, the SP utilities are scaled by an unknown constant *μ*, which must be estimated.

Thus, systematic utilities were defined as follows:

$$V_{RP} = \alpha' w + \beta' x + \delta' c \quad (7)$$

$$\mu_i \, V_{SPi} = (\alpha_i' w + \beta' x + \gamma' z) \, \mu_i \quad (8)$$

Where:

- *"i"* denotes the specific ATIS scenario.

- Vector ***w*** represents a dummy variable for the alternative constants of each model.

- All relative coefficients (α, α_i) are unconstrained.

The SP constants capture the influence of each ATIS scenario on travelers' decisions. Therefore the comparison of the RP and the SP constants give the pre-tripe switching propensity due to information provided by ATIS. Sharing β in both RP and SP models implies that trade-offs among the attributes included in **x** are the same in both actual travel behavior and the SP behavior. In the model, the **x** vectors represent all travel-related coefficients, such as travel time, expected delay, the congestion level on alternate route and scheduled delay variables. Vectors ***c*** are specific to the RP model and include information source variables used in the RP context. Factors inherent in SPs are represented by **z** with the corresponding coefficients γ. In this case, a variable representing the actual choice included in **z** may capture the effect of justification bias. In the combined model, the coefficients γ are restricted to be the same among the five SP models, assuming the same marginal contribution of **z** to the SP utilities. The joint estimation of RP and SP data is conducted by using the tree logit methodology. The construction of the artificial tree and the required steps for the model estimation are described by Bradley and Daly [80].

The RP portion of the model describes travelers' decisions when they become aware of unexpected congestion along the route. The following alternatives were used in the estimation:

7. Did not change normal travel pattern.

8. Change Route (CR).

9. Left Earlier (LE) from the origin.

10. Left later (LL) from the origin.

11. Used public transportation (PBL).

12. Left earlier and changed route (LE and CR).

13. Canceled trip (CANCEL).

Seven major categories of variables were included in the model: a) travel time, b) expected delay, c) schedule delay, d) usual bottleneck delay, e) congestion on alternative route, f) knowledge of travel time and g) information sources.

Travel time is included as a generic variable. Travel time in each alternative was used as follows:

14. Do not change alternative; the reported usual travel time was used for estimation.

15. Change to alternative route; the reported travel time on the alternative route was used, and 0 was used if the travel time was not reported.

16. Leave earlier alternative; the reported travel time was used if the person left work 30 min earlier, and 0 was used if the travel time was not known.

17. Leave later alternative; the minimum of the usual travel time and the time for the leave earlier alternative was used.

18. Public transportation alternative; the transit travel time was used if it was reported, and 0 was used otherwise.

19. Leave earlier and change to alternative route; the minimum of travel time between the leave earlier option and change to alternative route option, if those were reported, was used, and 0 was used otherwise. It is assumed that this joint decision is the outcome of a trade off between the two options under consideration.

20. Cancel trip alternative. For the cancel trip alternative the travel time is 0.

Expected delay on the usual route is included as an alternative specific variable on the do not change alternative. The natural logarithm of the expected delay minus 2 min was used in the estimations. By using the logarithm, it was assumed that travelers have a reduced sensitivity to increasing delays, because the minimum reported delay was 3 min, so the assumption is that a delay of 2 min or less will not cause any traveler to change his/her travel pattern.

Scheduled delays, early and late, were calculated for travelers with a required work start time. The notation for the variables is:

- t_d= departure time.
- t_a= arrival time.
- t^*= desired arrival time.
- Δ=reported flexibility in arrival time.

Then:

- Late schedule delay (LSD), $t_a > t^*$

$$LSD = \max\,[0, t_a - t^* - \Delta]. \quad (9)$$

- Early scheduled delay (ESD), $t_a < t^*$

$$ESD = \max\,[0, t^* - t_a]. \quad (10)$$

Usual Bottleneck Delays is a usual dummy variable that takes the value of 1, if travelers experience a regular bottleneck, and 0, otherwise. This delay is most likely to occur on the Golden Gate Bridge toll plaza.

Congestion on Alternative Route is a dummy variable that takes the value of 0, if it is not congested and 1, if it is regularly or heavily congested. The congestion on the alternative route was included in the change route, change departure time, and change route alternatives.

The knowledge of travel times on behavior and experience on behavior were captured by creating five alternative specific dummy variables, for the alternatives that had observations with non-reported travel times.

Information sources that the travelers used were: Electronic sources (TV, radio, computer, phone); Non-electronic sources (word of mouth, direct observation); Both electronic and non-electronic sources. A dummy variable was created for the acquisition of information from electronic and non-electronic sources. These were included in the no-change alternative, leaving the non-electronic sources as the base case.

The SP portion of the model examines commuter responses to ATIS. For each ATIS a multinomial logit model was developed, with the following alternatives:

- Cannot say. It is assumed that these travelers would not change their travel patterns (do not change).
- Change route (CR).
- Leave earlier (LR).
- Leave later (LL).
- Take public transportation (PBL).

The cancel trip was not included in the model specification because a limited number of observations for this alternative. The main differences between models and the RP model are the absence of other information sources (fixed as ATIS in this case) and the presence of experience or justification variables. These are alternative specific dummy variables taking the value of 1 if the alternative was chosen under the RP model and 0 otherwise. To capture the potential biases introduced by the experienced delay, a dummy variable equal to 1 if the actual delay experienced was higher hen the initially expected delay reported in the RP situation was included in the departure time alternatives. Table 19 presents the results of a combined RP and SP model. All scale coefficients are significantly different from zero. Separate RP and SP models were also estimated and it was found that the combined model had a better fit than the separate models.

Table 19. Results of Combined RP and SP Model

Variables		Coefficients	t-statistics
Current info-	**Constant 1 (CR)**	-1.47	-3.9
	Constant 2 (LE)	-1.82	-4.9
	Constant 3 (LL)	-2.51	-6.5
	Constant 4 (PBL)	-3.66	-7.7
	Constant 5 (LE&CR)	-2.54	-6.1
	Constant 6 (CANCEL)	-5.25	-9.2
Qualitative info	**Constant 1 (CR)**	-1.24	-3.2
	Constant 2 (LE)	-0.66	-2.2
	Constant 3 (LL)	-1.98	-4.1
	Constant 4 (PBL)	-1.74	-3.6
Quantitative	**Constant 1 (CR)**	-0.63	-1.8
	Constant 2 (LE)	0.04	0.1
	Constant 3 (LL)	-0.71	-2.1
	Constant 4 (PBL)	-1.32	-2.9
Predictive-	**Constant 1 (CR)**	-0.49	-1.4
	Constant 2 (LE)	0.24	0.7
	Constant 3 (LL)	-0.69	-0.2
	Constant 4 (PBL)	-1.33	-2.9
Prescriptive Route-	**Constant 1 (CR)**	0.98	2.4
	Constant 2 (LE)	-0.88	-2.4
	Constant 3 (LL)	-2.75	-4.1
	Constant 4 (PBL)	-2.27	-3.6
Prescriptive Mode-	**Constant 1 (CR)**	-0.56	-1.6
	Constant 2 (LE)	-0.86	-2.4
	Constant 3 (LL)	-2.36	-4.0
	Constant 4 (PBL)	-0.10	-0.3
Travel Time		-6.47	-3.7
Log (Exp. Delay-2 min) (Do not change)		-0.19	-2.4
Late Schedule Delay (x10hrs)		-4.35	-1.5
Early Schedule Delay (x10hrs)		-0.50	-1.9
Usual Bottleneck Dummy (CR)		0.28	1.1
Usual Bottleneck Dummy (LE)		-0.16	-0.7
Usual Bottleneck Dummy (LL)		-1.46	-2.8
Usual Bottleneck Dummy (PBL)		0.66	2.0
Usual Bottleneck Dummy (LE&CR)		1.05	2.1
Congestion level (CR)		-0.23	-1.5
Travel Time Dummy (CR)		-1.62	-4.7
Travel Time Dummy (LE)		-0.39	-1.4
Travel Time Dummy (PBL)		-2.84	-4.3
Travel Time Dummy (LE&CR)		-2.10	-4.0
Info Both Dummy (Do not change)		-3.76	-4.9
Info electr. Dummy (Do not change)		-2.19	-4.1
Dummy Act>Exp. Del. (LE)		0.28	2.2
Dummy Act>Exp. Del. (LL)		0.37	2.1

Variables	Coefficients	t-statistics
Justification (Do not change)	-0.18	-1.2
Justification CR (CR)	1.62	4.4
Justification CR AND LE (CR)	1.38	3.1
Justification LE (LE)	1.33	4.4
Justification CR AND LE (LE)	1.01	2.8
Justification LL (LL)	2.38	4.5
Justification PBL (PBL)	3.92	4.4
(SP1-Qualitative Info)	1.10	4.6
(SP2-Quantitative Info)	1.05	4.6
(SP3-Predictive Info)	0.87	4.6
(SP4-Prescriptive Route)	0.68	4.5
(SP5-Prescriptice Mode)	0.74	4.5
Log likelihood (initial)	-4498.89	
Log likelihood (convergence)	-3677.57	
Number of observation	2703.00	
ρ^2	0.24	

Model 2

In the paper of Polak and Jones[81] the effect of pre-trip information on travel behaviour was described. The purpose of this study was to investigate travelers' requirements for different types of traveler information and methods of inquiry and to relate the process of information aquisition to changes in travel time. The research was done utilizing stated preference approach, based on a computer simulation of an in-home pre-trip information system offering information on travel times from home to City center, by bus and by car, at different time periods of the day. A novel feature of the stated preference excercise was that respondents efficiently generated their own choice set of alternatives through the process of information aquisition. The surveys were undertaken parallel in Athens, Greece and Birmingham, United Kingdom[81].

The essential idea was to develop a computer-based interview procedure that presented a credible simulation of an in-home, pre-trip information system. Respondents were allowed to make inquiries of the system. After they were satisfied they had aquired sufficient information, they were required to rank the 'enquired-about' alternatives in order of preference. The final version of the simulation had the following capabilities:

- It provided information on expected network travel times by bus and car, at different time periods of the day.
- In the case of car, information was also provided on expected parking search times in the city.

- A rudimentary public transport timetable was included, to enable the system to present information concerning expected arrival times of buses at stops.
- Respondents were able to inquire about either the expected travel conditions associated with the particular departure time or given these travel conditions, at what time they must depart in order to arrive at their destination in the city by a certain deadline.

Interviewing for the main survey was carried out at selected locations in Birmingham and Athens. A set of screening criteria were used in order to recruit only those people likely to have the greatest propensity to use and be affected by pre-trip information. A system of quota controls, on various personal and journey related factors were also used to ensure that the final sample contained an adequate representation of potentially significant segments of the population.

There are significant differences in the travel characteristics of the respondents from the two cities that relate to differences in social and institutional arrangements in Athens and Birmingham, respectively.

In Athens 66% of commuters have access to free parking versus 59% in Birmingham.

Another significant difference between the two cities is the flexibility that travelers have in the timing of their journey. The significantly greater flexibility in journey timing displayed by the Birmingham sample is possibly reflective of the higher penetration of flexible working-hours arrangements in Birmingham, and the greater restrictions in shop and public facility opening in Athens.

A further significant difference between the two cities concerns the extent to which the travelers' existing journey patterns reflect the adaptation to congested conditions. In Birmingham, almost one quarter stated that they had actively retimed their current car journey to avoid congestion. Re-timing was necessary to determine their ideal departure time. Departure times were shifted to either earlier or later than the original departure times. In Athens, only 8% of journeys had been re-timed and all had involved a shift to an earlier departure time. The average magnitude of the earlier shift was also significantly less then in Birmingham.

Respondents in Athens appeared to be more interested than their counterparts in Birmingham in making inquires concerning public transport options. These options have important implications for the effectiveness of such a system as demand management tools. In order to explore possible explanations for this finding, a logic model was estimated predicting the probability of a respondent inquiring about public transport option on Day 2, as a function of personal and journey related factors. The estimation results are summarized in Table 20, where a positive coefficient value indicates that the corresponding variable increases the probability of a public inquiry being made. The estimation results confirm the existence of a significant national difference in propensity to make bus-oriented enquires. The results showed that travelers in Athens showed a greater interest in bus services. Further, the results indicated that the probability of inquiring about buses decreases with increasing trip distance, maybe reflecting a perception by the travelers that bus travel is less competitive on longer distances.

The modal and timing characteristics of the first ranked alternatives on day 2 suggest that there may be significant differences in the impact of pre-trip information systems in the two cities. In Birmingham, those engaged on work trips appear most reluctant to contemplate switching mode but quite willing to consider significant re-timings of their trip. By contrast, those engaged in work trips, in Athens, present just the opposite tendency, with just a slight interest in re-timing, and a much greater willingness to use public transportation.

The data from the ranking exercise also enabled the exploration of travelers' underlying preferences. Table 21 presents a series of multinomial logit models developed by expanding the preference data into choice data.

