Development of a Simulation/Assignment Model for the NJDOT I-80 ITS Priority Corridor

FINAL REPORT

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Submitted by

Dr. Steven I. Chien (PI), Associate Professor
Department of Civil and Environmental Engineering
New Jersey Institute of Technology

Dr. Kyriacos C. Mouskos (Co-PI), Research Professor
Institute for Transportation Systems
City College of New York

Dr. Athanasios K. Ziliaskopoulos (Co-PI), Associate Professor
Department of Civil and Environmental Engineering
Northwestern University

NJDOT Research Project Manager

Karl Brodtdman

In cooperation with

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16. Abstract

The main objective of this research project was to implement a Dynamic Simulation/Assignment Model on NJDOT's I80 ITS priority corridor from I287 to the George Washington Bridge (GWB). The Visual Interactive System for Transport Algorithms (VISTA) was implemented and several case studies were customized to demonstrate the potential of evaluating ITS technologies using Dynamic Traffic Assignment (DTA) and traffic simulation. The NJDOT-VISTA system was developed by first identifying the infrastructure data that included: the GIS data, the roadway geometry, and the location of ITS devices (detectors, VMS signs). Then the traffic control data were identified (signal timing, speed limit, lane designation). The third data category of data included the retrieval of traffic flow data that are needed for the estimation of the dynamic OD matrix, a static OD matrix (provided by the North Jersey Transportation Planning Authority) and 15-minute traffic counts (provided by the NJDOT). The VISTA system, own dynamic OD estimation algorithm was used.

The calibrated NJDOT-VISTA system for the I80 corridor was then utilized to construct several case studies to demonstrate the potential use of the software for traffic management/operations, traveler information and transportation planning. Specifically the following case studies were developed: An incident management case study that included the evaluation of VMS sign location under incident conditions; A construction management case study that demonstrated the potential savings if information on the construction zone is provided to all travelers; A planning study on the evaluation of a set of potential combinations of VMS signs given a historical set of incident types for the network under consideration; A planning study on the evaluation of potential truck-related roadway improvements (special truck lanes, truck restriction). The case studies demonstrated the substantial usefulness of DTA modeling that produces the spatio-temporal trajectory of each vehicle from its Origin to its Destination. The main recommendations are: Develop a universal data model for NJDOT to supports transportation modeling; Develop a DTA-based model for the entire state; Develop an on-line DTA for I80 to support traffic operations, traveler information and short term and long term transportation planning.

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SUMMARY

The principal objective of this study was to develop a prototype dynamic traffic simulation and assignment tool was implemented and enhanced to assist NJDOT engineers, planners and policy makers in decision-making and effective design. The tool adopted for this purpose is the Visual Interactive System for Transport Applications (VISTA). The NJDOT I-80 Intelligent Transportation System (ITS) priority corridor was identified as the application corridor, data were collected from a number of agencies that operate on this corridor, and the necessary functionality was built to address the identified needs.

The VISTA belongs to the Simulation-based Dynamic Traffic Assignment (DTA) models. DTA models are used to estimate time-varying network conditions by capturing traffic flow and route choice behavior. **The principal output of a DTA model is the spatio-temporal trajectory of each vehicle from its Origin to its Destination that is based on some route choice behavior rule (e.g. User Equilibrium (UE), System Optimal (SO)).** The DTA models were envisioned by the Federal Highway Administration (FHWA) as tools that could be used initially as off-line tools to evaluate various types of Intelligent Transportation Systems (ITS) technologies and infrastructure improvements. **DTA models overcome the inherent deficiencies of static traffic assignment models, namely, time-dependent traffic flow dynamics and link interactions.**

In the implementation of the VISTA system on the NJDOT I80 corridor (called NJDOT-VISTA), the following functionality was demonstrated: 1) functionality, location and number of various vehicle detection devices (inductive loop detectors and fixed location Automated Vehicle Identification (AVI) detectors. TRANSCOM's System for Managing Incidents and Traffic (TRANSMIT) AVI detectors were emulated within the NJDOT-VISTA; 2) An Incident Management module was implemented and enhanced that allows the user to emulate an incident (specifying the location, occurrence time, incident duration, capacity reduction) and emulate the functionality of Variable Message Signs. The user specifies the location of a VMS and selects a set of downstream paths whose

estimated path travel time is desired to be displayed at a VMS. The user then has the option to specify the percentage of travelers that choose each designated path, run the DTA (UE) module (assuming that all travelers have perfect information about the incident) or simply leave the travelers to continue on the same paths as before the incident (run the RouteSim only). Several cases of incidents were emulated and parametric analysis on the potential impact of route diversion at the George Washington Bridge's (GWB) upper and lower level was conducted; 3) Estimation of environmental impacts through an integrated module of VISTA and FHWA's air quality analysis software called MOBILE6; 4) Implementation of a construction module and conduct of parametric analysis on potential route diversion routes in a similar manner as the incident management module; 5) Evaluation of various truck related infrastructure changes such as increase/decrease the number of lanes, special lanes for trucks only. Case studies were developed in the area near the GWB.

The main traffic flow components of the NJDOT-VISTA model are – these are common for Simulation-based DTA models: 1) A Dynamic OD matrix that was aggregated to 15-minute time intervals was estimated from a static OD matrix (obtained from the North Jersey Transportation Planning Authority) and 15-minute traffic counts (obtained from NJDOT detection locations) using a special OD estimation algorithm; 2) The mesoscopic traffic simulator called RouteSim was implemented using detailed roadway geometry, GIS, traffic control data (signal timing, speed limit, lane designation). RouteSim moves the vehicles from their origin to their destination at every iteration of the DTA algorithm; 3) A network loading module that assigns vehicles for each OD pair, and at each iteration on the generated paths – up to the present iteration – using an algorithm that has proven to converge to an User Equilibrium (UE) solution.

The main functional characteristics of the VISTA system include: 1) A modern data model that is based on a PostgreSQL database. All input and output data are stored in the SQL database. 2) A user-friendly GIS database platform that was specifically designed to include all necessary transportation data and interface it with the data warehouse and transportation algorithms (DTA, mesoscopic/microcopic traffic simulator RouteSim, vehicle routing, OD estimation, signal optimization) in an efficient way. 3) A

web-based user interface that allows any user to access it from anywhere and utilize it based on his/her authorization level.

The data for the I-80 corridor were obtained from the New Jersey Department of Transportation (NJDOT), the NJ Turnpike Authority, TRANSCOM, the Port Authority of NY and NJ, the North Jersey Transportation Planning Authority, and from NJ Institute of Technology.

The present form of the RouteSim simulator as implemented on the I-80 corridor that has 2,656 nodes, 5,818 links and 444,829 OD trips requires about 10 minutes to simulate a four hour time period. In another implementation in Chicago, IL for a network that has 17,122 nodes, 50,079 links and 1,142,520 OD trips, it requires 2 hours to simulate a 5-hour period. **These execution times are very encouraging even for real time operations as the model could also be used to run various what-if scenarios in cases of real time emergencies (e.g. incident management).**

Recommendations

Establish a comprehensive Universal Data Model (UDM) for NJDOT and provide full integration with all necessary NJDOT databases and statewide GIS system. NJDOT should e*stablish seamless procedures for the continuous updating of the database, ensuring data quality and security.*

Enhance the incident management, VMS and construction zone modules and customize them for NJ corridors.

Develop a DTA-based traffic forecasting system by integrating the VISTA system to the NJDOT's traffic surveillance system and all other related databases. The I80 could serve as a prototype since it has the most complete traffic surveillance system in NJ.

Replace the Static Traffic Assignment (STA) that is currently used for both the NJDOT North and South transportation planning models with one DTA model for the entire state. The transportation planners, traffic engineers and policy makers will then have a

common model that will provide **consistency** among all stakeholders that operate on New Jersey's transportation system.

Integrate into the NJDOT-VISTA model bus and train operations, park and ride facilities and detailed truck operations and develop an intermodal NJDOT-VISTA DTA model.

Given the establishment of a comprehensive NJDOT-VISTA DTA model, the NJDOT should require that all developers and consultants use this model to conduct their traffic impact analyses, which will provide *consistency* to the results of all studies.

Develop a statewide off-line and on-line response/emergency model that would be based on the NJDOT-VISTA DTA model. Use the off-line model to conduct analyses of various emergency scenarios and potential response strategies as well as training of emergency/security personnel. Use the on-line model as a traffic-forecasting tool and as an evaluation tool of various strategies based on the current and predicted status of the transportation network under a state of emergency (hurricanes, severe flooding, fires, security threats, other).

INTRODUCTION

Various relatively costly ITS technologies are considered for deployment along ITS
priority corridors operated by the NJ Department of Transportation (NJDOT). These
technologies include an array of sensing, control and information dissemination devices
that are intended to support various management and control systems. Such systems
include Freeway and Incident Management, Traveler Information and Integrated Traffic
Signal Control Systems. While it is well accepted that there will be significant benefits in
travel time, safety, and emissions reductions from these systems, it is not clear how
their benefits can either be assessed (before costly deployments are undertaken) or be
maximized.

Traffic simulation, assignment and optimization algorithms can be employed to model
the operations of these systems individually as well as the interactions between them.
These models would allow experimenting with "what-if" scenarios and evaluating the
impact of technologies and systems before they are actually deployed. Identification of
ineffective ITS technologies/strategies could save millions of dollars in deployment, by
more efficiently allocating the resources during the planning, design, operations and
maintenance phases.

The present state of practice of transportation simulation modeling does not have the
capability to represent the ITS technologies and adequately capture the travelers'
reactions to them. Specifically the widely used traffic simulation model CORSIM (as
well as the ones in its class, such as VISSIM, PARAMICS, WATSIM, AIMSUN) does not
have a true traveler behavior routing component (either User or System Optimal); they
instead move traffic by splitting it probabilistically at every intersection. Thus the above-
mentioned models cannot be used in their current form to evaluate technologies that
aim to affect changing the routing behavior of drivers. This can be easily seen in the
case of Variable Message Signs (VMS). VMS aims to provide location specific
information regarding traffic conditions (possibly problematic) somewhere downstream.
Clearly, since this is intended for drivers who are en-route, the only thing they could

adjust is their route. Thus, unless a simulation model can capture this routing behavior, it cannot be used to model, design, or operate a VMS. A VMS's benefit will be realized by the collective routing adjustments of all drivers exposed to the message displayed.

In order to be able to assess the benefits from the deployment of VMSs during the design stage, there is a need for a route-based simulator coupled with a driver behavioral component to compute the adjusted routes. CORSIM, VISSIM, PARAMICS, AIMSUN, WATSIM and other similar products cannot meet this functional requirement of such information provision systems. Given that a significant amount of money is allocated for the installation and operation of VMSs it is important that the locations be prudently selected, so that the information displayed will indeed be the most useful (and relevant) to the motorists and as a result it will make the most difference in terms of traffic performance and secondary accident occurrence.

In addition to the design needs of information provision devices (such as a VMS) there is a need of simulation, assignment and optimization tools to effectively operate these ITS devices. Specifically, the operating agencies need to develop strategies that can optimize the impact of the information provided via a VMS. This requires the use of a simulation model that can move vehicles on routes and the capability to change these routes in response to the information and control applied. CORSIM again lacks this capability. In addition, these corridors are fairly large and complex systems and properly representing them leads to large-scale networks that CORSIM does not have the capability to model. Current versions of CORSIM can barely simulate a 1000 node network for a 15-minute period, let alone actual 10,000 node networks for a 24-hour period. Finally CORSIM is a microscopic model, which makes it appropriate for precisely representing individual intersections, but also makes it inherently computationally intensive and prohibitive for meaningful networks.

An example of a rather successful deployment of a VMS sign in the NJ I-80 corridor is the use of travel time information for two routing alternatives at GWB using either the upper or lower deck through the I-80/ NJT extension. This travel time information is updated in real time through the TRANSMIT system's detectors that have been installed

by TRANSCOM. A route-based simulator should be able to evaluate the location of the existing VMS signs as well as other potential locations along the New Jersey Turnpike, I-80, Route 46, Route 4 and other major roadways in the corridor where travelers can take intelligent routing decisions. An extended and integrated VMS system on the I-80 corridor should cover all major alternatives leading into Manhattan from New Jersey such as Verazzano Narrows Bridge, Holland tunnel, Lincoln tunnel and GWB. An area wide simulator should be able to capture the various routing choices that travelers could potentially make and to reach their destination (e.g. Manhattan), including transit and intermodal options.

The new generation of traffic simulation/assignment models address this need by capturing the routing behavior of drivers. There are three such models available: DYNASMART, DYNAMIT, and VISTA. Another new notable development is the TRANSIMS planning/simulation model developed with substantial federal funding by the Los Alamos National Labs; TRANSIMS is designed mostly to address the demand generation needs by capturing the detailed activities of each person and seem to be more applicable for planning applications.[20] In addition, the assumptions built into the model seem to have raised negative reactions by the research community; the underlying "cellular automata" based traffic flow theoretical model has been criticized as inaccurate and is not well accepted. Finally, the routing component inside the model is not well document and appears to be static and incapable of capturing rapidly changing traffic conditions.

DYNASMART was developed by, Jayakrishnan, Hu and Ziliaskopoulos at the University of Texas at Austin. It was developed with federal funding to address precisely the ITS needs. It includes a traffic simulator and a routing component that compute drivers' choices accounting for the prevailing traffic control and supply conditions.

A similar model is the one developed by MIT (DynaMIT) that combines a microscopic and a mesoscopic model that assigns and simulates traffic. Both models are still in university research labs, operated by graduate students without sufficient user support tools so that an engineer at a DOT to meaningfully work with them. Finally, all the

above models appear to have problems with the computational requirements necessary to model large networks (to the best of our knowledge, they are limited to less than a couple thousand node networks).

In this project we implemented a mesoscopic assignment/simulation model called VISTA-DTA that is part of a general framework known as VISTA (A Visual Interactive System for Transportation Algorithms) (**http://vista.civil.nwu.edu**) developed at Northwestern University and is currently enhanced at NJIT; VISTA-DTA is an improvement of DYNASMART, both in terms of the traffic simulator (RouteSim) used and the drivers equilibration algorithm. RouteSim is based on Daganzo's (UC Berkeley) cell transmission model and it is coupled with Dynamic Traffic Assignment models to adjust the routing choices of users.[6] RouteSim overcomes most of the problems identified earlier for the other simulators. RouteSim has internally the capability to capture traffic signals, ramp meters and vehicle specific attributes (such as buses and trucks). RouteSim was modified to model the impact of the specific technologies considered by NJDOT. It is currently used to simulate the 6-county Chicago area 40,000-link network for the Regional Transportation Authority in reasonable times. It is also used by Ohio DOT to perform simulations on the Columbus network (6,000 nodes 15,000 links) at times faster than real time (1 hr of simulation in less than 30 minutes). Other deployments include the Cincinnati, OH for the US Army Corps of Engineers, Athens, Greece, Bronx, NY and others.

The basic characteristics of the VISTA-DTA include:
- It is a simulation/assignment model based on either UE or SO paths,
- Every vehicle moves on its UE or SO path until it reaches its destination,
- It is a mesoscopic simulation model with incremental data needs; it generates data that may currently be available,
- It is computationally efficient, can run in a distributed environment, and designed for large scale networks,
- It was designed especially for ITS applications,
- It is currently available and can easily be accessed through the web using an account,

- It has a user friendly windows based Graphical User Interface that any engineer or planner can easily be trained to use,
- It is platform free (Windows NT, Unix, Linux) such that any engineer/planner can access and use without any additional hardware and software.

In addition to the above features, additional enhancements were suggested to be implemented for the NJDOT-VISTA version:

- To be customized for a specific corridor in New Jersey,
- To rely only on existing data sets from all agencies that could potential maintain data,
- To integrate the data,
- To provide Cost/Benefit report modules,
- To be able to capture construction zones,
- To model Variable Message Sign logic with variable compliance level,
- To be able to assist NJDOT engineers to identify alternate routes,
- To represent TRANSMIT detectors,
- To survey reporting needs of NJDOT engineers and provide interfaces for such reports,
- To allow access to NJDOT engineers and planners for the duration of the project.

The report continues with the following chapters: The Priority Corridor applications chapter which reviews the concept of priority corridors and presents their necessary functionality; The NJDOT-VISTA system chapter that presents the basic functionality of the developed NJDOT-VISTA system for the NJDOT I-80 ITS priority corridor; it outlines the structure and the basic model capability with special consideration given to the Data-Base/Warehousing capabilities; The Data Issues chapter that describes the challenges phased by the research team in retrieving and integrating the necessary data into the NJDOT-VISTA system. The Cost/Benefits Analysis Case Studies chapter that presents a set of case studies developed; and the Conclusions and Recommendations chapter. Appendix A presents a Software Walk Through of the VISTA system.

PRIORITY CORRIDOR ITS APPLICATIONS

Introduction

The USDOT has defined an ITS Infrastructure (an integrated system of transportation components) consisting of traffic detection and monitoring, communications, and control systems required to support a variety of ITS products and services in metropolitan and rural areas. The ITS Infrastructure provides the building blocks for a fully developed transportation system. The ITS Infrastructure refers to those portions of ITS-related hardware, software, services, etc. that today, and increasingly in the future, will manage and support the transportation-related activities. The Deployment of the ITS Infrastructure components permits efficient operation and management of roadway and transit resources through the integration and use of currently available technologies, combined with strengthened institutional ties and inter-jurisdictional/interagency coordination.

In the last 2-3 decades, traffic volume and corresponding congestion has grown rapidly in major industrialized centers in the country. Increased congestion has impacted negatively on the area's infrastructure, as well as its accident rate, and the environment. And, these centers were becoming severe ozone/air quality non-attainment areas (as defined by the Clean Air Act Amendments of 1990), a condition that is exacerbated by stop-and-go traffic congestion. In addition to the Clean Air Act, other environmental laws slowed highway expansion and modifications. In addition, more media attention and public scrutiny resulted in greater public awareness of surface transportation issues. Ever increasing construction costs and funding constraints prompted the search for alternatives to traditional remedies. It became apparent that traditional highway and transit system expansion solutions would not be sufficient to meet ever-growing transportation demands in a resource limited environment.

As the region's transportation professionals began to broaden their thinking from construction and maintenance to transportation system operations, management, and coordination, ITS emerged as a long-term solution to most problems. ITS priority corridors were established to achieve one or more of the following:

(1) Improved operational efficiency,

(2) Reduced regulatory burden,

(3) Improved commercial productivity,

(4) Improved safety, and

(5) Enhanced motorist and traveler performance.

Background

In 1993, U.S. DOT designated four ITS Priority Corridors across the United States. With this designation came dedicated funding; the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 authorized over $500 million for ITS corridors, roughly half of which was to be divided among the four designated priority corridor sites over the six-year authorization. This funding has supported the following corridor priorities:

- Expanding the coverage of existing ITS services
- Enhancing ITS service capabilities
- Connecting the ITS services and functions to support compatibility among information databases and operational procedures.

In addition to the special funding, the priority corridor designation was a major impetus for institutionalizing interagency data sharing, in large part through the establishment of the Corridor Transportation Information Center. This was the "information hub" of the corridor and became an important "test bed" for corridor integration efforts. This was effectively used to achieve the objectives of the ITS priority corridor by USDOT:

- Advance ITS strategic planning
- Serve as national ITS test beds
- Demonstrate the benefits of ITS
- Showcase ITS to the public
- Evaluate ITS concepts and technologies

These goals were achieved in by various means and strategies. The 10 main program areas for ITS priority corridors were:

- Multimodal Traveler Information,
- Integrated Transit,
- Incident Management,
- Technical/Planning,
- Traffic Management Systems,
- Commercial Vehicle Operations,
- Traffic Signal Integration,
- Vehicle Transponder Systems,
- Advanced Incident Reporting/Mayday Security,
- Public/Private Partnerships.

A combination of these methodologies were used in each ITS priority corridor to optimize the impact of ITS deployment. Table 1 compares the four ITS priority corridors initially selected by USDOT.

One of the first tasks in each of the Corridors' work plans was to develop a Corridor Business Plan. In that process, it became apparent that institutional building and cooperation among participating agencies would be necessary for inter-regional or even intra-regional ITS deployment. Likewise, in the regional setting, the integration of existing and future ITS projects both within and across jurisdictional boundaries would be required to deploy corridor projects. As the Corridors have begun to roll out ITS, they have found that the Corridor's primary role is to provide value-added synergies to various deployments by member agencies.

The New Jersey Department of Transportation selected the I-80 corridor for ITS deployment. Many ITS applications were possible and there was a need for modeling these applications on a network-wide scale to choose the most efficient way to implement them. The next section discusses some of these applications.

Table 1. USDOT ITS Priority Corridors

Corridor Dimension	Houston	Southern California	GCM	I-95
Geographic Scale	small	large	Medium to large	Very large
Management Complexity	simple	Very complex	complex	Very complex
Public-public partnerships	High	High	High	High
Public-private partnerships	Low	Low	Low	Medium to Low
Major System Elements Emphasis	ATMS, ATIS, Transit	ATMS, ATIS, Emergency Response	ATMS, ATIS, Transit, Incident Management	CVO, Interregional Travel, Incident Management. ATIS, ETTM Intermodalism
Role with Existing ITS Projects	Expand Enhance	Expand Connect	Expand Enhance Connect	Enhance Connect
Initial Deployment Rollout	1995	1997	1996	1996

ITS and Planning Applications

The development of simulation-based dynamic traffic assignment models substantially enlarges the scope of transportation related studies and bridges the differences between traffic operations and transportation planning studies. The same model now could be used for either the evaluation of a traffic signal timing plan or for the change in capacity of a new roadway. In addition they could be used for the evaluation of travelers path choices based on the traveler information provided, especially under incident conditions. A simulation-based DTA requires substantial traffic flow data to be calibrated and correct geometric data. It is envisioned that in the future two types of models will be established: Off-line models that will be based on historical traffic flow data and real-time models that will be integrated with a traffic surveillance and communication system.

The off-line simulation based DTA models will replace the existing static based traffic assignment models that are now recognized as insufficient to produce accurate traffic flow estimates. Specifically they fail to capture the interactions among consecutive links,

they cannot model signal timing plans and the assumption of steady state conditions can only be observed during off-peak periods at uncontested networks.

The real time simulation based DTA models are expected to become the new traffic forecasting tools for traffic management, traffic operations, emergency management, fleet management and traveler information. In addition, they would become the main models for infrastructure planning modeling since they

The principal Measures of Effectiveness (MOEs) that could be produced by a simulation based dynamic traffic assignment model are outlined next.

VISTA-based Measures of Effectiveness (MOEs) for Traffic Management, Traveler Information and Infrastructure Planning

We emphasize the new dimension that simulation-based DTA models could report with the introduction of the entire distribution (e.g. average and variance) for each time period of analysis. In order to take advantage of the DTA model the analyst is encouraged to run it for the entire 24-hour period at a minimum disaggregation level of 15-minute time intervals. All statistics should be reported for each 15-minute time interval or less. Less disaggregate time periods such as 30 minutes or one hour could also be produced. The analyst however should always follow proper statistical procedures in defining the time period of analysis. Time periods with statistically different variances should not be combined into one time period as this leads to erroneous results and conclusions.

In the future, when data are expected to be available due to more coverage from traffic surveillance systems, the travel time interval reporting could go to the finest level based on the objective of the analysis, from the microscopic (sub-seconds) to macroscopic (e.g. 5, 10, 15, 30 and 60 minutes) – for example this capability exists right now on the roadways where the TRANSMIT system has been installed. The VISTA system could further produce each individual OD-path parameters (travel time, traffic volume, distance) based on the mode of transportation such as auto, bus, train, auto plus bus,

auto plus train, bus plus train, truck, truck plus train. The main MOEs that could be produced by the VISTA system are:

- *Total travel time distribution* of the network or sub-area for all vehicles, autos, trucks, buses, respectively.

- *Total Vehicle-Miles Traveled (VMT)* for all vehicles, autos, trucks, buses, respectively - this may be further disaggregated for each OD pair;

- *Path travel time distribution* per time period of the day for each OD pair; this may be disaggregated at an individual trip level such as auto only, transit only (bus or train), intermodal (auto plus bus, auto plus train, bus plus train), truck only, train only (CVO applications), truck plus train (CVO);

- *Shortest path travel time* distribution of EMS, police, fire department, towing services, Department of Homeland Security (DHS), from their current origins to the incident location and from the incident location to their next destination (EMS station, hospital, police station, other incident scene, etc.). This information is extremely useful for emergency services and they could be used for training purposes by examining the spatial distribution of their vehicles and their fleet assignment to multiple incidents occurring within the same geographical area and time period.

- *Link/Superlink travel time distribution* (mean and variance) per time period of the day (e.g. 5, 10, and 15 minutes). A superlink is a combination of two or more consecutive links into one link. The aggregation of links to superlinks is recommended in cases where the analyst tries to avoid situations where an upstream or downstream link has a significant impact on the operation on its upstream or downstream link(s). Examples of superlink definitions for signalized intersections could be straight through - straight through movement, straight through - left turn movement, straight through - right turn movement, etc., for freeways, basic freeway – off-ramp, on ramp – basic freeway, basic freeway –

off-ramp under weaving conditions, on ramp – basic freeway under weaving conditions, etc.

- *Link/superlink traffic volume per time period of the day* (e.g. 5, 10, 15, 30, and 60 minutes). The traffic volume per vehicle category or for all vehicles is used traditionally for capacity analyses, to estimate the impact of traffic volume on link/superlink travel time, ramp metering analysis, signal timing analysis, pavement deterioration, other. Under incident conditions this estimate could be used to optimize the ramp metering rates and/or the signal timing of various signalized intersections in the affected area.

- *Link/Superlink vehicle OD identification per time period of interest.* The analyst could further identify the specific OD paths that utilize each link per time period of interest. This result could aid the analyst to further study the impact of a roadway capacity reduction at a link of the network on the businesses within the vicinity of the impacted link, the travelers that pass through and utilize this link or the travelers who arrive in the area to do their business.

- *Air quality MOEs* such as CO, NOx, HCs for the entire network, sub-area, link/superlink, OD pairs, for all vehicles, autos, trucks, buses, respectively;

Traffic Management and Traveler Information

Incident management

Incident Traffic Management is a challenging task owing to the urgency associated with it, not only does this require a quick solution to mitigate traffic delays, but also requires detours to be posted immediately. Alternate routes must be identified quickly and information regarding these must be passed on to drivers well in advance of their arrival at the incident area. An incident management system is usually comprised by the traffic surveillance system, the incident response system and the travelers information system. The traffic surveillance system can be emulated in VISTA through the "installation" of various types of detectors at various locations. The incident response system refers to

the procedures followed by the emergency services (e.g. police, EMS, Fire department, towing services, other) that are usually employed when an incident occurs.

The VISTA system can emulate the routes that the emergency vehicles should follow in order to arrive at the scene of an incident given the prevailing traffic conditions. The VISTA system could utilize its time-dependent shortest path algorithm to identify the best route for each emergency vehicle from its current location to the incident location and from the incident location to its final destination (e.g. hospital, firehouse, police station, other). The incident duration is difficult to estimate in real time so historical data could be used to serve this purpose based on the accident severity and location. Furthermore, an incident management plan may include pre-set route diversion strategies. The analyst could use the VISTA system to emulate an incident management plan and conduct parametric analyses on the various parameters associated with it. The VISTA system could be used to analyze the incident management plan and estimate pertinent traffic flow characteristics.

One of the most popular media used for incident management is the Variable Message Sign (VMS). VMSs are an efficient medium to display this information. A VMS is a device used to manage traffic congestion by providing real-time traffic information to drivers, particularly to manage congestion caused by incidents because drivers cannot predict incidents. An effective implementation of a VMS sign is the display of the travel time for different routes downstream of its location. Consequently, some drivers will select alternate routes to reduce their travel time, thereby reducing traffic congestion.

VISTA can be used to study the short-term impacts of incidents to help planners evaluate different traffic management alternatives. Sensitivity tests for incident severity can be performed, which would help to develop the emergency infrastructure for any kind of incident. Specifically, variable message signs (VMSs) can be modeled in VISTA to display real-time traffic information and guide drivers away from the incident.

Methodology

Run DTA based on normal traffic conditions (no-incident). We **strongly recommend that the DTA be run for an entire 24-hour time period** to avoid the problems associated with partial paths and all O-Ds are completed (modeled) from their origin to their destination. The main output is the path of each vehicle from his/her origin to his/her destination based on the set objective rule (e.g. UE or SO). **The capability of the VISTA-DTA to be executed over a 24-hour time period or more depending on the analyst's needs is a significant departure over the traditionally used static traffic assignment methodologies.** A well-calibrated DTA model will produce the traffic flow profile of every link for each time period of the day based on the traffic dynamics that are the result of the inherently daily dynamic OD matrix.

Run various versions of DTA with the presence of an incident. The analyst could stage an incident within VISTA by specifying the time of occurrence, location, severity (capacity reduction) and expected clearance duration. The analyst then executes the DTA for a duration that should include at least 15 minutes prior to the incident and at least 15-minutes after the traffic flow impacts due to the incident have dissipated. The analyst can run various scenarios using the DTA and create his/her own reports of interest such as:

- *Assume that all vehicles do not have any knowledge of the incident (worst-case scenario).* The paths generated by the DTA under normal conditions will continue to be used by all travelers. Therefore only the RouteSim traffic simulator should be activated to produce the new traffic flow characteristics, mainly traffic flow rate and link/path travel times.

- *Assume that all vehicles have full knowledge of the incident and its duration (UE "best"-case scenario).* The vehicles are re-distributed, by executing the UE-DTA, on the network based on the expected traffic conditions due to the incident. This scenario assumes that all vehicles are equipped with in-vehicle navigation

devices having two-way communications and each driver will use the equilibrium route that minimizes his/her own travel time.

- *Run the DTA based on the SO assignment rule (Ultimate best-case scenario), trying to minimize the total travel time of the network.* This assignment is practically unrealistic since it assumes that the drivers will follow the routes that some ultimate authority will assign to them. However it could be used as a guideline for route diversion strategies under incident conditions. It also produces a lower bound on the total travel time of the network that can be used to evaluate the impact of proposed route diversion strategies and examine how far away they are from the best possible one. The analyst could thus conduct parametric analyses on the percentage of drivers who would follow the designated route diversion strategies and evaluate the impact on the total travel time of the network or on individual routes.

- *Run the DTA by assuming that some groups of vehicles know about the incident and some do not.* The analyst has the flexibility of running the DTA by assuming that only a percentage of vehicles have full knowledge of the incident conditions. This entails that the non-informed vehicles will continue on their original paths and the informed ones will be reassigned based on the UE DTA rule. Under another potential scenario, the analyst could assume that only trucks have full knowledge of the incident conditions or for that matter only a few truck companies have this information. Furthermore, in a similar fashion the analyst could emulate the functionality of VMS signs by assuming that only the OD paths that pass through the VMS locations will have knowledge of the incident. Similarly, the HAR functionality and in-vehicle navigation traveler information could be emulated within the VISTA system.

Incident management analyses could be conducted on the location and functionality of detectors, spatial location and response times to/from the incident of emergency services, impact of traveler information (e.g. VMS location and content) on the traffic

conditions for either all vehicles of groups of vehicles, evaluation of route diversion routes.

Traveler Information

In the NY/NJ metropolitan area people receive traffic flow information through Variable Message Signs (VMS), Highway Advisory Radio (HAR) and Commercial Radio. In the near future, TRANSCOM will roll its web-based TRIPS123 traveler information service for the entire metropolitan area. Furthermore, in the next decade the number of vehicles that will be equipped with *in-vehicle navigation systems* integrated with real-time traveler information systems is expected to rise significantly. The main traffic flow information that could be provided to the travelers are: location of incidents; type of an incident; expected incident delay; expected link travel time; expected OD path travel time for auto, bus, train, truck, auto plus bus, auto plus train, bus plus train, truck plus train; flooded roadways. In addition, other yellow page types of information such as restaurants, parking facilities, movie theaters, tourist attraction and other locations could also be provided.

Next we present some of the traveler information dissemination media could be emulated within the VISTA system such as Variable Message Signs (VMS), pre-trip travel information systems and mobile traveler information systems.

<u>*Variable Message Signs*</u>

A VMS is characterized by two parameters, its location and the message information. The location of a VMS dictates the number of travelers who will see the message displayed on the VMS. The VMS message dictates the action that a percentage of the drivers will take. One of the most effective messages that could be provided by a VMS is the travel time of a set of routes downstream of its location.

Highway Advisory Radio (HAR). The HAR systems provided traffic flow and incident information to the travelers usually through an AM or FM radio frequency usually covering a limited geographic location. The most common messages refer to pre-planned construction or incident along the roadway. Their usefulness is rather limited as

the information provided is usually not very specific enough. For example in case of an incident the message content may be to expect delays along the freeway or multilane highway. More informed messages such as the estimation of the expected travel time along two to three alternative routes between two points may give the travelers a better incentive to start listening to HAR.

The VISTA system could be used to emulate the HAR and conduct parametric analysis on the percentage of people who will follow the message and change their usual route to the "optimal" one predicted by the VISTA system. This analysis could be further enhanced if a travelers' survey is conducted that could identify the percentage of people who actually change their routes based on the HAR message – the VISTA system could then be used to emulate the percentage of people who actually change routes.

The analysis of an HAR system by VISTA could aid in the evaluation of the location of the HAR and the effectiveness of the messages provided either to the entire network, the corridor, or specific OD pairs or vehicle categories.

Pre-trip Web-Based Traveler Information Systems. Pre-trip web-based traveler information systems are now becoming more popular throughout the country as well as in Canada, Europe, Japan, Australia and other countries. The advantage of the web is that travelers could have a more efficient input/output interface and more functionality in terms of the travel information that they can receive. Whereas VMS and HAR can reach only a few travelers, the web could virtually be reached by anyone.

In the NY/NJ/CT metropolitan area, TRANSCOM in cooperation with its member agencies is nearing completion of the first comprehensive traveler information system that will be available through the web, called TRIPS123. It is based on a subscriber, non-subscriber basis where subscribers will be able to receive more information and will be provided with a more convenient input/output interface since a user profile will be created for them that will reduce the user input to a minimum. The TRIPS123 is expected to provide information on all modes (buses, trains, ferry, subway, auto, truck).

Mobile Traveler Information Systems

Mobile traveler information systems include pagers, cellular phones, and other RF-based devices. The information that could be provided to travelers while en-route is limited by the availability of the bandwidth of the communication system and the specific reception device. Traditionally the information is transmitted to all travelers, whether it does or does not affect them. The technology exists however to provide the travelers with personalized traffic flow information. Typical information that could be provided to mobile devices include: incident occurrence, location and severity; planned or existing construction zone location and severity; route diversion due to an incident or construction. User-specific traveler information may include: real-time best route (e.g. auto, transit or intermodal) estimation/prediction to the user's destination updated every few minutes – in the future seconds; a few alternate routes; specific traffic flow information for specific routes and major crossings based on the user's preferences.

Real time or off-line traffic volume and travel time estimation and prediction using the VISTA-DTA

One of the principal components of a real time Advanced Traffic Management System (ATMS) and Advanced Traveler Information System (ATIS) is the estimation and prediction of traffic volume and travel time per time interval (e.g. 1, 5, 10, 15 minutes). The current traffic forecasting models are based on traffic flow estimation and near term prediction that do not take into consideration the drivers' behavior (e.g. route changing under incident conditions). While they may be used successfully for predicting near-term recurrent congestion they are not expected to perform well for non-recurrent events when alternative route choices are present. In addition, their usefulness for short-term and long-term analysis of traffic flow information to travelers is rather questionable since they do not take into consideration the user behavior that is path based. In contrast, dynamic traffic assignment models are inherently based on the route choice of the travelers themselves (auto, transit or intermodal).

Vehicles as traffic probes

Vehicles equipped with a location device such as GPS could also be used as traffic probes. One of the first applications in the US of vehicle probes is TRANSCOM's System for Managing Incidents and Traffic (TRANSMIT), which has been implemented in a 200 roadway miles in the NY/NJ metropolitan area and expected to be expanded in the future to cover the entire metropolitan area. Vehicles equipped with an E-ZPass Radio Frequency tag - used for toll collection - are detected as they pass near the TRANSMIT system's roadside antenna readers. The TRANSMIT system produces estimates of the travel time distribution between two readers in real time based on the number of vehicles equipped with an E-ZPass tag that pass through during a 15-minute time period of the day.

The VISTA-DTA system is capable of emulating various traffic conditions and identify the travelers that may be affected by changes to the normal traffic conditions by knowing a priory the path that each vehicle is expected to follow to his/her destination. The VISTA-DTA currently produces these statistics for the time period of interest (e.g. period 6:00 – 10:00AM or a full 24-hour) and level of detail based on the estimated dynamic OD matrix. The VISTA-DTA system can produce estimates of the MOEs listed earlier for a specific time period of the day.

The analyst could use the TRANSMIT system's capability to produce link travel time distributions to continuously calibrate the VISTA system if it is implemented in the same network or corridor. The VISTA system could also be used to find the optimal location of TRANSMIT readers to support the desired objective based on the available budget. Similarly, the VISTA system could be used to emulate other types of detectors and identify the best spatial distribution to obtain the desired traffic surveillance system that would satisfy the specific objectives of the various stakeholders.

Future Traffic Forecasting DTA-based model

The NJDOT could use the VISTA system as the basis for its future traffic forecasting tools. Initially, a basic system could be developed that will be based on the existing traffic surveillance system. In the corridors where an operational traffic surveillance system exists such as the I-80 MAGIC system, a real-time VISTA-based traffic forecasting system could be developed. In areas where no traffic surveillance system exists or it is not connected with either the North of South traffic control center an off-line VISTA-based traffic forecasting system could be developed. The main components of the envisioned traffic forecasting system are:

- **The infrastructure data.** Infrastructure data include mainly an expanded GIS database that incorporates the roadway and interchange geometry and the traffic control devices.
- **Traffic Control data.** Traffic control data include the type of control at each intersection, the signal timing settings at each signalized intersection and the lane designation of each roadway and each intersection.
- **Traffic flow data.** Traffic flow data are needed for the calibration of the VISTA system. These data include: static OD matrices per vehicle category and time period of the day; vehicle counts at the link of the network including intersection movements per time period of the day, number of passengers at each transit stop, bus loadings and unloadings, bus dwell time distribution at each transit station, vehicle (auto, transit, truck, intermodal) link/superlink/path travel time distributions. These data will aid in the calibration of the VISTA-DTA system, mainly the dynamic OD matrix, the mode distribution, and the parameters of the RouteSim traffic simulator.
- **Off-line or real time estimation of the dynamic OD matrix.** A real time dynamic OD matrix could be continuously estimated based on the current traffic flows from various detectors (e.g. TRANSMIT, inductive loop detectors, other) located along the network based on a revised algorithm that should be able to run in real time. The development of such an algorithm will produce estimates of current traffic conditions even at places that do not have any detectors and predict the future traffic conditions based on the current prevailing conditions and historical information. Additional

calibration could also be undertaken off-line based on the historical data collected from the detectors as well as OD surveys.

Methodology

The methodology is similar to the one outlined earlier on incident management.

1. Develop the first calibrated VISTA model for the network under consideration based on historical information.
2. Integrate the VISTA system to the traffic surveillance system that will feed VISTA with traffic flow data such as traffic flow from each count detector, link travel time from location based devices (e.g. TRANSMIT, GPS), OD data from location based devices and periodic surveys.
3. Develop a real time VISTA-DTA model that will be continuously calibrated. Periodic off-line calibration will be conducted as well. This model will produce in real time:

- A continuously calibrated dynamic OD matrix and a VISTA-DTA,
- Prediction of the path travel time for each requested trip from a traveler (auto, bus, truck intermodal),
- Prediction of the path travel time for each requested trip from emergency vehicles (e.g. police, EMS, fire department, towing services, DHS, other),
- Link/superlink travel time and volume distributions, estimation and –prediction.

The VISTA system could be employed as a traffic-forecasting tool to produce estimates for various types of traveler messages in real time. In addition, it could be used as an analysis tool to estimate the impact of the provision of traffic flow information either to all the travelers, specific groups or percentage of traffic. Furthermore, it could aid the NJDOT in optimizing the performance of its traffic operations, transportation planning and emergency operations.

ITS Infrastructure Evaluation

VISTA for planning

One of the most important components in the deployment of ITS infrastructure is the evaluation of the impacts of such infrastructure on traffic to optimize the location and design of such infrastructure. For example, evaluation of VMS and detector locations and benefits are an important transportation planning problem.

The current transportation planning models utilize a static traffic assignment to estimate/predict the traffic flows on the links of the network. As demonstrated, DTA models are more accurate and they offer more functionality to the transportation planners who can now take more intelligent decisions on various types of infrastructure improvements – roadway/interchange changes, roadway user pricing, installation of detection devices, installation of VMS signs etc. A change in the capacity of a link of the network or the addition or deletion of a new roadway can be easily evaluated with a *calibrated VISTA-DTA* model since it will automatically produce the path choices off all drivers based on the new network configuration. Given a continuously updated data model and a calibrated VISTA-DTA model, **a comprehensive transportation asset management model could be developed that will be dynamic, producing up-to date cost-benefit analyses on on-going and proposed projects.**

ITS infrastructure planning

Identifying the "Optimal" Location of VMSs

Location is a key factor affecting a VMS's performance. A location too close to the congested area may leave drivers with only a few options to change their routes in search of a better one. If a VMS is located far from the congested area the traffic conditions may change by the time the drivers reach the area. Therefore, a combination of locations, both near and far from the congestion area, is the best way to optimize the use of the VMSs. The present version of VISTA includes the capability to install a VMS and conduct parametric analyses based on the information provided on the VMS. The location of a VMS sign can be evaluated based on the impact of the information that

could potentially have on the travelers that pass through it and the impact that the rerouted travelers may cause on the network and other travelers on the alternative routes that they have chosen.

More often than not, VMS locations are subject to some physical and political constrains. In such cases a few candidate locations are chosen during the planning process and a quantitative evaluation is performed to decide the best combination of these locations.

Planning models need historical incident data. These data will be aggregated to predict the probability that one type of incident will happen in the future. A good VMS location should be chosen such that it optimizes the expected performance of the network under all possible circumstances.

Methodology

- Run DTA based on normal traffic conditions (no-VMS and no-incident).

- Through historical incident information, "install" an incident on the roadway designating its location, severity (capacity reduction), and expected duration. In cases of many types of incidents in the same link, then run a selected number of historical incidents.

- Identify a set of VMS locations, select one and run the RouteSim based on the paths from the existing DTA.

- For each VMS location identify the alternative routes either through experience or using the results of the DTA – the DTA's output provides the selected routes for each OD pair and time period of the day.

- Emulate the VMS in VISTA by encoding it through one of the interfaces (see the software walk through in Appendix A). Each VMS will display the expected travel time for each alternative route.

- Conduct parametric analyses based on the percentage of drivers who pass through the VMS and follow the alternative routes. For example the analyst could specify that only 10% of the drivers who pass through the VMS will actually follow an alternative route.

- Conduct parametric analyses on the impact that the VMS display time delay from the incident occurrence time has on traffic conditions. This would show the impact of the incident detection time delay on traffic conditions for the various OD pairs that could be used as a measure for the allocation of funds for a more state of the art traffic surveillance system (e.g. spatial allocation and functionality of detectors).

- Run the UE-DTA by assuming that all drivers know about the incident ("best" case scenario – as before).

- Run the SO-DTA by assuming that all drivers will follow the routes selected by some ultimate transportation authority. This produces the absolute minimum.

- For each of the specific scenarios, analyze the output by querying the output database based on network-wide effects, sub-area effects, emergency services effects, specific ODs, vehicle categories (auto, truck, bus, train or intermodal) and other statistics of interest.

A similar methodology could be employed for the HAR location, coverage area and messaging.

Optimal Detector Location and Number

The VISTA system can simulate various types of detectors (Inductive Loop Detectors (ILDs), Video Image Detection Systems, Microwave Radar detectors, TRANSMIT type, GPS, other) based on their functionality and provide their principal traffic flow measurements. The transportation agency then given this capability it can analyze the location of various detectors based on the specific objective that the detectors are intended to satisfy. This can help planners to optimize the allocation of infrastructure resources and evaluate decisions without expensive and risky field studies.

Methodology

Run a calibrated VISTA-DTA for the network under consideration. This produces the path of each vehicle.

Evaluate the locations of various types of detectors by querying the database.

Traffic Counts

If an Inductive Loop Detector is installed at one link of the network then the analyst is capable of producing the expected traffic flows per time period of the day that this detector will produce.

Link travel times

TRANSMIT type detectors are used to estimate the travel time distribution between two fixed locations. The analyst "installs" the TRANSMIT detectors within VISTA and retrieves the travel time distributions and the number of data points for each time period of the day by querying the VISTA-DTA output database. The analyst could identify from this analysis whether these locations produce sufficient data samples for travel time estimation. Similarly the analyst could further estimate the time delay that will be required by an incident detection algorithm to detect an incident. This algorithm would have to be emulated within the VISTA system.

OD matrix estimation

OD matrix estimation is either based on link traffic counts or partial OD tables from location based systems. These are usually combined with OD surveys that are conducted periodically for the transportation network of interest. A traffic count based algorithm could be emulated within the VISTA system through the "installation" of traffic count detectors at various links of the network. The analyst could then evaluate various locations based on the accuracy of the proposed spatial distribution of the traffic count detectors. Similarly location-based detectors could be analyzed based again on the spatial distribution of these types of detectors.

The optimal location of various types of detectors is a non-trivial issue. The various stakeholders have different objectives from the traffic surveillance system. Where one detector could satisfy one or more objectives then this is recommended otherwise a new type of detector should be installed. The VISTA system could aid this process and produce the corresponding traffic flow measurements for each type of detector prior to implementation. A systematic analysis then could identify the best spatial distribution of the various types of detectors. Furthermore, optimization algorithms could be developed to aid this important issue in transportation planning that has a considerable impact in the operation of the transportation system.

Evaluation of park and ride facilities location/capacity

The park and ride program is one of the most important for the state of NJ given its density and the large number of commuters that work at Manhattan. NJDOT and New Jersey Transit are continuously evaluating their existing park and ride facilities to identify whether they are overcrowded or underutilized and try to find potential solutions. In addition, they actively looking into areas where new park and ride facilities should be built and what the capacity should be. Furthermore, NJDOT is looking into potential technology solutions that could aid in the better utilization of the existing facilities.

As part of a related project "Technical Solutions for Park and Ride Facilities" sponsored by the NJDOT, two prototype intermodal planning models were developed, a static model and a DTA-based model. The VISTA-DTA intermodal model is able to handle both to auto, transit only, and intermodal (auto plus transit) users. The capability of modeling intermodal trips is essential for the evaluation of park and ride facilities since the majority of the trips involve people who park their car at the facility and continue their journey to their destination with a bus or train or through carpooling**. The addition of new parking spaces to an existing facility could be evaluated by conducting parametric analyses by changing the number of new arrivals from the existing distribution of the OD matrix.** The DTA model will redistribute the OD paths based on the new parking capacities and demonstrate the impact of the new intermodal trips on

the network and the corresponding transit ridership. **Given this capability the analyst can evaluate the impact of a new facility or a capacity change on an existing facility could have on the surrounding transportation network.**

Recommendations

- **Develop a transportation planning model that will be semi-automatically self-calibrated to evaluate various short-term and long-term infrastructure improvements;**
- **Develop a user-friendly interface to produce the relevant MOEs for the proposed infrastructure change;**
- **Develop a statewide VISTA-DTA intermodal planning and operational model to evaluate the location and capacity of park and ride facilities;**
- **Develop a transportation network design model that will identify the "optimal" projects to be selected among a set of potential projects based on the NJDOT objectives and the budget availability.**

Construction and Maintenance Planning

Construction zone management is a special case of incident management with the special characteristic that the events are known beforehand. Another characteristic is that the travelers within a few days they readjust their paths to their destination based on the knowledge that they experience due to the impact of the construction zone. In principal a construction zone may involve capacity reduction that may be accompanied with diversion route(s) that are usually designed before construction begins. Subsequently, changes to the staging of the construction and the route diversion plans may also occur.

A construction zone closure differs from an incident as the former is closed throughout the simulation while the latter can begin and end during the simulation. Any network traffic problem that would result in a closure of lanes for the full length of the simulation, such as flood-induced road closures, can be analyzed with construction zone models.

The existence of construction zones reduces the capacity of the traffic network as a result of either lane-closures that are under construction or alterations on the geometric features of the roadway. Traffic delay analysis along critical corridors captures the traffic impacts, congestion, and potential bottlenecks. The delay analysis can provide information on road segments that are congested and can be potential bottlenecks in the network. A similar set of analyses can be performed for the selected set of the vehicles that will be affected directly from such closures. Additionally, the OD distribution of these vehicles can be determined, potentially leading to demand management policy studies if needed. The results of traffic impact analysis of construction zones can be later used in economic analysis of different construction zone scheduling assessments.

The advantage of using a mesoscopic simulation model and obtaining vehicle-level details at the same time is that VISTA is capable of studying not only the traffic impacts on the overall network, but also the impacts on a selected group of vehicles that would be affected by the construction directly. The VISTA system may be employed to evaluate the impact of one or more construction zones within a specific geographic area either during the design phase or during the construction and maintenance phase.

- The scheduling of the construction zone could be simulated by the VISTA system for all its stages that usually involve: roadway capacity changes, route diversion strategies and/or ramp metering and signal optimization strategies. This gives the transportation planner a powerful tool to analyze various construction schedules and present the results to the various stakeholders involved and recommend the most "optimal" one that would compromise the various objectives (e.g. network-wide travel time, specific OD path travel time, safety, economic impact on businesses etc.).

- The scheduling of a construction zone undergoes changes as unforeseen delays due to weather, funding, construction priority changes, or other factors are present. The VISTA system may be used to simulate new scheduling strategies in a dynamic way through the entire construction/maintenance time period that could span from a few days to a few years.

- A VISTA-based real-time traffic forecasting system could be developed that would emulate traffic conditions during the entire phase of the construction duration given that an automated traffic surveillance system is employed.

- The VISTA system may be used to evaluate the location of either permanent or portable VMS signs and various types of detectors during the construction duration and beyond. Such a practice may further aid the NJDOT to systematically study the traffic flow and safety impact of construction zones, making them living test beds.

- The VISTA system may be employed to evaluate the impact of the construction zone on the emergency plans of various entities such as police, EMS, Fire Department, Department of Homeland Security, other. The VISTA system may produce continuous estimates of path travel times for the entire fleet of all the agencies. These results may warrant spatial reassignment of their fleet and route changes during the construction duration. In particular, police, which is usually responsible for monitoring the construction zone and the route diversions could use the VISTA system to develop alternate route diversion plans in cases of incidents within the construction zone and best dispatch their fleet during such incidents. The police may further use VISTA, by emulating various types of construction zones, to evaluate their fleet dispatching under various potential events related to the construction zone.

- The I-80 corridor could be an ideal test bed for the implementation of the VISTA system as a planning and traffic-forecasting tool due to the existence of the MAGIC ITS system, the TRANSMIT system at GWB and the data collected by the PANYNJ at the GWB, Lincoln and Holland tunnel. Valuable data may be obtained that will aid in the calibration of the VISTA system and establishment of a real-time version.

Methodology

If a traffic surveillance system does not exist for the area where the construction zone is scheduled or is under way the following procedure may be employed:

- Run the DTA before construction begins under normal conditions.
- In cases that construction has started then run the DTA based on the current geometric and traffic flow conditions.
- Run the DTA for each stage of the construction. If alternative construction plans exist then run the DTA for each one of them. Summarize the MOEs for each alternative construction plan and present them to the stakeholders. **The analyst here should consider the entire construction time period.**

If a traffic surveillance system exists then the following methodology may be followed:

- Run the DTA before construction (base model).
- Integrate the VISTA system to the traffic surveillance system such that it has continuous feed from the various types of detectors.
- Develop a VISTA-DTA traffic forecasting model that will be continuously calibrated based on historical and real-time traffic flow data. Mainly this entails a continuous estimation of the dynamic OD matrix that would be based on VISTA's embedded algorithm. Conduct periodic off-line calibration/validation tests for the VISTA traffic forecasting model by assessing the traffic flow estimation and prediction deviations of the VISTA system to the actual traffic counts and/or travel time collected data.
- Run the DTA for each potential route diversion plan that was developed by the transportation agencies. Run additional scenarios of other alternative diversion plans. One of the potential route diversion plans that could be considered is the SO-DTA that produces the best potential performance of the network.

For either case the implemented VISTA system could be used as a training tool for transportation planners/engineers/operators and emergency services.

The VISTA-DTA should be continuously calibrated during the entire duration of the construction project through either an automated traffic surveillance system or through periodic traffic flow measurements. Such a practice will improve the model for future applications and will provide valuable MOEs to assess the impact of construction zones on the major stakeholders (travelers, businesses,

CVO, transit, transportation operations agencies and emergency services) during the construction phase on a continuing basis.

Recommendations

- **Develop a customized construction and maintenance module that will emulate the impact of the construction zone, alternative scheduling scenarios, and freeway ramp metering and arterial signal timing optimization.**
- **Develop a module for training transportation agency, emergency services personnel on the design, implementation and operation of a construction and maintenance zone.**

Commercial vehicle operations

Trucks are an integral part of the traffic stream with distinct features, such as routing behavior, turning movement delays, traffic stream and route choice behavior. Moreover, due to viaducts, low clearance bridges and city/state ordinances, they do not see the same network as seen by vehicular traffic. This creates unique modeling challenges that VISTA has efficiently incorporated into its models.

The user can specify restrictions for trucks on roadways (no trucks are allowed during certain periods of the day or only trucks are allowed) or they can specify different turning movement penalties for trucks. This way truck behavior at intersections can be captured by providing different turning delays for different intersections.

In this research project a truck related case study was developed to analyze the impacts of adding an exclusive truck way on the network ; note that this is considered as an option to reduce congestion and increase vehicle and pedestrian safety in some US cities. The truck study is one form of the general framework of the transportation network design problem and could thus serve as a model for the evaluation of infrastructure and operational improvements.

VISTA for transit and intermodal operations

Implementation of transit into VISTA for NJDOT

The VISTA system is capable of modeling passenger cars, buses, trains as well as intermodal trips. It has been employed by the Regional Transit Authority of Chicago to evaluate transit signal priority plans for its entire bus system. In another application it is implemented to emulate bus operations in the downtown are of the City of Newark as part of a project for the Great Cities University Consortium. The advantage of the VISTA-DTA is that it captures the users behavior due to the selected transit signal priority system that is employed. Contrary, simulation-based software such as COSRSIM or VISSIM they simply assume that travelers will not change their behavior, which may lead to erroneous results.

A VISTA-based person traffic assignment is nearing completion that will provide a much more powerful tool to the transportation and transit planners and traffic engineers to evaluate various transit related improvements such as: bus schedules, transit signal priority, location of park and ride facilities. This is a far more demanding traffic assignment in terms of both modeling and computational needs. In principle this DTA assignment is producing the path of each individual person from his/her origin to his/her destination. These paths include all potential types of mode choices for the travelers such as auto, bus, train, auto-bus, auto-train, bus-train. The walking path to transit stations is also included within the intermodal path of a person.

The VISTA-DTA person based DTA could be used for off-line evaluation of bus and train schedules, bus and train stops, paths using different modes, park and ride facility location and capacity. Furthermore, a real time model can be employed that could evaluate dynamically various bus schedules and propose the best alternatives given the prevailing and projected traffic conditions, dynamically change the signal timing plans for transit signal priority control, and to produce real time estimates and prediction of bus/trains travel times and arrivals at the bus/train stations that can be part of an advanced traveler information system (e.g. the TRIPS123).

- Develop a VISTA-DTA by including all bus and train schedules and the associated location of bus and trains. Conduct studies to identify the utility functions of the travelers with respect to their transport mode choices. Integrate these functions within the VISTA-DTA model. Calibrate the model using the traffic surveillance system, and travel time studies of the various bus and train routes.
- Bus/train schedule and/or transit stop location evaluation: Run the VISTA-DTA based on a set of alternative bus/train schedules and conduct comparative analyses. In the future, develop an optimal bus schedule algorithm.
- Real-time traveler information: Integrate the VISTA-DTA to the traffic surveillance system and the bus/train information system of New Jersey Transit. Develop a real-time VISTA-DTA. Produce estimates of OD paths in real-time based on the user's set of mode preferences that could include only one mode, two or more modes, no preference, shortest path, least number of transfers, cost, shortest distance.
- Develop a long-term plan for the continuous calibration of the VISTA-DTA system to support planning, traffic operations and traveler information systems.

Recommendation

Develop a comprehensive VISTA system that will incorporate passenger cars, buses, trains and park and ride facilities for NJDOT and New Jersey Transit. Develop a VISTA transit signal priority system, an optimal transit-scheduling module, and a real time multimodal/intermodal route-planning algorithm for traveler information.

VISTA for traffic operations

The VISTA system as implemented for the I-80 corridor incorporated only the major arterials and excluded local roadways. The corresponding signal timing plans were obtained from NJDOT and incorporated into the VISTA database. The VISTA system has its own signal warrant/optimization algorithm that is activated if the user desires to do so. It is realized, however that NJDOT engineers use a number of signal analysis

and optimization software such as HCS, SYNCHRO, PARAMICS, TRANSYT7F and CORSIM. The current version of VISTA has a two-way interface with SYNCHRO, although not implemented for this project. Similar interfaces can be developed for each one of these software to provide flexibility to the NJDOT engineers, planners and consultants to run their models on the desired software and take advantage of the VISTA data model and the VISTA-DTA. The VISTA-DTA will produce the path assignment of the vehicles based on the new signal-timing configuration and the associated MOEs.

Methodology

- Develop a statewide VISTA-DTA model that will incorporate all the existing data for both the freeways and surface streets.
- Identify deficiencies in infrastructure, traffic control and traffic flow data;
- Develop a plan to complete the first version of the transportation network;
- Develop a plan for a systematic updating of the VISTA data model for traffic operations. This procedure will include all potential stakeholders that collect transportation data in New Jersey.
- Develop a procedure for data fusion within the VISTA system.
- Develop two-way user friendly interfaces between VISTA and all the transportation software that the NJDOT considers as acceptable for traffic operations such as the Highway Capacity Software (HCS), SYNCHRO, CORSIM, PARAMICS, VISSIM, TRANPLAN, GIS software, CAD software (AUTOCAD, Micro station), other.
- Develop user-friendly procedures for NJDOT engineers/planners to evaluate various signal timing plans taking advantage of the VISTA-DTA capabilities that produces the OD paths for all vehicles based on each network configuration and signal control strategy. Any signal timing change practically changes the capacity of a specific movement. In the short term the travelers will not change their original paths, however over time they will readjust their paths based on the new signal timings. This feature cannot be captured by any of the available signal optimization software. Therefore the VISTA-DTA system could be used to evaluate any signal timing changes from the area wide point of view.

- Other functions of traffic operations such as incident management, emergency operations are discussed in other sections.

Recommendation

Develop 1) two-way interfaces of the VISTA model with various traffic operation software that NJDOT engineers and planners use, and 2) a user-friendly interface for each of the integrated software.

Establishment of a statewide traffic impact analysis module

One of the main functions of NJDOT is to issue access permits to businesses that want to build, expand a facility (restaurant, gas station, office complex, shopping center, etc.). The NJDOT requires from these corporations to perform traffic impact analyses. The present method relies on the analysis conducted by transportation consulting firms who usually collect traffic data in the vicinity of the location of the new or existing facility, combine them with historical traffic flow data and they develop a transportation planning model for the network around the facility, which sometimes may be very large (involving several hundred intersections) or very small (e.g. only one intersection). This methodology however has inherent deficiencies: 1) First, there is no consistency on the results of each model (e.g. two different consultants may work on the same network and they may use a different transportation planning model), 2) The collected data in the majority of the cases disappear, where they could be used to calibrate a statewide transportation planning model, 3) It is rather difficult and time consuming for the NJDOT engineers to evaluate the results of each traffic impact analysis study.

The establishment of a statewide VISTA system will provide a universal framework for conducting traffic impact analyses both by NJDOT engineers and planners and the consulting companies. This model will be continuously updated with the data collected by the consultants, NJDOT studies. A module could be devised within VISTA that will be able to efficiently evaluate the analyses produced by the consultants and identify any deficiencies. Such a module will provide consistency to all traffic impact analyses conducted for NJDOT and an efficient system of sharing related transportation data

among interested parties, avoiding duplicated data collection efforts and identifying erroneous data and inconsistent results.

Methodology

Develop a statewide VISTA-DTA model that will be owned by the NJDOT;

Each NJDOT traffic engineer, transportation planner, consultant will be given an account on the VISTA system that will give them access to the vista system:

- Specific NJDOT transportation planners/engineers will have full capability to change the database and run the VISTA models. Other professionals at NJDOT may be given privileges to run the models only. The remaining NJDOT personnel will be given access just to view the output of various models of the NJDOT-VISTA system.
- NJDOT personnel will be allowed to submit collected transportation related data to a central data unit. This data unit will be responsible for accepting the data and enter it in the data model, store the data for future reference or delete the data.
- Consultants and researchers will be allowed to run models only. This privilege will be allowed for specific models based on the study that is conducted. However they will be given privileges to send collected data based on the studies they are conducting. Each data retrieved by NJDOT will be examined and a decision will be taken to enter it into the VISTA data model, store it or delete it.
- Other professionals will be allowed just to view the data only.
- The consultant once he/she completes the traffic impact study will be required to submit all collected data and the model used such as SYNCHRO or HCS for the network that they studied. An automated procedure will be developed within VISTA to first identify any deficiencies in the data and the model used. It is noted here that the VISTA system will have capabilities to interface with all the accepted traffic impact analysis software that NJDOT will approve for their transportation planning, traffic engineering and access permit studies.
- The collected data from the traffic impact analyses once they pass the test from the data unit then they will be used to further calibrate the VISTA system.

This procedure will create a systematic and ***continuous updating*** of the transportation database for the entire state. Valuable data will not be lost in some shelves of a consulting firm or NJDOT office. In addition it will provide ***consistency*** in the results for traffic impact analyses since all of them will be using the same traffic assignment model, the NJDOT-VISTA-DTA. Furthermore, this procedure will decrease the costs associated with data collection, ***avoiding data collection duplication*** by having them accessible to various entities that want to analyze them al they want to use them to run various models. The various modelers at NJDOT, consultants and the researchers will benefit by having both the data and the models at their fingertips anywhere they are as long as they have Internet connection.

Recommendation: Develop a statewide traffic impact analysis module using the VISTA system

- **Develop universal procedures and data format for traffic flow data collection and dissemination to/from NJDOT that should be followed by all NJDOT engineers, planners and consultants,**
- **Develop a module to identify data inconsistencies in traffic impact analyses.**

VISTA for freight operations and planning

Analysis of truck routes for truck operation efficiency, safety and security. The VISTA system has the capability of modeling both passenger cars and trucks (see related implementation in Chicago, IL where Ziliaskopoulos completed an National Science Foundation sponsored truck study) taking into consideration both vehicle performance characteristics and turning movement requirements. Turning movements are particularly challenging for trucks especially tractor-trailers, which not only require substantially additional time to turn but also in some cases cause extra delays for other cars in the vicinity of an intersection.

The current NJDOT transportation network has designated truck routes forming a sub-network. The New Jersey Turnpike has designated truck restrictions along some

sections of the roadway. Trucks are not allowed to go through Holland tunnel and all commercial vehicles are usually restricted to use the upper level of the George Washington Bridge. In addition, commercial vehicles are often stopped at the bridges and tunnels for safety and security inspections. Furthermore, a roadway-pricing scheme is employed for the peak hours along the major toll facilities in New Jersey and the crossings into Manhattan that is operated by the Port Authority of New York and New Jersey (PANYNJ).

Truck related infrastructure changes may include: Addition of one or more lane(s) for cars only, trucks only or all vehicles; Addition of one new roadway connecting two points for cars only, trucks only or both; Deletion of lanes or roadways. Operational changes may include different roadway pricing for the peak and off-peak periods, prohibition for trucks to use certain lanes or roadways during certain time periods of the day.

The potential combinations of the proposed projects could be prohibitive if an exhaustive enumeration is sought. Traditionally, transportation planners consider only a few potential options. In such cases the VISTA-DTA could be employed to run all potential combinations and prioritize them according to the DTA-based estimated traffic flow MOEs. Then the stakeholders could further prioritize them based on their own specific needs (MOEs) given the traffic flow MOEs.

Methodology

- Run DTA without the proposed infrastructure or operational changes;
- Run DTA with the proposed infrastructure or operational changes or a combination;
- Analyze the before and after output data from the VISTA system. Potential MOEs for this analysis could include: Total network-wide travel time, truck travel time, Auto travel time, Link traffic volume per vehicle category and the associated percentage differences (before and after). In addition the analyst could further produce results for specific OD paths before and after the proposed improvements.

Recommendation

The VISTA system may be employed to model all these different types of truck related infrastructure and operational changes to evaluate various alternatives to improve the efficiency, safety and security of the transportation system as a whole and the efficiency of truck operations.

VISTA for emergency analysis

The VISTA system offers a framework for conducting emergency analyses in a seamless manner since most of the algorithms - DTA model, time-dependent route planning algorithms including intermodal algorithms - are already embedded into the system. The route planning algorithms are necessary for all emergency services such as EMS, fire department, towing services, police, and security related agencies. In addition, these route-planning algorithms are necessary for buses and other para-transit vehicles as well as for automobiles equipped with in-vehicle navigation systems that are crucial in offering evacuation services to the citizens.

The set of VISTA emergency and evacuation modules are envisioned to be used for off-line emergency analyses, real-time implementation and training exercises. In addition, for each module a semi-automated self-calibration procedure will be designed that will be based on data collected automatically by roadway detection devices (roadway based sensors) and in-vehicle devices (GPS, communication), as well as data collected by each agency for each emergency event. A database will be designed for each emergency category that will be continuously revised to best emulate the characteristics of the local conditions.

Recommendation

Establish a universal VISTA based evacuation module for the state of NJ that will cover: hurricane or severe storm, nuclear plant, hazardous material spill, fire, terrorist act or flooding. A set of modules will be designed for each of the emergency agencies that will be customized for their local area to be used for: continuous training of related emergency agencies, off-line evaluation of various

emergency alternatives, real-time implementation and continuous calibration based on feedback from each event.

Hurricane or severe storm

Develop a module that could be used to analyze various evacuation alternatives given that a severe storm is projected to arrive in NJ either from the Atlantic Ocean or from any direction of the continental USA. This module will at least offer the capability to estimate and predict the traffic flow conditions for each alternative and it could be combined with a comprehensive network design module (signal optimization and roadway capacity changes) such as the decision makers could choose the best alternative(s) prior to the implementation of such plan. In addition, a real-time VISTA evacuation module could be designed that will be able to run in times faster than real time, such that any changes due to the effect of the specific set of dynamic events have on the roadway capacity (roadway flooding, signal blackout, roadway closures due to security concerns, other) and operation can be emulated and a set of alternatives could be evaluated in real-time.

Methodology

- Develop a calibrated VISTA-DTA under normal traffic conditions for the network under consideration.
- Develop an evacuation module based on the direction of a hurricane or storm. Hurricane/storm history may be used for selecting a specific scenario. This evacuation module will include at least the evacuation plans developed by the state police. Furthermore, the VISTA SO DTA may be used to design evacuation plans based on the potential for reversibility of roadways where feasible.
- Run various scenarios of the VISTA-DTA by assuming that some links of the network have either reduced capacity or no capacity at all due to flooding, accidents, fallen trees and other reasons. This practice will aid in the identification of potential problems of each evacuation alternative. An alternative plan may behave better by providing more routing alternatives under roadway closures or severe capacity decreases.

- A real-time VISTA-based evacuation model may be developed that will be able to run faster than real time. This model will be able to produce new evacuation plans due to roadway closures or severe capacity reductions.

- Use the VISTA model to train emergency agencies in the allocation of their fleets during hurricane/major storms. The route planning algorithms within VISTA will produce the shortest path for each emergency vehicle to the scene of an incident such as vehicle accidents, persons trapped into buildings or disabled vehicles, transport of food and medical supplies to people and buildings, other.

- Develop a real-time emergency vehicle fleet assignment based on the VISTA system that will dynamically respond to various types of emergencies under emergency conditions. For each implementation of the VISTA system document the predicted path travel time for each vehicle and the actual time. This will aid in the improvement of the VISTA model for future applications.

- Develop a procedure for the continuous updating of emergency response plans based on historical experience for each emergency type and a continuously calibrated VISTA system.

- A user-friendly interface will be designed within VISTA for each type of emergency evacuation and the specific geographic area of NJ. Furthermore, a detailed plan for the implementation of the evacuation module will be designed, including a set of training courses for the relevant parties in NJDOT, and emergency services.

Nuclear plant emergency evacuation

The principal difference between a hurricane and a nuclear plant evacuation is the direction of the evacuation routes as well as the emergency agencies that are involved. The specific module will follow the directions of the Federal Emergency Management Agency (FEMA) for nuclear plant evacuation plans, the existing NJDOT evacuation plans and other suggested evacuation plans and emulate them within VISTA.

Hazardous material spill response/evacuation

A hazardous material spill usually involves roadway closures and evacuation of people within a relatively smaller radius than a nuclear spill. It may also involve special

agencies – usually the Environmental Protection Agency (EPA) - for the clean-up of the affected area. The corresponding VISTA module will incorporate the standard procedures followed by the EPA for each specific type of hazardous spill. As an off-line tool it could be used to evaluate various alternatives and for training of the emergency related services.

Fire response/evacuation

The principal characteristics of a fire incident may include roadway closures, route planning of emergency vehicles to/from the scene of the fire. This module could be designed with help from the fire department, EMS and police for each local area of NJ in order to ensure that the model represents adequately the impact of a fire and emulate at least the existing procedures. Then this module could be used for the evaluation of alternative plans. Furthermore, a real-time fire response/evacuation module could be developed that will aid the emergency services to optimize their functions based on continuously updated traffic conditions.

Flooding response/evacuation

The VISTA system has been adopted by the US Army Corps of Engineers for the analysis of flooding in the Mississippi valley. This experience may be transferred to the appropriate authorities in New Jersey on the use of the model. Flooding analysis can be useful in evaluating various alternatives to evacuate people, identifying alternative routes based on historical experience of flooded areas, and optimal assignment of rescue personnel and optimization of their routes. A real-time VISTA-flooding module could be used to continuously estimate, predict the traffic conditions based on information of the level of roadway flooding. Such a real-time module should incorporate the types of vehicles that could/could not traverse the flooded roadways (e.g. trucks, buses, SUVs, passenger cars). This type of analysis could help to inform travelers to avoid certain roadways based on the predicted roadway flooding levels.

Recommendation

- **Develop an off-line statewide response/evacuation model to conduct off-line analyses of various emergency scenarios and potential response strategies and training of emergency personnel**
- **Develop a real-time statewide response/evacuation model to aid in the estimation and prediction of traffic conditions and the optimization of the paths for the emergency vehicles and the evacuation routes.**

General Recommendations

- **Develop a module that will produce an automated set of traffic flow statistics for either all drivers or selected sets of drivers given a set of incidents, construction zones;**
- **Enhance the present VMS module to 2.1) Automate the generation of statistics based on the location of a VMS and the location and severity of an incident, 2.2) Develop algorithms for the determination of the optimal location and basic content of VMS signs based on the desired objective(s), 2.3) Develop an asset management plan for VMS locations and content;**
- **Develop a real-time DTA-based traffic flow and travel time estimation and prediction algorithm model. Develop 3.1) an enhanced off-line dynamic OD matrix estimation algorithm for the entire New Jersey state; 3.2) Develop a real-time dynamic OD matrix estimation algorithm for a network with relatively good traffic surveillance system;**
- **Develop an asset management model for the establishment of a statewide advanced traffic management system, traveler information system and infrastructure planning. This asset management plan will address both real time traffic operations, short term and long term related projects and the necessary costs for its implementation.**

NEW JERSEY DOT VISUAL INTERACTIVE SYSTEM FOR TRANSPORT ALGORITHMS (VISTA)

Introduction

What is VISTA?

The *Visual Interactive System for Transport Algorithms* (VISTA) is an innovative network-enabled framework that integrates spatio-temporal data and models for a wide range of transport applications: planning, engineering and operational.

It can be accessed via a cross-platform Java client or a web page: The client software allows performing all basic transportation GIS type operations, such as zooming, displaying multiple layers, adding intersections, street segments, signal controls, ITS devices, etc. as well as run the modules, access the data warehouse and see some reporting (mostly graphical, such as 2-D animation, plots of measures of performance).

The same functionality is provided through the web page, though more emphasis is given in the detail customizable reporting, rather than the graphics.

The pioneering feature of VISTA is that it runs over the network on a cluster of Unix/Linux machines (it follows Sun Microsystems paradigm of the NETWORK COMPUTER). This enables accessing it from *anywhere*, *anytime* and from *any machine* without worrying about available computational power of the client machine to run sophisticated Dynamic Traffic Assignment, Control and Simulation models.

Why was VISTA designed to run over the Internet?

The structure of VISTA is revolutionary; it uses the Internet not simply as an information dissemination medium but also as the means to access and run algorithms. Many of the traffic models and algorithms require an enormous amount of computing resources to run on any actual networks. For example, Dynamic Traffic Assignment computes the path choices of all drivers on the network and simulates their spatio-temporal trajectory,

while accounting for traffic signal transition, VMS strategies, ramp metering, tolls, detectors, etc. This is computationally daunting even for toy networks. VISTA can run very-large scale networks (e.g. the Chicago 6 county-area network) in reasonable time, no matter where you run it from, because it always runs on the cluster of servers and workstations.

The data warehouse can be simultaneously accessed by many users; each user logs on the system with his own authorization level and depending on that can see/modify data, run algorithms, create scenarios, run tests and produce reports. All modifications to the system must ultimately be approved by the VISTA Administrator. Enables the fact that it is distributed it enables relies on the existence of the Internet that provides a cheap and ubiquitous medium of communication among spatially disperse users.

For a brief, how-to tutorial on the VISTA functionality, please check the following link: http://vista.civil.northwestern.edu/documentation/tutorial

Why VISTA?

Transportation systems are complex entities that require substantial data to be monitored, controlled, maintained and improved, as well as various elaborate models to help a diverse group of agencies to operate the system. Data currently collected by transportation agencies can be loosely classified into the following types: planning, engineering and operational; a similar classification can be made for the models used. These data have certain similarities:

(i)   they are all concerned with the same network, traffic demand and control devices, albeit at different levels of aggregation and precision of representation,

(ii)   they are all spatio-temporal, i.e., they can be associated with spatial and temporal coordinates,

(iii)   they are often used by more than one models for different applications. Great benefits could be realized.

If these data are integrated into a single database or linked distributed databases and become accessible by all necessary models. Data and models could, in turn, be available to all involved entities: planners, engineers, operators, as well as various stakeholders, such as researchers, consultants, trucking companies, special interest groups and even the traveling public.

Presently, transportation professionals have to cope with fragmented databases, multiple and incompatible models, redundant and often conflicting data acquisition efforts, lack of coordination between various agencies and private companies operating on the same transportation facilities. This results into serious inefficiencies and waste of resources. For example, a transportation planner uses the network of a metropolitan area for air quality analysis with a certain format that is usually incompatible with a signal optimization or simulation software that the traffic engineer of the same urban area uses to optimize the operations on the urban network. Typically, both professionals independently collect and code the data for the same network and demand (albeit at different aggregation levels) without taking advantage of the existing resources at each other's agency.

Enabling technologies developed over the past few years have created unprecedented opportunities to overcome some of the problems above. These technologies include the explosion of the Internet and Internet support tools, terabyte size databases, distributed computing architectures, client server technologies as well as a new generation of transportation tools resulted from the evolution of Intelligent Transportation Systems. Many of these technologies have already been adopted by corporations and have led into the development of new business models.

VISTA aims to integrate spatio-temporal data and models for a wide range of transport applications: planning, engineering and operational. The client graphic user interface (GUI) is built in JAVA, so that it can be used over the Internet (or any other large network). The database efficiently stores and retrieves spatio-temporal data, by associating geographic coordinates and time stamps. The database is designed to efficiently manage a wide range of transport data: from off-line planning and engineering

to streams of real-time, such as those coming in from street sensors and newer vehicle based devices. Furthermore, the control and encapsulation of the data that becomes possible with such a system, help deal with problems arising from agency specific requirements.

VISTA Framework Architecture

The goal of VISTA framework is to meet the functional requirements by adopting successful practices from the Information Technology industry. VISTA is a networked system, accessible through the public Internet or a private Intranet. The models represent traditional and cutting-edge transportation algorithms capable of handling large-scale real-time needs (as will be discussed). The client is a machine-independent Java application. CORBA used to bridge the client with the modules and data, allowing the modules to be developed in languages other than Java. Other distributed-object technologies (RMI and DCOM for example) limit the languages or operating systems available for developing and deploying VISTA modules.

The system implemented so far includes:

- A Data Warehouse containing all the data needed by the models.
- Existing and new transportation models and tools (planning, engineering, control, monitoring, evaluation and operational).
- User interfaces for the various stakeholders (planners, engineers, policy makers, and operators) that enable access to the data and models from any computer hardware, at any location, at any time.
- The system uses CORBA to facilitate communication between the client application and the application server.
- Support capabilities for all relevant transportation applications.
- Functionality for interaction among users.
- Reporting tools.
- Security features providing access control and fine-grained permissions on data and models.

- Some basic administrative capabilities.

The system is intended for deployment at the state or regional level. The State Department of Transportation (DOT), the Metropolitan Planning Organizations (MPO's), County Engineers, City Engineers, Transit Agencies, Freight Agencies, and other stakeholders will have access to the system at various authorization levels to obtain/maintain data, run models and perform analysis. Policy makers at the Federal, State and Local governments will be able to monitor projects, obtain data, evaluate impacts of policies and make decisions. The overall structure of VISTA is outlined below.

The user interface is written entirely in Java, so it can easily be used on multiple platforms and across the Internet. It communicates with the Management Module through the Java Object Request Broker (ORB), allowing access to any user with a web browser and the Java plug-in. The Data Warehouse can be accessed through CORBA, C/C++ libraries, Open Database Connectivity (ODBC), and Java Database Connectivity (JDBC). Finally, by implementing an abstraction over the database interfaces, the underlying modules can easily migrate to work with a variety of other relational database management systems.

By maintaining a Data Warehouse, the efficiency is improved in managing crash data and performing safety analysis. Currently, accident data are maintained by multiple jurisdictions, involve many people employed by the agencies in coding and cleaning the data. If one needs to access the data for year 1999, in most states, she has to wait at a year or more for the data to become available. With the proposed system, the reporting officer will have the capability to directly input the data using a networked device, whether a palm pilot or a computer. These data will immediately become available to all agencies with minimum additional processing. Having the data available in a central Data Warehouse will allow safety experts to accurately correlate it to prevailing infrastructure, weather, traffic and control conditions (at the time of the accident) and develop appropriate countermeasures on time.
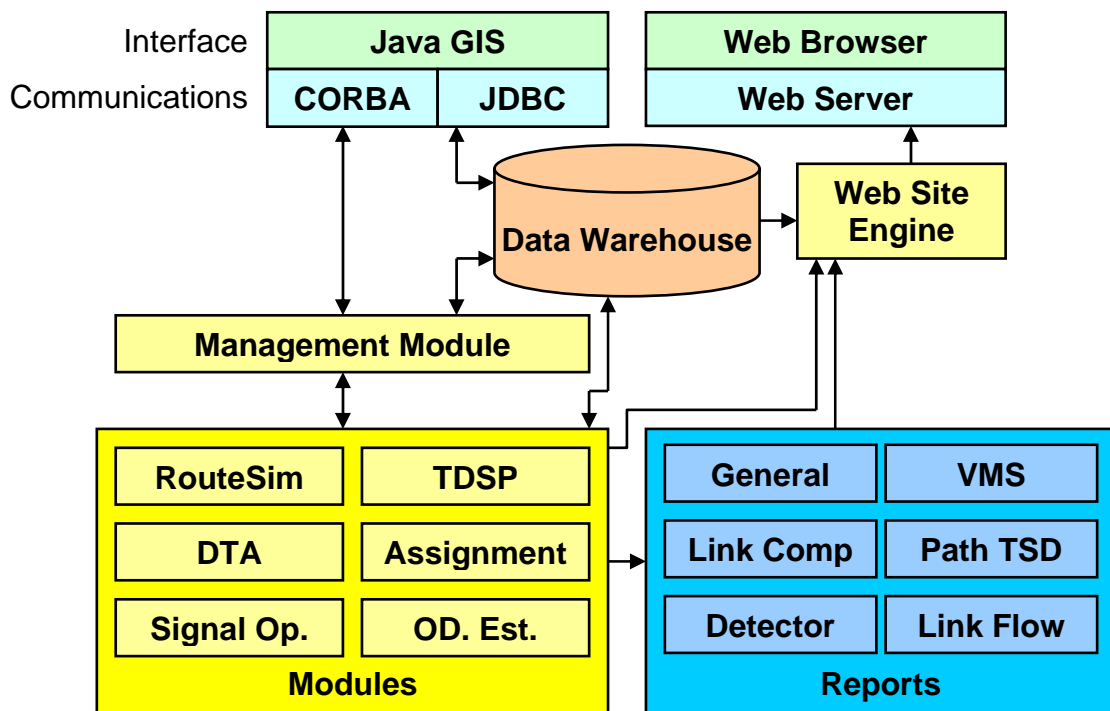
Figure 1. VISTA Structure

The presence of abundant data does not itself guarantee useful information for potential users. Furthermore, specific information requirements are often not known in advance when dealing with complex systems. These are the specific issues that have motivated the use of an RDBMS. Using a variety of access paths (JDBC, ODBC, and native

libraries), the Data Warehouse allows any tool access to the data, through one of these paths. This approach allows for the straightforward implementation of complex querying and reporting through the GIS or the web. Furthermore, this design ensures that if a desired functionality is omitted, a user can acquire the desired information using third party tools without changing the framework.

The networked nature of the VISTA framework also enables the parallelization of resource-intensive models. Some of the algorithms in VISTA can be migrated from serial to parallel implementations with minimal effort. This allows multiple processors to finish a model in a fraction of the time a single processor would require. A secondary

benefit of distribution is realized for the Data Warehouse. In a networked environment, many RDBMS packages can replicate data across multiple servers, adding a level of redundancy to protect the data.

The VISTA Data Model

The VISTA software iterates through time dependent routing algorithms and a mesoscopic traffic simulation model based on the cell transmission model. The VISTA software package stores data in a PSQL database. This can be accessed through either a GIS client interface, or a web reporting interface. The GIS interface provides data input and editing windows and is thus more user-friendly; however, the web interface is more convenient for querying and viewing many records at once. This section describes the data required for VISTA simulation through a discussion of VISTA's PSQL database tables.

As explained in the "Data Issues" chapter, the VISTA dynamic traffic assignment and simulation software requires network definition data, origin-destination demand definition data, signal definition data. Further, the model will be validated and OD demands will be calibrated against observed link flow data, which are also assigned to database tables.

Network Definition Data

The network definition data includes zone, node, link and cell definitions. The network-related PSQL tables are listed in Table 2 along with descriptions of the fields in each table. The zones, nodes and links are obtained from network data. The cell generation module is then used to split the links into cells, which form the basis of the cell transmission-based mesoscopic simulation.

Zones

Each network is divided into zones, which are geographic sub-regions that generate and attract OD demand. Zones are defined in the *zones* and *zonegeometry* tables.

Each zone is assigned an id number, and the physical shape of the zone is defined in the points column of the zonegeometry table. Further, each zone contains two centroid nodes, one for vehicles entering the network from the given zone and one for vehicles exiting the network to the given zone. Centroids are considered to be imaginary nodes that represent the source and destination of all demand from and to the given zone, and they must be listed in the *nodes* table with node type=100. Each zone is also assigned a list of actual nodes that exist within the boundaries of the zone. The zone centroids are connected to these actual nodes by centroid connectors, which are links with link type=100. Connectors can be created to join the centroids to one or all of the actual nodes in the zone; however, addition of connectors increases the number of links in the network, and thus also the computational time required for assignment and simulation.

Nodes

Nodes are defined in the *nodes* table, and each node is assigned an id number and an (x,y) coordinate location. Nodes are also defined in terms of their node type, with node type=1 for actual nodes, and node type=100 for centroid nodes. (x,y) coordinates are not important for centroid nodes and can be set to arbitrary values, such as (0,0), since centroids nodes are imaginary and do not exist in the physical world.

Links

Links are defined in the *links* and *linkdetails* table, where the data in the *links* table determines the appearance of each link in the VISTA GIS client, and the data in the *linkdetails* table is used to determine the vehicle path assignment. Each link is assigned an id number and a link type, where type=1 for actual links, and type=100 for centroid connector links. The geometry of each link is defined by a series of (x,y) coordinates in the points column of the *links* table. The first point in the series must correspond to the coordinates of the source node, and the last point must correspond to the coordinates of the destination node listed in the *linkdetails* table. The street name, length and speed are also defined for each link. The capacity of the link can be defined by defining the capacity directly, or by defining the number of lanes in the *linkdetails* table (if no

capacity value is explicitly defined, the cell generator assumes a capacity of 2,000 vehicles/hour/lane).

The geometry of centroid connectors is not important and can be set to arbitrary values, such as {(1,1),(2,2)}, since centroid connector links are imaginary and do not exist in the physical world. Also, centroid connectors are typically assigned a large number of lanes (for example, 10 in each direction), so that the capacity on the connectors is essentially infinite.

All links in VISTA are uni-directional. To represent bi-directional streets, two links must be defined.

Cells

When the network's nodes and links have been fully defined, VISTA's cell generator module is run to create the cells, which are used in the cell transmission-based mesoscopic simulation. In other words, cell data is not entered based on acquired data sets, as with the zone, node and link data, but instead is generated automatically using the cell generator module based on the node and link definitions. The cell definitions are stored in the *celldata* table, and each cell is assigned an id number, as well as a cell type to indicate whether the cell is an arrival cell (first cell in a link), a departure cell (last cell in a link) or an intermediate cell. Further, the link id of the link from which the cell was generated is shown, along with parameters such as jam density, saturation flow into and saturation flow out of the cell. For each arrival cell the number of links that precede that cell is given and the preceding links are listed. Similarly, for each departure cell the number of links that follow that cell is given and successor links are listed.