Table 20. Estimation results of the survey in Athens, GR and Birmingham, UK

Variable		Coefficient	(t-statistic)
Country			
	Greece	2.012	(7.21)*
	UK	-	
Gender			
	male	-0.088	(-0.35)
	female	-	
Age			
	16-24	0.015	-0.01
	25-44	-0.567	(-0.73)
	45-64	-0.725	(-0.92)
	>64	-	
Socioeconomic group			
	Professional/managerial	-0.31	(-0.74)
	Supervisory/administrative	0.17	(0.43)
	Skilled manual	0.203	(0.55)
	Semi/n-skilled manual and other	-	
Purpose			
	Work/education	0.211	(0.73)
	Other	-	
Frequency of journey to city center			
	>once per week	0.043	(0.12)
	<=once per week	-	
Free parking in the city center			
	Yes	-0.674	(-2.15)*
	No	-	
Journey re-time to avoid congestion?			
	Yes	0.125	(0.43)
	No	-	
Current travel time by car		-0.247	(22.45)*
Current parking search time		-0.019	(0.74)
Constant(enquire about bus)		1.423	(1.499)
Diagnostics			
	N	628	
	L(0)	435.29	
	L(convergence)	267.73	
	Rho-squared	0.384	

Table 21. Results of ranking-based preference modeling

Variable		Coefficient (and t-statistic)							
		Birmingham work		Birmingham non-work		Athens work		Athens non-work	
Later shift in departure time		-0.009	(-2.5)	-0.004	(-2.0)	-0.068	(-3.7)	-0.001	(-0.1)
Earlier shift in departure time		-0.017	(-2.3)	-0.001	(-0.4)	-0.006	(-0.9)	-0.012	(-0.8)
Travel time		-0.105	(-4.3)	-0.089	(-5.9)	-0.120	(-6.0)	-0.139	(-5.0)
Parking search time		-0.026	(-0.7)	-0.069	(-3.5)	-0.029	(-1.2)	-0.159	(-3.9)
Egress time		-0.099	(-1.0)	-0.037	(-0.9)	-0.016	(-0.4)	-0.101	(-1.2)
Bus dummy		-1.748	(-3.2)	-1.233	(-4.1)	-0.308	(-0.8)	-2.090	(-4.0)
Enquiry order (1=first etc.)		-0.467	(-2.9)	-0.490	(-3.5)	-0.259	(-2.8)	-0.144	(-1.1)
Diagnostics									
N		111		156		173		84	
L(0)		-110.1		-164.9		-218.2		-106.4	
L(convergence)		-72.4		-108.6		-163.9		-78.1	
Rho-squared		0.342		0.341		0.348		0.266	

Several interesting observations can be made on these models. In all of the models, the variable corresponding to the inquiry order of the options has a negative coefficient and, with the exeption of a small Athens non-work segment, it is statisticaly significant. This provides evidence that the process of information acquisition is structured according to travel preferences with travelers tending to inquire first about their more prefered options, and then, only subsequently less prefered alternatives.

Model 3

A joint model for route choice and departure time decisions with and without pre-trip information is formulated, based on the extensive home-interview of commuters in Taiwan, Jou[82]. The model specifications for both systematic and random components are formulated. A probit model is used for the joint model, allowing the introduction of state dependence and correlation in model specification.

How pre-trip information impacts commuters' decision-making is shown in Figure 46. The characteristics, shown in the figure, and whether a commuter receives pre-trip information from a commuter's decision making mechanism, relative to accepting or declining the departure travel time and route choice. S_{id} is indicator variable for departure time (d) switch for traveler *i* and S_{ir} is indicator variable for route (r) switch for traveler *i*. If the departure time/route switch has happened the value of corresponding variable is 1 and 0 otherwise. So, all possible combinations for commuter *i* are (0,0), (1,0), (0,1), (1,1).

A latent variable, internal to each traveler, in this study is part of the mechanism underlying the switching and cannot be measured nor observed directly. Commuters switch their departure time and route as long as their latent variable is greater than the threshold, which is set to 0 in this study. The functional structure is derived after observing the actual commuters' decision to switch or not to switch departure times or routes in response to exogenous information and expected traffic conditions.

Two scenarios are being investigated, with and without pre-trip information. Instead of performing estimations for these two variables and comparing them, a joint latent variable containing both scenarios has been introduced and derived for simplifying estimation. Because of the assumption of normal distributed error term in latent variable, probit framework has been introduced, because of its more flexible model specification through parameters in variance-covariance matrix. Both scenarios, with and without pre-trip information, are introduced to theoretically model commuters' choices. A joint model incorporating these two scenarios has been derived. The terms incorporated in the expressions are listed in Table 22, and the parameters and definitions of variance-covariance matrix latent variable are explained in Table 23.

Table 22. Definitions of latent variable elements

Element		**Definition**
I		With pre-trip information
N		Without pre-trip information
f (●)		Systematic component of departure time
h (●)		Systematic component of route
$\mathbf{X_i}$		Socio-economic characteristics for commuter *i*
$\mathbf{Z_{id}}$		Attribute vectors of departure time for commuters *i*
$\mathbf{Z_{ir}}$		Attribute vectors of route for commuters *i*
$\mathbf{\Theta_{id}}$ **and** $\mathbf{\Theta_{ir}}$		Parameters to be estimated
ε_{id}		Error term of departure time for commuter *i*
τ_{ir}		Error term of route for commuter *i*
w_i		A binary indicator variable; =1, if with pre-trip information; 0 otherwise

Table 23. Parameters and definitions of variance-covariance matrix in latent variables

Parameter		**Definitions**
σ_1^2		Variance of departure time latent variable with pre-trip information
σ_2^2		Variance of route latent variable with pre-trip information
σ_3^2		Variance of departure time latent variable without pre-trip information
σ_4^2		Variance of route latent variable without pre-trip information
γ_1		Covariance of departure time and route latent variables with pre-trip information
γ_2		Covariance of departure time and route latent variables without pre-trip information

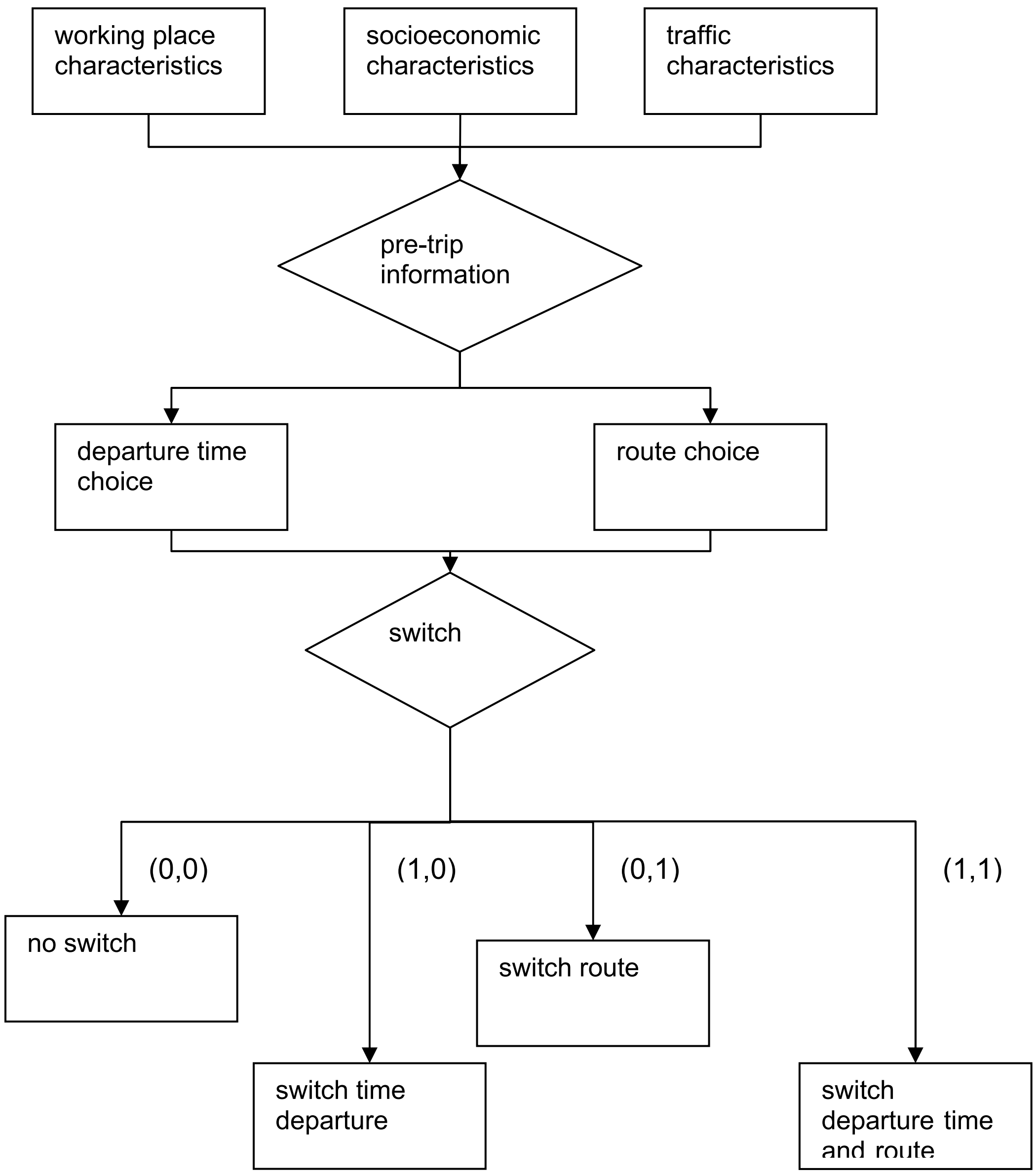


Figure 46. Impact of pre-trip information on commuters' decision-making

The following expressions are separate models for the two scenarios:

$$Y^{T}{}_{id} = f^{T}(X_{T}, Z_{id}, \Theta_{id}) + \varepsilon^{T}{}_{id} \qquad (11)$$

$$Y^{T}{}_{ir} = f^{T}(X^{T}, Z_{ir}, \Theta_{ir}) + \tau^{T}{}_{ir} \qquad (12)$$

Where T =I in scenarios with pre-trip information, and T=N in scenarios without pre-trip information. The random terms εIid and $\tau^{I}{}_{ir}$ are also assumed to be multivariate with zero means and general covariance can be expressed as:

$$\Sigma^{I} = \begin{bmatrix} \sigma_1^2 & \gamma_1 \\ \gamma_1 & \sigma_2^2 \end{bmatrix} \quad (13)$$

Where:

- γ_1 is the covariance of departure time and route with pre-trip information. It assumes contemporaneous correlation between departure time and route choice for a certain commuter, reflecting dependence on the same set of experienced traffic conditions.
- σ_1^2 and σ_2^2 are the corresponding variances of departure time and route latent variables, respectively, with pre-trip information.

Similarly,

$$\Sigma^{N} = \begin{bmatrix} \sigma_3^2 & \gamma_2 \\ \gamma_2 & \sigma_4^2 \end{bmatrix} \quad (14)$$

Where:

- γ_2 is the covariance of departure time and route with pre-trip information. It assumes contemporaneous correlation between the departure time and route choice for a certain commuter, reflecting dependence on the same set of experienced traffic conditions.
- σ_3^2 and σ_4^2 are the variances of departure time and route latent variables, respectively, with pre-trip information.

Latent variables for a joint model, with and without pre-trip information, of a departure time and route for a commuter with or without pre-trip information can further be developed as:

$$Y_{id} = w_i Y_{id}^{I} + (1 - w_i) Y_{id}^{N} \quad (15)$$

$$Y_{id} = w_i Y_{ir}^{I} + (1 - w_i) Y_{ir}^{N} \quad (16)$$

Y_{id} can be derived as:

$$Y_{id} = w_i\left[f^I(X_i, Z_{id}, \Theta_{id}) + \varepsilon_{id}^I\right] + (1-w_i)\left[f^N(X_i, Z_{id}, \Theta_{id}) + \varepsilon_{id}^N\right]$$

(17)

$$= w_i f^I(X_i, Z_{id}, \Theta_{id}) + (1-w_i) f^N(X_i, Z_{id}, \Theta_{id}) + (1-w_i)\varepsilon_{id}^N + w_i\varepsilon_{id}^I$$

Where:

- w_i is an indicator variable that has a value of 1 when there is a pre-trip information, and a value 0 for scenarios without pre-trip information.

And

$$\varepsilon_{id} = w_i\varepsilon_{id}^I + (1-w_i)\varepsilon_{id}^N \quad (18)$$

$$f(X_i, Z_{id}, \Theta_{id}) = w_i f^i(X_i, Z_{id}, \Theta_{id}) + (1-w_i) f^N(X_i, Z_{id}, \Theta_{id}) \quad (19)$$

Further:

$$Y_{id} = f(X_i, Z_{id}, \Theta_{id}) + \varepsilon_{id}$$

(21)

$$Y_{id} = h(X_i, Z_{id}, \Theta_{id}) + \tau_{id}$$

Also Σ (joint) can be derived as follows:

$$\Sigma = \begin{bmatrix} \sigma_D^2 & \gamma_{DR} \\ \gamma_{DR} & \sigma_R^2 \end{bmatrix} \quad (22)$$

Where,

$$\sigma_D^2 = w_i\sigma_1^2 + (1-w_i)\sigma_3^2 \quad (23)$$

$$\sigma_R^2 = w_i\sigma_2^2 + (1-w_i)\sigma_4^2 \quad (24)$$

$$\gamma_{DR} = w_i\gamma_1 + (1-w_i)\gamma_2 \quad (25)$$

Since we can assume that the probability distribution of S_{id} is related to probability density of Y_{id} by Pr (S_{id}=1) = Pr (Y_{id}>0) and we can assume that the probability distribution of S_{ir} is related to probability density of Y_{ir} by Pr (S_{ir}=1) = Pr (Y_{ir}>0), the sample strata for the choice of commuter *i* (S_{id}, S_{ir}) can be defined as follows:

- S_1: S_{id} =1 S_{ir}=1
- S_2: S_{id} =1 S_{ir}=0
- S_3: S_{id} =0 S_{ir}=1
- S_4: S_{id} =0 S_{ir}=0

The likelihood of the whole could be formulated as follows:

$$L = \left[\prod_{S_1} \int_{-f(.)}^{\infty} \int_{-h(.)}^{\infty} W(\varepsilon,\tau) d\varepsilon d\tau \right] \left[\prod_{S_2} \int_{-f(.)}^{\infty} \int_{-\infty}^{-h(.)} W(\varepsilon,\tau) d\varepsilon d\tau \right] \times \left[\prod_{S_3} \int_{-f(.)}^{\infty} \int_{-h(.)}^{\infty} W(\varepsilon,\tau) d\varepsilon d\tau \right] \left[\prod_{S_4} \int_{-f(.)}^{\infty} \int_{-\infty}^{-h(.)} W(\varepsilon,\tau) d\varepsilon d\tau \right] \quad (26)$$

Where W is the normal density function with two variables and can be written as:

$$W = (2\Pi|\Sigma|)^{-1} \exp\left[-\frac{(x\Sigma^{-1}x^T)}{2} \right] \quad (27)$$

Where Σ is defined above and x= (ε^T_{id}, τ^T_{ir}).