Table 2. Network Definition Tables

Table Name	Column Names	Value Type	Description
zones	id	integer	zone id number
	type	integer	zone type: all set to 1
	fromcentroid	integer	zone centroid from which vehicles generated at the zone enter the network
	tocentroid	integer	zone centroid where into which vehicles attracted to the zone leave the network
	num	integer	number of actual nodes in the zone
	nodes	integer array	list of actual nodes in the zone
zonegeometry	id	integer	zone id number
	points	set of points	(x,y) coordinates defining shape of zone
nodes	id	integer	node id number
	type	integer	node type: 1 for actual nodes, 100 for centroids
	x	real	x coordinate
	y	real	y coordinate
	iscontrol	boolean	{not used}
links	id	integer	link id number
	type	integer	link type: 1 for actual links, 100 for centroid connectors
	lanes	integer	number of lanes (determines appearance of link in GIS)
	points	set of points	(x,y) coordinates defining link geometry
linkdetails	id	integer	link id number
	type	integer	link type: 1 for actual links, 100 for centroid connectors
	source	integer	id of source node
	destination	integer	id of destination node
	length	real	length of link [ft]
	speed	real	speed on link [miles/minute]
	capacity	real	capacity of link [vehicles/hour]
	sname	text	street name
	lanes	integer	number of lanes (determines capacity of given link's cells)
celldata	id	integer	cell id number
	type	integer	cell type: 1 for first cell in a link, 2 for intermediate cell in a link 4 for last cell in a link
	link	integer	id of link from which cell was created
	jamd	integer	jam density of this cell [vehicles/mile]
	satin	integer	saturation flow into this cell [vehicles/hour]
	satout	integer	saturation flow out of this cell [vehicles/hour]
	otherlinks	integer	number of links that precede/follow the given link (depending on whether the cell is first or last in a link)
	olink	integer array	list of links that precede/follow the given link (depending on whether the cell is first or last in a link)
	blocks	integer	number of links that follow the given link (defined only for departure cells)
	info	integer array	list that show for each successor link the number of links that follow the given link, the number of links represented by the cell, the link that follows the cell (defined only for departure cells)
	blocklinks	integer array	{not used}

Demand Definition Data

The vehicle OD demand definition data includes static and dynamic demand definitions. The demand-related PSQL tables are listed in Table 3 along with descriptions of the fields in each table. The VISTA software requires exact vehicle departure times in order to assign and simulate vehicles; however, regional vehicle OD trip data is typically only available for a 24-hour period. The daily demand must then be factored down to represent the demand for the simulation period in question, for example, morning peak hour from 7:00-8:00am. This demand for the simulation period is then referred to as the "static" demand, since exact vehicle departure times are not specified. The VISTA software's demand profiler is then used to convert the "static" demand to "dynamic" demand, in which each vehicle is assigned a specific departure time within the simulation period.

Static Demand

Static vehicle OD demand is defined for each OD pair and vehicle type (cars, trucks, etc.), and each OD-vehicle type is assigned an id number and a demand quantity indicating the number of vehicles of the given type moving between the given OD pair during the whole simulation period.

Dynamic Demand

The values in the *static_od* table are then converted to dynamic demand using the VISTA demand profiler module. The demand profiler assigns exact departure times to each vehicle for dynamic traffic assignment and simulation. Dynamic demand is stored in the *demand* table, and each record in the *demand* table represents an OD pair, for a specific vehicle type and departure time. Each OD-vehicle type-departure time combination is assigned an id number, and a value representing the number of vehicles of the given type traveling between the given OD pair at given departure time. Using the demand profiler, different proportions of the static demand can be assigned to different intervals within the simulation period by assigning weights to each interval (weights

must sum to 1.0). Thus, the assignment interval listed in the *demand* table refers to the interval defined by the demand profiler.

Table 3. Origin-Destination Demand Definition Data

Table Name	Column Names	Value Type	Description
static_od	id type origin destination demand	integer integer integer integer integer	id number for OD pair type of vehicle: 1 for cars, 2… for other vehicle types id of origin zone id of destination zone number of vehicles of the given type moving between the given OD pair during the whole simulation period
demand	id origin dest ast vehs dtime type	integer integer integer integer integer integer integer	id number for OD pair and departure time id of origin centroid node id of destination centroid node assignment interval number of vehicles traveling between OD pair at given departure time vehicle departure time [seconds after simulation start] type of vehicle: 1 for cars, 2… for other vehicle types

Signal Definition Data

The signal definition data includes signal location and timing definitions. The signal-related PSQL tables are listed in Table 4 along with descriptions of the fields in each table.

Signal Locations

Signal locations are defined in the *controls* and *signals* tables. For each record in the *controls* and *signals* tables, an id number is assigned, referring to the node id of the intersection where the signal is located. The type field indicates the control type, where type=448 represents intersection signals (other types include type=708 for stop signs, etc.).

Signal Timing

Signal offsets are defined in the *signals* table, and signal cycle and phase plans are defined in the *phases* table. Each phase in the *phases* table is assigned a phase id,

along with the node id of the intersection where signal is located, and the phase number at that intersection. The phase number represents the phase number in the phasing sequence at a given intersection (typically is a value from 1-5), whereas the phase id is specific to each intersection-phase number combination. Each phase is also assigned a certain amount of green time, yellow time and red time, and the movements allowed during that phase's green time are listed in terms of approach and departure links. During one phase's green and yellow time, all other phases at that intersection have red by default. As such, the timered field in the *phases* table refers to all-red time at the end of the given phase, and not the total red time for the cycle. The phase type can be defined as pre-timed or actuated; however, for the Chicago TSP project, all signals will be assumed to be pre-timed.

Table 4. Signal Definition Tables

Table Name	Column Names	Value Type	Description
controls	id type	integer integer	node id of intersection where control is located control type: 448 for signals, 708 for stop and yield signs
signals	id type timeoffset	integer integer integer	node id of intersection where signal is located signal type: 448 signal timing offset for coordination of signals [seconds]
phases	id type nodeid link phase timered timeyellow timegreen nummoves linkfrom linkto	integer integer integer integer integer integer integer integer integer integer array integer array	phase id phase type: 1 for pre-timed, 2 for actuated node id of intersection where signal is located {not used} phase number amount of all-red time at the end of this phase [seconds] amount of yellow time at the end of this phase [seconds] amount of green time for this phase [seconds] number of movements allowed during this phase list of approach links in movements allowed list of departure links in movements allowed
sig_nodes	id intersection	integer integer	node id of intersection where signal is located 1 if there are 3 or more legs in this intersection, 0 if this intersection was created without cross-streets

Link Flow Data

When the model is complete, the results will be validated and OD demands will be calibrated against observed link flow data. The link flow table in VISTA is shown in Table 5 along with descriptions of the fields in the table. The *linkdetectors* table

describes the location of each detector. Each detector is assigned an id number, and a type value to indicate what the detector detects. The link on which the detector is located and its location along that link are listed, along with the lane location within that link. Also, the range of detection toward the head and tail of the link can be defined. Further the detector's operational status can be turned on or off.

The *counter* table stores the observed traffic counts for each detector and assignment period. When the model is complete and the dta-simulation procedure has been run, the OD demands will be calibrated such that the link flows produced by the simulation match the counts in the counter table.

Table 5. Link Flow Tables

Table Name	Column Names	Value Type	Description
linkdetectors	id	integer	link detector id number
	type	integer	set to type=65502 (detects occupancy and flow)
	lane	integer	the lane number (1,2,3,… from outside to median), 0
	link	integer	for all
	location	integer	link on which detector is located
	destinationr ange	integer	distance of detector to destination node of link
			the distance of detection toward the destination node
	originrange	integer	
	detects	integer	the distance of detection toward the origin node
			indicates whether or not the detector is operational
counter	id	integer	detector id
	linkid	integer	link on which detector is located
	ast	integer	assignment period
	veh	integer	number of vehicles observed in this period

VISTA Model Structure

The primary modules currently implemented in the VISTA framework include a large-scale traffic simulator (RouteSim), traditional (static) planning models, Dynamic Traffic Assignment models, network routing algorithms, signal optimization models, ramp metering and incident management models. The interactions among models are coordinated by the central management module. Although each of these models may have different data type and structure requirements, the format for this data is kept

uniform. The way in which the VISTA modules interact is represented in Figure 1. Each interaction is specified as either a synchronous or asynchronous invocation.

Management Module

The Management Module is the central component of the VISTA framework, and one of the only modules the user interface directly communicates with. It continuously runs on the server, handles incoming requests from remote interface modules, and executes the algorithm modules. A remote CORBA object can be described by its IDL file.

As discussed earlier, when the Management Module first runs, it creates an HTML file, which contains the Interoperable Object Reference (IOR) string as an HTML parameter. This string uniquely identifies the Management module as a CORBA object. By knowing this string, any CORBA enabled object present on the Internet has the ability to lookup and communicate with the Management object. Alternatively, a remote module could contact various system modules by accessing the CORBA naming service available on the central server.

When the Management module receives a remote call to execute an algorithm, it does so through various means. The simplest method is to use the ANSI system() function to execute a separate program. The input parameters are specified as command line arguments, and the resulting output read from a temporary file, then returned to the invoking interface object. This method is best for relatively small algorithms that need little computational time and data manipulation.

For larger, more complex systems such as Dynamic Traffic Assignment (DTA), the algorithm appears as a different CORBA module, which contains its own remote methods. For these cases, the remote methods are specified to be *asynchronous* or *oneway* (which is interpreted as *asynchronous* within the employed ORB implementations). For very complex system where distribution is a possibility, this option also allows further distribution within the algorithm to take place using the framework services.

RouteSim

The turning movement-based simulation approach is generally associated with microscopic simulation. Microscopic simulation models treat vehicles as individual entities according to car-following and gap-acceptance principles. Traffic signal operation, randomly assigned driver characteristics and stochastic traffic events allow these models to reflect real world traffic processes. Microscopic models are extremely detailed, but also computationally intensive and thus limit the size of networks that can be simulated. More specifically, computer simulation studies of highway traffic are most commonly carried out using various commercially available microscopic simulation packages, such as VISSIM, WATSIM and NETSIM, which are all PC Windows-based, and are thus limited to the computational power available on standard PCs. This memory constraint combined with the high computational requirements of microscopic simulation results in test scenarios that are typically limited to small networks of around 15 intersections. Complete trips cannot be modeled on networks of this size, so generation of traffic is left to intersection turning movement counts.

This turning movement-based approach ignores vehicle route changing behavior that results in reaction to the change in traffic conditions. Specifically, it is reasonable to assume that deployment of certain ITS schemes will change the traffic pattern thus changing travel times not only for the vehicles affected directly, but also of regular vehicles traveling both along and across the corridor. As a result, vehicles may choose to use or not to use their existing path depending on whether or not their approach is given the advantage, and may therefore change their travel route. However, the turning movement-based approach takes intersection traffic volumes and splits as an input parameter, thus assuming that the flows and turning movements on the corridor remain unchanged regardless of any shift in travel time advantage.

To avoid having to make this assumption, a large area including not only the priority corridor, but the whole trip-making region should be simulated with traffic generated based on assignment of OD trips. Using this OD assignment-based simulation approach, vehicle route choice behavior can be captured while accounting for the ITS

corridor effects on travel time. These effects are regional in nature and can only be captured by a simulation that is regional in scale, and not by individual simulation of short corridors.

There are currently no commercially available microscopic models capable of OD assignment-based simulation on a regional network; however, macroscopic and mesoscopic models are currently being developed. Macroscopic simulation programs, such as University of Texas' DYNASMART (Mahmassani et al, 1993), are based on equations of the traffic flow process, which predict conditions based on inputs such as traffic volume, number of lanes, and distribution of green time at an intersection.[23] Vehicles are treated collectively under the assumption that the aggregate behavior of sets of vehicles depends on the traffic conditions in their environment. Macroscopic models are deterministic in that the same inputs will always produce the same results. While macroscopic models are generally more computationally efficient and require less input data than microscopic models, microscopic models can be more realistic, and thus more widely acceptable than macroscopic models. Further, microscopic simulation models produce much more detailed output that allows users to customize their analyses of the results. In addition, most microscopic simulation models produce graphical animation that allows the user to view traffic control operations and traffic interactions on the simulated roadways, thus allowing the user to verify that the model is properly simulating the roadway conditions and to visually compare before and after scenarios.

Mesoscopic models, such as Northwestern University's VISTA model, predict traffic movements not for entire links, nor for individual vehicles, but for small sections of each link. RouteSim is a mesoscopic simulator based on an extension of Daganzo's (1994) cell transmission model introduced by Ziliaskopoulos and Lee (1996). In the cell transmission model, link conditions are simulated by evaluating flow at a finite number of intermediate points. In other words, the movements of small groups of vehicles are simulated as they enter and leave sections of each link. The principles of the cell transmission model are consistent with the hydrodynamic theory of traffic flow, but can also capture microscopic effects, such as queuing. Mesoscopic simulation provides

output on the cell location of each vehicle at every time step. This information is less detailed than the output provided by microscopic simulation (exact vehicle position, speed and acceleration at each time step) but is much more computationally efficient. Further, the detail provided by microscopic simulation depends on extensive calibration of driver behavior parameters, and the benefit of the increased level detail is questionable if these parameters are not correctly calibrated. The mesoscopic model does not attempt to provide such a high level of detail in its output, but nor does it demand as intense an effort in calibration. Also, unlike in macroscopic simulation, graphical output depicting vehicle movements can be obtained from mesoscopic simulation.

An advantage of RouteSim is that the simulation step and the representational detail are adjustable to the geometry of the network. Lengthy freeway segments that do not need to be modeled in detail are simulated as aggregate long cells and their state is updated infrequently - e.g. a two-mile freeway segment without on- and off-ramps could be modeled as a single cell and be updated every two minutes. On the other hand, close to intersections or problematic points where the evolution of queues, spatio-temporal traffic dynamics and signalization phases need to be captured in detail, the simulation step can be as small as two seconds. Simulation steps of this magnitude allow detailed representation of signalized intersections--i.e., signal control strategies, phasing, start-up/lost times and gap acceptance behavior. Note that while detail data (e.g., geometry, timing plans, turning movements) are required for accurately simulating a network with signalized intersections, RouteSim will run even if no such data are provided, by assuming (and prompting the user), geometry, control and traffic data.

The computational efficiency of the mesoscopic model allows mesoscopic simulators to solve large networks. The VISTA software takes advantage of this, and further is designed to run on Unix machines, which have much higher computational power than PCs. VISTA has been successfully run on networks with as many as 40,000 nodes and 60,000 links. The main enhancements over the basic cell transmission model are (i) the concept of adjustable size cells that improves the flexibility, accuracy and computational requirements of the model, and (ii) a modeling approach to represent signalized

intersections. The basic cell transmission model along with the enhancements yields a model that can simulate integrated freeway/surface street networks with varying degree of detail. RouteSim requires as inputs network geometry and path flow data. The path flow data can be generated from time-dependent or static origin-destination matrices or input directly by the user. Table 6 compares various aspects of simulation packages and simulation approaches.

In short, the memory limits of commonly available PC-based microscopic simulation packages make simulation of large regional networks infeasible. Using these packages, simulation is restricted to turning movement-based approach, which ignores vehicle route-changing behavior. Macroscopic and mesoscopic models have been developed with capability to assign complete vehicle trips to large networks, so that vehicle route-changing behavior is captured. The output provided by mesoscopic models is less detailed than that provided by microscopic models; however, this drawback is balanced by mesoscopic simulation's much less intensive calibration requirements. While less detailed than microscopic simulation, mesoscopic simulation remains more detailed than macroscopic simulation and allows higher quality graphical output.

Planning Models

System optimum and user equilibrium static assignment algorithms have been implemented and can be invoked through VISTA. The algorithms are deterministic approaches based on Frank-Wolfe's convex combinations method (Sheffi, 1985); a stochastic user equilibrium model is currently under development using a paired combinatorial logit model (Gliebe, *et al.*, 1998). The demand tables are part of the input data, since no trip generation, distribution and mode split modules are currently implemented. VISTA, however, provides a convenient framework for embedding such models, as well as using them in conjunction with dynamic traffic assignment models.

In addition, highway capacity analysis modules are currently being implemented so that the level of service for intersections and street segments can be computed for the

Table 6. Comparisons of Simulation Packages and Approaches

Available Software Packages	VISSIM, WATSIM, NETSIM	VISTA	DYNASMART
Simulation Approach	Turning movement count	OD assignment	OD assignment
Traffic Propagation	Microscopic car-following equations	Mesoscopic cell transmission model	Macroscopic Greenshield-type speed-density relationships
Typical time step	1 sec	2-6 sec	$\geq$ 6 sec
Direct Output	location, speed and acceleration for each vehicle at each time step	cell occupied by each vehicle at each time step	link occupied by each vehicle at each time step
Strengths	- detailed output - can capture driver behavior - queue evolution - transition of signal phasing	- can simulate large networks - requires less calibration	- can simulate large networks - requires less calibration
Weaknesses	- requires lots of calibration (gap acceptance, driver familiarity, driver reaction time) - computationally intensive, network size limited	- cannot precisely detect vehicle stops - less emphasis on driver behavior	
Ease of Use	Very difficult and time consuming; requires substantial experience;	Moderate training required; software ready; web-based	Difficult; still at the research community level
Quality of Graphics	High	Medium	Low
Maximum Network Size	Limited by PC RAM, typically ~15 intersections	No-limitation; Can be run on parallel Unix machines; networks with 40,000 nodes have been solved	No-limitation
Input Data Required	intersection turning movement counts, signal timing plans, car following and lane changing driver characteristics.	OD trip table, link traffic flows, traffic control and detailed geometry.	OD trip table, link traffic flows, traffic control and detailed geometry.
Calibration Required	Detailed and Intensive Driver behavior needed	Traffic flows and travel time distributions	Traffic flows and travel time distributions
Impacts that can be evaluated	Short term infrastructure and operational changes; limited area coverage	Short-term, long term infrastructure and operational changes; no limitation on area coverage	Short-term, long term infrastructure and operational changes; no limitation on area coverage

equilibrium flows. The computational procedures are done according to the Highway Capacity Manual suggestions. Existing software, such as the HCS, could also be interfaced.

Signal control models

Signal timing plans can be computed for isolated intersections based on simple delay functions and offsets for intersections along an arterial (McShane and Roess, 1990). Network-wide signal optimization models are currently under development, although any of the already existing models (e.g. TRANSYT) can be easily interfaced. The SYNCHRO software is now integrated with VISTA such that the user can develop the signal timing plans into VISTA, run the VSITA-DTA and determine the traveler assignment and then send them back to SYNCHRO for further iterations. Consequently one could also run the TRANSYT7F through SYNCHRO and then use VISTA to determine the path flows. In conclusion, the analyst can utilize the VISTA system to determine the traveler distribution based on the corresponding network-wide signal timing, overcoming the current myopic approach that travelers will not change their routes due to the signal timing – over time the travelers will indeed change their routes, especially cab drivers and truckers who usually lead the way. A user friendly graphic interface for viewing (or modifying) the intersection signal time plans has also been developed.

Dynamic Traffic Assignment (DTA)

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). This section briefly describes major works in the development of DTA.

Analytical DTA Models

This section provides a general overview of analytical DTA models. Analytical DTA approaches are typically classified as *mathematical programming models, control theory based formulations,* and *variable inequality formulations*. Although these models are rarely used for large networks, they are important for understanding DTA; details will be provided for an analytical cell transmission-based DTA models.

Cell Transmission-based Analytical DTA Models

A single- destination system optimal (SO) cell transmission-based DTA model was introduced as a linear program (LP) by Ziliaskopoulos (2000). More recently, Waller and Ukkusuri (2002) as well as Chang (2002) have proposed dynamic user optimal formulation based on the cell transmission model.

The SODTA model captures traffic phenomena, such as disturbance propagation and creation of shock waves on freeways, and can be easily adapted to account for traffic signal control and ramp metering. Moreover, the computational requirements of the model are adjustable, depending on the discretization interval and the required accuracy. The difference equations can be reduced to simple linear relationships of flow and occupancy. These linear relationships are used to describe the traffic evolution in the LP formulation.

Next, the underlying cell transmission model and the SODTA approach is discussed. This section is focused on the single destination version of the problem presented by Ziliaskopoulos (2000). According to the cell transmission model, the links of the network are discretized in small segments, called cells, in such a way that a vehicle moving at free flow speed cannot traverse more than one cell in one time interval. The cells are grouped into cell types, which are illustrated in Figure 2. Further, the following sets are defined:

C   set of cells: ordinary cells (C_O), diverging cells (C_D), merging cells (C_M), source cells (C_R) and sink cells (C_S)

E   set of cell connectors: ordinary cell connectors (E_O), diverging cell connectors (E_D), merging cell connectors (E_M), source cell connectors (E_R) and sink cell connectors (E_S)

$\Gamma(i)$ set of successor cells to cell i

$\Gamma^{-1}(i)$ set of predecessor cells to cell i

T   set of discrete time intervals

In addition, the following parameters are used in the formulation:

δ_i^t ratio of free flow speed / backward propagation speed for each cell and time interval

d_i^t the demand (inflow) at cell i in time interval t

τ discretization time interval

N_i^t maximum number of vehicles that can be present in cell i at time interval t

Q_i^t maximum number of vehicles that flow into or out of cell i during time interval t

The variables to be calculated are as follows:

x_i^t number of vehicles contained in cell i at time interval t

y_{ij}^t number of vehicles moving from cell i to cell j from time interval t to t+1

(i) ordinary cell   (ii) diverging cell   (iii) merging cell

(iv) source cell   (v) sink cell
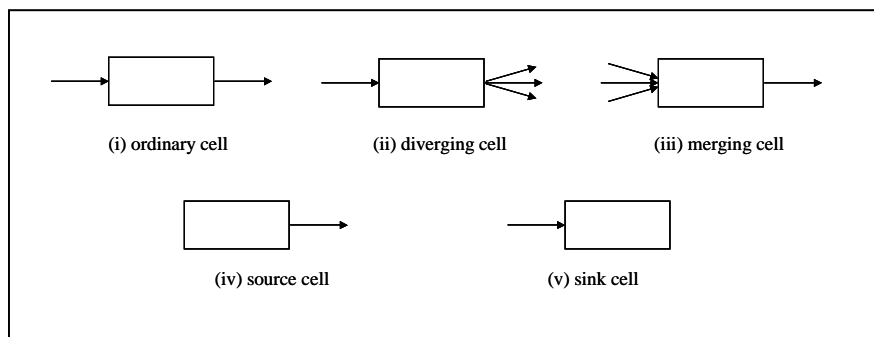
Figure 2. Classification of Cells

The basic relationships of the cell transmission model that describe the evolution of traffic flow are extensively discussed in Daganzo (1994) and in Ziliaskopoulos (2000). Here, we briefly review the basic relationships:

- *Ordinary cells and cell connectors:*

$$x_i^t = x_i^{t-1} + y_{ki}^{t-1} - y_{ij}^{t-1} \qquad \forall k \in \Gamma^{-1}(i), j \in \Gamma(i), i \in C_O, t \in T \tag{1}$$

$$y_{ki}^t = \min\{x_k^t, \min[Q_i^t, Q_k^t], \delta_i^t(N_i^t - x_i^t)\} \qquad \forall (k,i) \in E_O, t \in T \tag{2}$$

Relation (1) expresses the cell mass conservation. Relation (2) states that the flow between two ordinary cells is bound by the number of vehicles occupying the beginning cell, the remaining capacity at the ending cell, and the minimum of the maximum flow that can get out of the beginning cell and into the ending cell.

- *Diverging cells and cell connectors:*

$$x_i^t = x_i^{t-1} + y_{ki}^{t-1} - \sum_{j \in \Gamma(i)} y_{ij}^{t-1} \qquad \forall k \in \Gamma^{-1}(i), i \in C_D, t \in T \tag{3}$$

The inflow y_{ki}^t is given by (3); the outflows y_{ij}^t are determined by the following simple linear program:

$$\max \quad \sum_{j \in \Gamma(i)} y_{ij}^t \tag{4}$$

subject to

$$y_{ij}^t \le Q_j^t, \ y_{ij}^t \le \delta_j^t(N_j^t - x_j^t) \qquad \forall j \in \Gamma(i) \tag{5}$$

$$\sum_{j \in \Gamma(i)} y_{ij}^{t-1} \le x_i^t, \sum_{j \in \Gamma(i)} y_{ij}^{t-1} \le Q_i^t \qquad \forall i \in C_D, \forall t \in T \tag{6}$$

- *Merging cells and cell connectors:*

$$x_i^t = x_i^{t-1} + \sum_{k \in \Gamma^{-1}(i)} y_{ki}^{t-1} - y_{ij}^{t-1} \qquad j \in \Gamma(i), i \in C_M, t \in T \tag{7}$$

The cell connector (i,j) is ordinary and its flow y_{ij}^t follows (7); the inflows y_{ki}^t are determined by the following relationships:

$$\max \sum_{j \in \Gamma(i)} y_{ij}^t \tag{8}$$

subject to

$$y_{ki}^t \le x_k^t, \ y_{ki}^t \le Q_k^t \qquad \forall k \in \Gamma^{-1}(i) \tag{9}$$

$$\sum_{k \in \Gamma^{-1}(i)} y_{ki}^t \le Q_i^t, \ \sum_{k \in \Gamma^{-1}(i)} y_{ki}^t \le \delta_i^t(N_i^t - x_i^t) \qquad \forall i \in C_M, \forall t \in T \tag{10}$$

- *Source and sink cells and cell connectors:*

Boundary conditions consist of the states of the sink and source cells and the initial values x_i^0 of all cells $i \in C$. The sink cells are set to have infinite capacities ($N_i^t = \infty, \forall i \in C_S, \forall t \in T$) and allow infinite input flows ($Q_i^t = \infty, \forall i \in C_S, \forall t \in T$); thus, their occupancies are not constrained.
The input flow to a sink cell will be determined by the state and characteristics of its predecessor cell. The source cells have infinite capacity ($N_i^t = \infty, \forall i \in C_R, \forall t \in T$), but finite output flow. The basic relationship of the source cells is as follows:

$$x_i^t = x_i^{t-1} + d_i^{t-1} - y_{ij}^{t-1} \qquad j \in \Gamma(i), i \in C_R, t \in T \tag{11}$$

where d_i^t is the demand (inflow) at cell i in time interval t. The initial values x_i^0 can be set to initial traffic conditions in the network at the beginning of the time period of interest.

The relationships 12-24 are expressed as linear constraints in an LP to consistently propagate traffic in the following SO DTA model (Ziliaskopoulos, 2000):

Minimize $\sum_{t \in T} \sum_{i \in \frac{c}{C_s}} x_i^t$ (12)

subject to

$$x_i^t - x_i^{t-1} - \sum_{k \in \Gamma^{-1}(i)} y_{ki}^{t-1} + \sum_{j \in \Gamma(i)} y_{ij}^{t-1} = 0 \quad \forall i \in C \setminus \{C_R, C_S\}, t \in T$$ (13)

$$y_{ij}^t - x_i^t \le 0, y_{ij}^t \le Q_i^t, y_{ij}^t \le Q_j^t, y_{ij}^t + \delta_j^t x_j^t \le \delta_j^t N_j^t, \forall (i,j) \in E_o \cup E_R, t \in T$$ (14)

$$y_{ij}^t - x_i^t \le 0, y_{ij}^t \le Q_i^t, \forall (i,j) \in E_S, t \in T$$ (15)

$$y_{ij}^t \le Q_j^t, y_{ij}^t + \delta_j^t x_j^t \le \delta_j^t N_j^t, \forall (i,j) \in E_D, t \in T$$ (16)

$$\sum_{j \in \Gamma(i)} y_{ij}^{t-1} - x_i^t \le 0, \sum_{j \in \Gamma(i)} y_{ij}^{t-1} \le Q_i^t, \forall i \in C_D, \forall t \in T$$ (17)

$$y_{ij}^t - x_i^t \le 0, y_{ij}^t \le Q_i^t, \forall (i,j) \in E_M, t \in T$$ (18)

$$\sum_{i \in \Gamma^{-1}(j)} y_{ij}^t \le Q_j^t, \sum_{i \in \Gamma^{-1}(j)} y_{ij}^t + \delta_j^t x_j^t \le \delta_j^t N_j^t, \forall j \in C_M, \forall t \in T$$ (19)

$$x_i^t - x_i^{t-1} + y_{ij}^{t-1} = d_i^t, j \in \Gamma(i), i \in C_R, t \in T$$ (20)

$$x_i^0 = \zeta_i, \forall i \in C$$ (21)

$$y_{ij}^0 = 0, \forall (i,j) \in E$$ (22)

$$x_i^t \ge 0, \forall i \in C, \forall t \in T$$ (23)

$$y_{ij}^t \ge 0, \forall (i,j) \in E, \forall t \in T$$ (24)

Ziliaskopoulos also presented the dual formulation of the SO DTA problem and used it to show that the marginal contribution of an additional unit of demand at a given cell and time interval is the optimum value of the dual variable corresponding to the mass balance constraint at the given time interval. Further, he proved that the necessary and sufficient condition for SO DTA is that every unit of flow follows the time-dependent least marginal cost path to the destination. Table 6 presents a comparison of analytical DTA models.

Table 6. Comparison of Analytical DTA Models

Model	Approach	System Optimal / User Equilibrium	Single- / Multiple- Destination	Solution Algorithm Proposed	Propagation of Traffic	Includes Bus Movements	Calculates Mode Split
Merchant and Nemhauser (1978)	Nonlinear / Piecewise Linear Programming	SO	Single	No - standard mathematical programming approaches apply	Exit Function	No	No
Carey (1987)	Nonlinear Programming	SO	Multiple	No - standard approaches for convex non-linear problems apply	Convex Exit Function	No	No
Janson (1991)	Nonlinear Programming	UE	Multiple	Yes - heuristic algorithm	Link Performance Function	No	No
Ziliaskopoulos (2000)	Linear Programming	SO	Single	No - standard approaches for linear programming apply	Cell Transmssion Model	No	No
Waller and Ukkusuri (2002)	Linear Programming	UE	Single	No - standard approaches for linear programming apply	Cell Transmssion Model	No	No
Lo (1999)	Non-linear Mixed-Integer, Path Based	UE	Multiple	No	Cell Transmssion Model	No	No
Friesz et al. (1989)	Continuous Optimal Control Theory	Both	Single	No	Exit Function	No	No
Ran and Shimazaki (1989)	Optimal Control Theory	SO	Multiple	Yes - two-level decomposition algorithm	Exit Function	No	No
Ran and Boyce (1996)	Optimal Control Theory	UE	Multiple	No	Link Performance Function	No	No
Friesz et al. (1993)	Continuous Time Path-based VI	UE	Single	No	Link Performance Function	No	No
Wie et al. (1995)	Discrete Time Path-based VI	UE	Single	Yes - heuristic algorithm	Exit Function	No	No
Ran and Boyce (1996)	Discrete Time Link-based VI	UE	Multiple	Yes - decomposition using diagonalization	Link Performance Function	No	No
Chen and Hsueh (1998)	Discrete Time Link-based VI	UE	Multiple	Nested diagonalization algorithm	Link Performance Function	No	No
Lo and Szeto(2002)	Variational Inequality	UE	Multiple	Yes - alternating direction method for co-coercive VI problems	Cell Transmssion Model	No	No

Simulation-based DTA Models

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. This section describes and compares several well-known simulation-based DTA models.

Ziliaskopoulos and Waller (2000) introduced a simulation-based DTA model, called VISTA. The model's simulator, RouteSim, uses cell transmission rules (Daganzo, 1994) 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 VISTA 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 (2001) using this simulation capability in VISTA. This dissertation will build on this work by presenting a large-scale regional evaluation of transit signal priority using VISTA. Further, the routing algorithm will be extended to inter-modal applications.

Comparison

Several simulation-based DTA models have been reviewed in this section, and are listed in Table 7. Each model uses a different traffic propagation model, where TRANSIMS and INTEGRATION use microscopic simulators and DYNASMART, DYNAMIT and VISTA using mesoscopic logic. The microscopic simulators capture more detail than the mesoscopic simulators, but also require more computational power and time. Of the mesoscopic simulators, both DYNASMART and DYNAMIT combine speed-density relations with complex queuing and deceleration equations to capture vehicle movement along links. VISTA uses the cell transmission model, which automatically captures queue evolution without relying on the use of a speed-density relationship to capture vehicle movements.

Only DYNASMART, TRANSIMS and VISTA have incorporated buses movements into their simulators. This dissertation will demonstrate the use of VISTA to evaluate transit signal priority on a large-scale regional network. Further, the VISTA routing algorithm will be enhanced to capture inter-modal routes.

Table 7. Comparison of Simulation-based DTA Models

Model	Approach	System Optimal / User Equilibrium	Single- / Multiple-Destination	Solution Algorithm Proposed	Propagation of Traffic	Includes Bus Movements	Calculates Mode Split
DYNASMART	Heuristic Simulation-based	Both	Multiple	Yes- Medium to Large Networks	Mesoscopic, Moving-Queueing Segments	Yes - bus travel time dependent on general flow; stops and dwells	Yes - assignment to multi-modal network
DYNAMIT	Heuristic Simulation-based	UE	Multiple	Yes- Medium Size Networks	Mesoscopic, Moving-Queueing Segments	No	No
TRANSIMS	Heuristic Simulation-based	UE	Multiple	Yes- Unclear reports only On Small Networks	Microscopic, Cellular Automata	Yes - bus travel time dependent on general flow; stops and dwells	Yes - assignment to multi-modal network
INTEGRATION	Heuristic Simulation-based	UE	Multiple	Yes- Medium Size Networks	Microscopic, Car-Following	No	No
VISTA	Exact and Heuristic Simulation-based	Both	Multiple	Yes- Large and Very Large Networks	Mesoscopic, Cell Transmission Model	Yes - bus travel time dependent on general flow; stops and dwells	Under developement

Various DTA models have been implemented within VISTA:

(i)   A departure based and fixed arrival time version of simulation-based User Equilibrium (UE) DTA approaches using RouteSim to propagate traffic and satisfy capacity constraints (Ziliaskopoulos and Rao, 1995).

(ii)   A modified version of DYNASMART-X (Mahmassani *et al.* 1997) that is capable of modeling multiple user classes including user equilibrium and System Optimum (SO) users. This version is departure time based only, and uses DYNASMART to simulate traffic.

(iii)   Two analytical DTA models: a departure time and a arrival time approach; both approaches are linear programming and are solved with CPLEX.

(iv)   A combined departure and arrival time based analytical model that is also solved using CPLEX (Yue Li *et. al.*, 1998).

All these DTA models use the same geometry, control and demand data inputs; the demand tables need to be arrival and/or departure time based, depending on the model invoked. The simulation based DTA models access one of the simulator modules

(RouteSim or DYNASMART), time-dependent least time and cost path modules, as well as various other modules. Since these systems work in an iterative scheme, the computational time of sub-modules becomes of great importance. DTA models are the most time consuming models, but many of these modules have operations that can be run in parallel. For instance, the time-dependent shortest path algorithms have the ability to be distributed over multiple processors (Ziliaskopoulos et al. 1997). Furthermore, all modules related to the routing of the various classes in DYNASMART-X can be run on separate processors. Since VISTA is based on the CORBA specification, it can handle the communication and invocation of these modules on separate processors.

Some computational performance information for the modified DYNASMART-X system is included in Table 88.

Table 8. DTA CPU Time per Iteration

Module	CPU Time (seconds)
UE Module (TDSP Algorithm)	72
SO Module (TDLC Algorithm)	177
Simulator Module (DYNASMART)	265

This data is for one iteration of the DTA algorithm on a 444-link network, with a demand of 8000 vehicles during a 50-minute time period. The demand was broken evenly into two classes consisting of UE and SO behavior. There are three modules within this DTA system: UE consisting primarily of the Time-Dependent Shortest Path (TDSP) algorithm, SO consisting primarily of the Time-Dependent Least Cost (TDLC) algorithm, and the simulator module consisting of DYNASMART. As mentioned before, the two classes can be run in parallel. Therefore, the time incurred by the UE module is essentially negligible and the total time consists only of the SO and Simulator modules. This test was performed on a 167 Mhz dual processor UltraSparc II.

VISTA-DTA Solution Algorithm Implementation Details

Multiple DTA systems have been implemented in VISTA, though at this point only two are in the released Version 1.01. Specifically the available versions are the following:

- Dynamic Traffic Equilibrium with Drivers Departing at a Fixed Time (BASE_DUE) — ver. 1.01
- Dynamic Traffic Equilibrium with Drivers Arriving at a given Window and/or Departing at a given time (EXTENSION_FAT_DUE) -- ver. 1.02
- Dynamic Traffic Equilibrium with Buses and Trucks (EXTENSION_BT) -- ver. 1.01
- Dynamic System Optimum (BASE_DSO) -- ver. 1.02
- Stochastic Dynamic Traffic Equilibrium (STOCH_DUE) -- ver. 1.02
- Dynamic Person Equilibrium (Intermodal/Multimodal) — under development.

All models include at least the following three core modules: *the traffic flow simulator, the time-dependent shortest path algorithm, and the path assignment module.* Each module has singularities that are discussed in this document especially as they are applied on large-scale realistic networks.

The general iterative process that computes DTA are outlined in Figure 3 (general) and Figure 4 (accounting for buses). Figure 3 outlines the fixed arrival time general framework; this model requires (in addition to the above modules) a fixed arrival time based time-dependent shortest path module.
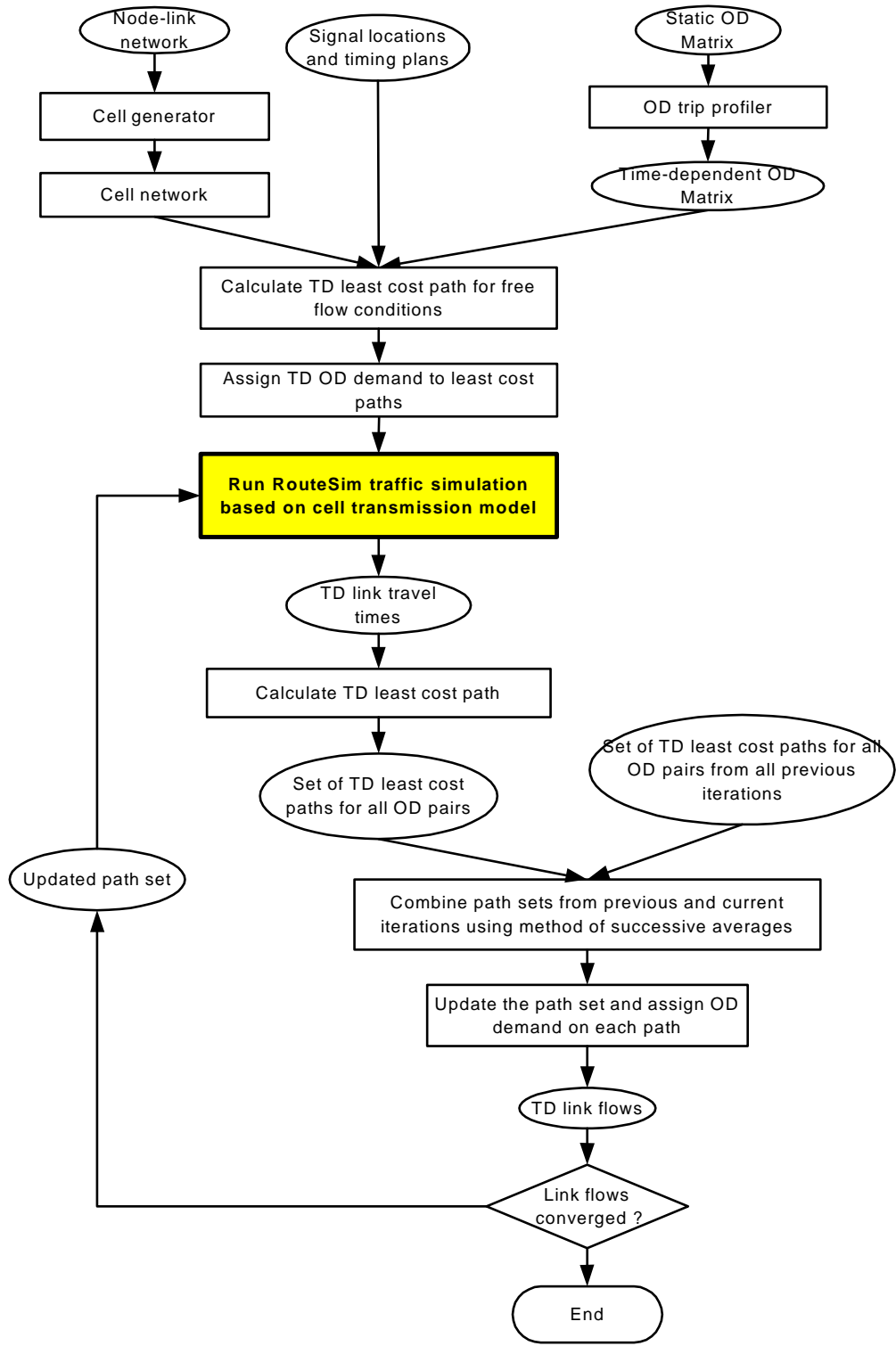
Figure 3. Dynamic Traffic Equilibrium with Drivers Departing at a Fixed Time (BASE_DUE) — ver. 1.01
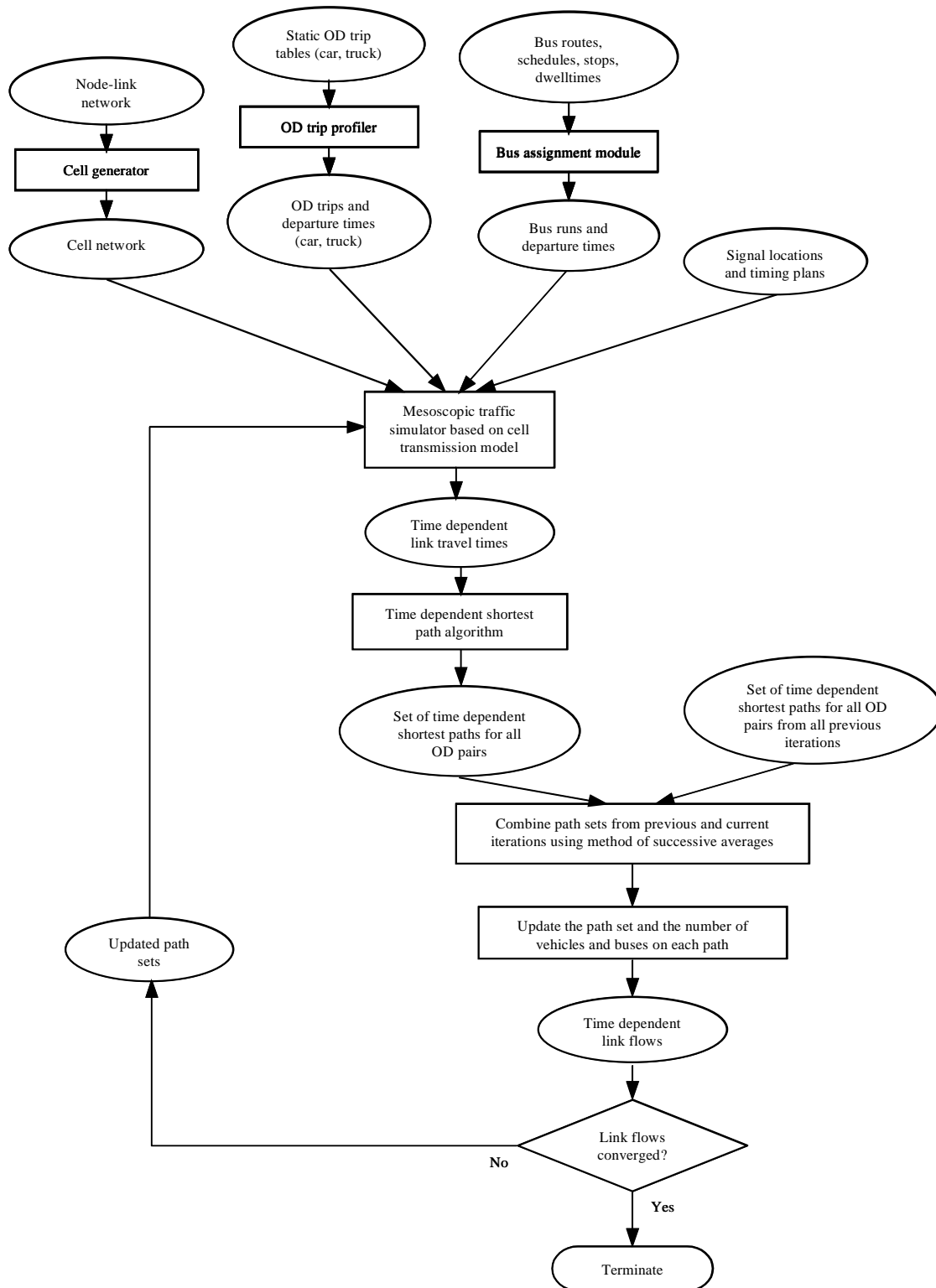
Figure 4. Dynamic Traffic Equilibrium with Buses and Trucks (EXTENSION_BT) -- ver. 1.01

Time Dependent Origin-Destination Matrix Calibration Module

A most up-to-date time dependent OD matrix is critical to the success of advanced traffic management systems for solving complex transportation problems. It is the one of the most important inputs to the online simulation that is usually used as the analysis tool in traffic control and management. A good time dependent OD matrix, when assigned to the network in simulation, can produce accurate estimation and prediction of the traffic states in the real world, which makes it possible to generate efficient traffic control strategies. Therefore, the calibration of time dependent OD matrix becomes a critical part in reaching the consistency of real time DTA models.