To test model's presented heterogeneity, Abdel-Aty's procedures are applied. The likelihood function looks as:

$$L = \int_{-\infty}^{\infty} \left[\prod_{S_1} \int_{-f(.)}^{\infty} \int_{-h(.)}^{\infty} W(\varepsilon,\tau) d\varepsilon d\tau \right] \left[\prod_{S_2} \int_{-f(.)}^{\infty} \int_{-\infty}^{-h(.)} W(\varepsilon,\tau) d\varepsilon d\tau \right] \times \left[\prod_{S_3} \int_{-f(.)}^{\infty} \int_{-h(.)}^{\infty} W(\varepsilon,\tau) d\varepsilon d\tau \right] \left[\prod_{S_4} \int_{-f(.)}^{\infty} \int_{-\infty}^{-h(.)} W(\varepsilon,\tau) d\varepsilon d\tau \right] f(v_i) d(v_i) \quad (28)$$

Model Specification

The latent variable is assumed to include the following components: initial, commuter characteristics, dynamic and myopic component. The short-term dynamic component is captured by myopic component, and dynamic component includes long-term dynamic effect.

The detailed departure time model specification is:

$$f(X_i, Z_{id}, \Theta_{id}) = w_i f^i(X_i, Z_{id}, \Theta_{id}) + (1 - w_i) f^N(X_i, Z_{id}, \Theta_{id}) \quad (29)$$

$$= w_i(\alpha_0 + \alpha_1 AGE_i + \alpha_2 GENDER_i + \alpha_3 NFAIL_{id} + \alpha_4 SD_i)$$
$$+ (1 - w_i)(\alpha_5 + \alpha_6 AGE_i + \alpha_7 GENDER_i + \alpha_8 NFAIL_{id} + \alpha_9 SD_i).$$

And the detailed route model specification is:

$$h(X_i, Z_{ir}, \Theta_{ir}) = w_i h^i(X_i, Z_{ir}, \Theta_{ir}) + (1 - w_i) h^N(X_i, Z_{ir}, \Theta_{ir})$$

$$= w_i(\beta_0 + \beta_1 AGE_i + \beta_2 GENDER_i + \beta_3 NFAIL_{ir} + \beta_4 SD_i)$$
$$+ (1 - w_i)(\beta_5 + \beta_6 AGE_i + \beta_7 GENDER_i + \beta_8 NFAIL_{ir} + \beta_9 SD_i).$$

Table 24. Model Parameters Specification

AGE_i		Age of commuter i: 1 if age<18; 2 if 18<=age<=30; 3 if 31<=age<=40; 4 if 41<=age<=60; 5 if age >61
$GENDER_i$		Gender of commuter i: =1 if male; =0 otherwise
$NFAIL_{id}$		Number of unacceptable arrivals (number of departure time changes) for commuter i in the most recent week
$NFAIL_{ir}$		Number of unacceptable arrivals (number of route changes) for commuter i in the most recent week
SD_i		Average absolute scheduled delay of commuter i in the most recent week: =abs(actual arrival time- work start time

Several assumptions have been made in conjunction with the departure model specified above (Table 24). First, initial components exist for both departure time and route choice. This initial band is asymmetric for commuter with pre-trip information vs. without pre-trip information. Second, the age and gender are modeled to have an effect, with younger commuters more likely to switch than older, and with male more likely to switch than female. Also, the latent variable may increase in response to more switches over a period of time, reflecting the relaxation of aspiration levels due to the uncertainty of experienced traffic conditions. Further, variable SD is defined as a difference between actual arrival time and work starting time in absolute values. This variable reflects inherent preferences and risk attitudes of each commuter and the characteristics of the working place.

It is important to note that the dependant variable in switching models is not an actual decision to switch for a particular commuter, but rather a response to a survey whether he/she switches his/her departure time or route. A commuter is considered as a departure time switching one if he/she changes his/her departure time more than 3 times in 5 weekdays for more than 10 minutes. A commuter is considered a route switching one whenever he/she chooses a route different from the day before. A commuter is considered a receiving pre-trip information one, if he/she reads (or hears) a traffic report before leaving home.

Table 25. Estimation results for the joint model

Component	Attributes/parameter	Estimates	t
DT initial (I)	$\alpha_0(I)$	-3.91	-10.21
DT initial (N)	$\alpha_5(N)$	-4.49	-5.36
DT Socio-economic 1 (I)	AGE(I)/ α_1	-1.30	-2.05
DT Socio-economic 1 (N)	AGE(N)/ α_6	-2.50	-6.36
DT Socio-economic 2 (I)	GENDER(I)/ α_2	1.75	6.02
DT Socio-economic 2 (N)	GENDER(N)/ α_7	1.28	3.92
DT Dynamic (I)	NFAIL(I)/ α_3	-1.52	-2.69
DT Dynamic (N)	NFAIL(N)/ α_8	-2.75	-4.63
DT Myopic (I)	SD(I)/ α_4	1.45	8.06
DT Myopic (N)	SD(I)/ α_9	0.81	6.45
R initial (I)	$\beta_0(I)$	-11.31	-3.45
R initial (N)	$B_5(N)$	-13.50	-3.62
R Socio-economic 1 (I)	AGE(I)/ $\beta_1(I)$	-5.78	-5.78
R Socio-economic 1 (N)	AGE(N)/ $\beta_6(I)$	-6.95	-4.9
R Socio-economic 2 (I)	GENDER(I)/ $\beta_2(I)$	1.15	3.03
R Socio-economic 2 (N)	GENDER(N)/ $\beta_7(I)$	0.75	2.19
R Dynamic (I)	NFAIL(I)/ $\beta_3(I)$	-3.78	-3.64
R Dynamic (N)	NFAIL(N)/ $\beta_8(I)$	-4.05	-5.12
R Myopic (I)	SD(I)/ $\beta_4(I)$	0.89	3.08
R Myopic (N)	SD(I)/ $\beta_9(I)$	0.30	9.3
DT standard deviation (I)	σ_1	15.12	4.6
DT standard deviation (N)	σ_2	12.32	5.97
R standard deviation (I)	σ_3	14.98	2.98
R standard deviation (N)	σ_4	10.56	3.45
Covariance for the correlation of R and DT (I)	γ_1	5.99	5.21
Covariance for the con-temporaneous correlation of R and DT (N)	γ_2	5.10	3.45
Standard deviation of v	σ_v	2.48	5.92
Log-likelihood convergence		-535.82	
Log-likelihood at zero		-930.21	
Likelihood ratio index		0.42	

Table 26. Log-likelihood ratio test for pre-trip information effects on departure time and route (separately and jointly)

Restricted on	L(U)	L(R)	Test statistics	Significant
DT w/o pre-trip information	-535.82	-554.12	36.60	Yes
R w/o pre-trip information		-555.32	39.00	Yes
DT and R w pre-trip information		-551.79	31.94	Yes
DT and R o pre-trip information		-560.12	48.60	Yes

The estimation results are presented in Table 25. The log-likelihood at convergence for the joint model system is –535.82. The log-likelihood when all parameters are zero is –930.21. The log-likelihood ratio rejects the null hypothesis that variable parameters and error correlations are zero. An informal goodness-of-fit ratio, ρ2 is on the high side at 0.42, indicating a good explanatory value of the model.

The results of the log-likelihood ratio test for pre-trip information effects on departure time and route, separately and jointly, are listed in Table 26. The results indicate that the coefficient associated with pre-trip information differ significantly from the case without pre-trip information, implying that pre-trip information has a different impact on both departure time and route latent variables.

Model 4

In this paper by Fujiwara et.al [83] the influence of pre-trip information on commuters, behavior is examined. The aim of this paper is to examine the effectiveness of a new discrete choice model dealing with departure time choice and travel mode choice. A paired combinatorial model (PCL) is developed to describe departure time choice behavior. Since the PCL model can relax the restrictive independence of irrelevant alternatives property of the conventional multinomial logit model (MNL), the differential correlations between discrete times alternatives, which are categorized by analysts, can implicitly be considered. Further, the PCL model has been expanded into a nested PCL model, which has a hierarchical choice structure between travel mode and departure time choices. An SP survey was made on commuters between Higashi-Hiroshima and Hiroshima. The main modes for commuting were car and rail. Hypothetical travel situations were set up in a survey. Departure time was classified in four categories, based on the pilot survey of actual travel situations. Travel time and the cost for the two modes, level of congestion, and crowdedness for rail were set up by departure time and shown in Table 27.

Table 27. An example of SP cards

Departure time	Travel mode & route	Travel time	Congestion	Travel cost	Option
- 6:30 am	Free road	70 mjn	0.5 km	free	1
	Toll road	45 min	0 km	800 yen	2
	Railway	40 min	have a seat	560 yen	3
6:30 am - 7:00 am	Free road	90 min	1.5 km	free	4
	Toll road	55 min	0.5 km	800 yen	5
	Railway	40 min	have no seat	560 yen	6
------	--				
7:20 am -	Free road	95 min	2.0 km	free	10
	Toll road	60 min	0.5 km	800 yen	11
	Railway	40 min	have a seat	560 yen	12

In the PCL model, the probability to choose option *i* is given by formula:

$$P_i = \sum_{j \neq i} P_{i/ij} P_{ij} \qquad (31)$$

$$P_{i|ij} = \exp\left(\frac{V_i}{1-\sigma_{ij}}\right) \Bigg/ \left[\exp\left(\frac{V_i}{1-\sigma_{ij}}\right) + \exp\left(\frac{V_j}{1-\sigma_{ij}}\right)\right] \qquad (32)$$

$$P_{ij} = \frac{(1-\sigma_{ij})\left\{\exp\left(\frac{V_i}{1-\sigma_{ij}}\right) + \exp\left(\frac{V_j}{1-\sigma_{ij}}\right)\right\}^{1-\sigma_{ij}}}{\sum_{q=1}^{n-1} \sum_{r=q+1}^{n} (1-\sigma_{qr})\left\{\exp\left(\frac{V_q}{1-\sigma_{qr}}\right) + \exp\left(\frac{V_r}{1-\sigma_{qr}}\right)\right\}^{1-\sigma_{qr}}} \qquad (33)$$

Where:

- Pi/ij is the conditional probability of choosing option i given the chosen binary pair (ij).
- Pij is the probability for the binary pair (ij).
- σij is the index of similarity between alternatives i and j.

The PCL model is consistent with random utility maximization if the condition 0≤ σ_{ij} ≤1 is satisfied. If $\sigma_{ij}=0$ for all pairs (i, j) then the PCL model becomes an MNL. Substituting the lower two equations into the first one, we have:

$$P_i = \frac{\sum (1-\sigma_{ij}) \left\{ \exp\left(\frac{V_i}{1-\sigma_{ij}}\right) + \exp\left(\frac{V_j}{1-\sigma_{ij}}\right) \right\}^{-\sigma_{ij}} \exp\left(\frac{V_i}{1-\sigma_{ij}}\right)}{\sum_{q=1}^{n-1} \sum_{r=q+1}^{n} (1-\sigma_{qr}) \left\{ \exp\left(\frac{V_q}{1-\sigma_{qr}}\right) + \exp\left(\frac{V_r}{1-\sigma_{qr}}\right) \right\}^{1-\sigma_{qr}}} \tag{34}$$

The estimation results for PCL are given in Table 28 for restricted and unrestricted cases. These models have four alternatives (see Figure 47): before 6:30, between 6:30-7:00, between 7:00-7:20, and after 7:20. The unrestricted PCL case has the similarity parameters σ_{ij} of all the pairs of alternatives, while the restricted PCL has three similarity parameters based on the "distance" between alternatives as follows:

$\sigma_1 = \sigma_{12} = \sigma_{23} = \sigma_{34}$ $\sigma_2 = \sigma_{13} = \sigma_{24}$ $\sigma_3 = \sigma_{14}$

Where:

- σ_1 is the similarity index between two subsequent alternatives.
- σ_2 is the similarity between every other alternative, and the
- σ_3 is the similarity between the first and the last alternative.

It is known that the departure time choice is influenced by the travel time and the delay probability. Here a variable, "safety margin," is employed for departure time choice models in addition to travel time attributes set up in SP experiment. This variable is equal to the difference between work start time and the expected arrival time at the work place. The estimation results are listed in Table 28.