The problem of estimating and calibrating OD matrices from traffic counts has been studied for more than twenty years. This approach becomes increasingly attractive as automatic traffic count data becomes more readily available. However, it is still a relatively open research problem, as no existing approach is capable of fully dealing with general networks (Peeta and Ziliaskopoulos, 2001).

The difficulties of Time Dependent OD Calibration (TDODC) problem are mostly related to representing network dynamics such as user behavior and equilibrium conditions. There are two broad categories of OD calibration models, DTA based and non-DTA based. Models that have a DTA component embedded in can robustly address the various issues of network dynamics. These DTA based models can be further categorized into simulation-based DTA models and analytic DTA models. We prefer to use simulation-based DTA models in TDODC, because by combining the traffic simulation procedure with the assignment algorithm, virtually all the limitations of existing analytic DTA formulations in terms of traffic modeling are circumvented (Mahmassani et. al 1993). And the assignment matrix is easier to compute by using simulation to estimate the time dependent travel cost of network links.

A MPEC TDODC model is designed to determine a Dynamic User Equilibrium (DUE) traffic flow solution that reproduce the link volume detected by traffic counts, if such a solution exists. And it also has a tendency to stay close to a prior target OD trip table.

And a LP TDODC model is also introduced. It minimizes the weighted total absolute deviation from traffic counts as well as from the a priori OD matrix. Although maintaining DUE flow pattern is not considered in the calibration procedure, it is fast and produces relatively good results.

This section presents solution procedures for calibrating time dependent OD matrices from traffic counts for general networks. A section then follows that discusses the mathematical formulation of the problem. Then a section follows that describes the implementation of the proposed calibration procedure in VISTA. Finally the last section summarizes the chapter.

Time Dependent OD Calibration Model Formulation

On the network $G(V, A, N, M, C, T)$ where V is the set of nodes, A the set of arcs, N the set of OD pairs, M the set of links with traffic counts (it is a subset of A), C the set of controls, and $[0, T]$ the assignment period.

Assignment intervals are used to explicitly represent within-period dynamics, so the variation of OD matrices over time is taken care of. For instance, the time period of interest (say morning peak) is subdivided into time intervals of equal length, e.g., 15 minutes each. A trip is allocated to a time interval if it enters the study area during that particular time period. In big network, the vehicles entering the network at time interval s may not be able to exit the network at the same time interval. To account for this, the assignment matrix $\{p_{ij}^{sa}\}$ produced from the DTA model is used to indicate the proportion of trips between OD pair j setting out in time interval s, traveling over link i during time interval a. It captures network topology, route choice assumptions and travel time. Given the assignment matrix $\{p_{ij}^{sa}\}$ and the OD matrix $\{d_{js}\}$, the estimated flow on link i at time interval a can be calculated as follows:

$$v_{ia} = \sum_{js} p_{ij}^{sa} d_{js} \tag{25}$$

where v_{ia} $\forall i \in M, a \in [0,T]$ is the estimated flow on link i in time interval a; d_{js} is the number of trips between OD pair j ($j \in N$) starting in time interval s ($s \in [0,T]$); This demand is assumed to be known from an estimation process and may later be allowed to vary between $[d_{js} - l_{js}, d_{js} + u_{js}]$; p_{ij}^{sa} is the proportion of trips between OD pair j starting in time interval s which travel over link i during time interval a. It is assumed that the assignment matrix $\{p_{ij}^{sa}\}$ remains unaltered after the update of the target matrix.

The assignment-simulation model VISTA-DTA will assign the demand to the network and move them through the network. Let $\bar{v}_{ia}$ $\forall i \in M, a \in [0,T]$ be the observed link flows from traffic counts that arrived at link i at assignment interval a.

The inputs to OD matrix calibration/estimation model include traffic counts (observed link flows), a target OD matrix and the assignment matrix. These inputs are not error free, and the reliability may vary. The traffic counts collected from traffic detectors usually include measurement errors. The target matrix is a preliminary estimate of the real OD matrix. It is very unlikely that the target matrix satisfies the equation set (25) thus being the solution to the OD matrix calibration problem. The assignment matrix is also uncertain since it cannot be observed directly and it has to be generated from the assumed traffic assignment model.

One possible consequence of errors in input data is that the equation set (25) becomes internally inconsistent and no feasible solution exists. To solve the inconsistency in the calibration process, it is therefore reasonable to allow for solutions derived from the calibration/estimation process that do not reproduce the observed volumes exactly. In this case, the problem is unconstrained and weights should be provided to show the relative levels of reliability attached to the target matrix compared with the information from the link count observations. Depending on the degree of belief that is put in the two information sources, different solutions arise.

Time Dependent OD Calibration – MPEC Approach

Let P be the set of all spatio-temporal paths from all origins to all destinations, i.e.,
$P = \{p^1, p^2, \dots p^\Pi\}$. Each path p^k, $1 \le k \le \Pi$ belongs to a set $P(j,s)$, which contains all paths departing at time $s \in [0,T]$ between OD pair j, $j \in N$.

We denote with:

ξ^{p^k} the number of vehicles choosing to follow path p^k -- Ξ in a vector notation;

$\psi^{p^k}(\Xi)$ the travel time on path p^k -- $\Psi(\Xi)$ in a vector notation.

The demand relationships $\displaystyle\sum_{p^k \in P(j,s)} \xi^{p^k} = d_{js}$ or $d_{js} - l_{js} \le \displaystyle\sum_{p^k \in P(j,s)} \xi^{p^k} \le d_{js} + u_{js}$ form a closed, bounded, convex space $D \subset R^\Pi$; any assignment Ξ in D is feasible, given that the traffic flow propagation law adopted prevents gridlock, thus vehicles can exit the network within T. Practically, it means that the traffic simulator can perform any assignment in D given sufficient assignment period T so that all assigned vehicles exit the network. Thus, given a Ξ in D the travel times, $\Psi(\Xi)$ can be computed in a reasonable time in VISTA-DTA.

The problem is to determine an assignment Ξ in D so that no vehicle can switch a path and improve its own travel time (equilibrium assignment Ξ^*) while the estimated link flow on the counter links does not deviate from their observed values for the respective time intervals, if such a solution exists. And it also has a tendency to stay close to the target OD trip table. It is recognized that the actual traffic flow may not conform to the user equilibrium solution due to incomplete information, and the OD matrix that can exactly duplicate the traffic counts may not exist due to possible inconsistencies in the observed link flow data. Although some manipulation techniques can be adopted to preprocess the observed link flow data to make it consistent, as in Van Zuylen and Branston (1982) for example, it is more appealing to let the model itself accommodates this feature (Sherali et al. 1994). Accordingly, the proposed model permits violations in

the user equilibrium conditions as well as deviations from the observed link flows. The objective function to be minimized in the proposed TDODC model is the sum of the total absolute deviation of the estimated link flow from the traffic counts, the total absolute deviation of the calibrated demand from the a priori demand and the cost gap value from the SSD-DUE (Simulation based Simplicial Decomposition algorithm for the Dynamic User Equilibrium) DTA model that indicates how close the solution is to the DUE conditions. To account for the uncertainties and relative reliabilities of different information, weight factors are used in the objective function.

It is assumed that C is exogenous to the demand and driver route choices. We will also make the rather mild assumption that $\Psi(\Xi)$ can be reasonably well approximated as a continuous function; in fact, for simplicity, $\Psi(\Xi)$ also denotes the continuous function approximating the path travel time produced by the simulator.

The TDODC problem is formulated as Mathematical Program with Equilibrium Constraints (MPEC). MPEC is an optimization problem with two sets of variables, $x \in \Re^n$ and $y \in \Re^m$, in which some or all of its constraints are defined by a parametric variational inequality or complementarity system with y as its primary variables and x the parameter vector. Many transportation planning and design problems can be formulated as MPECs. Typically, the outer objective function of the resulting MPEC represents the combined system and design costs, whereas each inner problem represents either an optimization or an equilibrium problem that describes the behavior of the users of the transportation network corresponding to a particular configuration of the network dictated by a given set of the design variables (Luo et al., 1996).

In the problem under consideration, the equilibrium assignment $\Xi*$ produced traffic counts $\bar{v}_{ia}$ $\forall i \in M, a \in [0,T]$ (observed link volume). Then the TDODC problem can be formulated as follows:

Minimize $W_v \sum_{i \in M} \sum_{a \in [0,T]} \left| v_{ia} - \bar{v}_{ia} \right| + W_d \sum_{j \in N} \sum_{s \in [0,T]} \left| d_{js} - \bar{d}_{js} \right|$ (26)

Subject to $\quad \Psi(\Xi^*)(\Xi - \Xi^*) \geq 0$, $\forall \Xi \in D$

$\bar{v}_{ia}$ = the number of trips observed on link i at assignment interval a, $i \in M$; $a \in [0, T]$

v_{ia} = the estimated flow on link i at assignment interval a; as specified in Equation (25)

$\quad\quad i \in M$; $a \in [0, T]$

d_{js} = the number of traffic in the calibrated/estimated OD matrix between OD pair

$\quad\quad\quad j$ entering the network at time interval s, $j \in N$; $s \in [0, T]$

$\bar{d}_{js}$ = the number of traffic in the a priori OD matrix between OD pair j entering the

$\quad\quad\quad$ network at time interval s, $j \in N$; $s \in [0, T]$

p_{ij}^{sa} = the percentage of traffic between OD pair j entering the network at time interval s

$\quad\quad\quad$ arriving at link i at time interval a, $p_{ij}^{sa} = 0$, $\forall s > a$, $j \in N$, $i \in M$, $a, s \in [0, T]$

W_v = weight for traffic counter deviation

W_d = weight for demand deviation

This is an MPEC with OD demand $d \in D$ as the first-level variable and link flow $v \in D$ (from which $\Xi \in D$ is computed) the lower-level variable. The mapping function in the lower-level VI is independent of the first-level variable d but the feasible set D is dependent on d. The space D is compact and $\Psi(\Xi)$ is assumed to be continuous; thus, there is at least one solution to the VI problem; the same cannot be said for MPEC. The MPEC is not convex and we will be looking just for a local optimum.

Also, as stated earlier, $\Psi(\Xi)$ is not likely to be monotone, which precludes us from using most projection and other well-known solution algorithms for VIPs that usually require monotonic cost functions (to find a local optimum solution). The proposed approach is not limited to monotone cost functions.

We will rely on the concept of a convex hull formed by extreme points. The feasible space of Ξ, i.e., D is a convex polyhedron defined by extreme points, each of which is on the boundary of the feasible space. Suppose $P = \{p^1, p^2, .. p^\Pi\}$ is the set of ALL possible paths. There is a subset of these paths $s^{js} = \{p^{js1}, p^{js2}, ... p^{jsK}\}$ for each j, s; the path set s^{js} is assigned with either the low $d_{js} - l_{js}$, or the high $d_{js} + u_{js}$ demand.

Denote with S^M the set of m extreme demand solutions $S^M = \{s^1, s^2, .. s^M\}$, the convex hull, $H(S^M)$, defined by the extreme point is feasible, i.e. any convex combination of the extreme points is within the hull. We denote by S the set that includes all extreme patterns, then $D = H(S)$, and the VI(Ψ, D) can be restated as follows:

$$S^T \Psi(S\lambda)(\lambda - \lambda^*) \geq 0 \text{ for all } \lambda \in \Lambda \text{ and } \Lambda = \{\lambda : \sum_{i-1}^{M} \lambda_i = 1, \lambda_i \geq 0\}.$$

Any subset of S ($S^{Jn} = \{s^{J1}, s^{J2}, ... s^{Jn}\}, n \leq M$) creates also a convex hull $H(S^n)$. The proposed algorithm will be approximately solving the VI problem while trying to minimize the objective function of the MPEC.

We use a gap function as a proxy of the violation of the VI problem and the deviations from traffic counts and target OD table. The following proxy function is used in TDODC algorithm:

$$\Phi = [\Psi(\Xi) - \Psi^*(\Xi)] \cdot \Xi + W_v \sum_{i \in M} \sum_{a \in [0,T]} |v_{ia} - \bar{v}_{ia}| + W_d \sum_{j \in N} \sum_{s \in [0,T]} |d_{js} - \bar{d}_{js}| \qquad (27)$$

We propose computing the next demand solution $\{d\}^n$ by minimizing the proxy function on the line defined by the previous demand solution $\{d\}^{n-1}$ and the extreme demand solution $\{d\}^{(n-1)*}$ -- generated by assigning either low $d_{js} - l_{js}$, or high $d_{js} + u_{js}$ to the network depending on whether the particular path goes through a link that appears to have deficit or excess counts.

Whether to assign the low bound or the high bound of the demand to the network is determined by the value of ε_{js}, $j \in N; s \in [0,T]$ which is computed from the following equation set:

$$\sum_{j \in N} \sum_{s \in [0,T]} \delta_{ij}^{sa} * \varepsilon_{js} = \bar{v}_{ia} - v_{ia} = e_{ia} \qquad \forall\ j \in N,\ i \in M,\ a, s \in [0,T] \qquad (28)$$

where δ_{ij}^{sa} is the link incident matrix, $\forall j \in N; a, s \in T; i \in M$, $\delta_{ij}^{sa} = 1$ when there is traffic between OD pair j entering the network at time interval s arriving at link i at time interval a, otherwise $\delta_{ij}^{sa} = 0$. It is assumed that $\{\delta_{ij}^{sa}\}$ will not be changed after the update of current OD demand. Equation set (28) can also be expressed as follows:

$$\varepsilon_{kr}^{m} = e_{ia} - \sum_{j \in N} \sum_{s \in [0,T]} \delta_{ij}^{sa} * \varepsilon_{js}^{m-1} \qquad (29)$$

Equation set (29) can be solved by Gauss-Seidel method for large networks to circumvent the computer memory shortage in dealing with large-dimension matrix $\{\delta_{ij}^{sa}\}$ and $\{\varepsilon_{js}\}$. But it is difficult to ensure the convergence property in Gauss-Seidel method.

We modify Equation (28) into a minimization problem that can be approximately solved as a LP problem using CPLEX method and software. The OD calibration program will call CPLEX functions to solve this LP problem and get the OD adjustment values $\{\varepsilon_{js}\}$ from CPLEX.

The equation set (29) can be expressed as the following minimization problem:

$$\text{Minimize} \sum_{i \in M} \sum_{a \in [0,T]} \left| (\bar{v}_{ia} - v_{ia}) - \sum_{j \in N} \sum_{s \in [0,T]} \delta_{ij}^{sa} * \varepsilon_{js} \right| \qquad \forall\ j \in N,\ i \in M,\ a, s \in [0,T]$$

$s.t.$

$$\varepsilon_{js} \geq -d_{js}, \ \forall j \in N, \ \forall s \in [0,T] \tag{30}$$

The minimization problem of (30) can be approximately solved as a LP problem as follows:

$$\text{Minimize} \sum_{i \in M} \sum_{a \in [0,T]} \left(s_{ia}^+ + s_{ia}^- \right) \tag{31}$$

s.t.

$$(\bar{v}_{ia} - v_{ia}) - \sum_{j \in N} \sum_{s \in [0,T]} \delta_{ij}^{sa} * \varepsilon_{js} = s_{ia}^+ - s_{ia}^-, \qquad \forall \ j \in N, \ i \in M, \ a,s \in [0,T]$$

$$\varepsilon_{js} \geq -d_{js}, \qquad \forall j \in N, \ \forall s \in [0,T]$$

$$s_{ia}^+ \geq 0, \qquad \forall i \in M, \ \forall a \in [0,T]$$

$$s_{ia}^- \geq 0, \qquad \forall i \in M, \ \forall a \in [0,T]$$

Although $\{\varepsilon_{js}\}$ obtained from solving (31) cannot solve the equation set (30) exactly, it is not a problem since the values of $\{\varepsilon_{js}\}$ are only used to determine the direction of the change to current OD demand solution, i.e., $\{d\}^{(n-1)*}$. Then the next OD demand solution is computed as follows:

$$d^n = (1 - \lambda_n)d^{n-1} + \lambda_n d^{(n-1)*} \tag{32}$$

where λ should satisfy the following relationship:

$$\lambda = \arg\min \left\{ \Phi = [\Psi(\Xi) - \Psi*(\Xi)] \cdot \Xi + W_v \sum_{i \in M} \sum_{a \in [0,T]} |v_{ia} - \bar{v}_{ia}| + W_d \sum_{j \in N} \sum_{s \in [0,T]} |d_{js} - \bar{d}_{js}| \right\} \tag{33}$$

where $\Psi*$ is the vector of the least travel time paths for each j, s

The λ can be solved in a few iterations of running VISTA-DTA with a simple line search. Note that since it is limited to a line of feasible points—between the last solution and the new extreme point—instead of considering the whole convex hull, so the solution λ value is only an approximate optimum.

The steps of the MPEC TDODC algorithm is as follows:

Step 1: Read demand $\bar{d}_{js}$ and counter $\bar{v}_{ia}$ from database,

Set $n = 0$, $\{\varepsilon_{js}\}^{(0)} = 0$ $\forall j \in N; a, s \in T; i \in M$

Step 2: Run SSD-DUE DTA module for the a priori (target) OD demand.

Step 3: Get link flows v_{ia} and assignment matrix δ_{ij}^{sa} (link incident matrix) $\forall j \in N; a, s \in T; i \in M$ from the output of DTA model (sim.vat file).

Step 4: $n = n + 1$

Compute the adjustment values $\{\varepsilon_{js}\}^{(n)}$ for each OD pair by solving the LP problem shown in formulation (31) using CPLEX.

Step 5: Get the demand extreme point $d^{(n-1)*}$ for d^{n-1}:

if $\varepsilon_{js}^n \geq k$, then $d_{js}^{(n-1)*} = upb * d_{js}^0 = d_{js}^0 + u_{js}$ (e.g., $upb = 2$)

if $-k < \varepsilon_{js}^n < k$, then $d_{js}^{(n-1)*} = d_{js}^{n-1}$

if $\varepsilon_{js}^n \leq -k$, then $d_{js}^{(n-1)*} = lowb * d_{js}^0 = d_{js}^0 - l_{js}$ (e.g., $lowb = 0.5$)

$k > 0$

OR $\quad d_{js}^{(n-1)*} = d_{js}^{n-1} + \varepsilon_{js}^n$

Compute λ according to Equation (33) using the following Golden Section Search method.

Golden Section Search

Step 5a: Compute gap Φ_n according to Equation (27) for the following values of candidate λ by running SSD-DUE DTA model:

(i) $a = 0$,

(ii) $b = a + 0.38 * (d - a)$,

(iii) $c = a + 0.62 * (d - a)$ and

(iv) $d = \min(1.5 * \lambda_{n-1}, 0.8)$

Step 5b: If $\Phi(a)$ or $\Phi(b)$ is the minimum then set

$d = c, c = b, b = a + 0.62 * (c - a)$

$\Phi(d) = \Phi(c),\ \Phi(c) = \Phi(b)$

Compute $\Phi(b)$ by running SSD-DUE DTA module to assign demand $d = (1 - b) * d^{n-1} + b * d^{(n-1)*}$ to the network

If $\Phi(d)$ or $\Phi(c)$ is the minimum then set

$a = b, b = c, c = b + 0.38 * (d - b)$

$\Phi(a) = \Phi(b),\ \Phi(b) = \Phi(c)$

Compute $\Phi(c)$ by running SSD-DUE DTA module to assign demand $d = (1 - c) * d^{n-1} + c * d^{(n-1)*}$ to the demand

Step 5c: If $d - a < \max(0.25 * \lambda_{n-1}, 0.01)$ then set λ_n to the candidate λ values that generates the minimum gap value among $\Phi(a)$, $\Phi(b)$, $\Phi(c)$, and $\Phi(d)$ and STOP; otherwise, go to **Step 5b**

Set $d^n = (1 - \lambda_n)d^{n-1} + \lambda_n d^{(n-1)*}$

Step 6: Running SSD-DUE DTA module by assigning the new demand $\{d\}^n$ to get the link flows $\{v_{ia}\}$ and assignment matrix $\{\delta_{ij}^{sa}\}$ (link incident matrix) from the output of DTA (sim.vat file). Compare the values of $\sum_{i \in M}\sum_{a \in [0,T]}|v_{ia} - \bar{v}_{ia}|$ for the last two iterations, if the difference is less than the specified value, STOP; otherwise go to **Step 4**.

Step 7: Evaluate the calibration result and output the result.

Time Dependent OD Calibration – LP Approach

In solving the MPEC TDODC formulation introduced above, it is necessary to have several VISTA-DTA runs, which may take a long time on large networks. The LP (Linear Programming) TDODC approach introduced in this section only needs to update the OD trip table once, and therefore just one VISTA-DTA run is needed in the calibration procedure. However, the LP approach does not maintain DUE flow pattern in the calibration procedure, and has a relatively strong assumption that the assignment matrix $\{p_{ij}^{sa}\}$ keeps the same after updating the OD demand table.

Using the same notations as in the previous sections, the TDODC is formulated as a minimization problem as follows:

$$\text{Minimize } W_v \sum_{i \in M}\sum_{a \in [0,T]}\left|\bar{v}_{ia} - \sum_{j \in N}\sum_{s \in [0,T]}p_{ij}^{sa}(\bar{d}_{js} + \varepsilon_{js})\right| + W_d \sum_{j \in N}\sum_{s \in [0,T]}|\varepsilon_{js}| \tag{34}$$

s.t.

$$\varepsilon_{js} \geq -\overline{d}_{js}, \quad \forall j \in N, \quad \forall s \in A$$

The objective function in formulation (34) minimizes the deviation from traffic counts as well as the deviation from target OD trip table. Formulation (34) is then converted to a linear programming problem as shown in formulation (35), which can be solved in CPLEX to get the adjustment values of $\{\varepsilon_{js}\}$ to the target OD matrix $\{d_{js}\}$.

$$\text{Minimize } W_v \sum_{i \in M} \sum_{a \in M} \left(s_{ia}^+ + s_{ia}^- \right) + W_d \sum_{j \in M} \sum_{s \in [0,T]} \left(\varepsilon_{js}^+ + \varepsilon_{js}^- \right) \tag{35}$$

s.t.

$$\overline{v}_{ia} - \sum_{j \in N} \sum_{s \in [0,T]} p_{ij}^{sa} (\overline{d}_{js} + \varepsilon_{js}^+ - \varepsilon_{js}^-) = s_{ia}^+ - s_{ia}^-, \quad \forall j \in N, \forall i \in M, \quad \forall a, s \in [0,T]$$

$$\varepsilon_{js}^+ \geq 0, \qquad \forall j \in N, \quad \forall s \in [0,T]$$

$$\varepsilon_{js}^- \geq 0, \qquad \forall j \in N, \quad \forall s \in [0,T]$$

$$-\varepsilon_{js}^- \geq -\overline{d}_{js}, \qquad \forall j \in N, \quad \forall s \in [0,T]$$

$$s_{ia}^+ \geq 0, \qquad \forall i \in M, \quad \forall a \in [0,T]$$

$$s_{ia}^- \geq 0, \qquad \forall i \in M, \quad \forall a \in [0,T]$$

The calibrated time dependent OD demand will be:

$$d_{js} = \overline{d}_{js} + \varepsilon_{js}^+ - \varepsilon_{js}^- \qquad \forall j \in N, \quad \forall s \in [0,T] \tag{36}$$

Model Implementation

The proposed two TDODC models are implemented in VISTA as shown in Figures 5 and 6, respectively. The output of the SSD-DUE DTA model provides the information of each vehicle entering the network during the study period, including the path and the arrival time at each link on the path.

Figure 6 shows the TDODC procedure of the MPEC approach. Note that there is a loop between SSD-DUE DTA and MPEC ODC model, and both of these two blocks are colored in purple to indicate that the assignment-simulation procedure is embedded.

Figure 7 shows the TDODC procedure of the LP approach and note that there is no loop in this procedure.

Model Evaluation

The mean absolute error (MAE) is adopted to examine the performance of the proposed calibration models. The performance of the model is measured in two aspects, i.e., the closeness to the observed link flows, and the closeness to the target OD matrix.

$$MAE = \frac{\sum\limits_{i \in M} \sum\limits_{a \in [0,T]} |v_{ia} - \bar{v}_{ia}|}{M * T} \tag{37}$$

measures the "distance" between the estimated link flows and the traffic counts;

$$MAE^d = \frac{\sum\limits_{j \in N} \sum\limits_{s \in [0,T]} |d_{js} - \bar{d}_{js}|}{N * T} \tag{38}$$

measures the "distance" between the target OD matrix and the calibrated OD matrix.
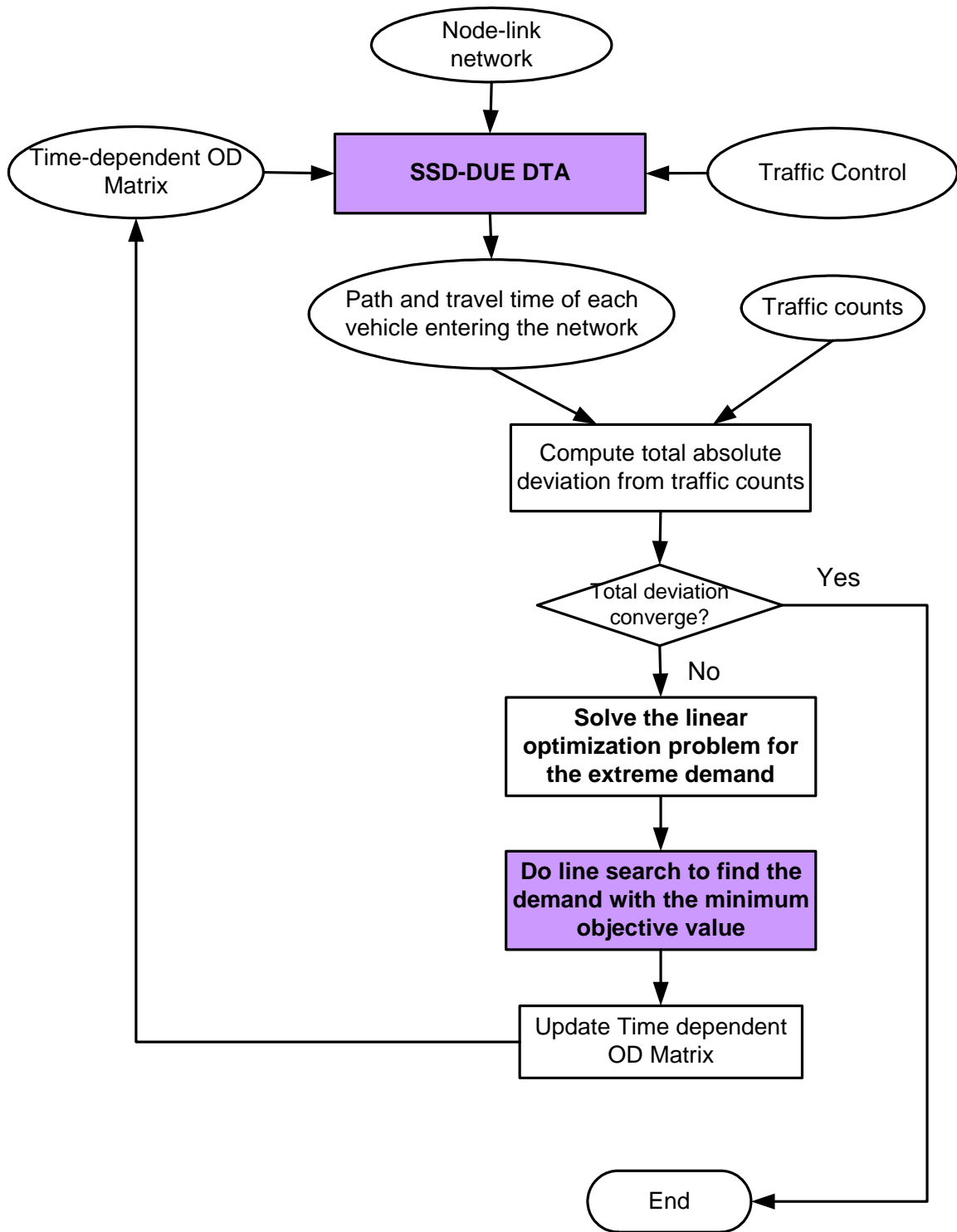
Figure 5. Implementation of MPEC TDODC algorithm in VISTA
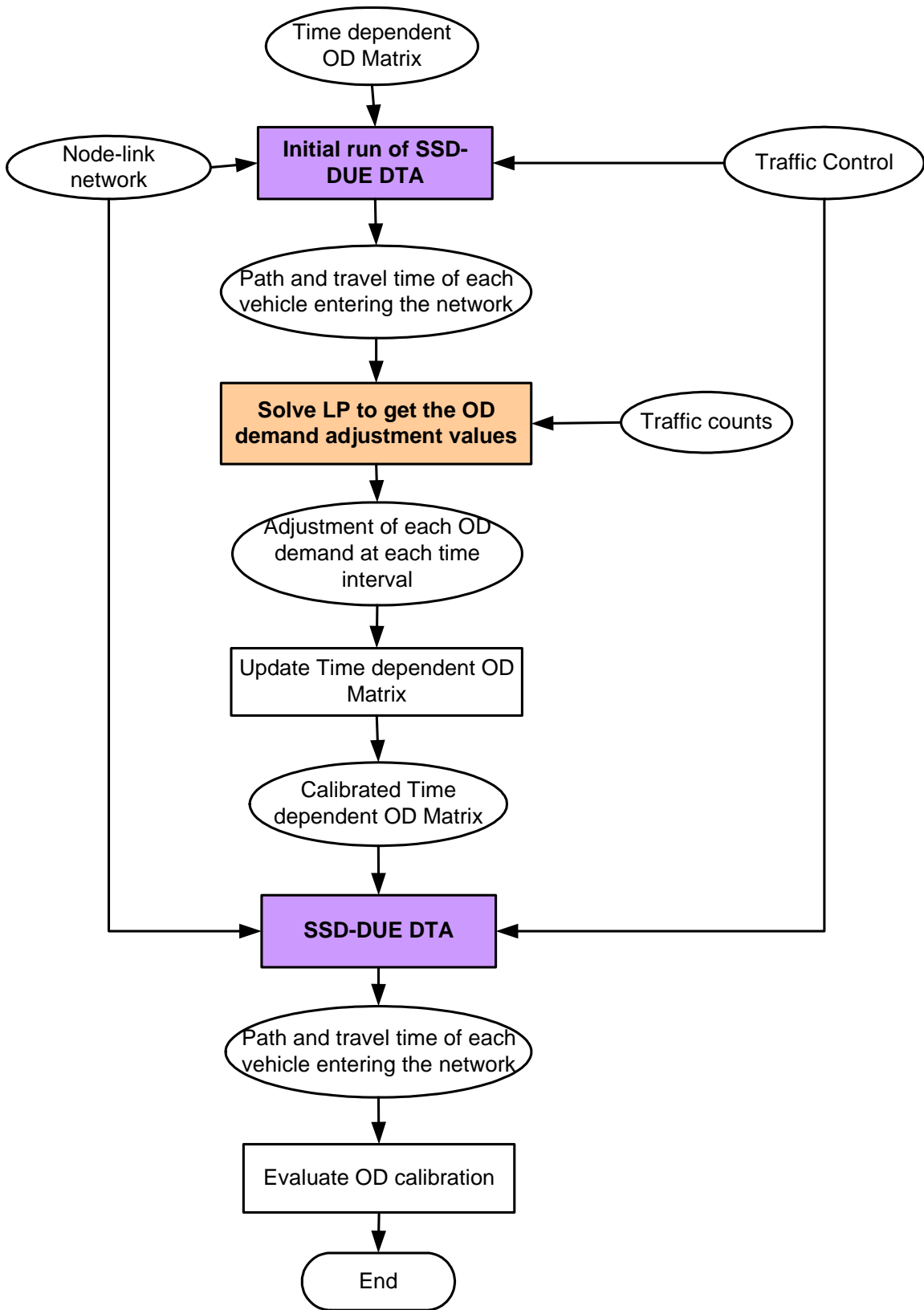
Figure 6. Implementation of LP TDODC algorithm in VISTA

Summary

The DTA based time dependent OD calibration methods proposed in this chapter could be applied to big general networks that are most likely to appear in reality. It may be significantly advantageous in real-time applications where a most up-to -Date time dependent OD matrix is required. The proposed models are implemented in VISTA.

MPEC approach intends to determine path flows that will approach user-equilibrium values, replicate observed flows on links, and concur with the specified the a priory trip table values to as much of an extent as possible, while LP approach reduces the deviation from the traffic counts while stay close to the preliminary estimated OD matrix with high computational efficiency.

The assumption in LP approach that the assignment matrix $\{p_{ij}^{sa}\}$ keeps the same after updating the OD demand table could be too strong when the large adjustments to the a priori OD demand are required. If we combine the two proposed approaches by using MPEC approach at the beginning of the calibration and then LP approach, it is possible to have a good and fast solution.

DATA ISSUES

In this section, the data required for the simulation-assignment model for an ITS priority corridor are described. Next, the data sets acquired for the various sources are listed, and the challenges in integrating these data sets are explained. Finally, the impacts of these assumptions on the simulation results are discussed.

Data Required for Model Development

A simulation-based DTA model for an ITS priority corridor requires network definition data, dynamic OD demand data, signal definition data, detector and VMS location data. Further, traffic counts and observed travel times are required for calibration and validation of the model.

The road network is defined by nodes and links, which represent intersections and road segments. For any corridor simulation, the network should not only cover the target corridor but a region big enough to encapsulate the full trip length, such that changes in path choice could be captured and the distribution of travel time benefits can be observed for different OD pairs. The network should also be detailed enough to capture important local routes that might impact drivers' route choice and also the roads prohibited for commercial vehicles.

The vehicle demand data set defines the number of vehicles that travel between each OD pair during a given period of time, and can be classified as static and dynamic demand. In order to assign and simulate vehicles, dynamic models require time-varying demand, such that exact vehicle departure times are known. However, regional vehicle OD trip data are typically only available in static format, such that vehicle trips are aggregated over a certain period of time, usually a 24-hour period. The aggregate demand must be factored down to obtain the demand for the length of the simulation period, for example, the morning peak hour from 7:00-8:00am. This demand is then profiled to convert the static demand to dynamic demand to obtain a specific departure time for each vehicle entering the network in the simulation period.

The geographic sub-regions that make up origin and destination zones must also be defined. Zone definition data typically include polyline definitions to indicate the shape and location of each zone, along with zone centroid locations. Centroids are imaginary nodes that represent the source and destination of all demand from and to the given zone. The zone centroids are connected to the actual nodes encompassed by that zone by imaginary centroid connectors. Connectors are created to join the centroids to one or all of the actual nodes in the zone. However, each additional centroid connector increases the number of links in the network, and thus the computational time required for the calculation of vehicle paths.

The signal definition data include signal location and phase timing plans. Signals are located on nodes in the network. Phase movements and splits define the operation of the signal for each cycle length.

For simulation of ITS devices, basic information about the device attributes and location are required. Several type of detectors are deployed on the New Jersey ITS priority corridor, such as Loop detector, TRANSMIT detector, etc. Even though their physical characteristics and the underlying principles are widely different, the basic logical functionalities are the same: detect the existence of vehicles. VISTA users can specify the detector type and its functionality and RouteSim can simulate them accordingly and report their readings. VMS are connected to a group of detectors to capture the travel time on different routes. The location of VMS and the connected detectors is required for simulation.

When the model is complete, the OD demand should be calibrated to match observed traffic counts. This calibration process will improve the dynamic demand as assumptions were made when the demand was converted to dynamic demand. Next, we demonstrate how the model's results were validated against observed travel time data.

Data Acquired for the Simulation-Assignment Model

Model Input Data

Model input data include the network, demand, ITS device and signal data. The project scope did not include any project-specific data collection; instead, it relied on data sets acquired from existing sources. Most of the data consist of planning data acquired from the local metropolitan planning organization (NJTPA), the New Jersey DOT, The Port Authority of New York and New Jersey (PANYNJ), and the Transportation Operations Coordinating Committee (TRANSCOM). Another source of data was the Topologically Integrated Geographic Encoding and Referencing system (TIGER) data from US Census Bureau and Aerial Photos from Mapquest Web. These data were used as reference for data fixing and integration. The data sets used in this project are as follows:

- NJDOT 1999 Pavement data.
- NJDOT 2002 Straight Line Diagrams.
- NJDOT I-80 corridor GIS data and traffic counts.
- NJDOT intersection layout and signal plan.
- NJRTM public use data set (GIS data and Trip data).
- PANYNJ Gorge Washington Bridge layout and 15-minute traffic counts.
- TRANSCOM detector location (TRANSMIT detectors), VMS location map and Link information data.
- Toll plaza detector cumulative data print outs
- 2001 Tiger Line data.

The NJDOT 1999 Pavement data included the State Highways in New Jersey State with basic GIS information. It is very abstract and lacked detailed road information, such as turns and ramps.

The straight-line diagrams contain very detailed road layout information in PDF format, including all state and Interstate highways. Speed limits and number of lanes are also available.

The I-80 corridor data is GIS data in ESRI shape-file format. It has a lot of road layout details, including highway ramps and local roads. It is restricted to I-80 corridor and has very limited information on related state highways and local roads.

The NJDOT intersection data are very limited. The signal timing plan and intersection location were in separate data sets. It was not always possible to match the location and phase information for every available signal plan. Some of the phase timing plans used during simulation were automatically generated.

The NJRTM public data from NJTPA have geo-coded network information. It also has AM/PM peak hour volume data and a 24 Hour (Daily) Truck volume. Its geographic information is relatively simple, which is good for planning purpose and not detailed enough for this study. The trip information is used to generate OD pairs and the base information for OD calibration.

The George Washington Bridge area is the hotspot of this study of the I-80 corridor. There is an upper deck and a lower deck on the bridge and both have detectors installed. The TRANSMIT detector location and related VMS information was obtained from TRANSCOM. The bridge layout file in AutoCAD format (provided by the PANYNJ) helped to fix the GIS data.

The print outs from toll plazas are not very useful as they are too difficult to utilize. Moreover, toll plazas were not a priority topic in this study. However, in a future study they should be incorporated into the NJDOT-VISTA model, as they are important facilities that impact the traffic that passes through them.

Tiger Line data usually are not accurate enough for traffic simulation / evaluation purposes. They do not constitute a connected network in many locations and they lack one-way, two-way roadway information thereby they may lead to erroneous traffic

assignments. It is employed here as a source of street names and used as a reference for data integration.

Model Calibration and Validation Data

For calibration and validation, expressway traffic counts data sets used are as follows:

- NJDOT I-80 expressway detector counts locations from 1998 to 2001.
- Port Authority of New York and New Jersey (PANYNJ) George Washington Bridge (GWB) traffic reports.

Traffic counter locations were identified by road name and mileposts. The data were aggregated into 15-minute counts before being used for OD calibration.

Challenges with Data Integration

The data sets for the corridor were obtained from various data sources and none of these were originally created to support assignment-simulation models. The detail and accuracy were quite different for different data sets and they were not consistent with each other. A lot of effort had to be allocated to integrate them together, and manual fixes could not be avoided.

Geographic information and traffic network

After close inspection of all the data sources that provided geographic information, the NJDOT I-80 corridor GIS data was selected to be the basis of the network. It contains almost every piece of roadway in the study area. Besides state and interstate highways, it also includes highway ramps, express lanes, local roads and intersections. Different directions of highways were presented separately.

Since this layer was merely a shape-file and not an actual traffic network, a lot of data cleaning work was needed. A set of tools were developed to automatically generate nodes and establish connectivity. GIS lines were matched with the network links as much as possible and directions were fixed. A lot of local roads were removed, leaving

just major arterials and expressways. Any other imperfections have been cleaned manually. Figure 7 presents the original GIS used as was provided by NJIT, while Figure 8 presents the roadways that were modelled in VISTA.
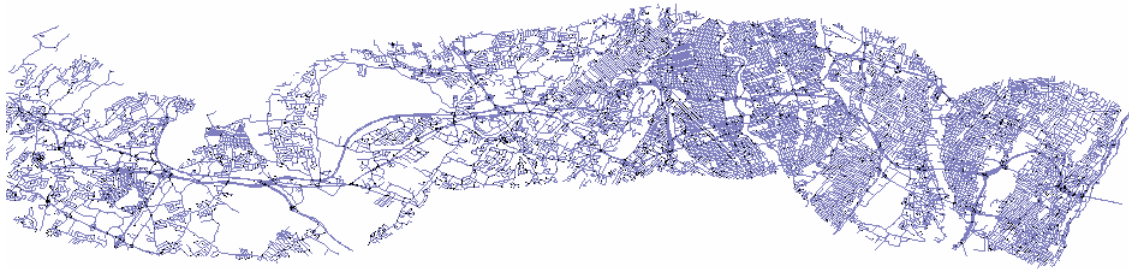
Figure 7. The I-80 Corridor Roads GIS Data from NJIT
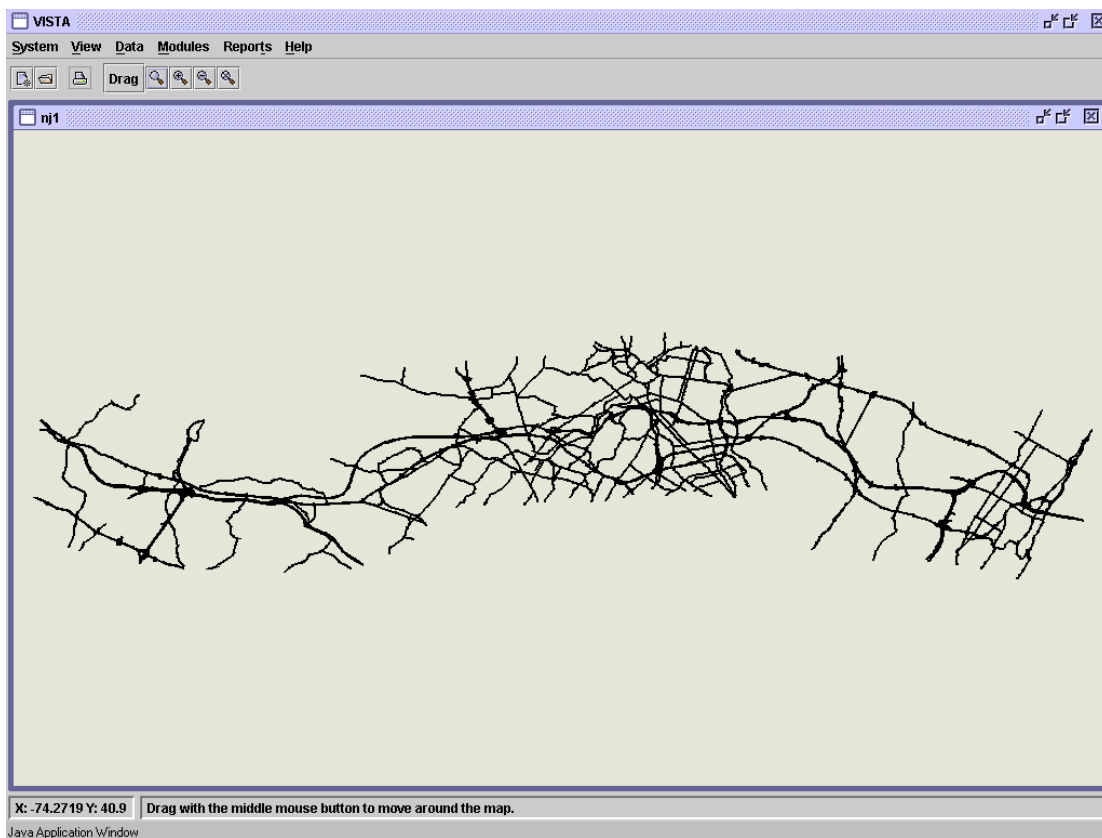
Figure 8. The I-80 Priority Corridor Network in VISTA

The next step was to provide roadway names on the network. Another set of utilities was created to bring in street names from a detector dataset. These were mapped using geometry from U.S. Census TIGER files. Due to geometric inconsistencies between the GIS layer and the TIGER files, many streets had to put in manually. The street names were essential as they allowed other data, like the TRANSMIT detectors to be incorporated into the network easily.

Lane and speed information for roads was input manually. There were multiple conflicting sets of data for number of lanes and speed limit. The following rules were employed to decide which number to use:

- According to experience, choose the number from the dataset that has better quality and is more reliable,
- If the data qualities are basically equal, choose the most updated one,
- If the age of the data is similar or no time information is available, choose the most reasonable one,
- If no data at all for a link, use the value of nearby links on the same road or a reasonable value for the roads in the same category.

Figure 9 presents an illustration of the I80 network in VISTA with roadway names.
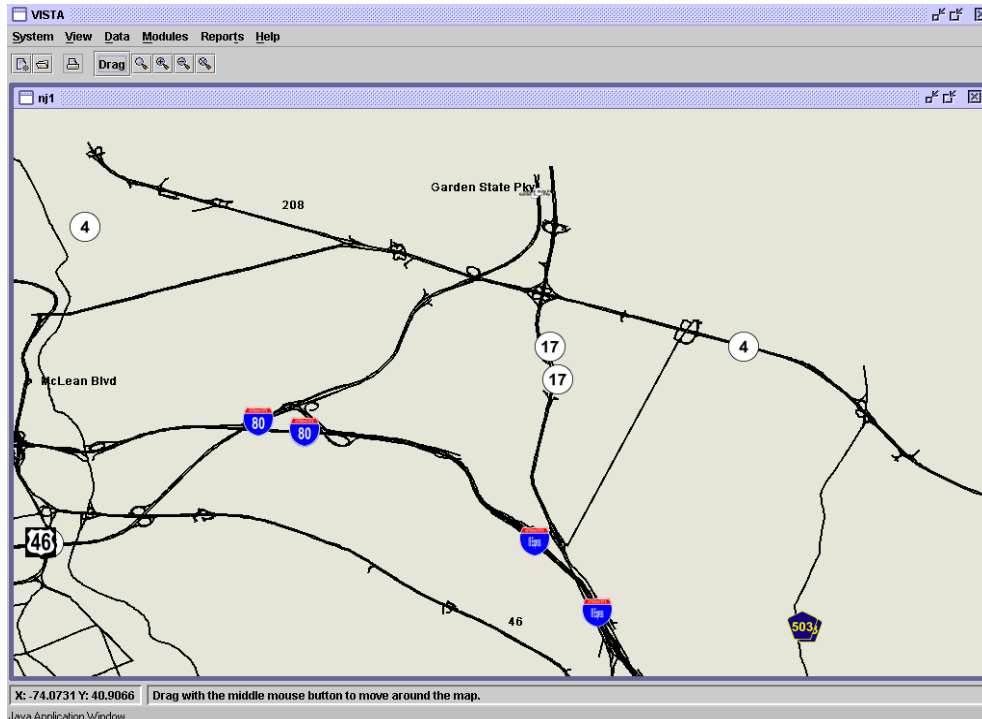
Figure 9. VISTA Network with Street Names

OD Trip Data

The OD trip data set was originally created for planning purposes. It contained data in terms of number of trips made during the morning and afternoon peak hours. The data was not detailed enough to be used for this study. In order to extract the OD trip information for the I-80 corridor area, the planning network was imported into the VISTA system. Simulation-Assignment modules were run using the (planning) OD data obtained and trip information was captured. The trips made within the study area were further extracted and aggregated. These OD trip data were mapped into the study network and used as demand. Demand in the study area is zone based, the zones being defined as a collection of nodes near the original node from the planning network. Most zones cover intersections or interchanges. A set of utility programs were created to perform this mapping operation.

Intersections and signal plan

As mentioned earlier, the intersection information and signal plans were obtained from different sources. The timing plans are in the form of descriptive tables in Microsoft Word format. Locations are given by street names. They covered Routes 1, 4, 9, 17, 29, 23 and 46.

The intersection information are in the form of CAD files. They covered partial intersections on Routes 1, 4, 9, 17, 20, 21, 23, 46, 80, 95, 280 and 287. Some of these are outside the study area.

The two datasets mentioned above did not overlap and file formats made it impossible for automation of the data importation process. Only a small number of signal timing plans could be identified and were manually input.

Thanks to the handy signal optimization tool in the VISTA framework, missing signals were generated automatically. **However, integration of local signalized intersections into the network will improve the accuracy of the NJDOT VISTA-DTA model developed.**

Detector and VMS devices

Detector information was provided by both TRANSCOM and the NJDOT.

TRANSCOM 's TRANSMIT detectors were provided with location in longitude and latitude, which were geometrically mapped on the links. Some manual cleaning was required due to data accuracy.

NJDOT's detectors were provided with street name and milepost. Several mileposts were identified from the map with Longitude and Latitude. These known points were used to calibrate the distance between mileposts obtained from the GIS data. These detectors were integrated into the network using street names from the TIGER line data. The accuracy of the mileposts was not satisfactory and additional check and fixes were performed manually.

The locations of Variable Message Signs in the network was provided by TRANSCOM in the form of a bitmap image, showing the study area and the VMS location signs are located. These were input manually.

Impact of Data-Related Assumptions on Simulation Results

The NJDOT VISTA-DTA model developed is capable of providing insight into the potential impacts of various scenarios and strategies of ITS device deployment if it is decided to further expand it for the entire North Jersey and a substantial data effort is undertaken such that all the infrastructure data, traffic control data and traffic flow data become available. Currently only commercial GIS databases provide a correct navigational network, however they do not include the necessary data for the VISTA-DTA system. NJDOT has most of these data in different places and they have to be integrated with its GIS system based on the VISTA data needs

The simulation results will allow several ITS and infrastructure scenarios to be evaluated, so that decisions can be made regarding the most optimal strategies. Application of the simulation results to the real-world evaluation and decision-making requires realistic data sets and simulation model. However, it has been found that detailed regional data are difficult to obtain, so many assumptions have to be made to integrate different data sets. Without accurate data, a clear understanding of the impact of data-related assumptions on simulation results is required, and this will require sensitivity tests of the simulation model to the various input data. Large variations in predicted impacts will indicate that the model is very sensitive to the data, and more accurate data are required, while slight variations will indicate that the data assumptions are acceptable and will not change the final implementation decision regarding different scenarios.

<u>**Recommendations**</u>

The I-80 corridor is one of the best candidate areas in New Jersey for a full-scale implementation of the NJDOT-VISTA system both as an off-line and as a real-time simulation/assignment model. The main features of the corridor are:

- NJDOT will soon begin operation of its MAGIC ITS system that is supported by a traffic surveillance and communication system. The MAGIC system could provide traffic counts from its traffic surveillance system.

- The New Jersey Turnpike Authority and the New Jersey Highway Authority – these two authorities are now merged - could provide traffic counts at the toll plaza locations at the New Jersey Turnpike and the Garden State Parkway. In addition, additional traffic counts could be provided by various detectors along both roadways. Potentially, travel time data between toll plazas could be obtained from the E-ZPass toll collection system.

- TRANSCOM could provide TRANSMIT link data at the GWB and the Lincoln tunnel. In addition, in the future, implementation of the TRANSMIT system along both the NJT and GSP could produce TRANSMIT link travel time data and partial OD data.

- The PANYNJ could provide traffic flow data from its traffic surveillance system at the GWB, Lincoln tunnel and Holland tunnel. Currently only GWB has detailed traffic flow data, however, in the near future (2-3 years), they will be available at both the Holland and Lincoln tunnel.

- The North Jersey Transportation Planning Authority (NJTPA) could provide updated OD tables.

- New Jersey Transit (NJTransit) will provide bus and train schedules including bus and train stops. Furthermore, NJTransit could provide bus and train location data based on their AVL system. Given this information, a person-based simulation/assignment model will be developed.

- NJDOT and NJTransit will provide park and ride facility data such as locations and capacities. Where feasible park and ride traffic flow data will further aid in the establishment of a true simulation/assignment intermodal model for NJDOT and NJTransit.

- The New York City DOT could provide traffic count data, signal timing data, and geometry for its network in the vicinity of the main crossings into Manhattan (GWB, Lincoln and Holland tunnel). This will provide a more comprehensive model for the I-80 and produce more accurate results both for the inbound and the outbound approaches from/to New Jersey/New York.

- Counties and municipalities as well as the NJDOT could provide traffic counts from their signalized systems in the North Jersey area, along with updated signal timing plans and the geometry of their network.

- Consulting firms continuously collect data for the transportation studies (OD surveys, traffic counts, signal timing, geometry, other) they are conducting, which are very valuable and should be retrieved and integrated into the NJDOT-VISTA system.

- Given that traffic data are either readily available or they could be obtained from the various agencies, implementation of a full-scale NJDOT-VISTA system could provide the transportation agencies of the entire NY/NJ metropolitan area with a powerful tool to conduct their analyses to further improve their operations. **Economies will be realized** for all transportation related studies since the data will be readily available. Each transportation agency will **spend minimal time** in providing data for their facilities to either consultants or researchers. Each analyst will realize **consistency** in his/her study since he/she will be using the same data as every other analyst, providing consistency in the output of each study.

Methodology

- Collect data from all the agencies in the North Jersey for a period of one month. Traffic flow counts should be provided at a disaggregate level of 15 minutes or less. Raw traffic count data at the least disaggregate level will be most welcome if they exist and produce a more accurate simulation/ assignment model.

- Calibrate an off-line model based on one-month traffic flow data to reflect the I-80 corridor for the entire North Jersey and all the crossings into Manhattan from New Jersey. **This study will produce NJDOT-DTA models for each 24-hour day of the week from Monday to Sunday.**

- Develop a real-time NJDOT-VISTA-DTA by integrating its servers to the traffic surveillance systems of all the agencies (MAGIC, TRANSCOM, PANYNJ, NJTA, NJHA). Initially this model may be restricted to the MAGIC and TRANSMIT system since they are readily available and it would rather be easy to hook up the VISTA servers to the communication backbone of the two systems. In the future all the other agencies would be inspected to integrate their systems.

- Develop a systematic procedure for transportation data collection and data fusion from each transportation agency and consulting firm that will minimize the time required by agency personnel and ensure data accuracy.
- Develop a real-time semi-automated calibrated NJDOT-VISTA system. The VISTA dynamic OD estimation algorithm will be modified to be continuously updated based on the traffic flow data and the transit data from the various agencies. Periodic OD surveys would further aid in more accurate calibrations of the OD matrix.

The envisioned VISTA-based simulation/assignment model will aid the NJDOT in

- **conducting short term and long term infrastructure related studies based on a continuously calibrated model;**
- **conducting traffic management and operation studies such as signal timing optimization, traffic impact analyses, incident management plans, construction management plans; and**
- **emergency analyses for major hurricane/storms, flooding, hazardous material spills, security threads and other.**

TRANSCOM will benefit through the provision of a continuously calibrated system that could be used within its TRIPS123 traveler information system to produce more accurate estimates/prediction of traffic flow conditions and route planning for each desired OD by any traveler. At the very least the NJDOT VISTA-DTA is capable of providing a more accurate route planning or intermodal algorithm for each traveler based on historical traffic information and related transit schedule and stop information. The functionality of the TRIPS123 will be further enhanced by the integration within the VISTA system for transit information, which is expected to produce more accurate real-time further intermodal route planning to transit users. Furthermore, they could use the NJDOT-VISTA system to conduct analyses on the location of future TRANSMIT readers in New Jersey.

The NJTransit and NJDOT could use the models to evaluate the locations of park and ride facilities. NJTransit could use the models to evaluate various transit scheduling

plans and the introduction of new transit services such as rapid bus transit, para-transit, and train service.

COST / BENEFIT ANALYSIS CASE STUDIES

The transportation professionals and researchers usually conduct various types of cost/benefit analyses that address a specific or a combination of strategic goals and objectives such as safety, efficiency, economic impact, and environmental impact. The VISTA-DTA system is capable of producing various Measures Of Effectiveness (MOEs) that could aid in the quantification of the benefits associated with each operational or infrastructure project. In this study a cost analysis was not carried out as it entails the implementation of an actual project to produce accurate cost estimates. It would be beneficial for the NJDOT to carry out an extensive study where the costs associated with traffic management, traveler information and infrastructure planning are collected for various projects and then incorporated into the VISTA system. In parallel, associated cost/benefits analysis modules could be developed based on these cost estimates and the **Measures of Effectiveness (MOEs)** that the VISTA system produces for each specific project, which comprise part of the benefits of a particular project.

The next section presents the use of VISTA for Cost / Benefit studies as illustrated by four case studies, correspondent to four typical application scenarios.

Data overview

Network data

The network used for cost-benefit analysis scenarios is the right part of the whole I-80 corridor, close to the George Washington Bridge (GWB) (I80 NJSmall). This network extends from the junction of Interstate 80 and 95 at the west and the GWB at the east (See Figure 10). Table 9 provides a summary of the NJ Small data.

Demand data

The demand data are extracted from the whole corridor network with fixes and aggregation. The demand is further improved by running OD calibrations against real world counter data.
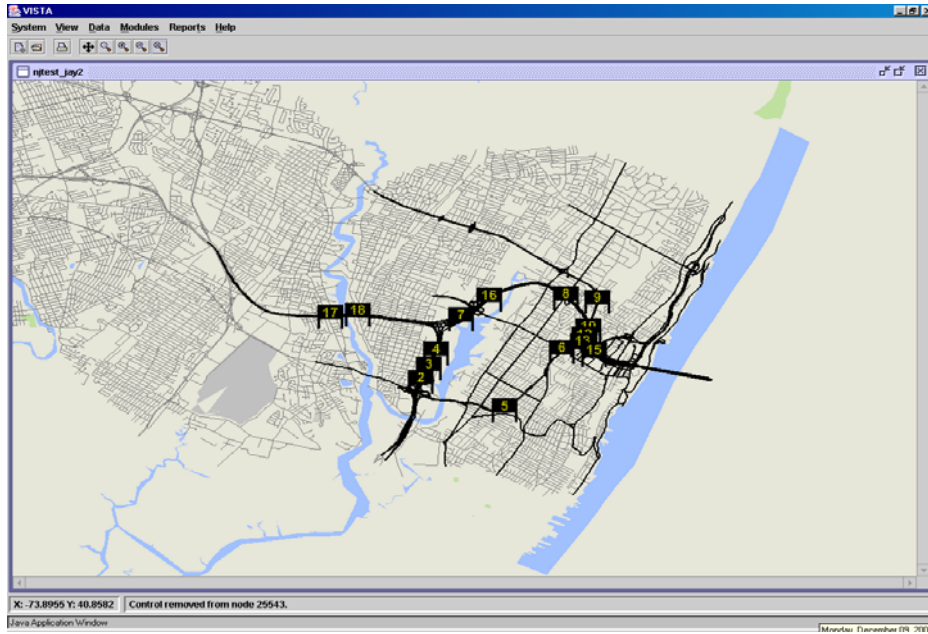
Figure 10. The George Washington Bridge Network (I80 NJ Small)

Control data

The VMS and detectors are extracted from the full network.

Summary

Table 9. Network Overview

Item	Counts in network
Nodes	557
Links	1166
VMS Panels	0
Detectors	167
TRANSMIT Detectors	25
Zones	140
OD Pairs	2769
Demand Total	161111
Demand passenger Vehicles	158598
Demand Commercial Vehicles	2513
Buses	0
Bus Routes	1
Simulation Length	3600 (s)
Assignment Interval	900 (s)

Methodology for Incident Management Scenario

Analysis of the Location of a Variable Message Signs (VMS). VISTA can be used to evaluate various components of incident traffic management strategies. In this case study we demonstrate the analyst how he could evaluate the location of a VMS using the VISTA-DTA. VMS can be used to show real-time traffic information and is an effective medium for incident traffic management, by providing information/guidance to drivers. VMS is usually attached to detectors to get real time traffic information and a strategy from a Traffic Management Center (TMC).   In this case study the VISTA system was implemented to emulate the traffic surveillance system for GWB that utilizes TRANSMIT detectors and the travel time information for the upper and lower bridge levels provided by VMS signs on the I-80/NJT extension near the vicinity of the bridge.

There were four scenarios considered:

- Base case without VMS, nor incident;
- Scenario 1 with incident but without VMS;
- Scenario 2 with incident and VMS enabled, run RouteSim only;
- Scenario 3 with incident and VMS enabled, run both assignment model and simulation.

Base case

Assignment models and simulation were run on the base case network first. Basic network statistics are collected by running the General report module; the emission module was used to collect pollution related data.

Scenario 1

An incident was added to I-95/I-80 on link 4985 (see Figure 11) with the following parameters (see Table 10):
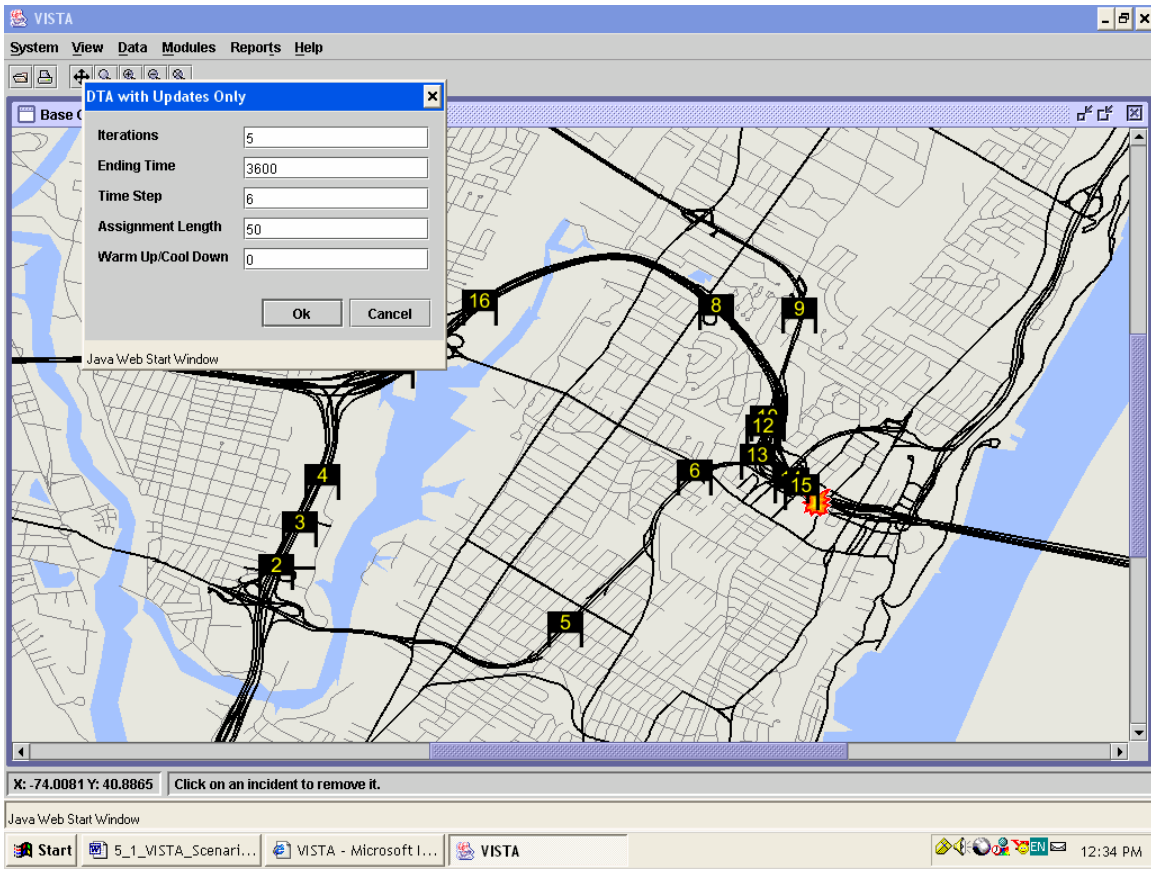
Figure 11. Scenario Network with VMSs and Incident on I-95

Table 10. Incident Settings

Parameter	Value	Explanation
Start Time	0	Together with End time, define the timeframe during which the incident will be present
End Time	1800	
Link	4985	The link ID on which the incident took place
Location	0	Defines the offset of the incident form the start point of the link (feet)
Length	100	The length of the street in feet which would be having the incident (feet)
Lanes	2	Specifies the number of lanes that would be affected by the incident.
Severity	0.5	This specifies the severity of the incident on a scale of 0 to 1.0 with 1.0 being the most severe case, warranting total road closure.

The VMSs were still disabled. Run the RoutSim module to simulate the incident impact on drivers who have no additional information about the incident at all. This is the

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worse-case scenario. Then the general report was used to gather network-wide statistics.

Scenario 2

In addition to the incident, one VMS (number 8 – see Figure 12) is also enabled in this scenario. Other VMSs still remain deactivated. The configurations of this VMS are as follows (Table 11):

Table 11. VMS Settings

Parameter	Value	Explanation
Location	0	Defines the offset of the incident form the start point of the link (feet)
Lanes	3	Specifies the number of lanes on that link that would be getting the info from this VMS.
Compliance	0.3	Governs the extent to which the drivers use the VMS suggestion on a 0 to 1 scale: 1 means full compliance

We also need to specify the potential alternative routes in the VMS. One of the pre-configured routes includes the link on which we added the incident. The other route is an alternate route towards the same general direction but does not include the link on which we have the incident. This way the VMS is able to give the information about the incident in advance and certain amount of traffic (depending on the compliance factor) takes the "advice" and chooses the alternate route. Hence the travel time for some of the vehicles goes down.

Run the simulation module RouteSim, and then run the general report to get network level statistics.
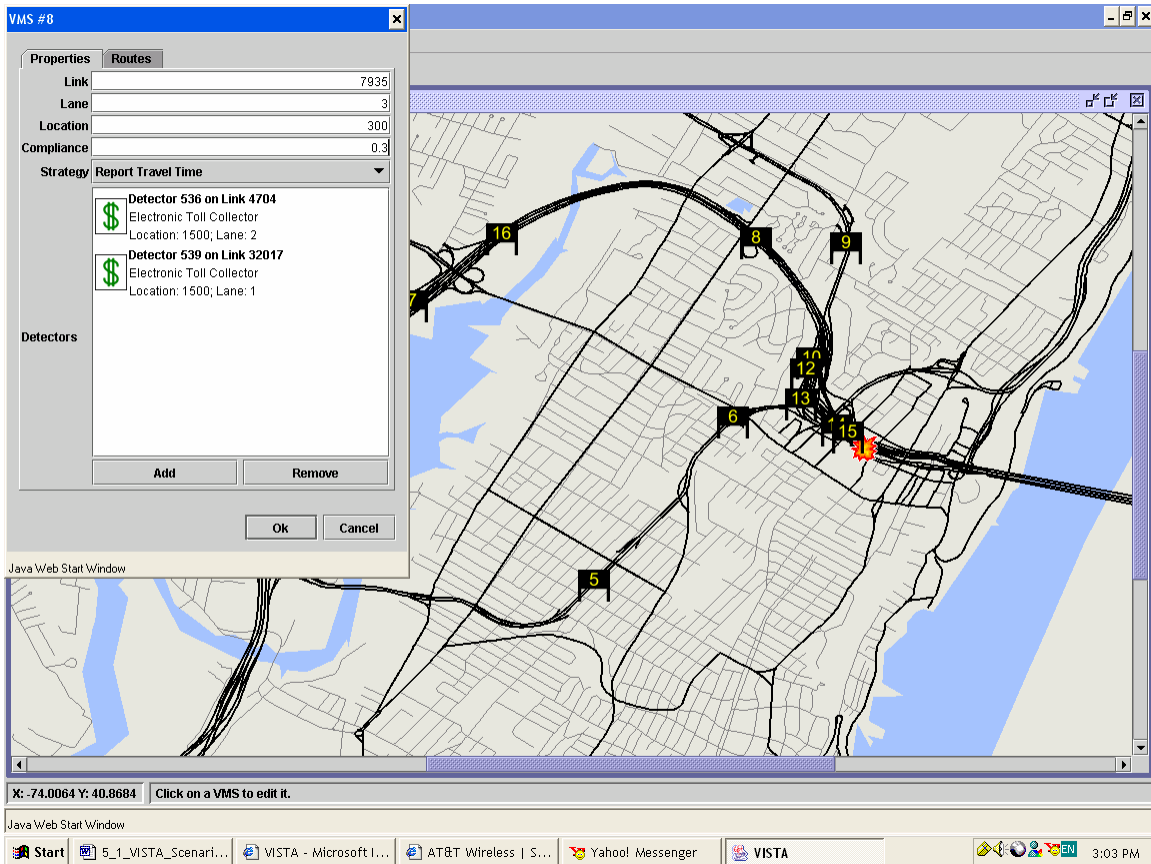
Figure 12. VMS Configuration

Scenario 3

The only difference between scenario 2 and scenario 3 is that we used the DTA module to perform assignments as well as simulation. This correspondents to the situation that perfect information about the incident is available to every driver. This is the best-case scenario although not necessarily the optimal one. For example the analyst could execute instead the System Optimal DTA and see how the drivers could be rerouted to achieve the best results network-wide (e.g. minimum total network travel time). This information may be used to reroute people through specific routes rather than allow them to choose their own and at the same time it could serve as the lowest possible total travel time for comparative analyses.

Results and discussion

Table 12. General Reports for Base Case and Scenarios

	Base Case	Scenario 1	Scenario 2	Scenario 3
No. Vehicle Entered	95880	93979	93979	95233
Total Travel Time (Hours) Entered Vehicles Only	46036	47547	47361	47880.0
Average Travel Time (Minutes) Entered Vehicles Only	28.81	30.36	30.25	30.17
Total Vehicle Miles Traveled	165,365	144,938	144927.51	145277.93
Average Delay (Min/Veh) Entered Vehicles Only	26.3	28.07	28.01	27.91

When the incident happened, the network performance decreases, showed as average travel time increased. The use of VMS relieved the congestion. There is potential to further achieve better results as is shown in the above table (Table 12). When drivers can receive more information, the congestion could be further reduced.

ITS infrastructure Evaluation Scenario

In this case study, 15 candidate locations were chosen out of which three VMS are to be installed to provide traffic information of the upper and lower decks of the George Washington Bridge. The VMS shows the travel times on the two decks and drivers will make their decisions accordingly. Two types of incidents will be evaluated for the best location.

Methodology

Historical incident data

A list of all incidents in the past in this region, including type, location, time and severity are collected for transportation planning. Then the probability that one type of incident will happen in the future is forecasted. In this case study, in order to simplify our work and for demonstration purpose, we assume that there are only two types of incidents that might happen in the future. The corresponding incident data are listed in Table 13.

Table 13. Incident Data

Incident	Link	Location	Length	Time	Lanes	Severity	%
1	4704 (Lower)	2000 ft	100 ft	600 s – 1800 s	1 of 4	0.6	40
2	32017 (Upper)	1500 ft	200 ft	0 s- 3000s	4 of 4	0.3	60

Incident type 1 happens at the lower deck of the bridge, it starts from 600 seconds from the beginning of peak period until 1800 seconds, lasting 20 minutes. Only one lane out of the four lanes is affected and the severity level is 0.6 (1.0 means complete closure and 0.0 means no impact). We assume that 40% of all incidents are this type. Incidents here do not necessarily mean accidents, but can be any unexpected situation that could cause the traffic to slow down. Incident type 2 occurs at the upper deck, lasting 50 minutes, and is less severe but more often. We also assume that the two types of incidents do not happen at the same time.
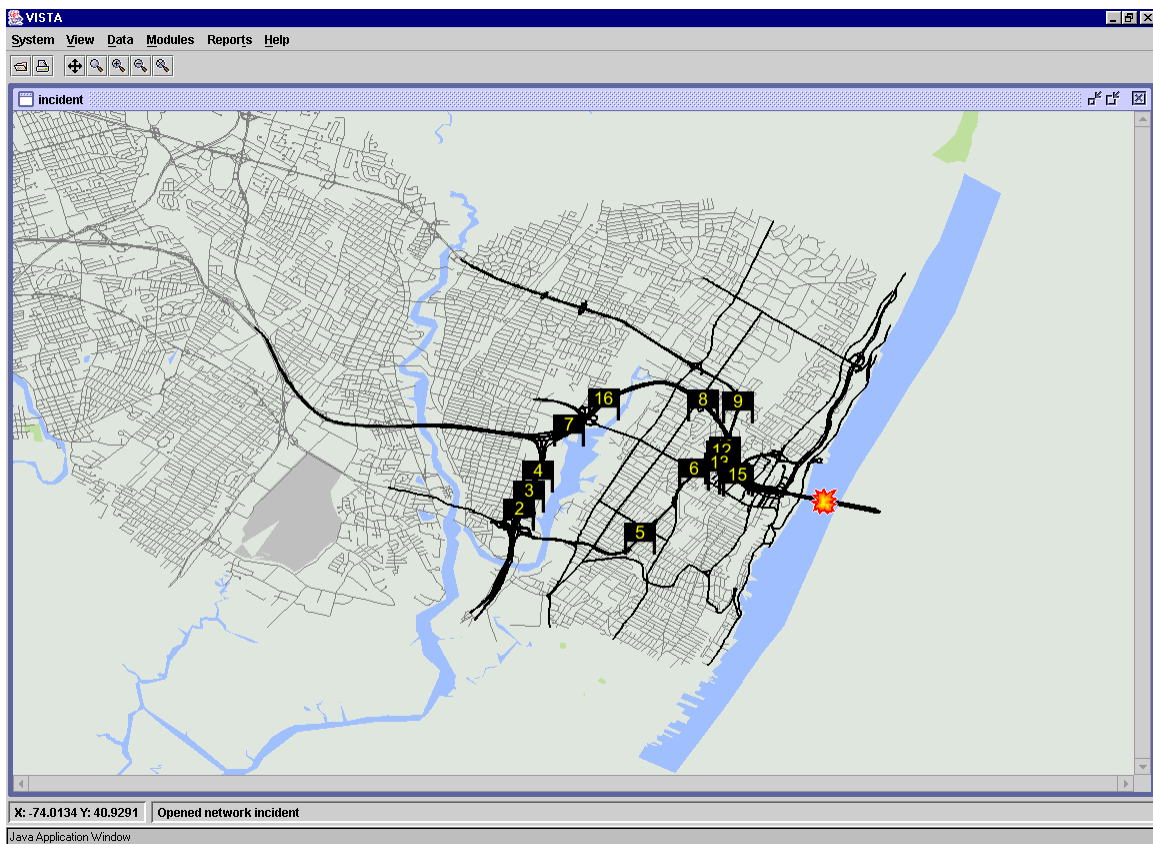
Figure 13. Incident on the Bridge

VMS data

Table 14. Scenarios

Scenario	VMS Locations
No VMS	None
VMS Location 1	13, 14, 15
VMS Location 2	2, 6, 12
VMS Location 3	5, 8, 14

There are 15 candidate VMS locations in the network, spreading along I-80 and I-95 from George Washington Bridge to the east. Among these locations, three will be selected for installation of VMSs to display traffic information of the bridge.

Each of the 15 locations has a "virtual" VMS, indexed from 2 to 16. When a virtual VMS is enabled, it acts like a real VMS displaying information. The VISTA system enables the user to view these results on the screen. When a virtual VMS is disabled, it has no impact on drivers.

The network contains 159 detectors and 17 TRANSMIT detectors. All the 15 VMSs are connected to two TRANSMIT detectors on the two decks of the bridge. In this case study we are trying to evaluate three potential combinations of VMS locations (See Table 14. The accident is assumed that occurs either at the lower or upper deck of GWB.

Results and analysis

Travel time results

The results for all the test runs are summarized in Tables 15 to 22 for each scenario.

Table 15. "No VMS" Scenario for Incident Type 1

Assignment	Start	End	No. Veh.	Total TT (H)	AVG (M)	STD (M)	MAX (M)	MIN (M)
0	00:00:00	00:15:00	30672	10938.0	21.4	22.45	60.0	0.0
1	00:15:00	00:30:00	27185	9287.0	20.5	17.36	45.0	0.0
2	00:30:00	00:45:00	25053	5480.0	13.12	10.91	30.0	0.0
3	00:45:00	01:00:00	22392	1838.0	4.93	4.81	15.0	0.0
Total	00:00:00	01:00:00	105302	27544.0	15.69	17.31	60.0	0.0

Table 16. "VMS Location 1" Scenario for Incident Type 1

Assignment	Start	End	No. Veh.	Total TT (H)	AVG (M)	STD (M)	MAX (M)	MIN (M)
0	00:00:00	00:15:00	30701	10372.0	20.27	21.77	60.0	0.0
1	00:15:00	00:30:00	27176	8816.0	19.46	17.2	45.0	0.0
2	00:30:00	00:45:00	24366	5154.0	12.69	10.96	30.0	0.0
3	00:45:00	01:00:00	22195	1808.0	4.89	4.83	15.0	0.0
Total	00:00:00	01:00:00	104438	26150.0	15.02	16.9	60.0	0.0

Table 17. "VMS Location 2" Scenario for Incident Type 1

Assignment	Start	End	No. Veh.	Total TT (H)	AVG (M)	STD (M)	MAX (M)	MIN (M)
0	00:00:00	00:15:00	30729	9713.0	18.97	20.88	59.0	0.0
1	00:15:00	00:30:00	27196	8453.0	18.65	16.89	45.0	0.0
2	00:30:00	00:45:00	23920	4883.0	12.25	10.87	30.0	0.0
3	00:45:00	01:00:00	22567	1778.0	4.73	4.76	15.0	0.0
Total	00:00:00	01:00:00	104412	24829.0	14.27	16.33	59.0	0.0

Table 18. "VMS Location 3" Scenario for Incident Type 1

Assignment	Start	End	No. Veh.	Total TT (H)	AVG (M)	STD (M)	MAX (M)	MIN (M)
0	00:00:00	00:15:00	30701	10370.0	20.27	21.77	60.0	0.0
1	00:15:00	00:30:00	27176	8815.0	19.46	17.2	45.0	0.0
2	00:30:00	00:45:00	24366	5153.0	12.69	10.96	30.0	0.0
3	00:45:00	01:00:00	22195	1807.0	4.89	4.83	15.0	0.0
Total	00:00:00	01:00:00	104438	26147.0	15.02	16.9	60.0	0.0

Table 19. "No VMS" Scenario for Incident Type 2

Assignment	Start	End	No. Veh.	Total TT (H)	AVG (M)	STD (M)	MAX (M)	MIN (M)
0	00:00:00	00:15:00	30729	10191.0	19.9	21.57	60.0	0.0
1	00:15:00	00:30:00	27188	8605.0	18.99	17.11	45.0	0.0
2	00:30:00	00:45:00	23973	5072.0	12.7	11.03	30.0	0.0
3	00:45:00	01:00:00	22165	1791.0	4.85	4.82	15.0	0.0
Total	00:00:00	01:00:00	104055	25662.0	14.8	16.77	60.0	0.0

Table 20. "VMS Location 1" Scenario for Incident Type 2

Assignment	Start	End	No. Veh.	Total TT (H)	AVG (M)	STD (M)	MAX (M)	MIN (M)
0	00:00:00	00:15:00	30729	10192.0	19.9	21.57	60.0	0.0
1	00:15:00	00:30:00	27188	8610.0	19.0	17.11	45.0	0.0
2	00:30:00	00:45:00	23973	5076.0	12.71	11.03	30.0	0.0
3	00:45:00	01:00:00	22165	1791.0	4.85	4.82	15.0	0.0
Total	00:00:00	01:00:00	104055	25671.0	14.8	16.77	60.0	0.0

Table 21. "VMS Location 2" Scenario for Incident Type 2

Assignment	Start	End	No. Veh.	Total TT (H)	AVG (M)	STD (M)	MAX (M)	MIN (M)
0	00:00:00	00:15:00	30729	9691.0	18.92	20.84	60.0	0.0
1	00:15:00	00:30:00	27203	8318.0	18.35	16.87	45.0	0.0
2	00:30:00	00:45:00	23574	4834.0	12.3	10.89	30.0	0.0
3	00:45:00	01:00:00	22470	1767.0	4.72	4.76	15.0	0.0
Total	00:00:00	01:00:00	103976	24611.0	14.2	16.31	60.0	0.0

Table 22. "VMS Location 3" Scenario for Incident Type 2

Assignment	Start	End	No. Veh.	Total TT (H)	AVG (M)	STD (M)	MAX (M)	MIN (M)
0	00:00:00	00:15:00	30729	9689.0	18.92	20.84	60.0	0.0
1	00:15:00	00:30:00	27203	8318.0	18.35	16.87	45.0	0.0
2	00:30:00	00:45:00	23574	4833.0	12.3	10.89	30.0	0.0
3	00:45:00	01:00:00	22470	1767.0	4.72	4.76	15.0	0.0
Total	00:00:00	01:00:00	103976	24608.0	14.2	16.31	60.0	0.0

From these results, we can conclude that for Incident Type 1 (severe but short), all three VMS location combinations reduce average travel time and "VMS Location 2" performs best.

For Incident Type 2 (less severe but long), only Location Combination 2 and 3 reduce average travel time while Location Combination 1 performs poorly.

Delay results

The corresponding delay summary results are displayed in Tables 23 to 30.

Table 23. "No VMS" Scenario for Incident Type 1

Assignment	Start	End	No. Veh.	Total TT (H)	AVG (M)	STD (M)	MAX (M)	MIN (M)
0	00:00:00	00:15:00	30672	10938.0	21.4	22.45	60.0	0.0
1	00:15:00	00:30:00	27185	9287.0	20.5	17.36	45.0	0.0
2	00:30:00	00:45:00	25053	5480.0	13.12	10.91	30.0	0.0
3	00:45:00	01:00:00	22392	1838.0	4.93	4.81	15.0	0.0
Total	00:00:00	01:00:00	105302	27544.0	15.69	17.31	60.0	0.0

Table 24. "VMS Location 1" Scenario for Incident Type 1

Assignment	Start	End	No. Veh.	Total TT (H)	AVG (M)	STD (M)	MAX (M)	MIN (M)
0	00:00:00	00:15:00	30701	10372.0	20.27	21.77	60.0	0.0
1	00:15:00	00:30:00	27176	8816.0	19.46	17.2	45.0	0.0
2	00:30:00	00:45:00	24366	5154.0	12.69	10.96	30.0	0.0
3	00:45:00	01:00:00	22195	1808.0	4.89	4.83	15.0	0.0
Total	00:00:00	01:00:00	104438	26150.0	15.02	16.9	60.0	0.0

Table 25. "VMS Location 2" Scenario for Incident Type 1

Assignment	Start	End	No. Veh.	Total TT (H)	AVG (M)	STD (M)	MAX (M)	MIN (M)
0	00:00:00	00:15:00	30729	9713.0	18.97	20.88	59.0	0.0
1	00:15:00	00:30:00	27196	8453.0	18.65	16.89	45.0	0.0
2	00:30:00	00:45:00	23920	4883.0	12.25	10.87	30.0	0.0
3	00:45:00	01:00:00	22567	1778.0	4.73	4.76	15.0	0.0
Total	00:00:00	01:00:00	104412	24829.0	14.27	16.33	59.0	0.0

Table 26. "VMS Location 3" Scenario for Incident Type 1

Assignment	Start	End	No. Veh.	Total TT (H)	AVG (M)	STD (M)	MAX (M)	MIN (M)
0	00:00:00	00:15:00	30701	10370.0	20.27	21.77	60.0	0.0
1	00:15:00	00:30:00	27176	8815.0	19.46	17.2	45.0	0.0
2	00:30:00	00:45:00	24366	5153.0	12.69	10.96	30.0	0.0
3	00:45:00	01:00:00	22195	1807.0	4.89	4.83	15.0	0.0
Total	00:00:00	01:00:00	104438	26147.0	15.02	16.9	60.0	0.0

Table 27. "No VMS" Scenario for Incident Type 2

Assignment	Start	End	No. Veh.	Total TT (H)	AVG (M)	STD (M)	MAX (M)	MIN (M)
0	00:00:00	00:15:00	30729	10191.0	19.9	21.57	60.0	0.0
1	00:15:00	00:30:00	27188	8605.0	18.99	17.11	45.0	0.0
2	00:30:00	00:45:00	23973	5072.0	12.7	11.03	30.0	0.0
3	00:45:00	01:00:00	22165	1791.0	4.85	4.82	15.0	0.0
Total	00:00:00	01:00:00	104055	25662.0	14.8	16.77	60.0	0.0

Table 28. "VMS Location 1" Scenario for Incident Type 2

Assignment	Start	End	No. Veh.	Total TT (H)	AVG (M)	STD (M)	MAX (M)	MIN (M)
0	00:00:00	00:15:00	30729	10192.0	19.9	21.57	60.0	0.0
1	00:15:00	00:30:00	27188	8610.0	19.0	17.11	45.0	0.0
2	00:30:00	00:45:00	23973	5076.0	12.71	11.03	30.0	0.0
3	00:45:00	01:00:00	22165	1791.0	4.85	4.82	15.0	0.0
Total	00:00:00	01:00:00	104055	25671.0	14.8	16.77	60.0	0.0

Table 29. "VMS Location 2" Scenario for Incident Type 2

Assignment	Start	End	No. Veh.	Total TT (H)	AVG (M)	STD (M)	MAX (M)	MIN (M)
0	00:00:00	00:15:00	30729	9691.0	18.92	20.84	60.0	0.0
1	00:15:00	00:30:00	27203	8318.0	18.35	16.87	45.0	0.0
2	00:30:00	00:45:00	23574	4834.0	12.3	10.89	30.0	0.0
3	00:45:00	01:00:00	22470	1767.0	4.72	4.76	15.0	0.0
Total	00:00:00	01:00:00	103976	24611.0	14.2	16.31	60.0	0.0

Table 30. "VMS Location 3" Scenario for Incident Type 2

Assignment	Start	End	No. Veh.	Total TT (H)	AVG (M)	STD (M)	MAX (M)	MIN (M)
0	00:00:00	00:15:00	30729	9689.0	18.92	20.84	60.0	0.0
1	00:15:00	00:30:00	27203	8318.0	18.35	16.87	45.0	0.0
2	00:30:00	00:45:00	23574	4833.0	12.3	10.89	30.0	0.0
3	00:45:00	01:00:00	22470	1767.0	4.72	4.76	15.0	0.0
Total	00:00:00	01:00:00	103976	24608.0	14.2	16.31	60.0	0.0

From these tables, we can conclude that for Incident Type 1 (severe but short), all three VMS location combinations reduce average travel time and "VMS Location 2" performs best.

For Incident Type 2 (less severe but long), only Location Combination 2 and 3 reduce average travel time while Location Combination 1 performs poorly.

Evaluation of VMS location

Table 31 summarizes the network performance per VMS location scenario while Table 32 presents the corresponding potential savings in travel time and delay.

Table 31. Network performance

Scenario	VMS installed at	Incident 1 (40%)		Incident 2 (60%)		Overall Expected Value	
		Avg Travel Time (min)	Delay (min)	Avg Travel Time (min)	Delay (min)	Avg Travel Time (min)	Delay (min)
No VMS	None	15.69	13.78	14.8	12.79	15.16	13.19
Location 1	13,14,15	15.02	13.03	14.8	12.80	14.89	12.89
Location 2	2, 6, 9	14.27	12.13	14.2	12.09	14.23	12.11
Location 3	5, 8, 14	15.02	13.03	14.2	12.08	14.53	12.46

Table 32. Expected savings in travel time and delay

Scenario	VMS installed at	Avg Travel Time (min)	Savings over No VMS (%)	Delay (min)	Savings over No VMS (%)
No VMS	None	15.16	---	13.19	---
Location 1	13,14,15	14.89	1.77	12.89	2.23
Location 2	2, 6, 9	14.23	6.12	12.11	8.19
Location 3	5, 8, 14	14.53	4.14	12.46	5.51

Installing VMS reduces average vehicle travel time and reduces delay. However installing VMS at different locations will have different impact on traffic conditions.