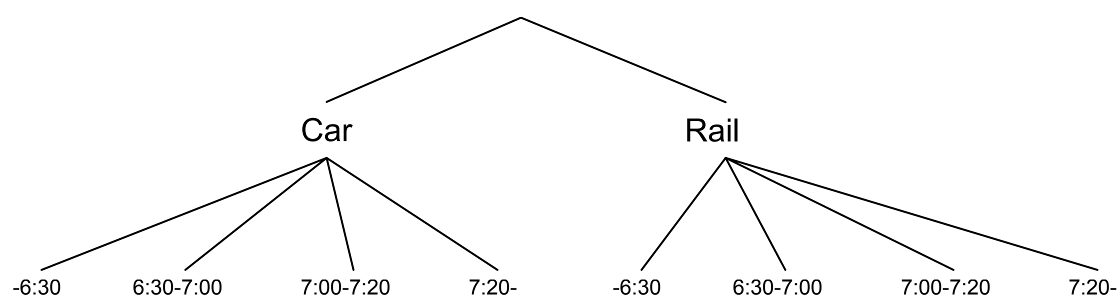


Figure 47. Hierarchical choice structure of the nested PCL model

Table 28. Estimation results of departure time choice models

Variable			Unrestricted PCL model		Restricted PCL model		MNL model	
Travel time		[G]	-0.040	(2.16)	-0.037	(2.99)	-0.039	(1.81)
Safety margin		[G]	-0.046	(4.41)	-0.046	(3.93)	-0.050	(4.18)
Traffic congestion		[C]	-0.528	(0.99)	-0.575	(1.13)	-0.677	(1.11)
Crowdedness in vehicle[a)]		[R]	1.688	(4.90)	1.610	(4.27)	1.754	(4.91)
Constant		[1]	0.426	(1.23)	0.076	(0.24)	0.461	(1.59)
Constant		[2]	1.203	(4.01)	1.100	(2.89)	1.581	(4.89)
Constant		[3]	3.689	(6.68)	3.297	(5.47)	3.631	(7.22)
Similarity parameter	σ_{12}		0.000	(0.004)	-------		-------	
	σ_{13}		0.000	(0.01)	-------		-------	
	σ_{14}		0.647	(1.88)	-------		-------	
	σ_{23}		0.000	(0.11)	-------		-------	
	σ_{24}		0.587	(1.08)	-------		-------	
	σ_{34}		0.000	(0.002)	-------		-------	
	σ_1		-------		0.000	(0.00)	-------	
	σ_2		-------		0.250	(0.40)	-------	
	σ_3		-------		0.679	(1.66)	-------	
Initial likelihood[b)]			-231.5		-231.5		-231.5	
Maximum likelihood			-192.7		-197.1		-192.7	
Rho-squared			0.150		0.153		0.153	
% correct			55.1		55.1		55.1	
No of samples			167		167		167	

Parameter (t-value), a) =1, if possible to have a seat for rail; =0, otherwise, b) L(0), [G]:generic variable, [C]:car specific variable, [R]:rail specific variable, [1]:-6:30 specific variable, [2]:specific variable, [3]: -7:20 specific variable

A nested PCL model is developed by modifying the PCL from Table 28 in order to analyze travel time and mode choices. It includes a hierarchical choice structure. Since PCL is in the logit family, it can be expanded to the nested model in the same way as the ordinary nested logit model. Figure 47 presents the assumed hierarchical structure. The choice probability of alternative I in the nested model is:

$$P_i = P_{i|r} \cdot P_r$$

$$P_{i|r} = \frac{\sum_{j \neq i} (1-\sigma_{ij})(Q_{i.ij} + Q_{j.ij})^{-\sigma_{ij}} Q_{i.ij}}{\sum_{q=1}^{C_r - 1} \sum_{t=q+1}^{C_r} (1-\sigma_{qt})(Q_{q.qt} + Q_{t.qt})^{1-\sigma_{qt}}} \qquad (37)$$

Where:

$$Q_{i.ij} = \exp\left\{\frac{aX_{ir}}{1-\sigma_{ij}}\right\} \quad (38)$$

$$P_r = \frac{\sum_{k \neq l} (1-\sigma_{kl})(D_{k.kl} + D_{l.kl})^{-\sigma_{kl}} R_{k.kl}}{\sum_{g=1}^{R-1} \sum_{h=g+1}^{R} (1-\sigma_{gh})(D_{g.gh} + D_{h.gh})^{1-\sigma_{gh}}} \quad (39)$$

Where:

$$D_{k.kl} = \exp\left\{\frac{(bY_k + \lambda_k L_k)}{1-\sigma_{kl}}\right\} \quad (40)$$

$$L_k = \ln \sum_{i}^{c_k - 1} \sum_{j=i+1}^{c_k} (1-\sigma_{ij}) \left[\exp\left(\frac{aX_{ik}}{1-\sigma_{ij}}\right) + \exp\left(\frac{aX_{jk}}{1-\sigma_{ij}}\right)\right]^{1-\sigma_{ij}} \quad (41)$$

Where X and Y are vectors of explanatory variables, and a and b are their parameter vectors, respectively. L_k is the log-sum variable and λ is its corresponding parameter. Table 29 shows the parameters of the nested PCL model.

The estimated parameters indicate that the informed level of travel service given by pre-trip information significantly affects the departure time choice. It was also shown that similarity parameters among alternatives are not statistically significantly in this SP study. The nested PCL is effective in describing the hierarchical choice structure between travel mode and departure time choice.

Model 5

In the paper of Guan and Nishii[84] a P&BR (Park and Bus Ride) system is presented which is presumed to aid in the reduction of congestion in the Kofu area, in Japan. A social experiment was adopted for that purpose. Questionnaires were given to commuters participating in the experiment, and the data on the commuting behavior and Stated Preference data for the P&BR was obtained. Based on combined experiment data (ED) and SP data the model for estimating the corresponding P&BR demand is proposed. During the experiment days, a questionnaire-based survey on P&BR system was conducted to obtain data regarding their regular commuting behavior on the non-experiment days and SP data for the P&BR system. At the same time, the commuting behavior of people who joined the list of test subjects but did not use the system on experiment days and other commuters, who did not join the list, were surveyed to obtain ED data.

Table 29. Nested PCL models for usual departure time choice and travel mode choice

Variable		Travel mode choice model		Departure time choice model	
Travel cost (100yen)	[G]	0.476	(2.33)	-------	
Travel time	[G]	-------		-0.036	(1.90)
Safety margin	[G]	0.017	(1.41)	-------	
Traffic congestion	[C]	-------		-0.618	(1.23)
Crowdedness in vehicle [a)]	[R]	-------		1.332	(2.88)
Constant	[R]	2.087	(1.42)	-------	
Constant	[1]	-------		1.004	(0.90)
Constant	[2]	-------		1.910	(3.21)
Constant	[3]	-------		2.537	(4.98)
Similarity parameter	σ_{12}	-------		0.000	(0.0008)
	σ_{13}	-------		0.004	(0.032)
	σ_{14}	-------		0.000	(0.000)
	σ_{23}	-------		0.345	(0.279)
	σ_{24}	-------		0.545	(0.517)
	σ_{34}	-------		0.632	(1.268)
Log-sum parameter	λ	0.277	(3.80)	-------	
			[2.80]		
Initial likelihood [c)]		-115.8		-231.5	
Maximum likelihood		-53.3		-203.6	
Rho-squared		0.540		0.100	
% correct		91.0		50.3	
No of samples		167		167	

Parameter (t-value from 0) [t-value from 1], a), b), [G], [C], [R], [1], [2], [3]: See table 1

Based on the previous SP/RP combined models, the ED/SP model is proposed, where equation (42) defines each utility function of the ED model and equation (43) the SP model:

$$u^{ED}_{in} = \beta' x^{ED}_{in} + \alpha' w^{ED}_{in} + \varepsilon^{ED}_{in} = \nu^{ED}_{in} + \varepsilon^{ED}_{in} \qquad (42)$$

$$u^{SP}_{in} = \beta' x^{SP}_{in} + \gamma' z^{SP}_{in} + \varepsilon^{SP}_{in} = \nu^{SP}_{in} + \varepsilon^{SP}_{in} \qquad (43)$$

u_{in}: utility for individual (n)'s alternative (i).

$\boldsymbol{v_{in}}$: deterministic term of utility for individual (n)'s alternative (i).

$\boldsymbol{\varepsilon_{in}}$: random term of utility for individual (n)'s alternative (i).

$\boldsymbol{x_{in}}$, $\boldsymbol{w_{in}}$, $\boldsymbol{z_{in}}$: explanatory variable vector for individual (n)'s alternative (i).

β', α', γ': unknown coefficient vector.

When the log-likelihood functions of ED and SP models are expressed by equation (44), the jointly log-likelihood function of the ED and the SP model is expressed by equation (45).

$$L^{ED}(\alpha', \beta') = \sum_{n=1}^{N^{ED}} \sum_{i=1}^{I_n^{ED}} \delta_{m}^{ED} \cdot \log(P_{ni}^{ED}), \; L^{SP}(\beta', \gamma', \mu) = \sum_{n=1}^{N^{SP}} \sum_{i=1}^{I_n^{SP}} \delta_{ni}^{SP} \cdot \log(P_{ni}^{SP}) \quad (44)$$

$\delta_{ni}^{ED,SP}$={1:choice (i) is selected; o: others}; N: sample size; i: number of choices.

$$L^{ED+SP}(\alpha', \beta', \gamma', \mu) = L^{ED}(\alpha', \beta') + L^{ED}(\beta', \gamma', \mu) \quad (45)$$

To estimate the jointly log-likelihood function, a step-by-step procedure estimation is proposed:

Step 1 By maximizing the log-likelihood function, obtain the estimates of **parameters of the SP model, μ^β' and μ^γ', before making the following calculation:**

$$t\hat{}^{ED}_{in} = \mu\hat{}\beta' x^{ED}_{in} \quad (46)$$

Step 2 The utility function of the ED model is as follows:

$$v^{ED}_{in} = \lambda t^{ED}_{in} + \alpha' w^{ED}_{in} \quad (47)$$

By maximizing equation (47), obtain the estimates λˆ and α'ˆ before calculating the estimate of each parameter by using the following equations:

$$\mu\hat{} = 1/\lambda\hat{}, \; \beta\hat{} = \mu\beta'\hat{}/\mu\hat{}, \text{ and } \gamma\hat{} = \mu\gamma'\hat{}/\mu\hat{} \quad (48)$$

The accuracy of estimates *α', β'* and *γ'* is improved by executing Step 3.

Step 3 To obtain scaled SP data, multiply x and z by μˆ. Pool SP and ED data to estimate the SP and the combined model simultaneously.

The parameter estimation procedure of the above section are presented in Table 30.

Table 30. Results of the estimation procedure

		SP model		Combined model	
		β	t	β	t
		Kaikokubashi route			
Alternative peculiar dummy		0.4937	2.5825	0.3373	2.0706
Parking cost		0.4809	2.0466	0.6394	3.1764
Commuting time		-0.0406	-6.5249	-0.0205	-6.6728
Cost		-0.0003	-8.0745	-0.0002	-9.313
Scale parameter		-	-	1.88	4.986
		Shikishima route			
Alternative peculiar dummy		1.0339	3.9441	0.8701	4.0773
Parking cost		-	-	-	-
Commuting time		-0.0389	-5.4871	-0.0460	-6.2700
Cost		-2.87E-4	-7.2593	-3.00E-4	-8.7135
Scale parameter		-	-	0.92	5.6304
	Kaikokubashi route		Shikishima route		
	SP model	Combined model	SP model	Combined model	
Sample size	539	702	447	574	
L(□	-280.9	-335.67	-251.31	-292.27	
Hit ratio	0.6957	0.7393	0.689	0.7439	
ρ^2	0.2481	0.2691	0.1889	0.2654	

Further, sensitivity analysis was performed on the Combined model and on the SP model. Table 31 shows the four cases tested.

Table 31. Cases tasted on the SP and the Combined model

Case	**Time slot**	**Parking cost**
A	5-15 minutes	no charge
B	5-15 minutes	2000yen/month
C	10-20 minutes	no charge
D	10-20 minutes	2000yen/month

The change rates for P&BR demand in accordance with the change in the parking costs and the time gaps between buses arrivals are shown in Figure 48.

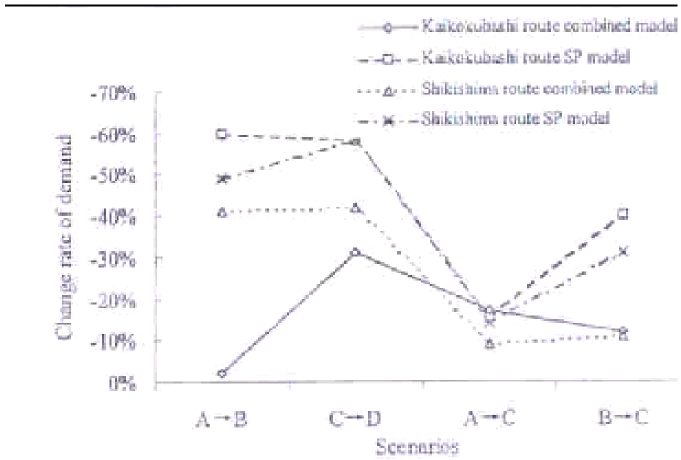


Figure 48. The results in two routes

These results indicate that the SP model is sensitive to changes, while the corresponding combined model is stable against these changes.

Modeling the impact of en-route information on drivers' behavior in Route-Choice

<u>Model 6</u>

The modeling of driver behavior, using a computing paradigm called *Intelligent Agent,* is a new concept introduced by Dia, H. [72, 85]. This model was used in conjunction with a traffic simulation component to evaluate the impact of providing drivers with real time information. This approach allows the modeling of interactions between drivers, coordinating their goals and updating their decisions in real time and day-to-day basis.

In the *Intelligent Agent* paradigm, each driver is modeled through an autonomous software component. An intelligent agent represents a person making a trip. Each intelligent agent is assigned a set of goals that must be achieved (for example, travel from point A to B at minimum cost) and takes input from a database of knowledge comprising of certain beliefs, intentions, and preferences. The main advantage of using Intelligent Agents in travel behavior modeling is that they are active entities that interact with their environment (for example, modify the action decisions based on the available real time traffic information) and in consort with other agents. The first requirement of this model is the identification of parameters that define each user. Suitable Parameters and their potential values would be obtained from the survey that was conducted on the peak-period automobile commuters traveling along a traffic commuter corridor in Brisbane, Australia.

Two types of questionnaires were selected for distribution, of which only one about en-route information is relevant to our study, and will be discussed.

The survey will comprise of questions that will fall into the following categories:

21. Personal information: age, occupation, gender

22. Normal travel pattern: day-to-day behavior such as work schedule, route choice and response to recurring congestion.

23. En route response to unexpected congestion information: do they change certain travel decisions.

24. Willingness to change driving patterns: What incentive is needed to do so?

The model consists of a commercially available microscopic traffic simulation model (PARAMICS) that was used to simulate the commuter corridor. The traffic simulation follows a deterministic fixed time step approach. The dynamic driver model is used to direct individual vehicles on the corridor and specifies how a particular driver approaching a given node selects the next link to be taken. This output is provided to the traffic simulation model through an Application Programming Interface (API).

The model was tested for various scenarios and compared to the base scenario that reflects the network condition without any ATIS strategy.

Model 7

Another experiment using an interactive multi-user simulator - developed at the University of Texas at Austin - was conducted, to examine trip-making behavior in response to different information strategies of varying information quality and credibility (71).

First, in order to make the experiment realistic, some personal as well as travel related data were collected from the participants. The data collected indicated that the average actual travel time to reach the workplace was 26 minutes. About 63.95 % of the participants reported tolerance to lateness in excess of 5 minutes. The average preferred arrival time was 19.6 minutes before work time began.

Using the above data, the experiment was set up to represent a real life situation. Using the simulator, behavior data under various controlled situations of ATIS was collected from participants that were actual commuters.

The data was analyzed using a regression analysis model and the results were further verified and probed by developing multivariate probit models.

The two principal objectives of the experiment were:

25. To model the compliancy behavior of ATIS users and ascertain the key factors that influence compliancy decisions. Specifically, the experiment investigates the association between switching decisions and compliancy decisions to determine how the quality of supplied information affects the overall compliancy rate.

26. To investigate how different potential ATIS information strategies, characterized by a wide range of information, quality, and credibility, affect commuters' travel decision. The following three aspects were examined:

- Nature of information: Prescriptive vs. Descriptive
- Information quality: trip time information based on reliable prediction, prevailing conditions, perturbed prediction, differential predicted, differential prevailing and random.
- Feedback: own trip experience, recommended, actual best.

Studies have been concerned with the users' immediate route choice decisions in response to supplied information. Such information, however, also influences the evolution of the traffic system through its effect on users' day-to-day decision process.

The set up of the study is similar to the set of many studies conducted in this area and can be read by referring to the paper.

The objectives were achieved through the effect of the three experimental factors:

- The commuters that had access to the ATIS system were given prescriptive or descriptive information and their reaction to this type of information was measured.
- In terms of information quality, 6 levels of information type were supplied: from highly precise travel time to randomly generated travel time values.
- In terms of feedback, 3 levels of feedback were used: the first level displayed users own experience such as the actual trip time, the second level displayed the information on the recommended path along with the information in the first level, the third level displayed the information on the actual best path in addition to information in the first level.

Two types of mathematical models were employed to analyze the users' compliance behavior. These models capture the effects of the characteristic strategies, traffic system and the commuters on this behavior:

- Event-count models of the observed frequency of distribution.
- Discrete-choice models of individual decisions, to comply and follow traffic information received.

The first Poisson regression model was estimated to investigate the relative difference in behavior under the three experimental factors represented as binary indicators in the model. The results showed that the users tend to comply more with prescriptive information. Also, a hierarchy of information quality tends to exist with more reliable information, and higher rate of compliance. Third, the user complied more, if he obtained feedback of the actual best path followed by recommended path and least with the information from his own experience.

A second Poisson regression model was estimated relating information quality, experience, information switching interaction, nature of information and post trip feedback to compliancy behavior. The estimators showed that overestimation and underestimation of estimated travel time significantly reduced the likelihood of compliance with underestimation having a greater negative effect. Next, the role of experience on compliance behavior was examined. First, the influence of recent experience and frequency of experience was predicted. The experiment showed a strong negative response to recent experience of traffic jams after the consumer changes routes. The experiment also showed that the farther the distance, the system suggests that they divert, the less willing they are to comply. The proxy-switching cost is a highly influential variable.

In order to analyze the compliancy at disaggregate levels, by modeling compliancy decision of individual user at each decision node, a multivariate probit model structure with embedded logit, model was developed. It was used to verify the above results and to provide a deeper insight into some of the underlying mechanisms of how users combine ATIS with past experience in the system. The estimates from this model had the similar results as the regression models developed. In addition, the models showed that compliance not only depends on how accurate the information is but also on how frequently it is accurate (reliability). The model also showed that the greater number of switches to later departure times, the higher the compliance. The reader can obtain more information on this subject from the studies conducted by Ben-Akiva and Bolduc[86] , Brownstone and Train[87] and Bhat[88].

Model 8

The paper by Polydoropoulou et.al [89]**,** aims to understand how people deal with unexpected congestion during the *en-route* stage and how might they respond to ATIS. The travelers' route selection decisions were investigated through both an SP and an RP survey of Bay Area automobile commuters. Then binary logit models were developed to capture the variables and choices that affect the utility functions developed.

On repetitive commute trips, individuals follow their pre-selected travel pattern. If the travel conditions differ from the expected and travel time exceeds certain thresholds, then they might decide to switch travel pattern. The choices open to travelers acquiring en-route information include route diversion and switching destination, mode and/or parking choice. This paper focuses only on the en-route decision to divert to an alternate route when travelers, through different types of information sources, become aware of unexpected traffic congestion.

Mail-back questionnaires were distributed to peak period automobile commuters crossing the Golden Gate Bridge in February of 1993.

It involved the collection of both RP data on actual en-route travel response to unexpected congestion, and SP data in instances where the response to hypothetical ATIS scenarios was reported. The relationship between traveler response to qualitative, quantitative, predictive delay information, and prescriptive information given by hypothetical ATIS could then be modeled in combination with real-life (reported) behavior.

The survey provided data on attributes of alternative choices (routes). This data were needed to develop a route choice model, which is sensitive to network performance and congestion delays, as well as ATIS characteristics. When faced with the hypothetical situation of having an in-vehicle ATIS device giving accurate delay information on the same trip, a majority of respondents were willing to use this information. Twenty seven percent of travelers would switch to the alternate route when qualitative information is provided to them. This increases to 52% under quantitative information for the usual route, 55% under predictive information for the usual route, 58% when delay information on usual route and travel time on best alternate route are available, and 61% under prescriptive information to take the alternate route.

A unique aspect of this research was the estimation of ATIS user response from a combination of two data types: 1) RP data where the actual behavioral response to unexpected delay is reported and 2) SP data, where traveler behavior in hypothetical ATIS scenarios is reported. RP and SP data were combined to address the validity issue inherent in using SP data The utility maximized by each traveler in the RP context is given by:

$$U_{RP} = V_{RP} + \varepsilon \qquad (48)$$

Where V_{RP} is the systematic utility function influencing the RP decisions; and

ε represents the random utility components influencing the RP decisions.

The utility maximized by each traveler in the SP context is given by:

$$U_{SP} = V_{SP} + \gamma \qquad (50)$$

where V_{SP} is the systematic utility function influencing the SP decisions, and

γ represents the random utility components influencing the SP decisions.

It is assumed that the non-measured components of the RP utility (ε) and the SP utilities (γ) are independently and identically Gumbell distributed, and the level of noise in the data sources is represented by the variance of ε and v. We define μ^2 to be the ratio of the variances:

$$\mu^2 = \text{var}(\varepsilon) / \text{var}(\gamma) \qquad (51)$$

And therefore the SP utilities can be scaled by μ

$$\mu U_{SP} = \mu V_{SP} + \mu\gamma \qquad (52)$$

so that the random variable (*μγ*) has a variance equal to that in the RP utility (ε). It is possible to use both RP and SP observations in a logit estimation procedure that requires equal variance across observations. However, the SP utilities are scaled by an unknown constant *μ*, which needs to be estimated.

Thus, systematic utilities were defined as follows:

$$V_{RP} = \alpha' w + \beta' x + \delta' c \quad (53)$$

$$\mu_i V_{SPi} = (\alpha_i ' w + \beta' x + \gamma' z)\, \mu_i \quad (54)$$

where *i* denotes the specific ATIS scenario.

Vector w represents the dummy variables for the alternative specific constants of each model. All relative coefficients (*α, α_i*) are unconstrained. The SP constants capture the influence of each ATIS scenario on travelers' decisions. Therefore the comparison of the RP and the SP constants gives the en-route switching propensity due to information provided by ATIS.

Sharing β in both RP and SP models implies that trade-offs among attributes included in x are the same in both actual travel behavior and the SP behavior. In the model, the x vectors represent all travel related coefficients, such as travel time, expected delay, and congestion level on the alternate route. These variables are not affected by the information provision, but are actual characteristics of the alternatives. Vectors c are specific to the RP model and include the cause of delay and information source variables used in the RP context.

Factors inherent in SPs are represented by z with the corresponding coefficients γ. In this study, a variable representing the actual choice, included in z, captures the effect of inertia or justification bias. The experience variables are related to the actual delay reported in the RP situation.

The RP portion of the model describes travelers' decisions when they become aware of unexpected congestion on their usual route. A binary logit model was estimated with the dependent variable being the choice among "switching to an alternate route" and "do not change travel pattern."

The following section describes the specification of the variables. The variables included in the model are: 1) Travel time, 2) Expected delay, 3) Congestion on alternate route, 4) Knowledge of travel times, 5) Trip direction, 6) Cause of delay, and 7) Existing information sources.

The SP portion of the model examines commuter response to ATIS. The utility function of each SP model is given in equation (53). The stated preference is a categorical dependent variable, denoted by y, and represented by:

- y = 1 if the response is "definitely take usual route".
- y = 2 if the response is "might take usual route".
- v = 3 if the response is "can't say".
- y = 4 if the response is "might take best alternate route" and

- y = 5 if the response is “definitely take alternate route”.

The dependent variables have five categories, therefore four threshold values, $\theta_{1,}$ $\theta_{2,}$ θ_3 and θ_4 can be identified in the utility scale. The corresponding probabilities are:

- $P(y= 1) = P (\mu U_{SP} <= \theta_1)$
- $P(y=3) = P(\theta_1 < \mu U_{SP} <= \theta_2)$
- $P(y=3) = P(\theta_2 < \mu U_{SP} <= \theta_3)$
- $P(y=4) = P(\theta_3 < \mu U_{SP} <= \theta_4)$
- $P(y=5) = P(\mu U_{SP} >= \theta_4)$

Since the SP utility functions have an intercept, one of the four threshold parameters is not identifiable, so the first one is arbitrarily set equal to zero.

The SP model specification is similar to the RP model specification. Travel time, expected delay, congestion on alternate route, and knowledge of travel time variables are shared between RPs and SPs. The SP model differs from the RP model in terms of the absence of the actual cause of delay (which was tested and found statistically insignificant in the SP scenarios) and the actual information sources (fixed as ATIS in the SP scenarios). The SP models include three new variables. A dummy variable that captures inertia/justification bias is included in the SP experiment. The variable takes a value of 1 if the alternative route was chosen under the RP situation and 0 otherwise. It is expected that travelers who switched routes in the RP situation, are likely to report taking an alternate route in the SP scenarios to justify their prior actual choice. To capture the effect of knowledge regarding traffic conditions, given travelers actual choice, two variables were created: 1) A variable equal to the actual delay experienced if the respondent switched routes in the RP situation. It is expected that the more delay the traveler experienced on the alternate route, the less likely he or she is to switch to the alternate route in the SP scenarios. 2) A dummy variable equal to 1, if the actual delay experienced was higher than the initially expected delay on the usual route, and 0 otherwise. It is expected that travelers who used their usual route and experienced more delay than expected will be more prone to switch in the SP scenarios. The bounds of the SP scenarios are unrestricted among the SP models.

The main results of this study are:

27. The more elaborate information on delay on the usual route (from qualitative, to quantitative, to predictive), the more likely travelers are to take the alternate route.

28. ATIS’ suggestion to take the best alternate route in an unexpected delay situation results in increased probability of route change. This means that a priori people have a propensity to comply with ATIS suggestions.

29. Quantitative information for both usual and alternate route has the maximum effect on travelers' decisions to switch to an alternate route. This reflects the travelers' preference to make an informed decision rather than comply with ATIS instructions.

30. Travel time is negatively and statistically significant, meaning that travelers will choose the alternative with the lowest expected travel time.

31. The longer the expected delay on the usual route, the more likely travelers are to change route.

32. Perceived congestion on the alternate route slightly reduces the possibility of taking an alternate route,

33. The source of information has a significant effect. Travelers are more likely to switch to an alternate route when they became aware of the delay by radio only, or when they become aware of the delay first by radio and then by their own observation, compared with observation and then radio, or observation only.

34. Drivers are less likely to switch to an alternate route on their home-to-work trip.

35. Weather as a cause of delay reduces route diversion probability. This might be explained by the fact that adverse weather affects the whole transportation network; where travelers tend to stay on their usual route, with the expectation that route diversion may not save travel time.

36. People who switched to an alternate route in the RP situation are more likely than others to switch in the SP scenarios.

The results show that with accurate delay information, commuters can overcome their behavioral inertia when faced with unexpected congestion.

The response to various types of ATIS messages is not well understood; it can either cause a spatial transfer of congestion, or worse, lead to increased congestion. Traffic operations managers and ATIS designers must account for the different responses that specific ATIS messages might cause due to an incident.

The basic theory states that behavioral response is predicated by stages of conflict arousal and motivation. Arousal is the stimulation that evokes reaction; motivation is the behavior that effects reaction. Arousal and motivation stem from an internal need to fulfill goals and the resultant activities are a function of all variables that arouse and direct behavior. The response will be influenced by (1) the amount of arousal, (2) the motivation of decision maker during choice, (3) factors of the problem domain, and (4) associations among cognitive elements. A primary factor in predicting an individual's response to conflict arousal is a function of behavioral situations.

Model 9

The conflict assessment and resolution theories popularized in psychology applied by Adler (5) in understanding of en-route driver behavior. Central to the formulation are two basic suppositions: (1) a driver's actions are directed toward meeting a set of travel goals, and (2) changes in behavior occur only as a direct result of the driver's perception that these travel goals will not be achieved.