It can be found that Location combination 2, which installs VMS at location 2, 6 and 9, performs best among the three location decisions.

We can also conclude that different location combinations perform differently in different incident situations. For example, Location Combination 2 (VMS at 2, 6 and 9) performs best during incident type 1 (severe but short), while Location Combination 3 (VMS at 5, 8 and 14) performs slightly better during incident type 2 (less severe but long). Therefore, locations for VMS should be considered carefully. All incidents should be considered and evaluated, because one VMS location that reduces congestion during one incident may perform poorly during another incident.

Actual planning processes should consider the complete incident history and forecast the probability of an incident in the future. For each incident type, the set of locations will be evaluated. Travel time and delay need to be averaged over all incident type for each candidate location. Variance is also an important variable that should be considered.

In the transportation planning process, the measures of effectiveness include not only the average travel time and congestion index (delay) of different vehicle classes but also the associated investment costs, operational considerations, and environmental impacts, etc.

The analyst can take advantage of the path-based analysis of the VISTA-DTA system and evaluate several potential locations of a combination of VMS signs. A complete analysis should include the potential routing alternatives from the location of each VMS, the benefits for all stakeholders and the associated costs. This procedure can be automated into a VMS evaluation module that will include a user-friendly input/output interface. The output could be customized to produce a summary of all the pertinent MOEs of each transportation agency.

Construction and Maintenance Planning Scenario

Methodology

Adding construction zone into VISTA

A hypothetical 500ft 1-lane construction zone closure was created on link 7909 (see Figure 14).   The parameters are shown in Figure 15. The traffic impacts were calculated from different reports.
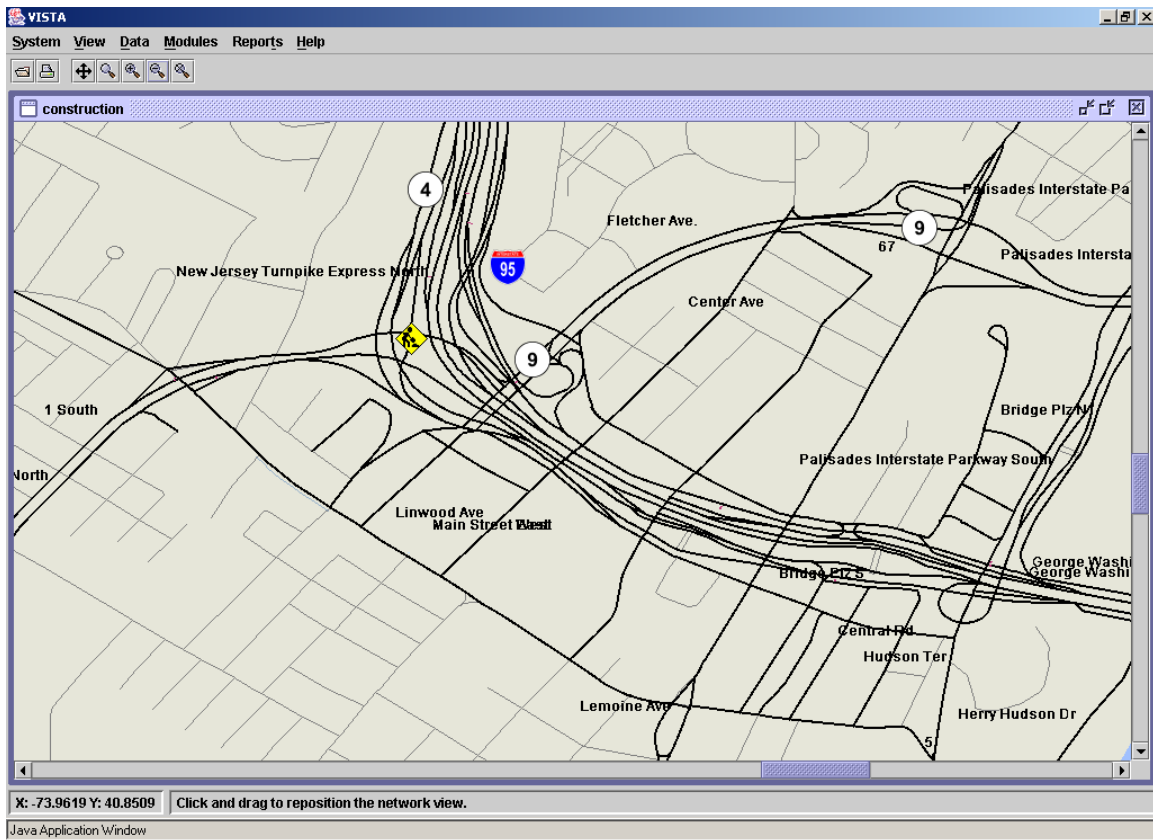
Figure 14. Adding Construction Zone
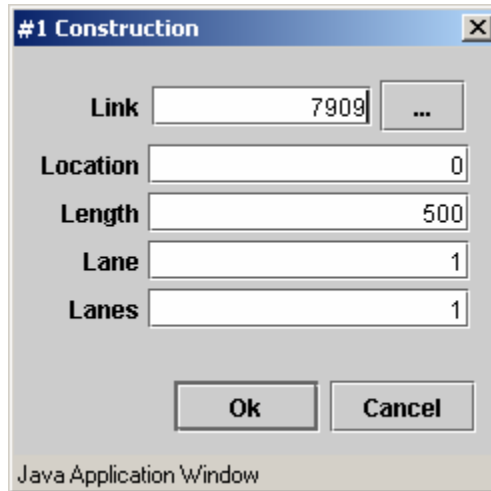
Figure 15. Construction Zone Parameters (as displayed in VISTA interface)

Scenarios

Besides the base case, which has no construction Zone, there are 2 more scenarios:

Scenario 1 has construction zone enabled, with no information provided to drivers (Run RouteSim only since drivers will follow the same paths as before). This scenario demonstrates the situation where no ITS system is involved which also is the worst case in terms of performance.

Scenario 2 assumes all drivers have perfect information (Run UE DTA – all drivers have full information on the expected delays over the entire network), resulting in the best result that could be achieved if people are left to make their own decisions. This could be achieved only by a universal in-vehicle navigation system, a network-wide traffic surveillance system with continuous updates of traffic flow conditions and a two way communication system between the traffic operations center, the traffic surveillance system and the travelers.

Results and analysis

Network level statistics

Table 33. Vehicle Travel Time

Scenario	No. Vehicles.	Total Travel Time (H)	Average Travel Time (M)	STD (M)
Base case	158598	108754.0	41.14	23.08
Scenario 1	158598	112763.0	42.66	23.19
Scenario 2	158598	112263	42.47	23.04

Table 34. Vehicle Delay

Scenario	Vehicle Count	AVG Delay (M/Veh)	Delay STD (M)
Base case	158598	39.63	23.9
Scenario 1	158598	41.36	24.01
Scenario 2	158598	41.15	23.81

The corresponding vehicle travel time and vehicle delay statistics for each scenario at the network level is displayed in tables 33 and 34, respectively.

Construction zone closure statistics

Table 35. Impacted Vehicles

	Scenario 1	Scenario 2
Affected Vehicles	4342	3770
Travel Time Total (H)	2660.0	2177.0
Travel Time AVG (M)	36.77	34.65
Travel Time STD (M)	11.27	11.47

Table 36. Congestion Index

	Scenario 1	Scenario 2
Effective Vehicles count	1117	1122
Delay AVG (M/Veh)	29.12	25.29
Delay STD(M/Veh)	15.24	14.9

Table 35 presents summary statistics for the impacted vehicles only due to the construction for each scenario while Table 36 presents the corresponding congestion index.

From the above tables, it is observed that 572 out of 4342 vehicles in scenario 1 whom could have changed their routes to avoid the construction zone if they could be informed. Therefore, it could be argued that an ITS system could have reduced the average delay from 29.12 minutes per vehicle (under no information) to 25.29 minutes per vehicle (full information) for those impacted vehicles, correspondingly. At the network level, the corresponding reduction in travel time could have been at a level of 500 hours, which is substantial.

Commercial Vehicle Operations (CVO) Scenario

Analysis of truck routes for truck operation efficiency, safety and security

The VISTA system has the capability of modeling both passenger cars and trucks taking into consideration both vehicle performance characteristics and turning movement requirements. The current NJDOT transportation network has designated truck routes forming a sub-network. The New Jersey Turnpike has designated truck restrictions along some sections of the roadway. Trucks are not allowed to go through Holland tunnel and all commercial vehicles are usually restricted to use the upper level of the George Washington Bridge. In addition, commercial vehicles are often stopped at the bridges and tunnels for safety and security inspections. Furthermore, a roadway-pricing scheme is employed for the peak hours along the major toll facilities in New Jersey and the crossings into Manhattan operated by the PANYNJ.

CVO Infrastructure Improvements

The impact of trucks on the transportation network is substantially different to that of automobiles. Trucks have a significantly higher impact on 1) roadway capacity; 2) roadway pavement deterioration; 3) roadway safety; and 4) air quality emissions (NOx, CO, HC) and fuel efficiency. The roadway design must therefore take into consideration the predicted truck volume. The VISTA-DTA could be used to evaluate various alternatives and produce the various MOEs such that all transportation stakeholders can take more intelligent decisions. Some of the truck related MOEs of interest for the evaluation of infrastructure changes are:

Before and after implementation based on the time period of interest:

- Total travel time for trucks, autos, buses,
- OD path travel time for truck, auto, bus and intermodal trips,
- Link travel time distribution for truck, auto, bus and intermodal trips,
- OD path traffic volume for truck, auto, bus, intermodal trips,
- Link travel time distribution for truck, auto, bus and intermodal trips,
- Link traffic volume distribution for truck, auto, bus and intermodal trips,
- Air quality MOEs per trip category, for the network, sub-network, path or link,
- All the above MOEs during the proposed construction.

The analyst could then further examine who benefits or disbenefits from these proposed infrastructure changes, estimate the associated costs and provide the various stakeholders with a basis for conducting comparative analyses.

CVO Traffic Information

The analyst could use VISTA to emulate various real time conditions scenarios by providing information directed to specific classes of vehicles. The messages for trucks usually include congestion levels, estimated route travel times, route prohibitions or truck route designations. Currently at GWB the PANYNJ displays the message "Trucks use Upper Level Only" for trucks that are Manhattan bound from New Jersey in addition to the estimated upper level and lower level travel times. Under a general scenario a message could be posted that says, "Trucks must follow Route X" or "Trucks are prohibited on Route Y." Truck related messages may be combined with an incident management strategy to further alleviate the traffic conditions due to an incident. The MOEs mentioned earlier for the infrastructure improvements are also relevant here especially the OD path and link based MOEs.

Training

The VISTA system could be used to train transportation planners in conducting before and after analyses of various truck-related infrastructure changes. In addition

transportation managers/operators, truck operators, emergency services could be trained to handle various types of real time truck related roadway events such as crashes, hazardous spills, security incidents, other.

The scenario selected for the CVO area is a potential truck related infrastructure improvement that is described in the next section.

Truck Infrastructure Improvement Scenario Methodology

The case study consists of 2 parts:

- The base case: Running Dynamic Traffic Assignment/Simulation for the base case and obtaining reports such as travel time and vehicle counts.
- The truck-only expressway case: Under this case we add a truck-only expressway in the network. The Dynamic Traffic Assignment/Simulation will be run for this case and the results will be compared with the base case to assess the impacts of the proposed new truck-only expressway.

The proposed truck-only expressway is represented by link 200000 and link 210000 (Figure 16); cars were prohibited.

The two scenarios were processed with DTA and simulation.
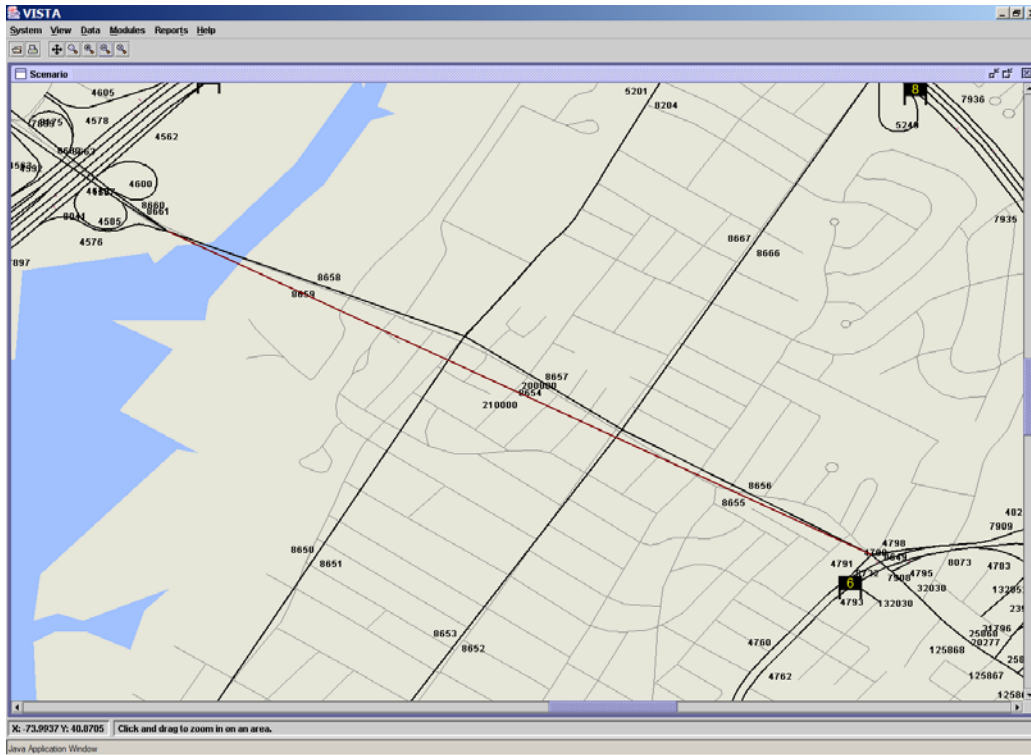
Figure 16. Truck Express Route

Results and analysis

Total travel

Tables 37, 38 and 39 present a summary of the results for the base case and the modeled scenario for all vehicles, passenger cars, and trucks respectively.

Table 37. All types of Vehicles

	Start	End	No. Veh.	Total TT (H)	AVG (M)	STD (M)	MAX (M)	MIN (M)
Base case	00:00:00	01:00:00	122919	78488.0	38.31	25.01	75.0	0.0
Scenario	00:00:00	01:00:00	122919	78670.0	38.4	25.41	75.0	0.0

Table 38. Passenger Vehicles

	Start	End	No. Veh.	Total TT (H)	AVG (M)	STD (M)	MAX (M)	MIN (M)
Base case	00:00:00	01:00:00	94566	60332.0	38.28	25.02	75.0	0.0
Scenario	00:00:00	01:00:00	94566	60505.0	38.39	25.41	75.0	0.0

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Table 39. Heavy Vehicles

	Start	End	No. Veh.	Total TT (H)	AVG (M)	STD (M)	MAX (M)	MIN (M)
Base case	00:00:00	01:00:00	28353	18156.0	38.42	24.98	75.0	0.0
Scenario	00:00:00	01:00:00	28353	18165.0	38.44	25.41	75.0	0.0

A rather small increase in travel time is observed for both the passenger cars and trucks based on the new scenario versus the base case study. Other case studies could be considered such as: 1) All vehicles use the new roadway; 2) Only trucks-trucks are allowed to still use the other roadways; 3) Trucks only - trucks are prohibited to use the original roadway; 4) only passenger cars are allowed on the new expressway.

Vehicle Miles Traveled

Table 40. All type of Vehicles

	Starting Time	Ending Time	Vehicle Count	Total VMT (Miles)
Base case	00:00:00	01:00:00	122919	68659.95
Scenario	00:00:00	01:00:00	122919	62883.3

Table 41. Passenger Vehicles

	Starting Time	Ending Time	Vehicle Count	Total VMT (Miles)
Base case	00:00:00	01:00:00	94566	52767.86
Scenario	00:00:00	01:00:00	94566	48359.35

Table 42. Heavy Vehicles (base case)

	Starting Time	Ending Time	Vehicle Count	Total VMT (Miles)
Base Case	00:00:00	01:00:00	28353	15892.09
Scenario	00:00:00	01:00:00	28353	14523.95

The value of Vehicle Miles traveled under the new scenario decreased significantly, indicating that more vehicles took the shorter route. This could have been observed more transparent if and OD pair analysis was selected. Such module exist in the VISTA

software and it can be activated rather easily. This was demonstrated during the tutorials to NJDOT engineers and planners.

Delay

Table 43. All types of vehicles

	Starting Time	Ending Time	Vehicle Count	AVG Delay (M/Veh)	Delay STD (M)
Base Case	00:00:00	01:00:00	122919	37.42	25.0
Scenario	00:00:00	01:00:00	122919	37.57	25.45

Table 44. Passenger Vehicles

	Starting Time	Ending Time	Vehicle Count	AVG Delay (M/Veh)	Delay STD (M)
Base Case	00:00:00	01:00:00	94566	37.39	25.01
Scenario	00:00:00	01:00:00	94566	37.56	25.46

Table 45. Heavy Vehicles

	Starting Time	Ending Time	Vehicle Count	AVG Delay (M/Veh)	Delay STD (M)
Base Case	00:00:00	01:00:00	28353	37.52	24.96
Scenario	00:00:00	01:00:00	28353	37.61	25.45

The delay MOE showed a similar pattern as the one in the travel time measure. The two scenarios are basically the same.

MOBIL6 Emission report

The VISTA software has embedded an interface with the FHWA's air quality analysis MOBILE6 software. The figures and tables presented in this section present a sample of the MOBILE6 data that could be produced.
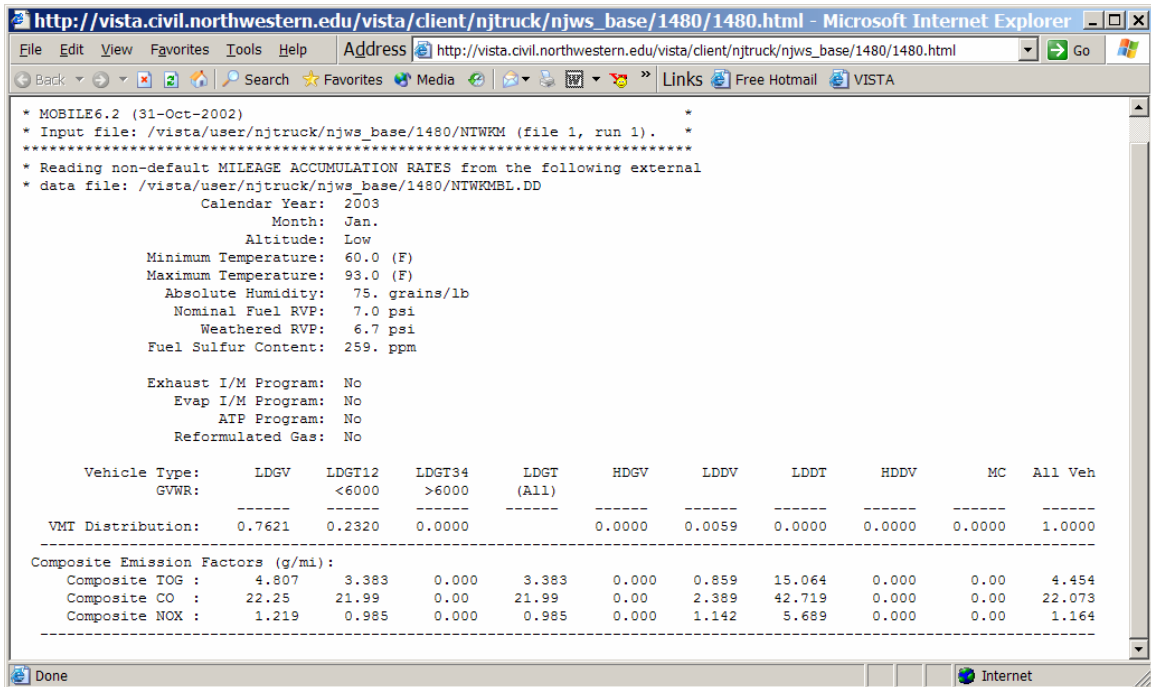
Figure 17. MOBILE6 Emission Report on Base Case
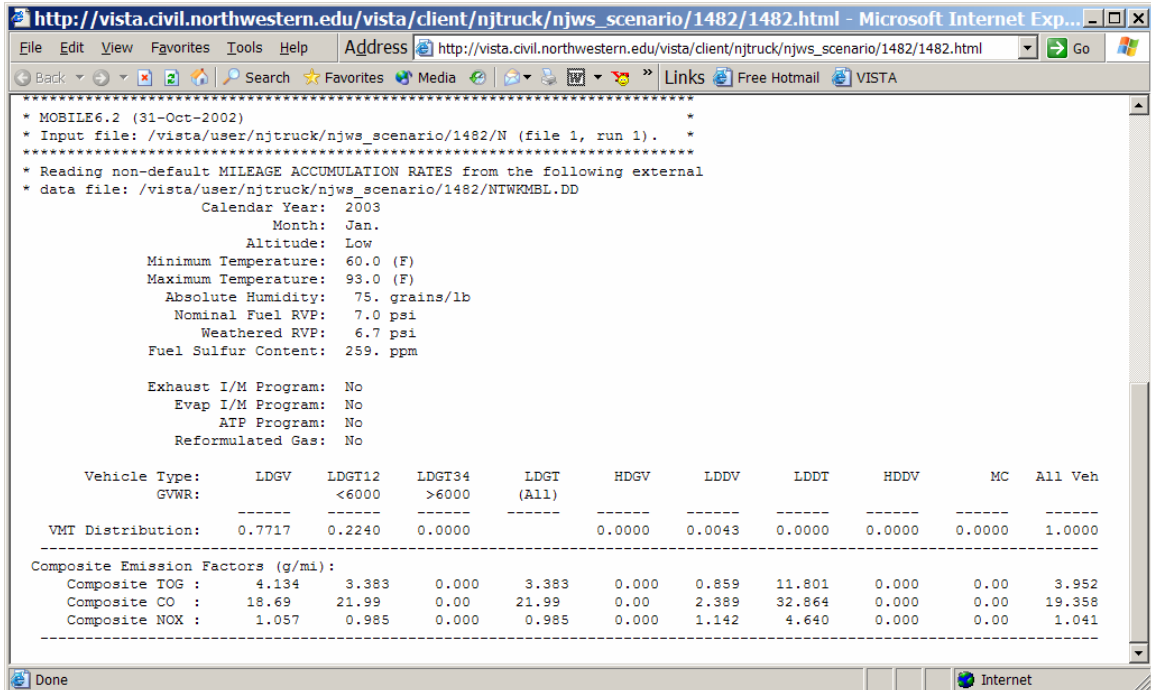
Figure 18. MOBILE6 Emission Report on Scenario Case

The MOBILE6 emission report on the whole network showed less pollution was generated. This could be an important factor for decision makers.

Table 46. Emission Results for All Types of Vehicles in the Network

Composite Emission Factors for all vehicle types (g/mi):	Base Case	Scenario
Composite TOG	4.454	3.952
Composite CO	22.073	19.358
Composite NOX	1.164	1.041

Recommendation

The VISTA system may be employed to model all the different types of truck related infrastructure and operational changes to evaluate various alternatives to improve the efficiency, safety and security of the transportation system as a whole and the efficiency of truck operations.

CONCLUSIONS AND RECOMMENDATIONS

This project developed core capabilities for NJDOT within a framework known as Visual Interactive System for Transport Algorithms (VISTA) to enable planners and engineers to evaluate basic ITS technologies considered to be used on its roadway system; as ITS technologies advance such needs for assessing their impact are expected to be increased.

It was established in this research that the present state of practice of transportation simulation modeling did not have the capability to represent the ITS technologies and adequately capture the travelers' reactions to them. Specifically the widely used traffic simulation models (CORSIM, VISSIM, PARAMICS, WATSIM, AIMSUN) do not have a driver routing component (either User or System Optimal).

As Intelligent Transportation Systems (ITS) evolve, various ITS technologies are deployed along the priority corridors operated by the New Jersey Department of Transportation (NJDOT). In order to provide an effective method to evaluate the impacts of these technologies on the corridor and maximize the benefits from them, a dynamic traffic simulation and assignment tool was enhanced to assist NJDOT engineers and policy makers in decision-making and effective design.

The tool adopted for this purpose is the Visual Interactive System for Transport Applications (VISTA) that incorporates a suite of models, provides database support and flexible reporting capabilities. The tool was customized for the NJDOT needs as identified by their engineers, planners and administrators in a series of meetings and tutorial sessions held throughout the project performance period. The I-80 corridor was identified as the application corridor, data were collected from a number of agencies that operate on this corridor, and the necessary functionality was built to address the identified needs. The enhanced tool (called NJDOT-VISTA) has been completed and demonstrated to NJDOT engineers and administrators in a final tutorial session on June 2003. The principal characteristics of the implemented NJDOT-I-80-VISTA system are:

I-80-VISTA data model

The VISTA software package stores input and output data in a **PSQL database**. The VISTA system has its **own GIS database platform** that was specifically designed to include all necessary transportation data and interface it with the data warehouse and transportation algorithms in an efficient way. However, if necessary, the user has the capability to interface its own GIS platform to the VISTA warehouse and import its data in an efficient manner. The PSQL database can be accessed through either a *GIS client interface*, or a *web-reporting interface* at various levels of authorization (full authorization or limited authorization). An engineer or planner at NJDOT may be given full authorization to edit the database and run any model from wherever she/he is; another consultant may be able to view the database and download necessary data for a study that his/her company is conducting. **This data model is consistent with the way major corporations conduct their businesses over the Internet or private Intranet creating efficiencies, reducing duplications of data collection, and allowing utilization of the same data by all stakeholders.**

The GIS interface provides a user-friendly data input and editing windows. The web-reporting interface is more convenient for querying and viewing many records at once and is recommended for more experienced users. The principal data required by the various VISTA transportation algorithms are:

1) *Network infrastructure data:* link and intersection geometry and topology, traffic control type (signalized, unsignalized);
2) *Traffic control data:* signal timing, unsignalized control type, lane designation;
3) *Traffic flow data:* dynamic (or static) Origin-Destination (OD) matrix per vehicle class (auto, truck, person) per time period of the day, bus and train schedules, traffic flow rates per vehicle class and time period of the day from historical traffic counts.

The data for the I-80 corridor were obtained from the New Jersey Department of Transportation (NJDOT), the NJ Turnpike Authority, TRANSCOM, the Port Authority of

NY and NJ, the North Jersey Transportation Planning Authority, and from NJ Institute of Technology.

Recommendation

Establishment of a comprehensive Universal Data Model (UDM) for NJDOT

Given the prototype NJDOT-VISTA data model that was developed for the I-80 corridor, a comprehensive data model can be established for the entire state. An incremental plan could be developed that will utilize the efficiencies provided by the VISTA system to establish this model. Specifically, we propose the following:

Upgrade the existing GIS system

to incorporate all the necessary items that the VISTA transportation algorithms need. This new GIS system must be navigational and have the correct geometry, link and node characteristics.

Upgrade the data model

to incorporate transportation related data that are currently not part of a universal database such as accident data, land-use data, weather, environmental data, other.

Establish seamless procedures for the continuous updating of the database, ensuring data quality and security

These procedures will involve all main players who are involved in the operation and planning of the transportation system. These players may include: transportation planners, traffic operators, contractors, consultants, police, EMS, Fire department, Department of Homeland Security, other. For example, a procedure could be established for the automatic entry of an accident record directly by the police officer into the VISTA data model as soon as the police officer completes his/her report through the Internet or some other secure state network. A contractor/engineer could submit the new roadway configuration during the construction and immediately after construction to the VISTA data model ensuring that the transportation algorithms will "know" this new geometric change. Data collected by a consultant for a traffic impact

analysis can be uploaded to the data model providing a continuous feed and calibration of the VISTA-DTA model. The efficiencies of the establishment of such a UDM system will be enormous.

The VISTA Transportation Models

RouteSim Mesoscopic Simulator

RouteSim is a mesoscopic simulator based on an extension of Daganzo's (1994) cell transmission model introduced by Ziliaskopoulos and Lee (1996). **In the cell transmission model, link conditions are simulated by evaluating flow at a finite number of intermediate points. In other words, the movements of small groups of vehicles are simulated as they enter and leave sections of each link. The principles of the cell transmission model are consistent with the hydrodynamic theory of traffic flow, but can also capture microscopic effects, such as queuing. The computational efficiency of the mesoscopic model allows mesoscopic simulators to solve large networks faster than real time.** The main enhancements over the basic cell transmission model are (i) the concept of adjustable size cells that improves the flexibility, accuracy and computational requirements of the model, and (ii) a modeling approach to represent signalized intersections. The cell transmission model can be used to simulate integrated freeway/surface street networks with varying degree of detail. **While RouteSim is designed as a mesoscopic model, it allows the user to utilize a microscopic traffic simulator to produce more detailed results for a sub-network of interest.**

The basic characteristics of RouteSim include:

- It is a simulation/assignment model based on either UE or SO paths,
- Every vehicle moves on its UE or SO path until it reaches its destination,
- It is a mesoscopic simulation model with incremental data needs; it generates data that may currently be available,
- It is computationally efficient, can run in a distributed environment, and designed for large scale networks,

- It was designed especially for ITS applications,

- It is currently available and can easily be accessed through the web using an account,

- It has a user friendly windows based Graphical User Interface that any engineer or planner can easily be trained to use,

- It is platform free (Windows NT, Unix, Linux) such that any engineer/planner can access and use without any additional hardware and software.

In addition to the above features, additional enhancements were suggested to be done for the NJDOT-VISTA version:

- To be customized for a specific corridor in New Jersey
- To rely only on existing data sets from all agencies that could potential maintain data
- To integrate the data
- To provide Cost/Benefit report modules
- To be able to capture construction zones
- To model Variable Message Sign logic with variable compliance level
- To be able to assist NJDOT engineers to identify alternate routes
- To represent TRANSMIT detectors
- To survey reporting needs of NJDOT engineers and provide interfaces for such reports
- To allow access to NJDOT engineers and planners for the duration of the project

The present form of the RouteSim simulator as implemented on the I-80 corridor that has 2,565 nodes, 5,818 links and 444,829 OD trips requires about 10 minutes to run. In another implementation in Chicago, IL for a network that has 17,122 nodes, 50,079 links and 1,142,520 OD trips, it requires 2 hours to simulate a 5-hour period. **These execution times are very encouraging even for real time operations as the model could also be used to run various what-if scenarios in cases of incident management.**

The VISTA Dynamic Traffic Assignment Model (DTA)

DTA models are used to estimate time-varying network conditions by capturing traffic flow and route choice behavior. **The principal output of a DTA model is the start/end time and time-dependent shortest path that is based on some route choice behavior rule (e.g. User Equilibrium (UE), System Optimal (SO)) for each individual vehicle.** The DTA models were envisioned by the Federal Highway Administration (FHWA) as tools that could be used initially as off-line tools to evaluate various types of Intelligent Transportation Systems (ITS) technologies and infrastructure improvements, such as: 1) functionality, location and number of vehicle detection devices; 2) Impact of traveler information messages and location of Variable Message Signs (VMS); 3) Evaluation of incident management plans; 4) Evaluation and optimization of traffic control measures (location, type of control, signal timing); 5) Estimation of environmental impacts; 6) Evaluation of various types of infrastructure changes such as increase/decrease the number of lanes, vehicle class related changes such as special truck lanes or HOV lanes, addition/deletion of roadways or intersections/ interchanges, changes in interchange/ intersection configuration; 7) Conducting more accurate and robust traffic impact analyses, other. **DTA models overcome the inherent deficiencies of static traffic assignment models, namely, time-dependent traffic flow dynamics and link interactions.**

The VISTA-DTA is a simulation-based model developed by Ziliaskopoulos and Waller (2000). The model utilizes the RouteSim mesoscopic traffic flow simulator, which at each iteration produces the traffic flow propagation given the results from the *network flow loading module* and the *time-dependent shortest path algorithm*. The network flow loading module requires knowledge of the dynamic OD matrix for each vehicle class. The DTA algorithm stops when a convergence criterion is met. The dynamic OD matrix was estimated by VISTA's proprietary dynamic OD algorithm using the NJTPA's static OD matrix for the North Jersey transportation planning model and the traffic flow data obtained from the agencies operating on the I-80 network.

The implemented VISTA system on the I-80 corridor provides NJDOT with a prototype to build on and establish a VISTA-based UTM for the entire state. It has been demonstrated that engineers and planners can now utilize this prototype to experiment with "what-if" scenarios and evaluate the impact of technologies and systems before they are actually deployed. Identification of effective and ineffective ITS technologies / options could save millions of dollars in deployment, by more efficiently allocating the resources during the planning, design, operations and maintenance phases, while improving the time saving for the motorists. Various typical scenarios were selected and studied in this report. They systematically unleashed the power of VISTA and showed how this sophisticated framework can benefit planning and operation.

In the short term the current static traffic assignment model used in both the North and South Jersey transportation planning models can easily be replaced by the VISTA-DTA. This will "free" the modeling from standard link travel time functions and their cumbersome calibration procedure with the basic characteristics of the transportation network (geometry, signal timing, lane designation) that will set up the basis for a continuous UTM model. Where traffic flow data are collected either from automated detectors or through studies the model will perform more accurately, and it will be dynamically updated.

The establishment of a **comprehensive data model** that is integrated with the necessary transportation algorithms to support traffic operations and transportation planning is now more than necessary as each state tries to more efficiently allocate their resources to improve the transportation system. Each transportation agency, DOT and the federal government could develop a more **comprehensive asset management plan that will be continuously updated based on the results of a calibrated Universal Transportation Model.**

VISTA-based Measures of Effectiveness (MOEs) for Traffic Management, Traveler Information and Infrastructure Planning

The main MOEs that could be produced by the VISTA system are:

- Total travel time distribution of the network or sub-area for all vehicles, autos, trucks, buses, respectively.
- Path travel time distribution per time period of the day for each OD pair; this may be disaggregated at an individual trip level such as auto only, transit only (bus or train), intermodal (auto plus bus, auto plus train, bus plus train), truck only, train only (CVO applications) truck plus train (CVO);
- Path travel time distribution for emergency vehicles, to/from the scene of an incident, such as police, EMS, Fire Department, Department of Homeland Security, Environmental Protection Agency, towing services, other;
- Total Vehicle-Miles Traveled (VMT) for all vehicles, autos, trucks, buses, respectively - this may be further disaggregated for each OD pair;
- Air quality MOEs such as CO, NOx, HCs for the entire network, or sub-area for all vehicles, autos, trucks, buses, respectively;
- Air quality MOEs for each OD pair, link (as before);
- Traffic volume distribution per vehicle class for each OD path, link/superlink of the network, per time period of the day.
- Link/superlink travel time distribution per time period of the day.

Next we present the main modules that have been implemented under this study and we further expand on other capabilities of VISTA.

VISTA for ITS operations

Traffic Management and Traveler Information

Incident management

An incident management system is usually comprised by the traffic surveillance system, the incident response system and the travelers information system. The traffic surveillance system can be emulated in VISTA through the "installation" of various types of detectors at various locations. The incident response system refers to the procedures followed by the emergency services (e.g. police, EMS, Fire department, towing services, other) that are usually employed when an incident occurs. The VISTA system

can emulate the routes that the emergency vehicles should follow in order to arrive at the scene of an incident given the prevailing traffic conditions. The VISTA system could utilize its time-dependent shortest path algorithm to identify the best route for each emergency vehicle from its current location to the incident location and from the incident location to its final destination (e.g. hospital, firehouse, police station, other). The incident duration is difficult to estimate in real time so historical data could be used to serve this purpose based on the accident severity and location. Furthermore, an incident management plan may include pre-set route diversion strategies. The analyst could use the VISTA system to emulate an incident management plan and conduct parametric analyses on the various parameters associated with it.

Incident management analyses could be conducted on the location and functionality of detectors, spatial location and response times to/from the incident of emergency services, impact of traveler information (e.g. VMS location and content) on the traffic conditions for either all vehicles of groups of vehicles, evaluation of route diversion routes.

Construction Zone Management

The construction zone management is a special case of incident management with the special characteristic that the events are known beforehand. Another characteristic is that the travelers within a few days they readjust their paths to their destination based on the knowledge that they experience due to the impact of the construction zone. In principal a construction zone may involve capacity reduction that may be accompanied with diversion route(s). A construction zone case study for the I-80 was emulated using the VISTA system.

Base Case

No construction zone is present – the VISTA-DTA produces the paths based on normal traffic conditions.

Scenario 1

A construction zone is enables at the I-80 involving two lanes. No information is provided to the travelers – The previous paths based on the case study are loaded into the RoutSim simulator that produces the new traffic flows and corresponding travel times taking into consideration the capacity reduction due to the construction zone.

Scenario 2

Assume that all travelers know about the incident and they readjust their paths based on full information – The VISTA-DTA is now executed with the new network configuration producing the new path assignment resulting in new traffic flows and path travel times.

The above case study could be extended to include Variable Message Signs (VMS) and the VISTA system may be employed to conduct parametric analyses based on the location and content of the VMS. In addition, various route diversion plans may be evaluated including associated arterial signal timing optimization and freeway ramp metering. Furthermore, the transportation analyst could run an extended analysis of the entire schedule of all proposed construction zones of the transportation network and conduct alternative analysis. The latter may provide a powerful tool to the NJDOT by ensuring that the traffic conditions due to various construction zones do not degrade the performance of the transportation network unnecessarily. Then the analyst could rank all potential scheduling scenarios based on some criteria (e.g. corridor/ network travel time, specific OD path travel time, other).

Recommendation: Develop a customized construction and maintenance module that will emulate the impact of the construction zone, alternative scheduling scenarios, and freeway ramp metering and arterial signal timing optimization.

Analysis of real time traffic flow information to travelers

In the NY/NJ metropolitan area people receive traffic flow information through VMS, Highway Advisory Radio (HAR) and Commercial Radio. In the near future, TRANSCOM

will roll its web-based TRIPS123 traveler information service for the entire metropolitan area.

The VISTA system is capable of emulating various traffic conditions and identify the travelers that may be affected by changes to the normal traffic conditions by knowing a priory the path that each vehicle is expected to follow to his/her destination. Given this capabilities, the analyst could produce estimates of the impact of traffic flow information to all or to a set of travelers such as: trucks only, travelers following a specific path only, drivers following a common OD or a set of ODs, transit travelers only and any combination that the analyst wants.

"Optimal" Location of VMS. The present version of VISTA includes the capability of the analyst to install a VMS and conduct parametric analyses based on the information provided on the VMS. The location of a VMS sign can thus be evaluated based on the impact of the information that could potentially have on the travelers that pass through it.

The VMS case study implemented for the I-80 corridor in the vicinity of George Washington Bridge considered the following potential scenarios:

Base case without VMS, no incident. This produces a DTA assignment without the impact of an incident, producing the normal paths that the users take to their destination.

Scenario 1 with incident but without VMS. An incident occurs and travelers do not have any information. The user specifies 1) the location of the incident, 2) its severity (percentage of capacity reduced) and 3) its expected duration. The RouteSim simulator utilizes the existing paths from the base case to produce the impact of the incident on the same OD paths.

Scenario 2 with incident and VMS enabled, run RouteSim only. Under scenario 2 the user sets 1) the location of the VMS, 2) the content – in this case study the estimated travel time through the upper and lower GWB levels was provided, 3) the

compliance rate – the percentage of travelers who follow the shortest route (upper or lower deck). This allows the analyst to conduct parametric analyses on the impact of the VMS location and compliance rate on the entire network and specific OD pairs.

Scenario 3 with incident and VMS enabled, run both assignment model and simulation. Scenario 3 assumes that all travelers know about the incident and they redistribute themselves according to the DTA. This provides a powerful tool to the analyst to study the impact of providing the information to all travelers versus to a limited number of travelers (e.g. those passing through VMSs or receiving information through a wireless phone service).

In a more comprehensive scenario we considered the evaluation of three potential locations for VMSs based on assumed historical information of incidents at the upper and lower level of GWB. **It was concluded - as expected - that different VMS location combinations perform differently under varying incident situations. These case studies demonstrated that a comprehensive analysis of the location of VMS signs prior to implementation could be cost effective.**

Real time traffic volume and travel time estimation and prediction

One of the principal components of a real time Advanced Traffic Management System (ATMS) and Advanced Traveler Information System (ATIS) is the estimation and prediction of traffic volume and travel time per time interval (e.g. 1, 5, 10, 15 minutes). The VISTA-DTA currently produces these statistics for the time period of interest (e.g. period 6:00 – 10:00AM or a full 24-hour) and level of detail based on the estimated dynamic OD matrix. The system implemented for the I-80 corridor utilized the NJTPA's static OD matrix and historical 15-minute traffic flows from NJDOT, NJTA and PANYNJ.

A future model could be developed that will produce a new dynamic OD matrix in real time given the current traffic flows from various detectors (TRANSMIT, inductive loop detectors, other) located along the network based on a revised algorithm that should be able to run in real time. The development of such an algorithm will produce estimates of current traffic conditions even at places that do not have any detectors and predict the

future traffic conditions based on the current prevailing conditions and historical information. Additional calibration would be done off-line based on the historical data collected from the detectors as well as OD surveys. **The principal advantage of using a DTA model for traffic flow estimation and prediction is that it is path based versus the traditional forecasting models that are link based and they do not take into consideration the drivers' behavior.**

Recommendations

Develop a module that will produce an automated set of traffic flow statistics for either all drivers or selected sets of drivers given a set of incidents, construction zones;

Enhance the present VMS module to

- **Automate the generation of statistics based on the location of a VMS and the location and severity of an incident,**
- **Develop algorithms for the determination of the optimal location and basic content of VMS signs based on the desired objective(s),**
- **Develop an asset management plan for VMS locations and content;**

Develop a real-time DTA-based traffic flow and travel time estimation and prediction algorithm model. Develop 3.1) an enhanced off-line dynamic OD matrix estimation algorithm for the entire New Jersey state; 3.2) Develop a real-time dynamic OD matrix estimation algorithm for a network with relatively good traffic surveillance system;

Develop an asset management plan for the establishment of a statewide advanced traveler information system.

VISTA for planning

Evaluation of proposed infrastructure improvements

The current transportation planning models utilize a static traffic assignment to estimate/predict the traffic flows on the links of the network. As demonstrated DTA models are more accurate and they offer more functionality to the transportation planners who can now take more intelligent decisions on various types of infrastructure improvements – roadway/interchange changes, roadway user pricing, installation of detection devices, installation of VMS signs etc. A change in the capacity of a link of the network or the addition or deletion of a new roadway can be easily evaluated with a *calibrated VISTA-DTA* model since it will automatically produce the path choices off all drivers based on the new network configuration. Given a continuously updated data model and a calibrated VISTA-DTA model, **a comprehensive transportation asset management plan could be developed that will be dynamic, producing up-to date cost-benefit analyses on on-going and proposed projects.**

Recommendation

- **Develop a transportation planning model that will be a semi-automatically self-calibrated to evaluate various short-term and long-term infrastructure improvements;**
- **Develop a user-friendly interface to produce the relevant MOEs for the proposed infrastructure change;**
- **Develop a transportation network design model that will identify the "optimal" projects to be selected among a set of potential projects based on the NJDOT objectives and the budget availability.**

Evaluation of park and ride facilities location/capacity

The park and ride program is one of the most important for the state of NJ given its density and the large number of commuters that work at Manhattan. NJDOT is continuously evaluating its existing park and ride facilities to identify whether they are

overcrowded or underutilized and try to find potential solutions. In addition, it is actively looking into areas where new park and ride facilities should be build and what the capacity should be. Furthermore, NJDOT is looking into potential technology solutions that could aid in the better utilization of the existing facilities.