Decisions to divert or otherwise change from original travel plans occur when a threshold of tolerable conflict is exceeded, and the driver perceives an alternate course of action that would reduce the perceived level of conflict below that threshold. Assessment and response to conflict arousal directly relate to the driver's abilities to perceive and predict network conditions in conjunction with familiarity of network configurations and accessible alternate routes.

To test the approach, an interactive computer based driving simulation, FASTCARS (Freeway and Arterial Street Traffic Conflict Arousal and Response Simulator), was developed. FASTCARS integrates a driver simulation program with the conflict model approach to create a data collection tool for analyzing en-route driver behavior personal thresholds to tolerable conflict, the degree of conflict severity above which people attempt to respond to the situation.

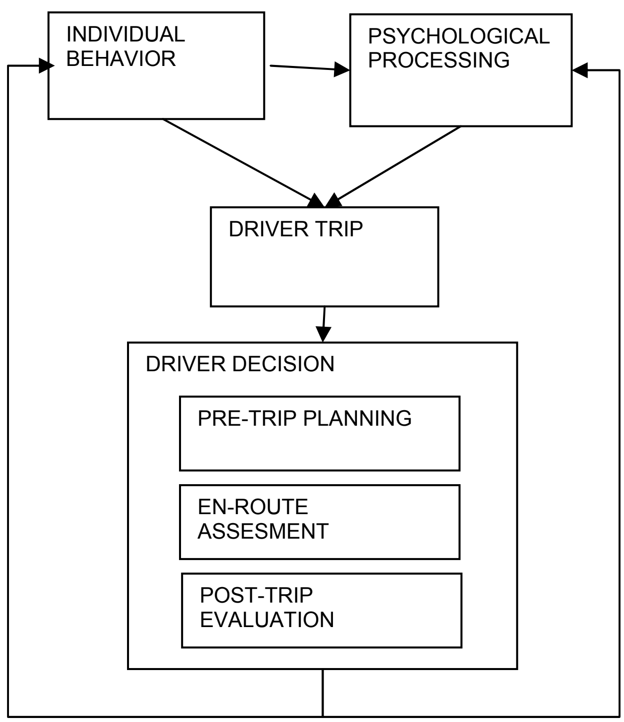


Figure 49. General Schemas for Driver Behavior

Individual behavioral differences and experiences lead to the specification of different threshold levels between decision makers. Literature suggests that through increased experience, individuals learn to endure larger degrees of conflict. Over time, threshold to conflict severity also increases as individuals are more certain and comfortable with their experiences.

The proposed framework for modeling en-route driver behavioral choice is based on conflict theory and is constructed through the relationships between driver behavior, cognitive processing abilities, and components of the decision making process shown in Figure 49. The general approach suggests that travel is defined by three stages: pre-trip planning, en-route assessment and adjustment, and post-trip evaluation. The first two stages involve direct decision making in real-time. The third stage is a longer-term evaluation of past trip-making success creating the link between past performance and future impression that shapes driver behavior over time.

Although the focus of this research was en-route behavior, to enable a complete modeling approach, it is important to consider pre-trip and post-trip decision processes, as these affect the en-route choices of the trip maker.

The author proposes that en-route travel is characterized by 4 main components: (1) initial travel strategies (defined in pre-trip planning), (2) conflict arousal and motivation, (3) information acquisition and processing, and (4) travel adjustment. The en-route decision process is depicted in Figure 50.

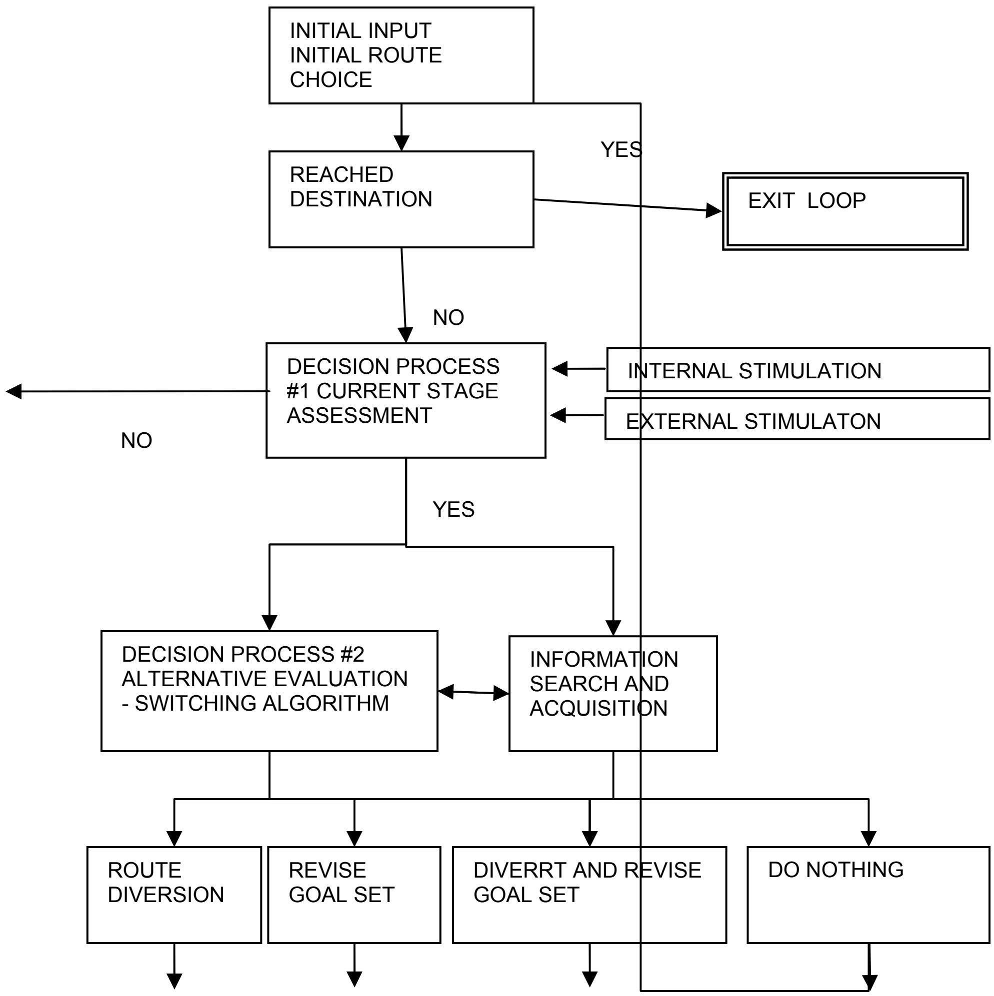


Figure 50. General schema for driver behavior model

Modeling Effort

During pre-trip planning, a driver establishes a set of goals to be achieved. The relative importance of goal attainment is defined by a set of preference weights attributed to each goal. Depending on the units that measure each goal, the decision-making process may be specified as either objective (e.g., minimize cost) or multi-objective (e.g., balance a set of conflicting goals measured in varied units such as cost and time).

For a given trip i at time t, the set of travel goals, $G^{it}_{d}(X)$, for driver d can be given as:

$$G_d^{it}(X) = [G^{it}_{1d}(x1), G^{it}_{2d}(x2), \ldots\ldots\ldots, G^{it}_{gd}(xg)] \quad (55)$$

Where:

G_{gd}^{it} (x_g) = Travel goal g for driver d at time t for trip I

x_g = Set of performance indicators for goal g

Although drivers approach route choice differently, the decision process may be modeled by standard methods. For this analysis, a *Weighted Objective Decision Method* was assumed. In this model, the objectives are ranked according to preference and relative weights are assigned in proportion to the strength of preference. Utility for a specific route or link is measured by the additive sum of the expected value of the goal attainment level multiplied by the relative weight. The selected alternative is the one that maximizes the expected utility,

$$\hat{U}^r = \sum_{g=1}^{G} W_g \hat{V}_g^r \tag{56}$$

Where:

$\hat{U}^r$ = Total predicated utility for route r

W_g = Relative weight for goal g

$\hat{V}_g^r$ = Perceived expected value for goal g on route r

In the formulation above, the value of goal attainment for a specific route is based on a driver's perception and prediction of travel conditions and associated utility levels. For any trip, at a given time, there is an actual value of utility V for a route, however, this value of utility is unknown to the driver. Instead, each driver bases his decisions on some perceived level of utility. This perceived utility may be stated as the actual utility biased by personal behavior (e.g., risk) and an uncertainty factor ρ such that:

$$\hat{V}_g^r = \rho_g^r V_g^r \tag{57}$$

The parameter ρ is a function of the driver's behavior, experience, and knowledge of the route and the system. At each time t + At, driver's cognitive processing is updated which in turn changes the factor ρ = ρ + Δρ.

As the trip maker is traveling trough the chosen route, he/she periodically evaluates his/her progress towards attaining his/her goals. The assessment phase is initiated when drivers become more uncertain that their goals may not be met, if they were to continue on the current path under the current travel conditions. As travel conditions change, and the conflict levels increase, the desire to alter travel behavior becomes more apparent. The threshold to conflict tolerance may be defined as the level of overall utility for a given route, below which the route becomes undesirable, or:

$$\hat{U}^r < U^r \quad (58)$$

Where:

$\hat{U}^r$ = Threshold utility level for route r

U^r = Perceived utility on route r

Once a significant conflict arousal has been inflicted, the trip maker responds by either diversion of route or goal revision. Response is triggered by high arousal and motivation. Diversion occurs under high motivation and goal revision under low motivation. Both responses are based on the ability to reduce conflict and improve the utility of travel.

High motivation occurs when drivers project that diverting to an alternate path i will result in a significant gain in marginal utility. Diversion will occur, if the perceived utility on the alternate path `i' is greater than the utility projected for the current path `c' by some improvement threshold η:

$$\hat{U}^c + \eta < \hat{U}^j \quad (59)$$

Several factors impact both the prediction of utility and switching propensity Mahmassani and Jayakrishnan[90]. First, there is some inherent uncertainty associated with estimating utilities. With imperfect information of travel conditions, the prediction is based on limited perception and memory. The inertia resulting from uncertainty that refrains many drivers from switching paths is based on the risk-taking behavior of drivers defined earlier by the parameter *ρ*.

Often motivation to switch depends on the set of alternatives. Under high conflict but low motivation, it is possible that drivers will remain on course but revise the weights of the goal set. Adjusting the level of expectation through a reordering of the weights may reduce the levels of anxiety and frustration that was increasing as a result of the inability to meet previously defined objectives (i.e., reduce cognitive dissonance). If W represents the new ordering of weights on the objective space, the revised utility of the current course of action is:

$$Max(U'^c + \eta, U'^j) \quad (60)$$

These weights may change in response to conflict several times during the course of a trip. It is likely that the experience will lead drivers to rethink the initial ordering of the weight set and to consider which orderings were more effective in reducing conflict during the trip.

FASTCARS, in conjunction with the modeling framework proposed, is an interactive computer-based simulator that has been developed for in laboratory experimentation to gather data for estimating and calibrating predictive models of driver behavior under conditions of real-time information. The simulation integrates a model of multi-objective goal specification and evaluation, a hypothetical traffic network, simulated real-time information technologies, and interactive driver travel choices. FASTCARS is designed to model en-route travel decision-making. FASTCARS provides an artificial environment that replicates spatial and temporal situations that arouse conflict and motivation during travel. The combination effects of perception, conveyed through visual representation of traffic conditions, and prediction, through real-time information availability, form the background choice domain. A scoring and evaluation format, based on weighted additive utility models, provides a basis for analyzing behavior and preference. The experimental set up in FASTCARS can be reviewed in detail by referring to this paper.

FASTCARS has provisions for VMS within its simulation environment, and hence can be effectively and easily adopted to study the effect of Parking and Transit Information on drivers.

Model 10

In this experiment (Mahmassani and Liu[(74)]) data was collected using a simulation-assignment model based on the corridor network version of theDYNASMART model that includes en-route path switching. DYNASMART is a simulation-based DTA model that has similar characteristics to the VISTA and DYNAMIT models. All user responses are directly input into this model, thus the traffic conditions are presented in real-time. The simulator comprises three main components: the traffic performance simulator, the network path processing component and the user decision-making component. The traffic performance component is a fixed time step mesoscopic simulator. This component processes the link trip time and delays, and provides this as input to the network path processing component which in turn calculates the path time. This information is given to the user and data on path switching decisions is recorded. The setup of this experiment can be reviewed from the paper.

Forty-five participants were randomly recruited and their behavior studied. A post-experiment questionnaire revealed that 95.6% of the participants perceived the information as accurate and approximately 76% tended to adopt the information for future use.

Next, a model of the decision process that determines en-route path switching as a function of the user's cumulative and recent experience with the system was developed and calibrated using multinomial probit framework. This took into account the traveler's learning from the past experience with the system and captured the serial correlation arising from repeated decisions made by the same traveler.

The model is based on the theory that commuter 'i' does not switch routes or path as long as the corresponding trip time saving TTS_{ijt} (at decision node j on day t), which is the trip difference between the current path TTC_{ijt} and the best path TTB_{ijt} remains within the commuters route indifference band IBR_{ijt} as follows:

$$TTS_{ijt} = TTC_{ijt} - TTB_{ijt} >= 0, \; j = 1,2,3,4,5,\ldots.N \;\; t = 1,2,\ldots\ldots.T \quad (61)$$

$$\phi_{ijt} = \begin{cases} -1 & if \quad 0 \le TTS_{ijt} \le IBR_{ijt}, \\ 1 & otherwise. \end{cases} \quad (62)$$

Φ_{ijt} (j=2,3,4,5…N) equals 1 when user switches his or her path at decision node j, with Φ_{ijt} equals –1 otherwise.

From the model proposed in (Mahmassani and Jayakrishnan[90]), the above model can be adopted and the new equation is:

$$\phi_{ijt} = \begin{cases} -1 & if \quad TTS_{ijt} - TTB_{ijt} \le \max[\eta_{ijt} TTC_{ijt}, \pi_{ijt}], \\ 1 & otherwise. \end{cases} \quad (63)$$

Where

$$\eta_{ijt} = g_r(X_i, Z_{ijt}, \theta_{ijt}) + \xi_{ijt,r} \qquad \xi_{ijt,r} \approx MVN \;(0, \Sigma \xi_r), \quad (64)$$

$$\pi_{ijt} = g_r(X_i, Z_{ijt}, \theta_{ijt}) + \xi_{ijt,r} \qquad \xi_{ijt,m} \approx MVN \;(0, \Sigma \xi_m), \quad (65)$$

η_{ijt} represents the relative indifference band, as a fraction of the $TTC_{ijt.}$. π_{ijt} denotes the corresponding minimum path time savings, from decision node j to the destination, necessary for the user I to switch from the current path on date. Both quantities are random variables, with the mean values anticipated to vary symmetrically with the users' characteristics and experience to date. As such, both quantities consist of systematic and random variables.

The systematic component of relative indifference band and the minimum time savings are $g_r()$ and $g_m()$, respectively. They depend on user's inherent attributes X_i and vector of performance characteristics Z_{ijt} experienced by user 'i' up to decision point j on day t, θ_{ijt} is a vector of parameters to be estimated. The random terms $\xi_{ijt,x}$ and $\xi_{ijt,m}$ are assumed to be normally distributed, with zero means and general covariance structure.

Comparing Eqns. (61) and (62), the expression for indifference band for en-route switching is obtained as follows:

$IBR_{ijt} = \max [\eta_{ijt} TTC_{ijt}, \pi_{ijt}]$

Based on research, the specifications of the route switching band consist of the following components:

37. initial band
38. user characteristic component
39. information reliability component
40. myopic component
41. scheduled delay component
42. unobserved component.

For the purpose of the analysis, the variables included in the en-route behavior model are shown in Table 32.

Table 32. Variable definitions for the indifference band in joint departure time and route switching model

Element	Definition	
AGE_i	Age of commuter i, 1 if age<20: 2 if 20<=age<=39; 3 if age 40<=age<=59; 4 if age >60	
$GENDER_i$	Gender of commuter i, =1 if male; =0, if otherwise	
$ERRO_{ijt}$	Over-estimation error provided by real-time information; the relative error between actual travel time and travel time reported from the system when actual travel time is shorter then reported travel time	
	$ERRO_{ijt}$=max{(RTT_{ijt}-ATT_{ijt})/ATT_{ijt},0}	
	ATT_{ijt}:actual trip time from node (j-1) to node j	
	RTT_{ijt}:reported trip time provided by real-time information for commuter i from node (j-1) to node j	
	For pre-trip decision (j=1)	
	$ERRO_{i1t}$: average error from origin to destination on day (t-1)	
	$ERRO_{i1t}$=($ERRO_{i2t-1}$+...+$ERRO_{i5t-1}$+$ERRO_{i6t-1}$)/5	
	$ERRO_{i6t-1}$:relative over-estimation error from node 5 to the destination in day (t-1)	
$ERRU_{ijt}$	Under-estimation error provided by real-time information; the relative error between actual travel time and travel time reported from the system when actual travel time is longer then reported travel time	
	For en-route decision (j=2,3,4,5)	
	$ERRO_{ijt}$=max{(ATT_{ijt}-RTT_{ijt})/ATT_{ijt},0}	
	For pre-trip decision (j=1)	
	$ERRO_{i1t}$=($ERRO_{i2t-1}$+...+$ERRO_{i5t-1}$+$ERRO_{i6t-1}$)/5	
$SERRO_{it}$	Sum of the values of over-estimation error provided by real-time information including pre-trip and en-route on day t-1	

	$SERROit=(ERRO_{i2t-1}+ERRO_{i3t-1}+...ERRO_{i6t-1})$
Element	**Definition**
	$ERRO_{i6t-1}$: relative over-estimation error from node 5 to the destination in day (t-1)
$SERRU_{it}$	Sum of the values of under-estimation error provided by real-time information including pre-trip and en-route on day t-1
	$SERRU_{it}=(ERRU_{i2t-1}+ERRU_{i3t-1}+...ERRU_{i6t-1})$
	$ERRO_{i6t-1}$: relative under-estimation error from node 5 to the destination in day (t-1)
λit	A binary indicator variable, equal to 0 if $D_{it}=D_{it-1}$
ΔTRit	The difference between travel times of commuter i has adjusted between day t and t-1(min)
ΔDTit	The amount of departure time that commuter i has adjusted between day t and t-1 (min)
$SDPE_{ijt}$	Early-side schedule delay relative to commuter's preffered arrival time for commuter i at decision node j on day t (min)
	$SDPE_{ijt}=max\{PAT_i-RAT_{ijt},0\}$
	PAT_i: preferred arrival time for commuter i
	RAT_{ijt}: predicted arrival time for commuter i from node j to destination according to the travel time provided by the real-time information system ($RAT_{ijt}=CLOCK_{ijt}+TTC_{ijt}$)
	$CLOCK_{ijt}$:current clock time for commuter I at node j on day t
$SDPL_{ijt}$	Late-side schedule delay relative to commuter's preferred arrival time for commuter i at decision node j on day t (min)
	$SDPE_{ijt}=max\{RAT_{ijt}-PAT_i,0\}$
ω_{it}	A binary indicator variable, equal to 1 if SD>=0 (early-side), or equal to 0 if SD<0 (late-side)
κ_1	A binary indicator variable, equal to if j=1 (pre-trip route decision), or equal to 0 if j=2,3,4,5 (en-route decision)
a's,b's,c's,d's	parameters to be estimated
τ_{it}	Error term of departure time switching indifference band for commuter i on day t
$\xi_{ijt,r}$, $\xi_{ijt,m}$	Error term of route switching indifference band for commuteri at node j on day t(η_{ijt}, π_{ijt})

$$IBR_{ijt} = \max[\eta_{ijt} TTC_{ijt}, \pi_{ijt}], \quad j=1,2,3,4,5 \tag{66}$$

$$\begin{aligned}
\eta_{ijt} &= \kappa_1 a_1 + (1-\kappa_1)a_2 && \text{Initial band} \\
&+ a_3 GENDER_i + && \text{User characteristic component} \\
&a_4 ERRO_{ijt} + a_5 ERRU_{ijt} && \text{Information reliability component} \\
&+ a_6 SDPE_{ijt} + a_7 SDPL_{ijt} && \text{Schedule delay component} \\
&+ \xi_{ijt,r}, && \text{Unobserved component}
\end{aligned} \tag{67}$$

Initial band (68)

User characteristic component

Information reliability component

Schedule delay component

Unobserved component

$$\pi_{ijt} = \kappa_1 b_1 + (1-\kappa_1) b_2$$
$$+ b_3 GENDER_i +$$
$$b_4 ERRO_{ijt} + b_5 ERRU_{ijt}$$
$$+ b_6 SDPE_{ijt} + b_7 SDPL_{ijt}$$
$$+ \xi_{ijt,m},$$

The model parameters were estimated using a special purpose maximum likelihood estimation procedure that relies on Monte-Carlo simulation to evaluate the MNP choice probability.

The results of this experiment are:

- Females exhibit a wider mean indifference band than male commuters for en-route path switching.
- Trip makers become more prone to switch routes when the system provides under-estimated trip time information than when the system provides over-estimated trip time.
- Commuters tend to switch routes in response to higher differences between the predicted arrival time, at the destination node, and their own preferred arrival time.

Modeling the impact of transit information on travelers' behavior

Model 11

There have been very few studies relative to the effect of transit information system on traveler behavior. The study of Abdel-Aty et.al [91] relates the commuter perception of transit services available to them, their level of familiarity with it and the potential impact of transit information system on the propensity of commuters to use transit that currently do not use transit. For this study, an SP survey of the users of Santa Carla and Sacramento counties were conducted through computer aided interviews. Different questionnaires were prepared for transit and non-transit users. A methodical definition of transit and non-transit users was prepared for this study as shown in Figure 51.

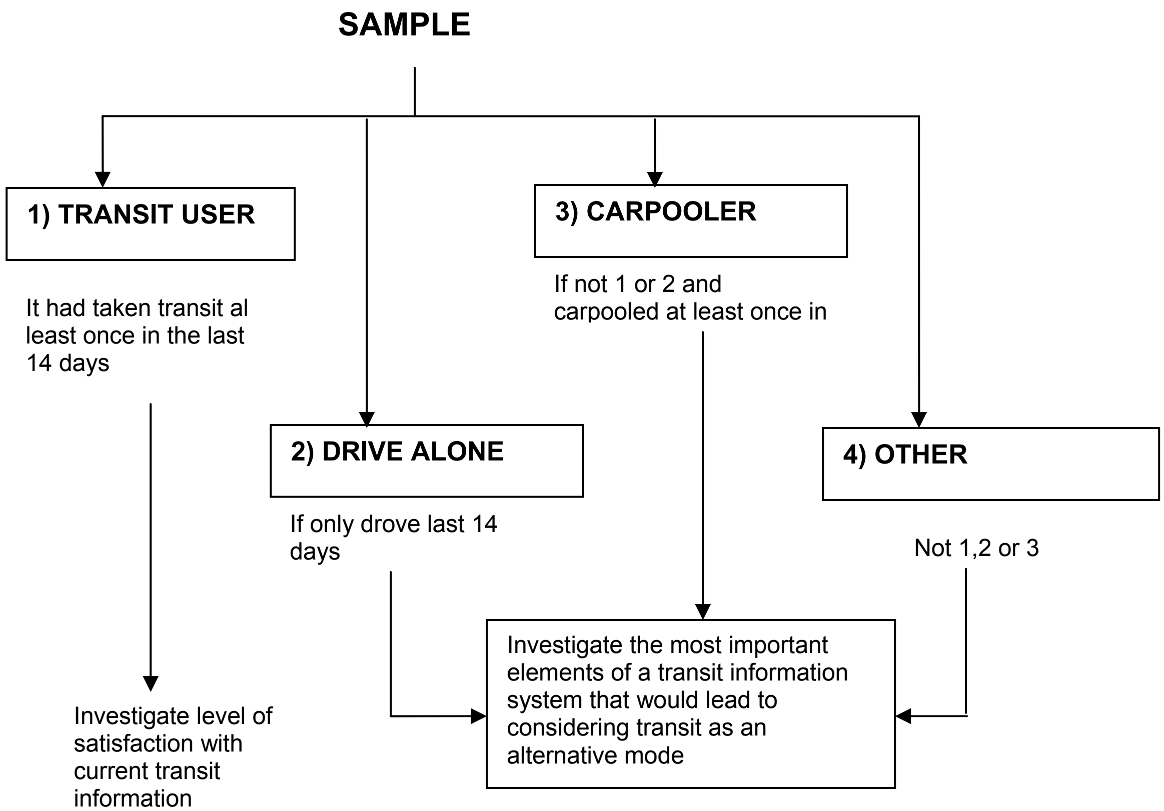


Figure 51. Basic branching in survey design

The following information was obtained from each correspondent:

- General commuter characteristics, including travel time, flexibility of work starting time etc.
- Traffic information that the respondents receive.
- Commuters' perception of transit service in their area.
- The most important types of transit information that commuters' desire and its potential impact on propensity to use transit.
- Stated-preference choice set that investigates the likelihood that non-transit users will use transit, if the desired information is available.
- Detailed information about transit use for transit users.

- Level of satisfaction of the transit users regarding the availability of different types of transit information, identifying the most important information desired by each respondent.

- Demographic and socio- economic data.

- Familiarity with transit service.

The results of the survey showed that 80.5% drove alone, 10.5% carpooled, 4.4% took transit and approximately 4.6% either rode a bicycle or walked. The average travel time was 24.75 minutes. Statistical test showed that richer people used transit.

The reasons for taking transit were as stated in this order from maximum preference to minimum are:

- car unavailable every day

- saves money

- dislike driving

- don’t own a car

- don’t have to pay for parking

- keeps air clean

- difficulty finding a parking space at work

Table 33. Main reasons for taking transit to work

Car unavailable every day	10 (24.39%)
Saves money	6 (14.63%)
Dislike driving	4 (9.76%)
Saves time	3 (7.32%)
Don't own a car	2 (4.88%)
Don't have to pay for parking	1 (2.44%)
Keeps air clean/people have to do their part	1 (2.44%)
Difficulty finding a parking space	1 (2.44%)
Undecided/Don't know	2 (4.88%)
Other	11 (26.83%)
Total	41 (100%)

In this study, a majority used bus service (68%) while train and light rail accounted for 12.5%.

Also, the study indicates that commuters who live relatively closer to transit stops use transit and approximately 26% drove to it. Also, a majority (83%) indicated that they wait 10 minutes or less on an average for transit service. About 48% had monthly passes and 36% paid for each ride.

It is also noted that 38% of non-transit users indicated that they might consider transit if more information were available.

Transit users were also asked to name the three most important items of transit information that needed to be improved. P&R information was ranked as the first most important by 4.5%, 2nd most important by 2.6% and third most important by 6.2% of transit users.

To investigate the potential impact of transit information on commuters' willingness to use transit, an SP survey of non-transit users was conducted. The travel time by transit was customized for each respondent based on actual travel time previously given in an interview. The travel time by transit was the respondents' travel time multiplied by a factor (0.75,1.00, 1.25, 1.50). This factor was generated randomly among the four choices. The response was scaled from 1 to 10: 1 denoting it extremely unlikely to use transit and 10 denoting it extremely likely to use transit.

In order to model the choice of non-transit users towards transit use, if certain information about transit use was available to them, an ordered probit model was used. This model was chosen from among various alternative models because it can model a dependent variable that takes more than two values, when these values have a natural ordering.