As part of a related project "Technical Solutions for Park and Ride Facilities" sponsored by the NJDOT, two prototype intermodal planning models were developed, a static model and a DTA-based model. The VISTA-DTA intermodal model is able to handle both to auto, transit only, and intermodal (auto plus transit) users. The capability of modeling intermodal trips is essential for the evaluation of park and ride facilities since the majority of the trips involve people who park their car at the facility and continue their journey to their destination with a bus or train or through carpooling. **The addition of new parking spaces to an existing facility could be evaluated by conducting parametric analyses by changing the number of new arrivals from the existing distribution of the OD matrix.** The DTA model will redistribute the OD paths based on the new parking capacities and demonstrate the impact of the new intermodal trips on the network and the corresponding transit ridership. **Given this capability the analyst can evaluate the impact of a new facility or a capacity change on an existing facility could have on the surrounding transportation network.**

Recommendation

Develop a statewide VISTA-DTA intermodal planning and operational model to evaluate the location and capacity of park and ride facilities.

VISTA for transit and intermodal operations

Implementation of transit into VISTA for NJDOT

The VISTA system is capable of modeling passenger cars, buses, trains as well as intermodal trips. It has been employed by the Regional Transit Authority of Chicago to evaluate transit signal priority plans for its entire bus system. In another application it is implemented to emulate bus operations in the downtown are of the City of Newark as

part of a project for the Great Cities University Consortium. The advantage of the VISTA-DTA is that it captures the users behavior due to the selected transit signal priority system that is employed. Contrary, simulation-based software such as COSRSIM or VISSIM they simply assume that travelers will not change their behavior, which may lead to erroneous results. Furthermore, a VISTA-based person traffic assignment is nearing completion that will provide a much more powerful tool to the transportation and transit planners and traffic engineers to evaluate various transit related improvements such as: bus schedules, transit signal priority, location of park and ride facilities. Furthermore, a real time model can be employed that could evaluate dynamically various bus schedules and propose the best alternatives given the prevailing and projected traffic conditions, dynamically change the signal timing plans for transit signal priority control, and to produce real time estimates and prediction of bus/trains travel times and arrivals at the bus/train stations that can be part of an advanced traveler information system (e.g. the TRIPS123).

Recommendation

Develop a comprehensive VISTA system that will incorporate passenger cars, buses, trains and park and ride facilities for NJDOT and New Jersey Transit. Develop a VISTA transit signal priority system, an optimal transit-scheduling module, and a real time multimodal/intermodal route-planning algorithm for traveler information.

VISTA for traffic operations

The VISTA system as implemented for the I-80 corridor incorporated only the major arterials and excluded local roadways. The corresponding signal timing plans were obtained from NJDOT and incorporated into the VISTA database. The VISTA system has its own signal warrant/optimization algorithm that is activated if the user desires to do so. It is realized, however that NJDOT engineers use a number of signal analysis and optimization software such as HCS, SYNCHRO, PARAMICS, TRANSYT7F and CORSIM. The current version of VISTA has a two-way interface with SYNCHRO, although not implemented for this project. Similar interfaces can be developed for each

one of these software to provide flexibility to the NJDOT engineers, planners and consultants to run their models on the desired software and take advantage of the VISTA data model and the VISTA-DTA. The VISTA-DTA will produce the path assignment of the vehicles based on the new signal-timing configuration and the associated MOEs.

Recommendation: Develop 1) two-way interfaces of the VISTA model with various traffic operation software that NJDOT engineers and planners use, and 2) a user friendly interface for each of the integrated software.

Establishment of a statewide traffic impact analysis module

One of the main functions of NJDOT is to issue access permits to businesses that want to build, expand a facility (restaurant, gas station, office complex, shopping center, etc.). The NJDOT requires from these corporations to perform traffic impact analyses. The present method relies on the analysis conducted by transportation consulting firms who usually collect traffic data in the vicinity of the location of the new or existing facility, combine them with historical traffic flow data and they develop a transportation planning model for the network around the facility, which sometimes may be very large (involving several hundred intersections) or very small (e.g. only one intersection). This methodology however has inherent deficiencies: 1) First, there is no consistency on the results of each model (e.g. two different consultants may work on the same network and they may use a different transportation planning model), 2) The collected data in the majority of the cases disappear, where they could be used to calibrate a statewide transportation planning model, 3) It is rather difficult and time consuming for the NJDOT engineers to evaluate the results of each traffic impact analysis study.

The establishment of a statewide VISTA system will provide a universal framework for conducting traffic impact analyses both by NJDOT engineers and planners and the consulting companies. This model will be continuously updated with the data collected by the consultants, NJDOT studies. A module could be within VISTA that will be able to efficiently evaluate the analyses produced by the consultants and identify any

deficiencies. Such a module will provide consistency to all traffic impact analyses conducted for NJDOT and an efficient system of sharing related transportation data among interested parties, avoiding duplicated data collection efforts and identifying erroneous data and inconsistent results.

Recommendation

Develop a statewide traffic impact analysis module using the VISTA system –

- **Develop universal procedures and data format for traffic flow data collection and dissemination to/from NJDOT that should be followed by all NJDOT engineers, planners and consultants,**
- **Develop a module to identify data inconsistencies in traffic impact analyses.**

VISTA for freight operations and planning

Analysis of truck routes for truck operation efficiency, safety and security. The VISTA system has the capability of modeling both passenger cars and trucks (see related implementation in Chicago, IL -) taking into consideration both vehicle performance characteristics and turning movement requirements. The current NJDOT transportation network has designated truck routes forming a sub-network. The New Jersey Turnpike has designated truck restrictions along some sections of the roadway. Trucks are not allowed to go through Holland tunnel and all commercial vehicles are usually restricted to use the upper level of the George Washington Bridge. In addition, commercial vehicles are often stopped at the bridges and tunnels for safety and security inspections. Furthermore, a roadway-pricing scheme is employed for the peak hours along the major toll facilities in New Jersey and the crossing into Manhattan operated by the PANYNJ.

Recommendation

The VISTA system may be employed to model all these different types of truck related infrastructure and operational changes to evaluate various alternatives to

improve the efficiency, safety and security of the transportation system as a whole and the efficiency of truck operations.

VISTA for emergency analysis

The VISTA system offers a framework for conducting emergency analyses in a seamless manner since most of the algorithms - DTA model, time-dependent route planning algorithms including intermodal algorithms - are already embedded into the system. The route planning algorithms are necessary for all emergency services such as EMS, fire department, towing services, police, and security related agencies. In addition these route-planning algorithms are necessary for buses and other para-transit vehicles as well as for automobiles equipped with in-vehicle navigation systems that are crucial in offering evacuation services to the citizens.

The set of VISTA emergency and evacuation modules are envisioned to be used for off-line emergency analyses, real-time implementation and training exercises. In addition, for each module a semi-automated self-calibration procedure will be designed that will be based on data collected automatically by roadway detection devices (roadway based sensors) and in-vehicle devices (GPS, communication), as well as data collected by each agency for each emergency event. A database will be designed for each emergency category that will be continuously revised to best emulate the characteristics of the local conditions.

Recommendation

Establish a universal VISTA based evacuation module for the state of NJ that will cover: hurricane or severe storm, nuclear plant, hazardous material spill, fire, terrorist act or flooding. A set of modules will be designed for each of the emergency agencies that will be customized for their local area to be used for: continuous training of related emergency agencies, off-line evaluation of various emergency alternatives, real-time implementation and continuous calibration based on feedback from each event.

Hurricane or severe storm

Develop a module that could be used to analyze various evacuation alternatives given that a severe storm is projected to arrive in NJ either from the Atlantic Ocean or from any direction of the continental USA. This module will at least offer the capability to estimate and predict the traffic flow conditions for each alternative and it could be combined with a comprehensive network design module (signal optimization and roadway capacity changes) such as the decision makers could choose the best alternative(s) prior to the implementation of such plan. In addition, a real-time VISTA evacuation module could be designed that will be able to run in times faster than real time, such that any changes due to the effect of the specific set of dynamic events have on the roadway capacity (roadway flooding, signal blackout, roadway closures due to security concerns, other) and operation can be emulated and a set of alternatives could be evaluated in real-time.

The evacuation module will further include a **real-time assignment and route planning of emergency vehicles** (EMS, fire department, police, towing services, security vehicles, food and medical supply vehicles, other) to/from damaged areas or the scene of incidents.

Furthermore, a **dynamic optimal network design module could be developed** that will find the best alternatives for 1) a dynamic fleet assignment for emergency agencies, 2) a dynamic network-wide capacity restoration such as tree removal, flooding reduction, pavement restoration, bridge rehabilitation and other capacity reduction, and 3) dynamic fleet assignment of utility companies for power restoration.

A **user-friendly interface** will be designed within VISTA for each type of emergency evacuation and the specific geographic area of NJ. Furthermore, a detailed plan for the implementation of the evacuation module will be designed, including a set of training courses for the relevant parties in NJDOT, and emergency services.

Nuclear plant emergency evacuation

The principal difference between a hurricane and a nuclear plant evacuation is the direction of the evacuation routes as well as the emergency agencies that are involved. The specific module will follow the directions of the Federal Emergency Management Agency (FEMA) for nuclear plant evacuation plans, the existing NJDOT evacuation plans and other suggested evacuation plans and emulate them within VISTA.

Hazardous material spill response/evacuation

A hazardous material spill usually involves roadway closures and evacuation of people within a relatively smaller radius than a nuclear spill. It may also involve special agencies – usually the Environmental Protection Agency (EPA) - for the clean-up of the affected area. The corresponding VISTA module will incorporate the standard procedures followed by the EPA for each specific type of hazardous spill. As an off-line tool it could be used to evaluate various alternatives and for training of the emergency related services.

Fire response/evacuation

The principal characteristics of a fire incident may include roadway closures, route planning of emergency vehicles to/from the scene of the fire. This module could be designed with help from the fire department, EMS and police for each local area of NJ in order to ensure that the model represents adequately the impact of a fire and emulate at least the existing procedures. Then this module could be used for the evaluation of alternative plans. Furthermore, a real-time fire response/evacuation module could be developed that will aid the emergency services to optimize their functions based on continuously updated traffic conditions.

Flooding response/evacuation

The VISTA system has been adopted by the US Army Corps of Engineers for the analysis of flooding in the Mississippi valley. This experience may be transferred to the

appropriate authorities in New Jersey on the use of the model. Flooding analysis can be useful in evaluating various alternatives to evacuate people, identifying alternative routes based on historical experience of flooded areas, and optimal assignment of rescue personnel and optimization of their routes. A real-time VISTA-flooding module could be used to continuously estimate, predict the traffic conditions based on information of the level of roadway flooding. Such a real-time module should incorporate the types of vehicles that could/could not traverse the flooded roadways (e.g. trucks, buses, SUVs, passenger cars). This type of analysis could help to inform travelers to avoid certain roadways based on the predicted roadway flooding levels.

Recommendation

Develop an off-line statewide response/evacuation model to conduct off-line analyses of various emergency scenarios and potential response strategies and training of emergency personnel, 2) Develop a real-time statewide response/evacuation model to aid in the estimation and prediction of traffic conditions and the optimization of the paths for the emergency vehicles and the evacuation routes.

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APPENDIX A: SOFTWARE WALK-THROUGH

Introduction

The VISTA software can be used to view and edit data inputs, and to run modules, reports and simulation animation. These functions can be accessed through either a web interface or a GIS client interface. The web interface displays data and reports in detailed table format, and allows the status of analysis and reporting tasks to be observed. The GIS client interface shows the data in graphic format, and includes windows for editing of input values. DTA and reporting modules can be run in both the web and client interfaces. Simulation animation is only available in the client interface, since it is inherently a graphic function. This document is a guide to using these functions in the VISTA software, beginning with instructions on logging into and out of VISTA.

Logging into and out of VISTA

The VISTA software runs over a network, and can be accessed anytime from any machine; however, access is password-protected, so users must log into and out of the software. This section explains how to log into VISTA, open a network and log out of VISTA in both the web and client interfaces.

<u>Logging into and out of the Web Interface</u>

Launch **http://vista.civil.northwestern.edu/** in Internet Explorer (see Figure A1-1), and login by entering your username and password in the Web Interface login box.
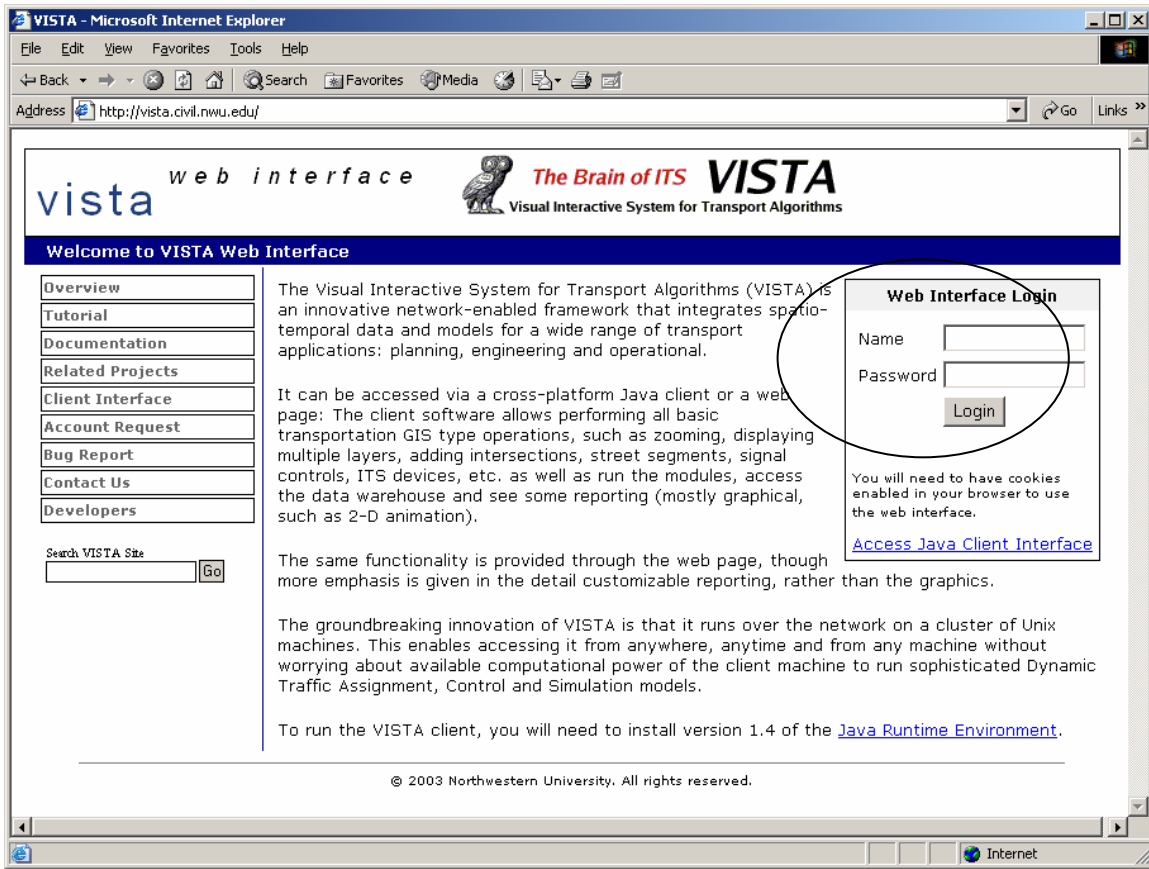
Figure A1-1. Web Interface Login Screen

The next screen is VISTA's Home screen (see Figure A1-2). From this page, a network can be selected for further examination. Further, the banner across the top of the screen includes links to Home, System, Modules, Data Analysis and Help. This banner appears in throughout the VISTA web interface, no matter what page or network in the VISTA web interface is open. The Home tab returns the user to VISTA's Home screen from any page in the VISTA web interface.

The System tab (see Figure A1-3) includes a menu from which the user can open the JAVA GIS client or a SQL query console. Further detail on the use of the SQL query console is provided in section 1.3.1. The System tab also includes an option to Exit (logout) of the VISTA web interface.

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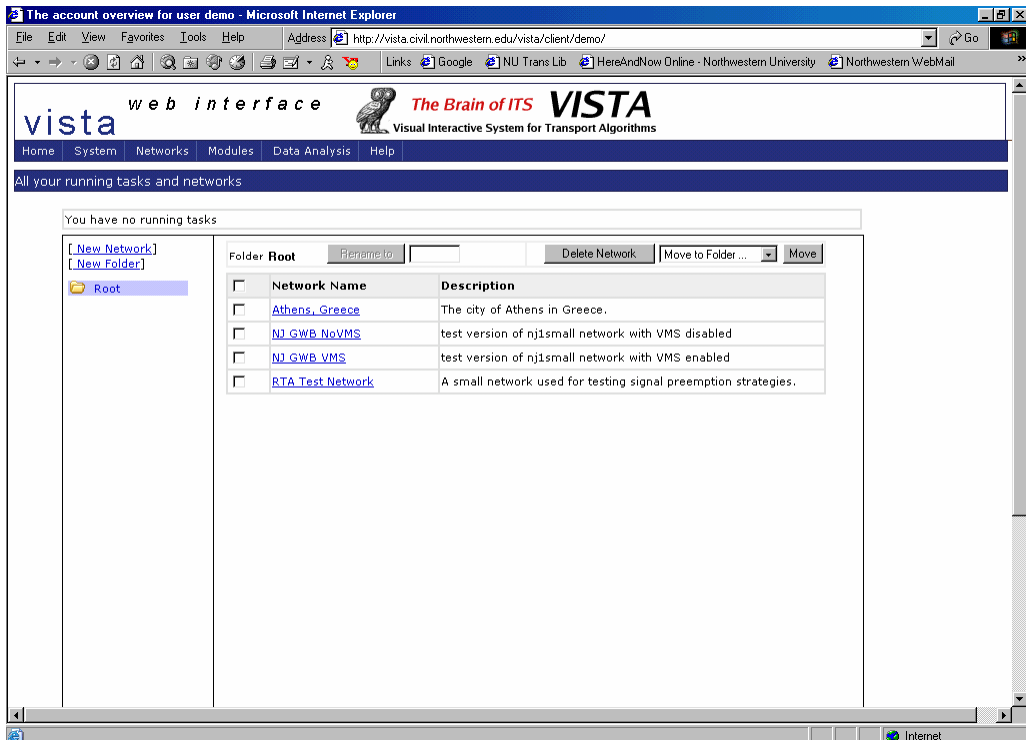
Figure A1-2. VISTA Home Screen
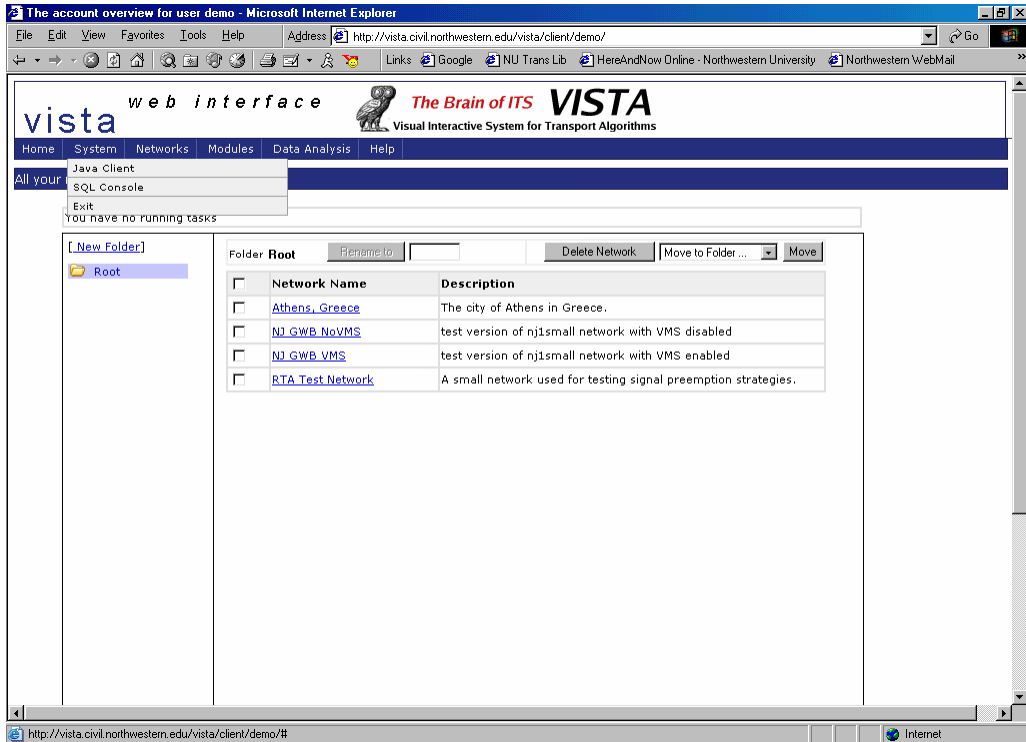
Figure A1-3. System Tab

The Networks tab (see Figure A1-4) includes a menu from which the user can select a network. This option is available from any page in the VISTA web interface.
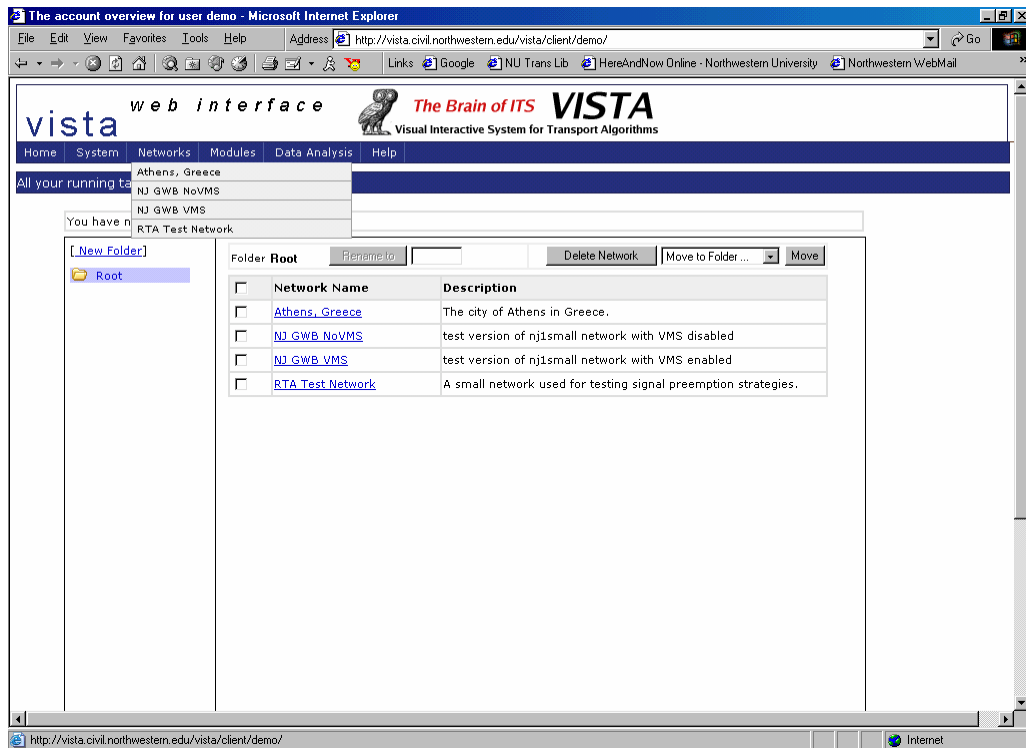
Figure A1-4. Networks Tab

The Modules and Data Analysis tabs provide access to modules and reports for any network.

When a network has been selected, a second banner appears with the tabs Task History, Overview and Tables. When the Task History tab is selected, a list of modules and reports previously run on the selected network appears (see Figure A1-5). Under the "Download" column, an icon can be selected to download report outputs.

When the Overview tab is selected, the general statistics related to the selected network appear (see Figure A1-6).
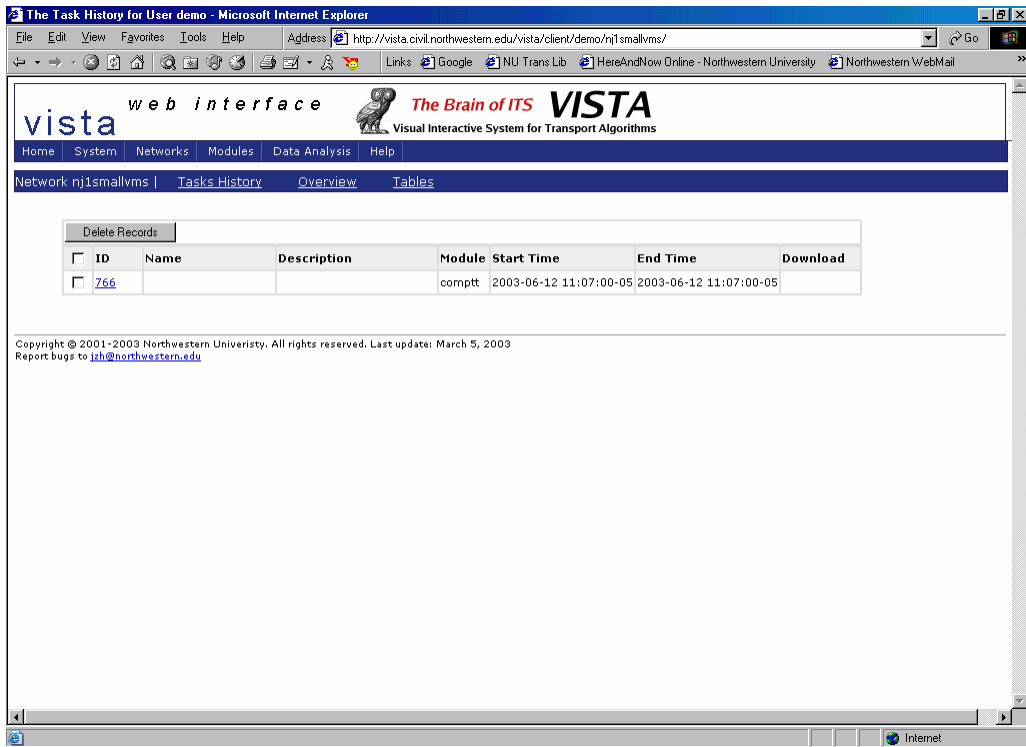
Figure A1-5. Task History
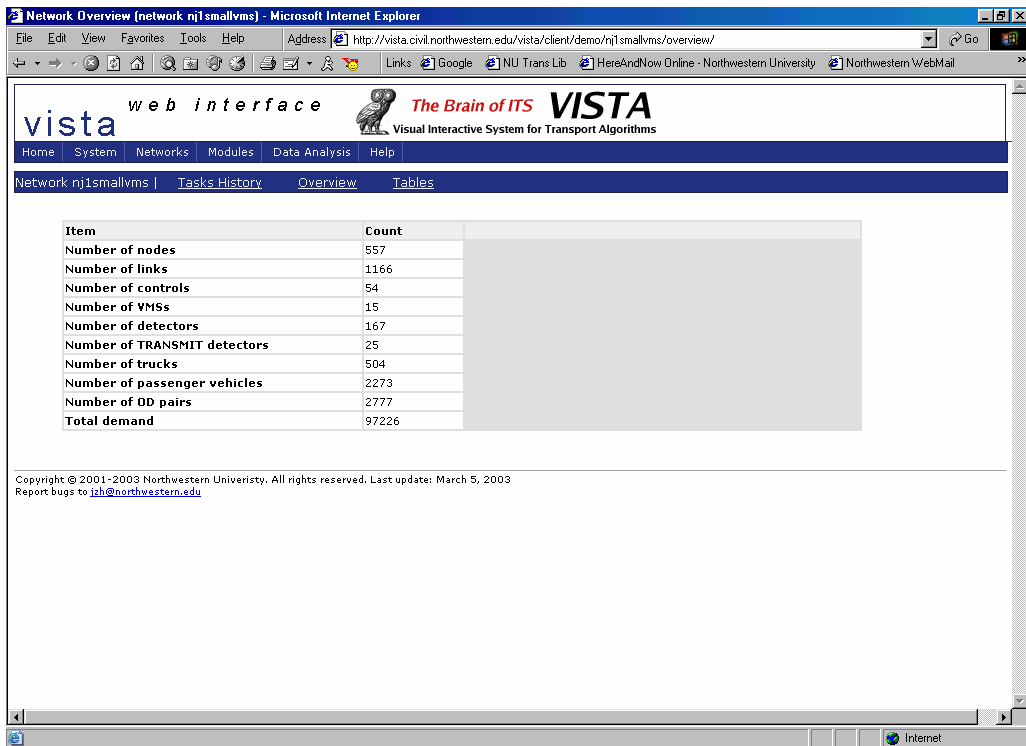
Figure A1-6. Reports List

Logging into and out of the Client Interface

Launch **http://vista.civil.northwestern.edu** in Internet Explorer and click on "Run the Vista Client" (see Figure A1-7). The Client Interface requires the Java Runtime Environment and Java Web Start to be installed on the client terminal. If these are not already installed on the client terminal, they can be downloaded from the links provided to the Java Runtime Environment and Java Web Start.
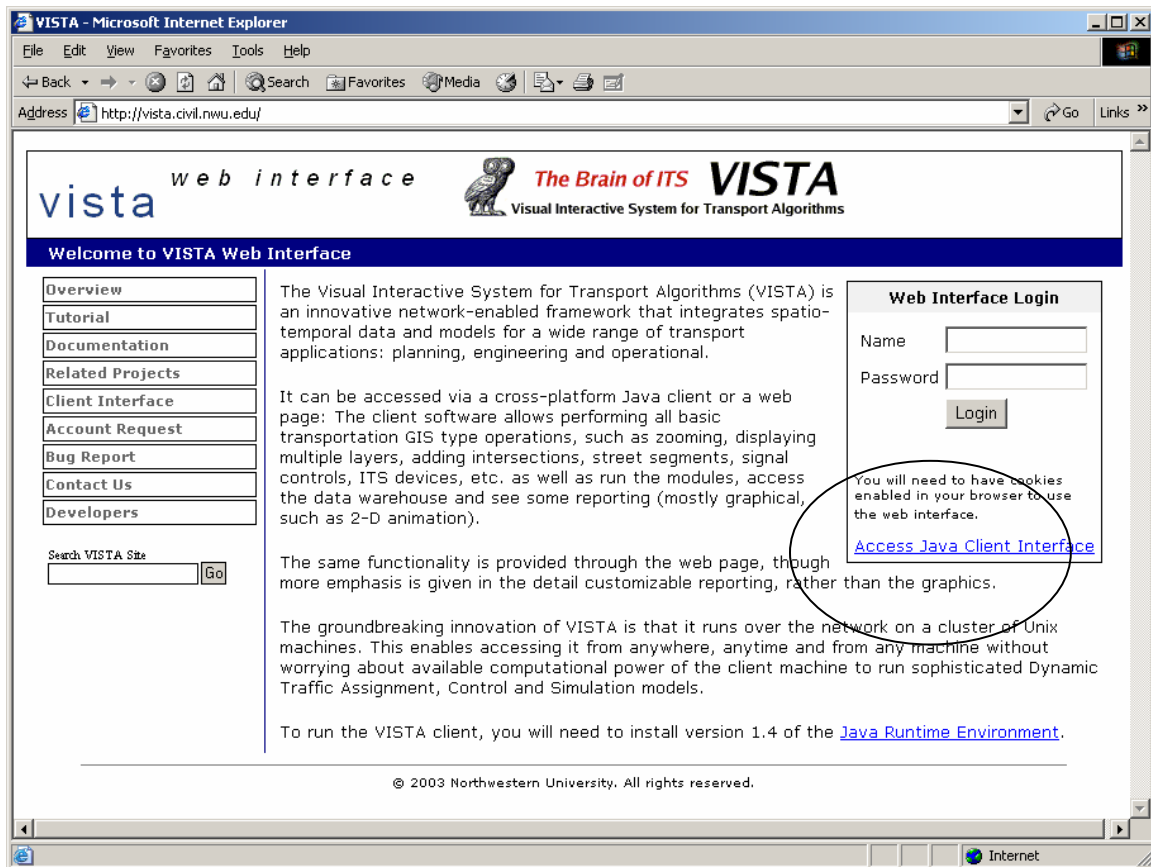
Figure A1-7. Link to the VISTA Client Interface

When the login window will appears (see Figure A1-8), enter your personal username and password. The server name is its.civil.northwestern.edu.
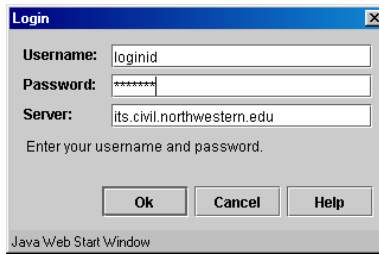
Figure A1-8. VISTA Client Interface Login Window

The client window will appear as shown in Figure A1-9.
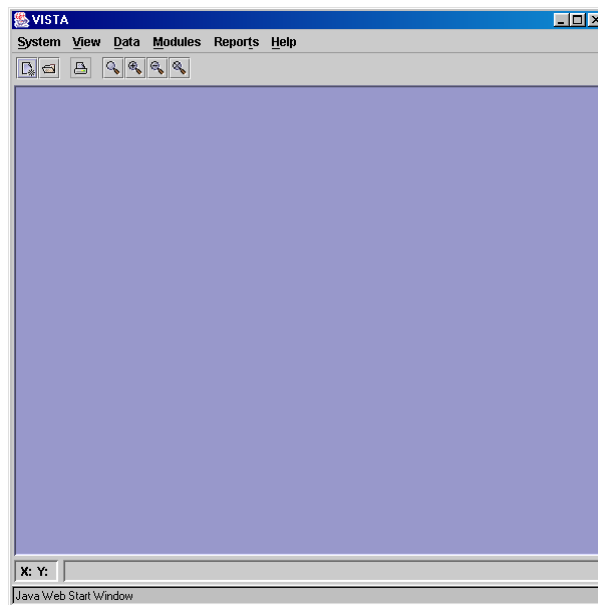
Figure A1-9. VISTA Client Interface Window

To open a network, click on the open button or System|Open (see Figure A1-10). When the Open Network window appears (see Figure A1-11), click on the desired network. The selected network will then be loaded for viewing (depending on the size of the network, this may take several minutes).
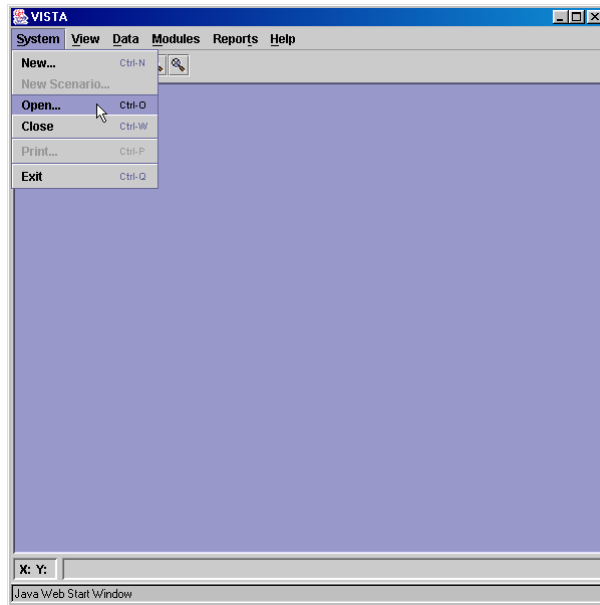
Figure A1-10. VISTA System|Open Menu Option
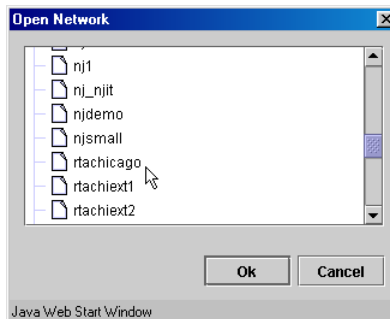
Figure A1-11. VISTA Open Network Window

When you are finished working in the client interface, you can logout by selecting System|Exit (see Figure A1-12). The VISTA client window will then close.
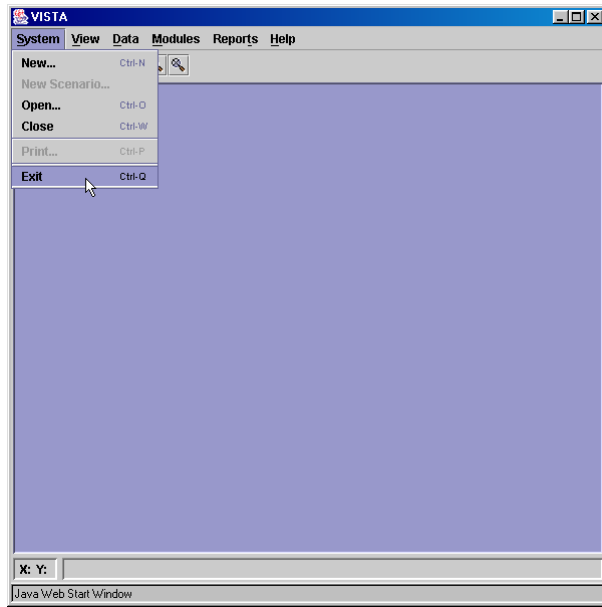
Figure A1-12. VISTA System|Exit Menu Option
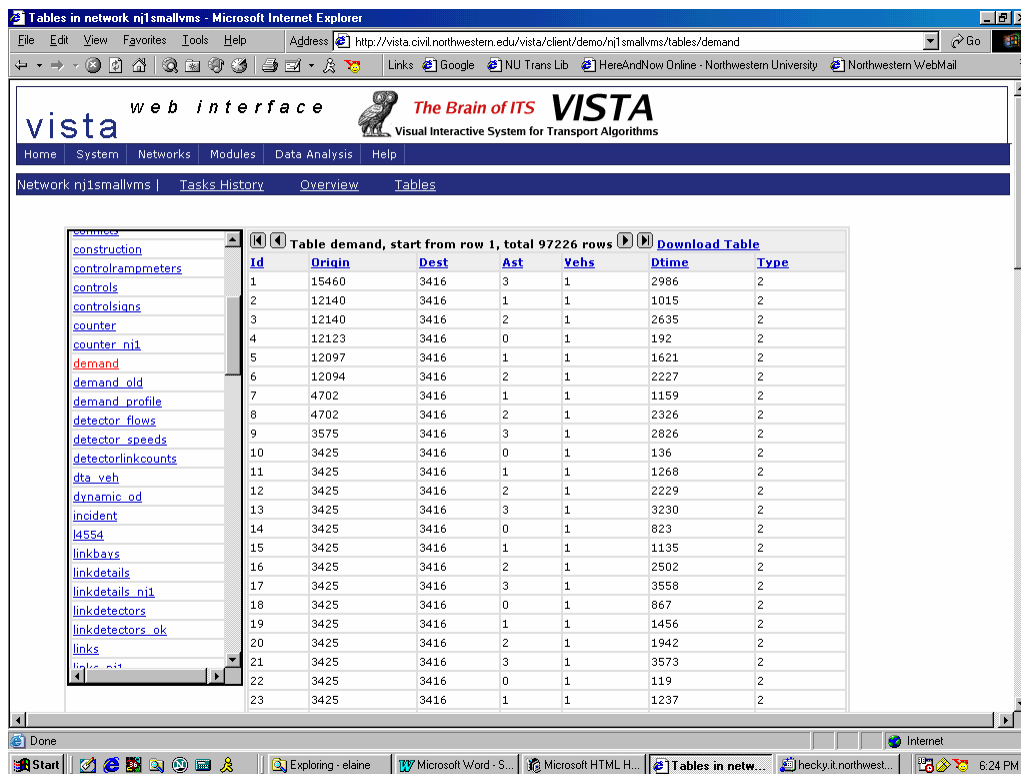
Viewing and Editing Data Inputs

The web interface allows for convenient and detailed querying and editing of data tables. The client interface allows for GIS-based viewing of the input data, as well as editing, adding and deleting of network elements.

Viewing and Editing Data in the Web Interface

The Tables tab can be selected (see Figure A1-13) to view table fields and records associated with the selected network. A list of database tables appears in scroll menu on the left, and a database table can be selected by clicking to highlight that table name. The records of the selected table appear to the right. Further, the "Download Table" link can be selected to have the records saved to a text file.

Figure A1-13. Web Interface Database Page

The database tables can also be queried by entering a PSQL "select" statement in the SQL console. First, the SQL console must be opened by selecting "SQL console" from

the System tab menu. The screen shown in Figure A1-14 then appears. In the SQL console screen, the user may then select a network from the pull-down menu in the top left, and then type a PSQL query in the query box. The "Execute" button is then selected to have the console return the results of the query. An example PSQL query and resulting table are shown in see Figure A1-15 (the complete table can be viewed by scrolling down). The results can also be saved to a text file by clicking on "Download Result".
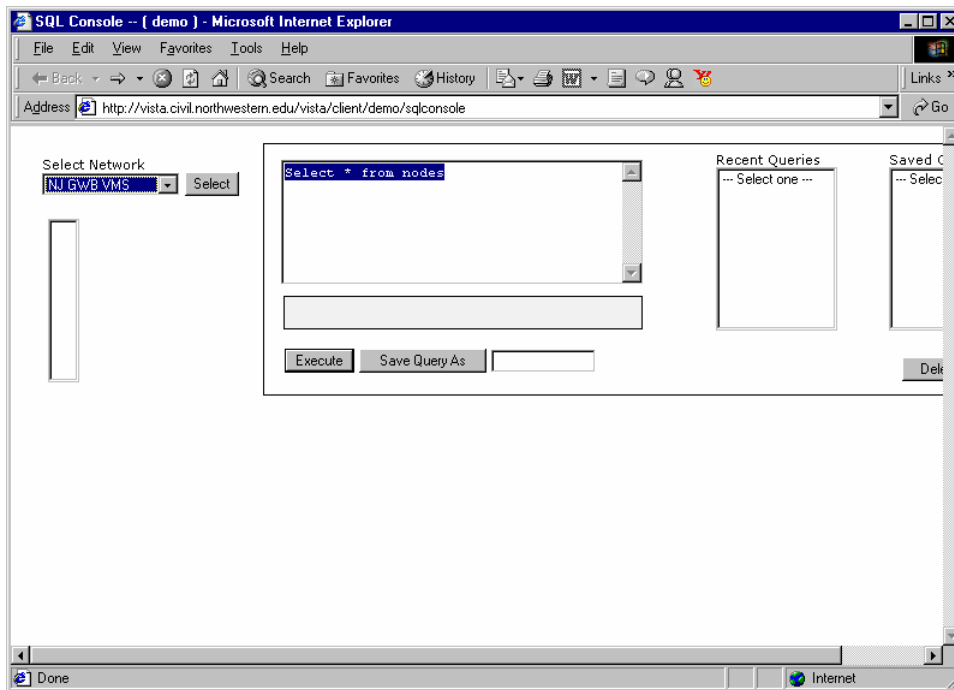
Figure A1-14. Database Table Records Shown in the Web Interface

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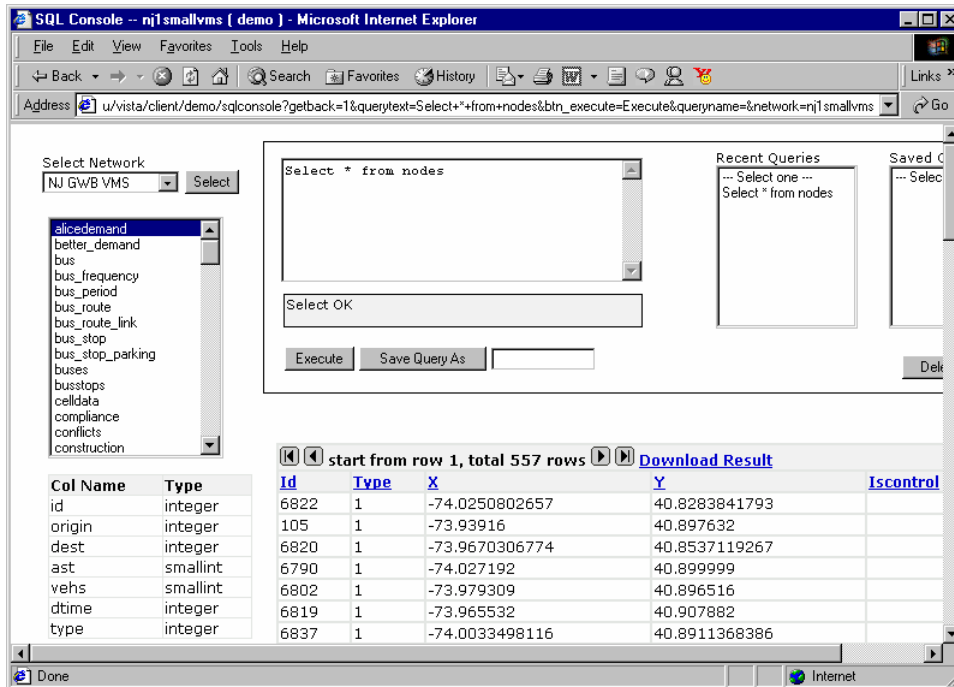
Figure A1-15. SQL Query and Query Result Table in Web Interface

Any PSQL query statement can be entered in the SQL box; for example, the statement

SELECT * FROM bus;

will return all fields (represented by *) of all records in the bus table. To narrow the search conditional expressions may also be specified in the target list; for example,

SELECT * FROM bus WHERE route=100;

will return all fields (represented by *) in the bus table, but only for buses on route 100. Boolean operators (and, or, not) are also allowed in the qualification of a query; for example,

SELECT * FROM bus WHERE route=100 AND starttime<600;

will return all fields (represented by *) in the bus table, but only for buses on route 100 that depart before 600 seconds of the simulation have elapsed.