The dependent variable is unobserved and is expressed as

$$Y^*_I = \beta' x_i + \varepsilon \qquad (69)$$

Where Y* = dependent variable coded as 0,1,2,3,……

β = vector of coefficients

xi = vector of independent variables

ε = error term, normally distributed N[0,1]

The dependent variable is observed as the likelihood to use transit, therefore let

$$\begin{aligned} &Y = 0 \text{ if } Y^* <= 0 \\ &Y = 1 \text{ if } 0 <= Y^* <= u_1 \\ &\vdots \\ &Y = j \text{ if } u_{j-1} <= Y^* \end{aligned} \qquad (70)$$

The threshold values μ_j and the coefficient vector β are unknown and should be estimated.

For a normal distribution, the probability that Yi falls into the jth category is given by

$$\mathrm{P(Yi = j)} = \Phi(\mu_j - \beta' x_i) - \Phi(\mu_j \quad \beta' x_i), \mathrm{j} = 0,1,\ldots\ldots\mathrm{J} \tag{71}$$

This model was run and the results were as follows:

- As the travel time by transit increased, commuters were less likely to use transit
- Commuters that already carpooled had a higher likelihood of using transit.
- Respondents over 70 years of age had a higher likelihood of using transit.
- Respondents that had a lot of control over their work starting time were less likely to use transit.
- Women are less likely to use transit
- Owning no car increases the probability of using transit.

Modeling the impact of parking information on drivers' choice of parking

Model 12

The use of VMS as a communications medium to provide travelers with up-to-date information on the number of open spaces at selected parking lots throughout a city, has been analyzed in Hester[92].

The aim of the paper was to focus on the behavior rules that govern drivers' performance when choosing among parking lots. What is relevant to our study is the mathematical model developed to capture the driver decision process towards parking, after reading the VMS and the variables involved in the model.

Studies have suggested that parking choices are based on a set of factors that reflect the environment and the decision maker, Thompson and Richardson[93]. Factors that reflect the environment include the in-vehicle travel time, time to drive to the parking lot plus find a space within the lot, egress time, i.e. time to walk from the parking lot to some final destination, parking fee at a lot, expected fine when parking illegally outside a lot, and expected time spent queuing, at the parking lot entrance.

The study revealed that the drivers' decisions are risky ones in this case, because the outcomes of a given choice are not always known with certainty. For example, based on the parking availability information on a VMS, a driver located at some distance upstream of several different possible lots will choose to park in one particular lot and then head toward that lot. However, when the driver arrives at the chosen lot, the lot might have become filled. Thus, at the time the driver makes a decision to park in a particular lot, it is not known which of the two outcomes will occur—the lot is full or the lot is not full. In this context, the driver might decide to combine the utilities of the outcomes of a particular choice in order to have some standard for comparing one risky decision to another.

A mathematical model based on utility was developed and tested. The decision to park in a particular lot was made more or less risky by varying the number *k* of open parking spaces at the lot and, therefore, the probability *p*(*k*) that the lot would be available when the driver arrived was assumed. Additionally, in order to approximate the load actually placed on the driver, participants had to navigate a virtual roadway while making their parking lot decisions, using an advanced driving simulator to present the actual stimuli. The set up of this experiment can be referred to by reading the paper. Two sets of experiments were conducted. Experiment 1 tested several plausible alternative versions of the expected utility EU theory. The results from this first experiment were consistent with the assumption that drivers minimized their expected travel time.

Experiment 2 dealt with the theory that describes the choice between several parking lots and is not relevant to our study. Hence only Experiment 1 is discussed here.

In Experiment 1, three different versions of the EU theory were tested. First, one assumed that some or all drivers attempt to minimize the expected travel time (METT) to a given lot (METT decision rule). Second, one might assume that some drivers attempt to minimize the walking distance (MWD) from the lot to the final destination (MWD decision rule). Finally, one might assume that some drivers attempt to minimize the time spent waiting at a lot for a parking space or, equivalently, they attempt to maximize the parking availability (MPA decision rule). In each parking scenario with several alternative lots, drivers were told as to how far it is to each lot, how long they will have to wait if the lot is full, how long a walk it is from each lot to the destination, and how many spaces are available in each lot.

Thus, it is simple then to determine for each scenario which lots would be chosen by drivers trying to MWD or MPA. However, it cannot so quickly be decided which lot in a scenario drivers trying METT would choose. Here we need to define several additional terms as follows:

- Tij(k) is the travel time to lot *i* with *k* open spaces when the destination is building *j*.
- $t_{d(i)}$ is the driving time to a lot *i*,
- $t_{w(ij)}$ is the walking time from a lot *i* to destination *j*,
- t_q is the waiting time in a queue at a parking lot if that lot were full when the driver arrived, and
- *p*(*k*) is the probability that a lot with *k* available spaces displayed on a VMS will be open when the driver actually arrives at the lot.

Assumptions:

- All parking lots have the same parking space capacity (number of parking spaces),
- The waiting time, t_q, is the same at all parking lots,

- The probability, $p(k)$, is the same for all parking lots.

The expected total travel time is a weighted average of the travel time, when the lot is not full and the travel time when the lot is full.

$$E[Ti\,j(k)] = p(k)[\,t_{d(i)} + t_{w(ij)}] + [1 - p(k)][\,t_{d(i)} + t_{w(ij)} + t_q] \qquad (72)$$

In order to predict the expected travel time in Eq. (71) for each lot in a given parking scenario, the walking, driving, and waiting times need to be known or estimated. In addition, the probability $p(k)$ needs to be known or estimated. The walking, driving and waiting time components were used directly in the model.

The probability $p(k)$ had to be estimated. Under real traffic and parking conditions, this probability could be estimated based on the historical arrival and departure distributions for each parking lot, real time estimates of arrivals and departures and a continuous estimate of the number of free parking spaces. In this study the following estimation procedure was used for probability $p(k)$. A realistic probability function is the one in which participants perceive nearly a 0% likelihood of arriving at a lot and finding it open, if there is less than some criterion number of open spaces in the parking lot. Above this criterion number, the perceived likelihood may rapidly increase as the number of open spaces increases until it reaches another, larger criterion number of spaces at or above which participants may perceive a nearly 100% likelihood of finding a lot full upon arrival. The relationship between the probability p that a lot is open and the number of available spaces k, is represented by a power function with two parameters, α and β.

$$p(k) = \frac{1}{2} + \frac{1}{2}\left[\frac{\beta^{(k-\alpha)} - \beta^{-(k-\alpha)}}{\beta^{(k-\alpha)} + \beta^{-(k-\alpha)}}\right] \qquad (73)$$

The shape of the function is much like the shape of the cumulative normal distribution. Manipulation of the parameter α in the above function adjusts the inflexion point in the curve. Manipulation of the parameter β adjusts the steepness of the ascent of the function from the *x*-axis. The parking scenarios in Experiment 1 were designed so that the three potential decision rules could be clearly differentiated. This was accomplished by creating a subset of scenarios where each strategy predicted the choice of a different lot. A computer algorithm was developed to identify the values of α and β that maximized the agreement between participants' responses and the decisions consistent with the METT choice rule. The maximum agreement was found with α equal to 8 and β equal to 1.6. The participants' responses overall were more often consistent with the decision to minimize the expected travel time (93.5%) than they were either with the decision to minimize the walking distance (78.3%) or the decision to maximize the parking availability (24.3%). The percentages do not add to 100, because in many of the scenarios two or more of the decision rules lead to the same lot choice.

APPENDIX H. SIMULATION-BASED DTA MODELS

DTA models are used to estimate time-varying network conditions by capturing traffic flow and route choice behavior. DTA models are typically classified as analytical approaches, including mathematical programming, variational inequality and control theory approaches, or as simulation-based heuristic models. Extensive work has been performed for all of these approaches, and an overview of this literature, along with a discussion of current and future challenges in DTA research and applications, can be found in Peeta and Ziliaskopoulos, 2001[(104)].

Over the past 16 years the United States Federal Highway Administration (FHWA) has sponsored the development of DTA models that could be used for planning, given the inherent faults of the static traffic assignment, and for Intelligent Transportation Systems (ITS) applications such as the estimation and prediction of traffic conditions. Under this research effort, the FHWA developed two mesoscopic DTA models, the DYNASMART developed at The University of Texas at Austin, and the DYNAMIT (Ben-Akiva *et al.*, 1994)[(99)] developed at the Massachusetts Institute of Technology (MIT). Parallel to this effort Ziliaskopoulos at Northwestern University, developed the RouteSim mesoscopic simulator and the VISTA DTA (VISTA) (Ziliaskopoulos 2000,[(106)] Ziliaskopoulos and Waller, 2000[(108)]).

A basic characteristic of these models is the utilization of a traffic simulator to emulate the traffic conditions especially for signalized systems where it is very difficult to capture the dynamics of traffic through analytical techniques. In general, simulation-based DTA models iterate between a traffic simulation module, a time-dependent shortest path module, and a network-loading module. First, given a set of vehicles and their travel paths, the traffic simulation module replicates complex traffic flow dynamics as the vehicles are propagated through the network. The link travel times reported by the simulator are then used to calculate the time dependent shortest paths. Those shortest paths are then combined with all previous sets of shortest paths, and the vehicles are loaded onto the network on those paths. A new iteration then begins as the simulator propagates vehicles through the network along the new combination of paths. The process stops when some user-specified convergence criterion is met. Next we briefly discuss some of the main simulation-based DTA models.

Mahmassani et al. (1993) [(102)] presented a simulation-based assignment model called Dynamic Network Assignment Simulation Model for Advanced Road Telematics (**DYNASMART**). The model simulates the movement of individual vehicles (Mahmassani 2001) [(103)] using a macroscopic speed-density relationship that is a modified version of Greenshield's equation. Abdelghany and Mahmassani (2001) [(96,97)] extended the simulator capability to capture bus movements. In addition, the routing algorithm in DYNASMART was enhanced to calculate inter-modal paths (auto, bus, train, auto plus bus, auto plus train, bus plus train). Abdelghany et al. (2001)[(97)] used the multi-modal model to evaluate bus preemption strategies at signalized intersections.

DYNAMIT is a simulation-based DTA model developed by Ben-Akiva et al. (1994)[(99)] at MIT. The simulator iterates between the update phase and the advance phase. During the update phase, queue lengths, link densities and speeds are updated, and in the advance phase, packets of vehicles are moved to their new positions.

TRANSIMS is a system of travel forecasting models developed at the Los Alamos National Laboratory. TRANSIMS (Los Alamos National Laboratory, 2002- http://transims.tsasa.lanl.gov)[(101)] propagates traffic based on cellular automata rules, and includes an inter-modal trip planning module that computes combined route and mode trip plans to accomplish the desired activities.

INTEGRATION (Van Aerde et al. 1996)[(105)] uses a microscopic traffic simulator based on car-following principles. Route choice, speed choice, lane choice and gap acceptance are captured, and the behavioral parameters have been calibrated such that the simulator results reflect macroscopic traffic relationships. The microscopic simulator captures shock waves, gap acceptance and weaving phenomena, which cannot be captured using macroscopic models; however, this logic is computationally intensive and limits the size of networks that can be solved.

The **VISTA** system was developed by Ziliaskopoulos at Northwestern University (Ziliaskopoulos and Waller (2000) [(108)]. The principal characteristics of VISTA are: 1) The travelers behavior is modeled using a DTA model that converges to an Dynamic User Equilibrium; 2) it utilizes a universal database model that is based on a spatial GIS that can be easily interface with other databases; and 3) it is Internet and/or Intranet based, providing access to the various stakeholders to run the various algorithms, view the results of the models, query the database, change the database based on the authorization level of each.

The VISTA model's simulator, called RouteSim, uses cell transmission rules (Daganzo, 1994)[(100)] for traffic propagation. In other words, the movements of small groups of vehicles are simulated as they enter and leave sections of each link. Links are divided into cells that are equal in length to the distance traveled in one time step by a vehicle moving at free flow speed. As such, if no congestion exists, all vehicles in a cell will move to the next cell forward in one time step; however, the number of vehicles that move forward is limited by the amount of space available in the next cell, and the maximum flow permitted across the cell boundary. If the number of vehicles attempting to move forward exceeds the space or flow constraints, some vehicles will not be able to move forward, and a queue will develop.

In the cell transmission model vehicle position is tracked only at a cell level, and vehicle speeds are estimated based on transmission time across cell boundaries. While this may be less detailed than other models, the cell length and time step can be reduced for a higher degree of detail. The RouteSim model does not require explicit calculation of speeds, and thus does not rely on the use of speed-density functions to propagate traffic; however, the principles of the cell transmission model are consistent with the hydrodynamic theory of traffic flow. Further, the model can capture many realities of the network, such as traffic signals, by using time-dependent cell capacities and saturation flow rates. The simulator has been enhanced to capture bus stopping behavior, and the roadway capacity reduction that results from a stopped bus. A preliminary evaluation of transit signal priority was presented by Agrawal et.al (2001)[98] using the simulation capability in RouteSim.

The DTA model assigns each vehicle to a path based on either the User Equilibrium or System Optimal rule. Under the User Equilibrium rule all vehicles for an OD pair are assigned to a set of paths that have equivalent travel time (cost). Under the system optimal rule, the vehicles are assigned such that the network-wide travel time is minimized (or equivalently, the path marginal costs are the same for all used paths for each OD pair). As such the user can trace the path of a vehicle per time interval from its origin to the destination. In addition, the VISTA-DTA model captures intermodal travelers and performs a person assignment that can be used to evaluate various transit related improvements such as bus/train schedules, transit stop locations, transit signal priority systems, location of park and ride facilities. The VISTA system can generate automated statistics per link, movement, an OD path as well as area wide statistics. Furthermore, the system is flexible enough to allow the user to conduct parametric analyses by allowing only a percentage of vehicles to change their original paths. This is particularly useful in incident cases where only a set of users may have information about the incident and any alternative routes.

The VISTA software was implemented for a project sponsored by the NJDOT to model the I80 corridor from I287 to the George Washington Bridge (GWB) (Chien et.al. 2004)[95].