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As a final note, you can specify that the results of a select can be returned in a sorted order or with duplicate instances removed; for example,

SELECT DISTINCT route FROM bus ORDER BY preemption;

The SQL box can also be used to insert, update or delete table entries; for example, the command,

INSERT INTO bus (id,type,route,starttime,preemption) VALUES (100,1,32,5,1);

will add a record in the bus table, corresponding to a bus of type 1 on route 32 with vehicle id 100. The bus departs at time 5 and triggers preemption strategy 1. To edit records that already exist in the database, the update command can be used; for example, the command

UPDATE bus SET preemption=1 WHERE route=50;

will set all buses on route 50 to trigger preemption strategy 1. In addition, records can also be deleted from the database; for example, the command

DELETE FROM bus WHERE route=50;

will delete all bus on route 50 from the bus table.

More detailed guides to PSQL commands are widely available on the internet. Two such tutorial pages are found at

http://www.us.postgresql.org/users-lounge/docs/6.5/tutorial/query.htm

http://www.eskimo.com/~ericj/comp/sql1b.htm

Viewing and Editing Data in the Client Interface

The client interface allows the user to view and edit the data in GIS-based format, but also provides access to the Data Warehouse where data can be viewed and queried in

detailed table format. This section begins with a discussion of basic tools for viewing networks, such as zooming and panning, as well as tools for adjusting the appearance and colors of network elements. Next, methods of editing data in the client are explained, and then methods of editing data through the client's data warehouse are explained.

GIS-based Viewing of Data

After logging into the client, a network can be opened to be viewed in GIS format (see Section 1.2.2). An example network, rtatest3, is shown in Figure A1-16.
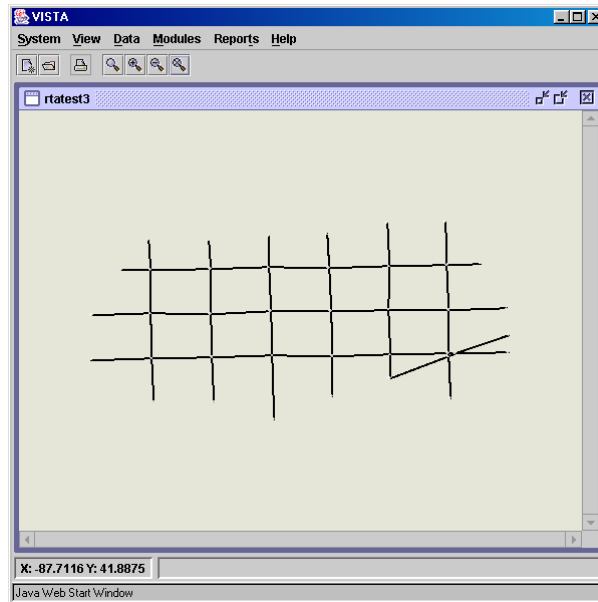
Figure A1-16. Sample Network, Rtatest3, in GIS Client Interface

The VISTA client window includes many options for adjusting the appearance of the network. For example, the client window can be maximized by clicking on the maximization button in the top right corner of the window (see Figure A1-17).
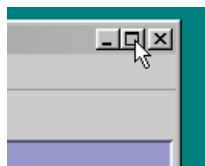
Figure A1-17. Client Window Maximization Button

To zoom into a particular area of the network, click on ⬚, then select the area you want to zoom into using the red box (see Figure A1-18).
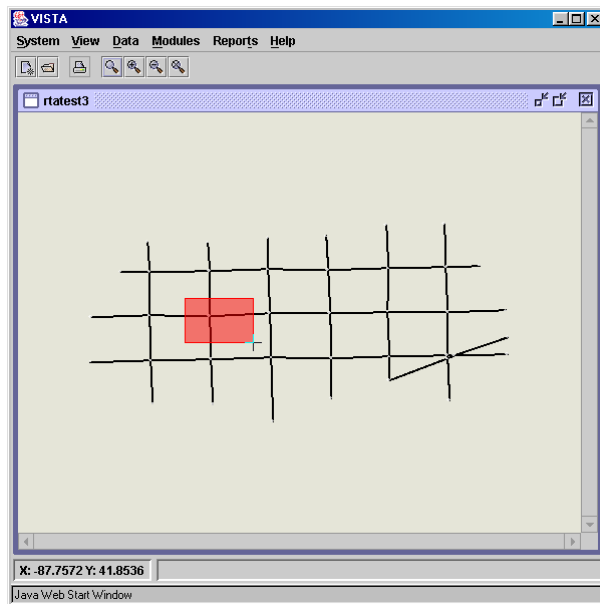
Figure A1-18. Client Interface Zoom Fnction

To zoom into the center of the screen by a predetermined amount, click on ⬚. To zoom out of the center of the screen by a predetermined amount, click on ⬚. To zoom out to the full network, click on ⬚.

In addition, a drag button ✛ , has recently been added to the button bar. The drag button is used to reposition the section of the network shown in the GIS client window. To reposition the network first click on the ✛ button, then click on a spot in the network and hold the mouse button as you drag the network to a new position. Let go of the mouse button to drop the network in its new position.

The color and appearance of the network nodes, links and other elements can be adjusted by right-clicking on any part of the network window to bring up the menu shown in Figure A1-19. The options most relevant to the transit signal priority project

include adjustments to the appearance of nodes, links, controls, bus stops and bus routes.

Figure A1-19. Client Interface Element Appearance Editing Menu

If the "Nodes" is selected from the menu, a node appearance editing window appears (see Figure A1-20). Nodes and node labels, which indicate node id numbers, can be made visible or hidden. Further, the color of nodes and node labels can be adjusted by clicking on the color boxes. A Color Picker window then appears (see Figure A1-21), and any color in the spectrum can be selected by adjusting the amount of red, green and blue. The alpha value adjusts the contrast of the checker pattern. Further, the label font can be adjusted by clicking on the label font box. A Font Picker window then appears such that the font and font size can be adjusted (see Figure A1-21).
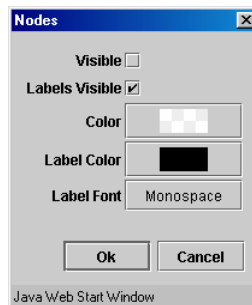
Figure A1-20. Client Interface Node Appearance Editor
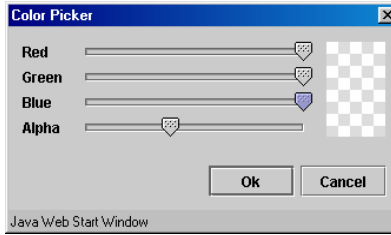
Figure A1-21. Client Interface Color Picker
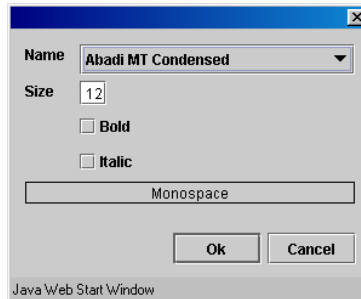
Figure A1-21. Client Interface Font Picker

Link appearance characteristics can also be adjusted by selecting "Links" from the element appearance editing menu (Figure A1-18). The link appearance editing window then appears (see Figure A1-22). This window allows links and link labels can also be set to be visible or hidden. Further, the colors and fonts can also be adjusted by clicking on the color and font boxes, to make Color Picker and Font Picker windows appear. Further, arrows can be made visible, so that the link directions are apparent, and lanes and centroids can also be made visible.
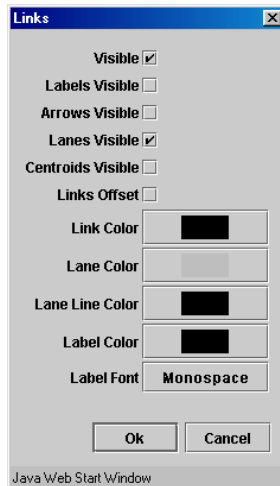
Figure A1-22: Client Interface Link Appearance Editor

When "Controls" are selected from the element appearance editing menu (Figure A1-18), a controls appearance editing window appears (see Figure A1-23). Controls can be made visible or hidden, and colors can be selected as they are with nodes and links. The colors selected appear only during animation, otherwise, only the "stop" color is shown as in Figure A1-24.
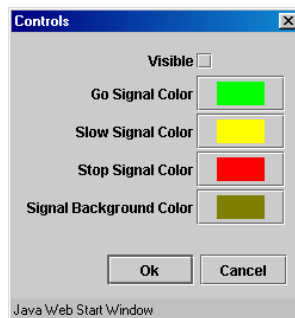
Figure A1-23. Client Interface Controls Appearance Editor
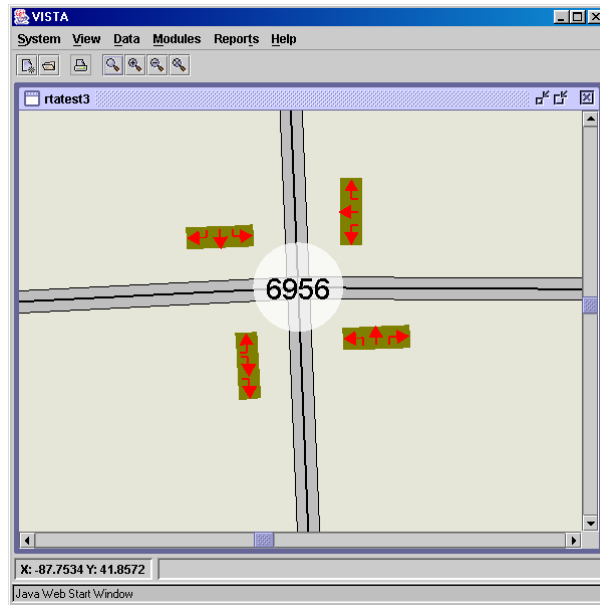
Figure A1-24. Representation of Controls in the Client Interface

When "Bus stops" are selected from the element appearance editing menu (Figure A1-18), a bus stop appearance editing window appears (see Figure A1-25). Similarly, when "Bus routes" are selected from the element appearance editing menu (Figure A1-18), a bus route appearance editing window appears (see Figure A1-26). Bus stops and bus routes can be made visible or hidden, and colors can be selected as with other network elements. Routes and stops appear slightly offset from the links, as shown in Figure A1-27.
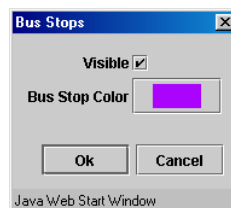
Figure A1-25. Client Interface Bus Stop Appearance Editor
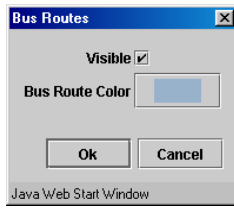
Figure A1-26. Client Interface Bus Route Appearance Editor
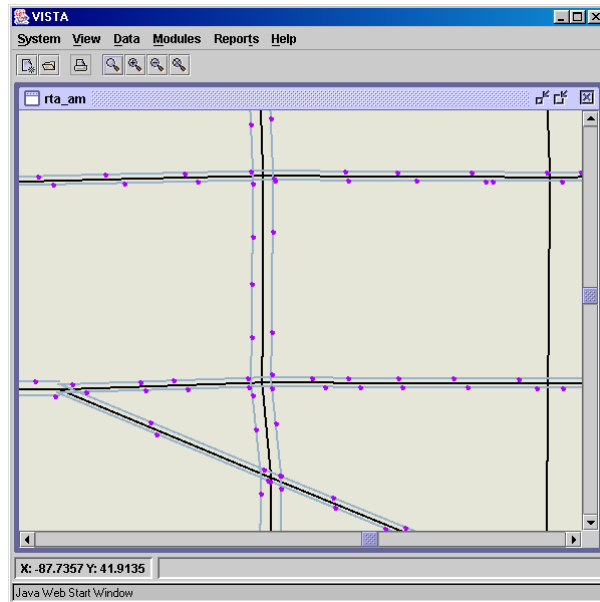
Figure A1-27. Client Interface Representation of Bus Routes and Bus Stops

GIS-based Editing of Data

The VISTA client allows network elements to be added, edited or deleted. The network data that can be altered are listed under the Data menu. The options most relevant to the transit signal priority project include adjustments to nodes, links, zones, controls and buses.

When "Nodes" is selected from the Data menu, the options of adding, removing, editing and finding a node appear (see Figure A1-28). When "Add Node" is selected, a node can be added to the network by clicking in the desired location. When "Remove Node" is selected, an existing node can be removed by clicking on that node. When "Edit

Node" is selected, an existing node can be selected by clicking on that node, and a window will appear in which the x and y coordinates of that node can be adjusted (see Figure A1-29). When "Find Node" is selected a "Find Node" window will appear, in which the desired node id can be entered (see Figure A1-30). That node will then be highlighted in the network window.
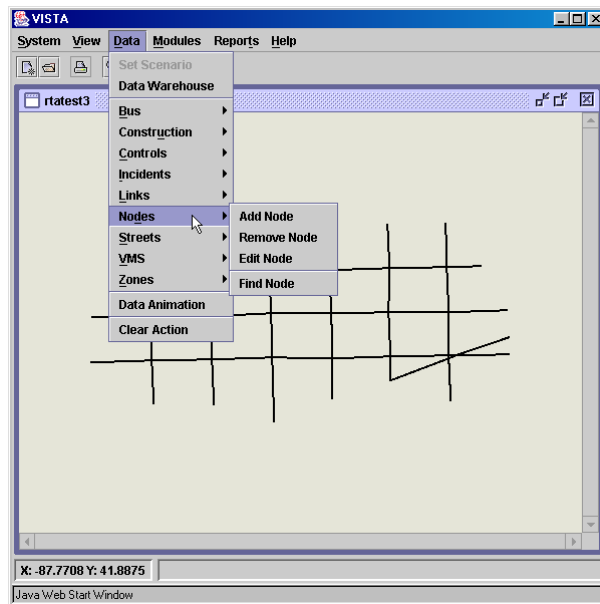
Figure A1-28. Client Interface Data|Nodes Menu Option
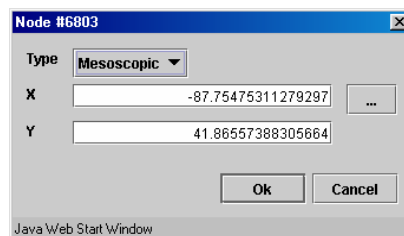
Figure A1-29. Client Interface Node Editing Window
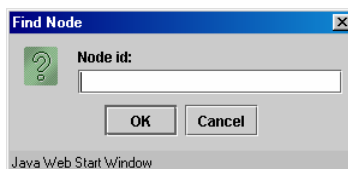
Figure A1-30. Client Interface Find Node Window

When "Links" is selected from the Data menu, the options of adding, removing, editing and finding a link appear (see Figure A1-31). When "Add Link" is selected, a link can be added to the network by clicking to join two nodes. When "Remove Link" is selected, an existing link can be removed by clicking on that link. When "Edit Link" is selected, an existing link can be selected by clicking on that link, and a Link Editor window with tabs to Attributes, Geometry, Bays and Detectors will appear. In the Attributes section (see Figure A1-32), link attributes, such as origin node, destination node, length, speed, number of lanes and capacity can be edited (capacity is optional if the number of lanes is entered). In the Geometry section (see Figure A1-33), the polyline coordinates can be edited to adjust the appearance of the link in the GIS. In the Bays section (see Figure A1-34), merge lanes and turning bays can be defined. In the Detectors section (see Figure A1-35), link detectors can be defined for use with the OD calibration module.
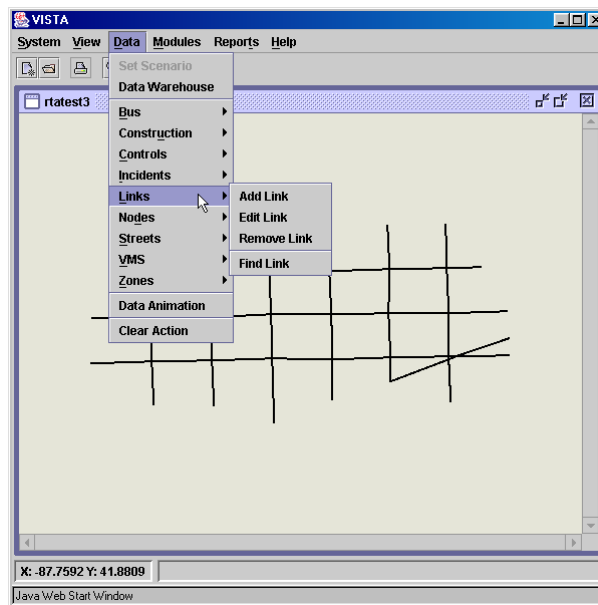
Figure A1-31. Client Interface Data|Links Menu Option
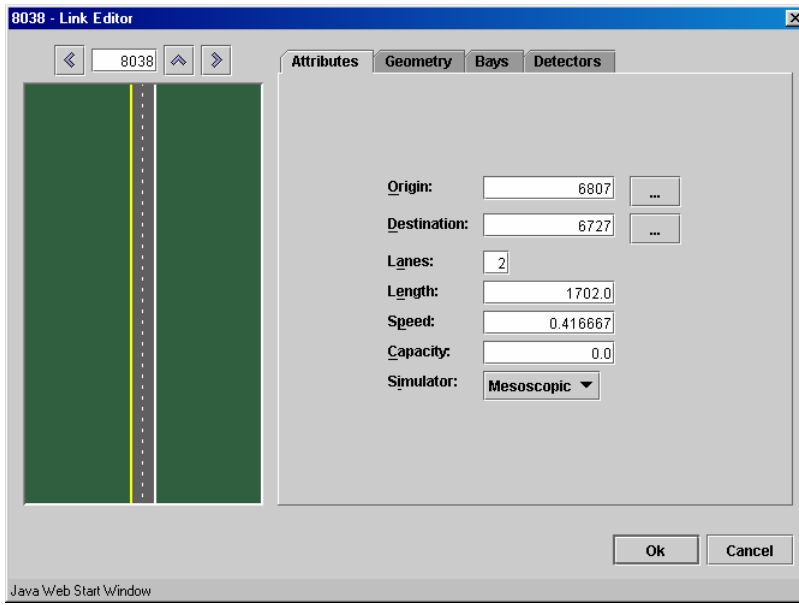
Figure A1-32. Client Interface Link Attribute Editor
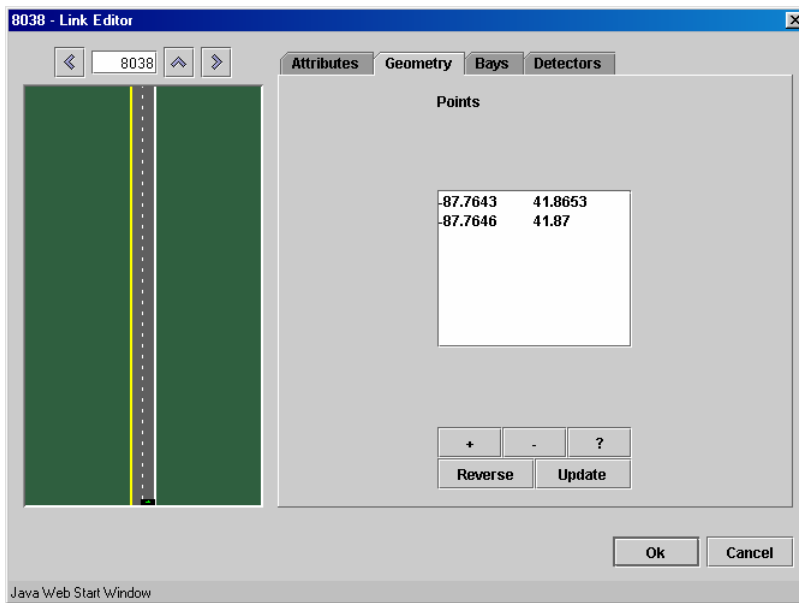
Figure A1-33. Client Interface Link Geometry Editor
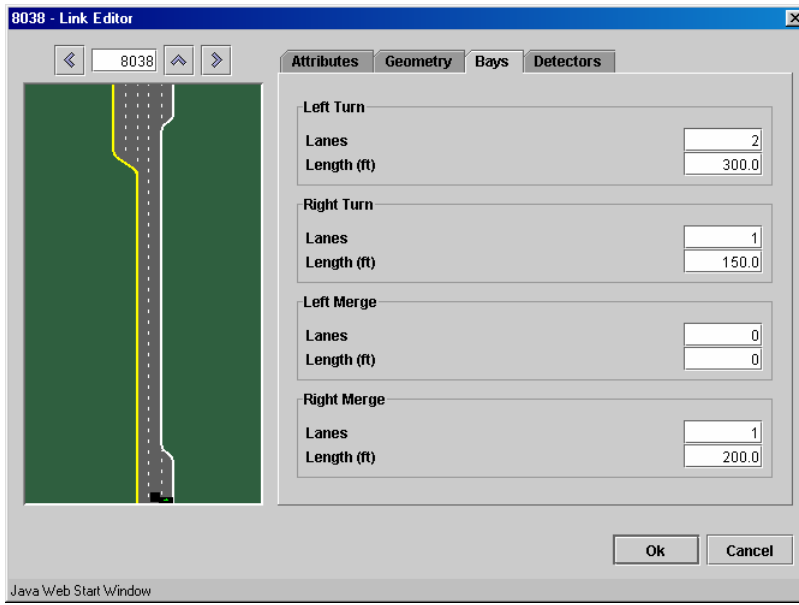
Figure A1-34. Client Interface Link Bay Editor
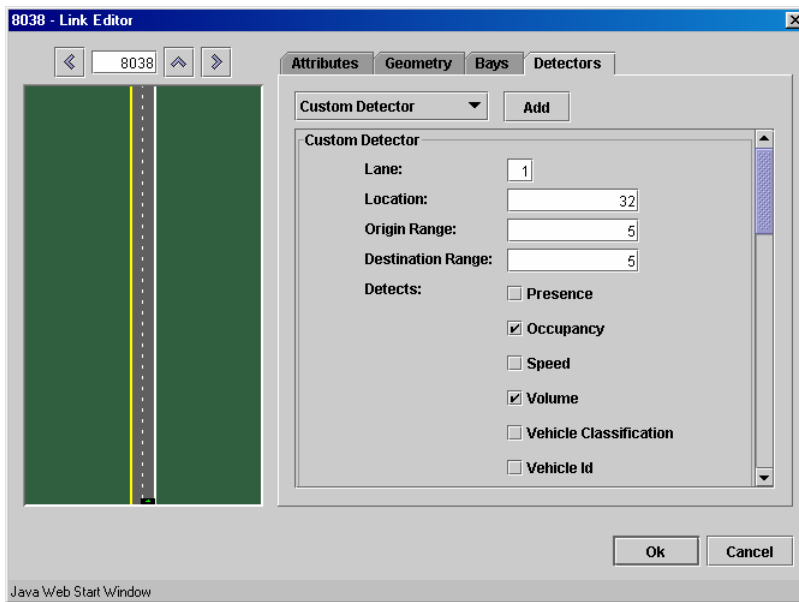
Figure A1-35. Client Interface Link Detector Editor

When "Find Link" is selected a "Find Link" window (see Figure A1-36) will appear, in which the desired link id can be entered. That link will then be highlighted in the network window.
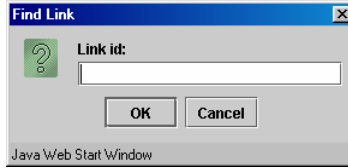
Figure A1-36. Client Interface Find Link Window

When "Zones" is selected from the Data menu, the options of adding, removing, editing and finding a zone appear (see Figure A1-37). When "Add Zone" is selected, a Create New Zone window will appear in which the nodes to be included in that zone can be specified (see Figure A1-38). When "Edit Link" or "Remove Link" are selected, an existing zone can be edited of removed by clicking on that zone. When "Find Zone" is selected a "Find Zone" window (see Figure A1-39) will appear, in which the desired zone id can be entered. That zone will then be highlighted in the network window.
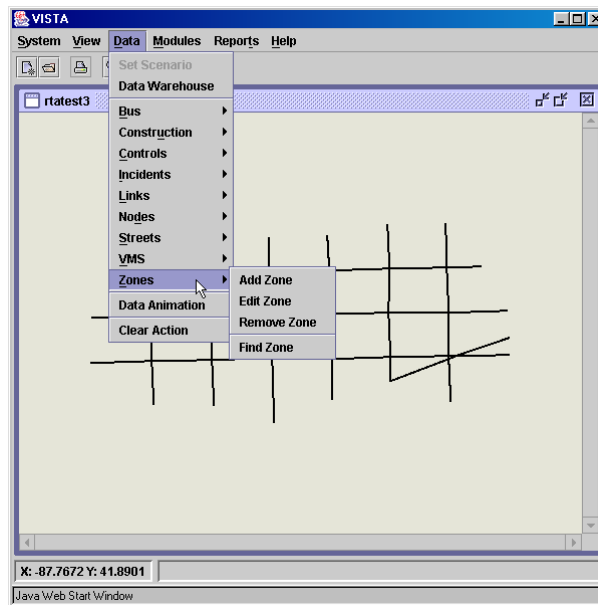
Figure A1-37. Client Interface Data|Zones Menu Option
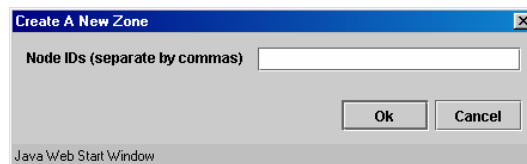
Figure A1-38. Client Interface Create a New Zone Window
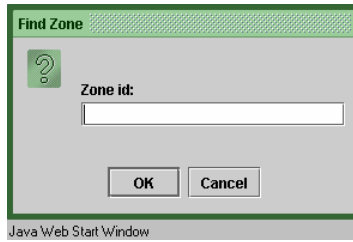
Figure A1-39. Client Interface Find Zone Window

When "Controls" is selected from the Data menu, the options of adding, editing and removing controls and signal preemption appear (see Figure A1-40).
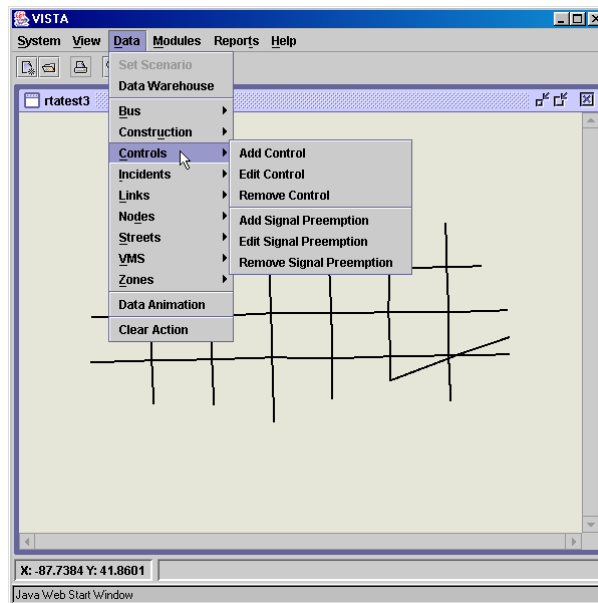
Figure A1-40. Client Interface Data|Controls Menu Option

When adding controls a node is selected, and the "Add Control" window will appear to allow the user to select the type of control to be added (see Figure A1-41).
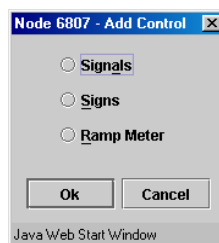
Figure A1-41. Client Interface Add Control Window

To edit controls select a node, and if the node is a signalized intersection, the Edit
Control window will appear (see Figure A1-42). This window allows signal timing plans,
offsets and phase movements to be edited.
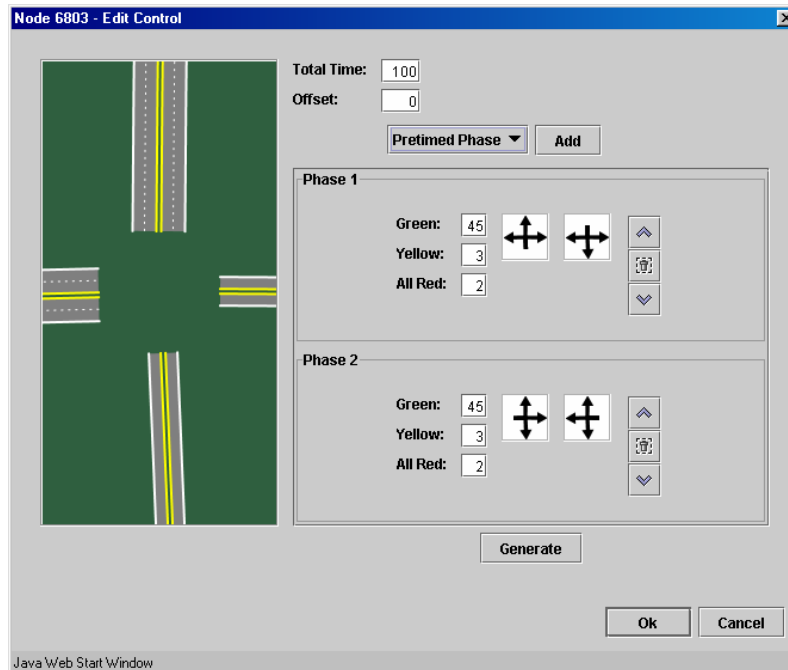
Figure A1-42. Client Interface Edit Control Window

If "Edit Signal Preemption" is selected from the Data menu, the "Choose Signal
Preemption" window appears (see Figure A1-43). When the user selects a signal
preemption plan from the drop down menu, a signal preemption editing window will
appear (see Figure A1-44), which allows the user to choose the signals to be included
in the preemption plan and to adjust the preemption parameters associated with that
plan. If "Add Signal Preemption" is selected from the Data menu, the signal preemption
editing window appears, so that the user can create a new plan from scratch. If
"Remove Signal Preemption" is selected from the Data menu, the Choose Signal
Preemption window appears, so that the user can select the preemption plan to be
removed from the drop down list.
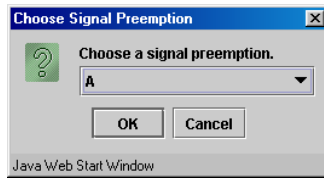
Figure A1-43. Client Interface Choose Signal Preemption Window
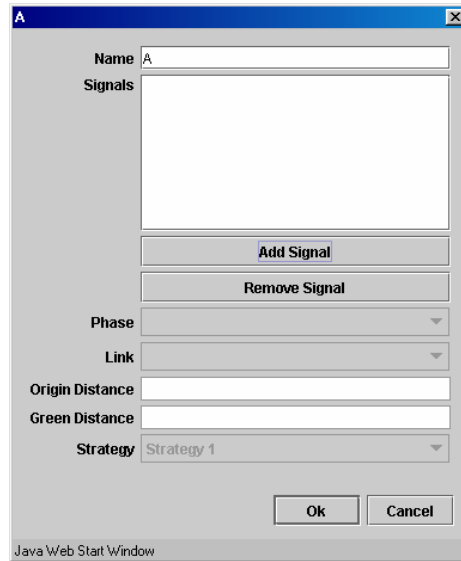
Figure A1-44. Client Interface Signal Preemption Editing Window

The Data|Bus option allows the user to add, edit and remove bus stops, bus periods and bus routes (see Figure A1-45). If the user chooses to add or edit bus stops a bus stop editing window appears (see Figure A1-46) in which the user can define the link on which the bus stop is to be located, the name of the bus stop, the location along that link (distance in feet from the destination end of the link), and length of the bus bay if one exists. If "Remove Bus Stop" is selected, the user can click on a bus stop to delete it from the network.
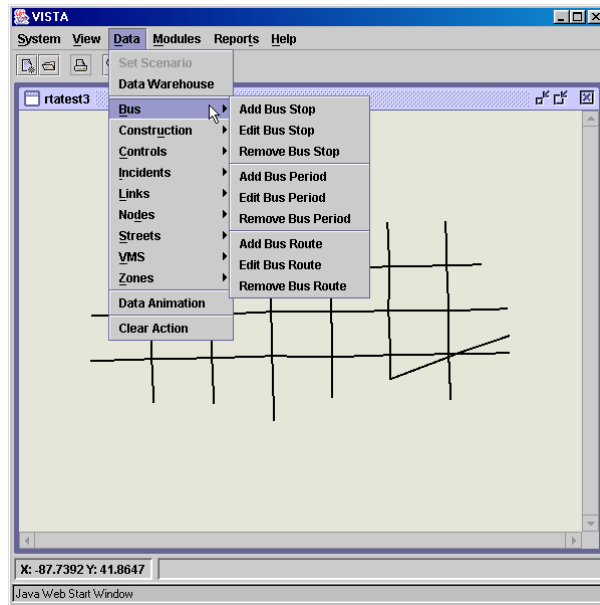
Figure A1-45. Client Interface Data|Bus Menu Option
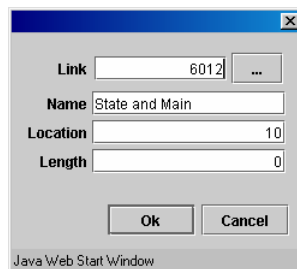
Figure A1-46. Client Interface Add/Edit Bus Stop Window

If the user chooses to edit bus periods a bus period selection window appears (see Figure A1-47) in which the user can select from the drop down menu the bus period to be edited. A bus period editing window then appears (see Figure A1-48) in which the user can adjust the start and end times of the selected bus period. If "Add Bus Period" is selected, a window similar to the bus period editing window (Figure A1-48) appears in which a new bus period can be defined. If "Remove Bus Period" is selected, the bus period selection window appears (Figure A1-47) from which the user can select the bus period to delete it from the network.
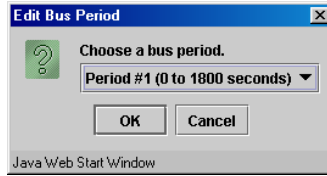
Figure A1-47. Client Interface Edit Bus Period Selection Window
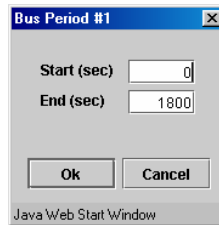
Figure A1-48. Client Interface Edit Bus Period Window

If the user chooses to edit bus route, the Choose Bus Route window appears (see Figure A1-49) in which select from the drop down menu the bus route to be edited. A bus route editing window then appears in which the user can adjust the route link definition (see Figure A1-50) and the schedule (see Figure A1-51) of the selected bus route (there are tabs for each at the top of the window). If "Add Bus Route" is selected, a window similar to the bus route editing window (Figures A1-39 and A1-40) appears in which a new bus route and schedule can be defined. If "Remove Bus Period" is selected, the bus route selection window appears (Figure A1-49) from which the user can select the bus route to delete it from the network.
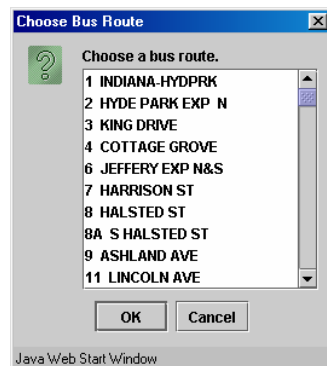
Figure A1-49. Client Interface Choose Bus Route Window
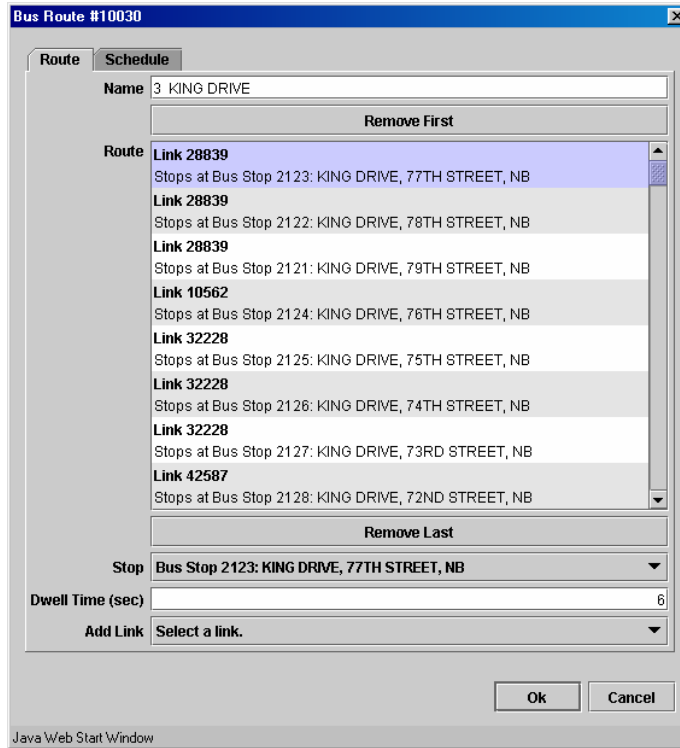
Figure A1-50. Client Interface Bus Route Editing Window (Route Links)
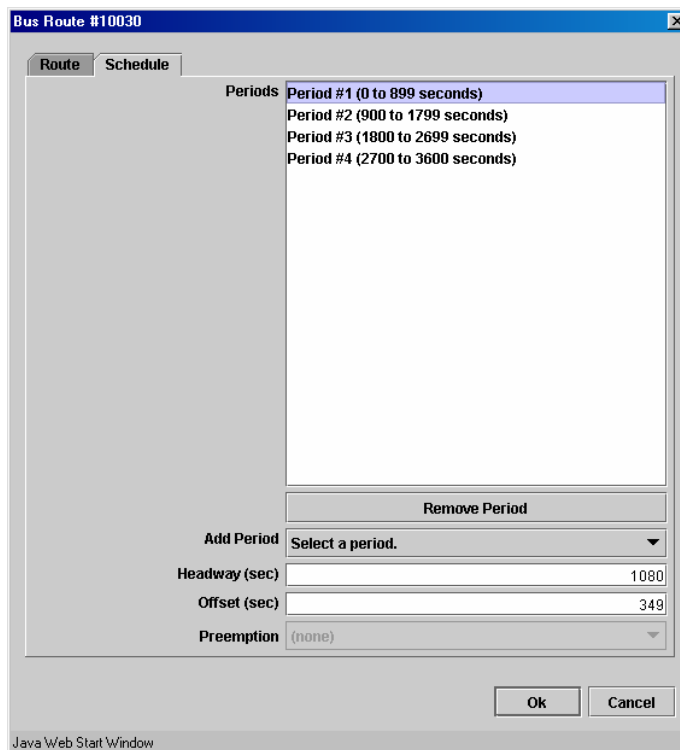
Figure A1-51. Client Interface Bus Route Editing Window (Schedule)

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Viewing and Editing Data in the Data Warehouse

The detailed data tables and queries available in the VISTA web interface can also be accessed through the GUI client interface using the Data Warehouse option in the Data menu (see Figure A1-52). When the Data Warehouse option is selected, the Data Warehouse window appears as shown in Figure A1-53. In this window, the File|Open option can be selected in order to open a specific table. The Choose Table window will then appear with a list of tables available in the database (see Figure A1-54). The user can then select one or several tables which will appear in the Data Warehouse window.
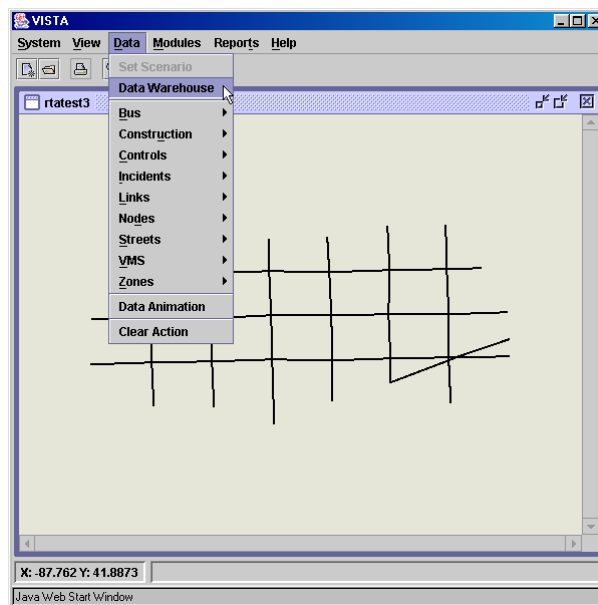
Figure A1-52. Client interface Data|Data Warehouse menu option
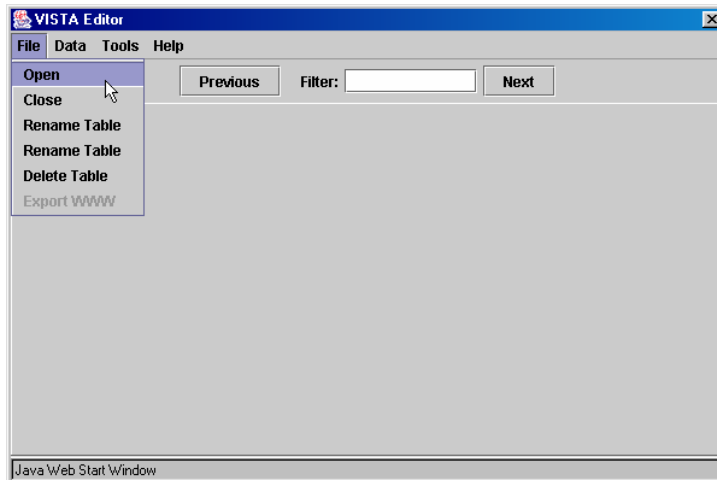
Figure A1-53. Data Warehouse File|Open menu option
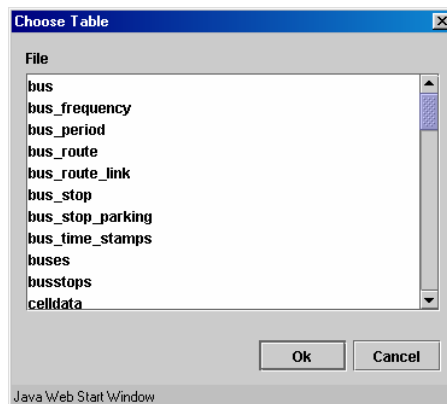
Figure A1-54. Data Warehouse Choose Table Window

Figure A1-55 shows the bus table for the example network. The tab at the bottom of the window shows that name of the table (bus), and multiple tabs will appear if several tables are open. If the table has more records than can be shown in one screen, the Previous and Next buttons at the top of the window can be used to see other records. Further, the table can be queried by entering an expression in the Filter box and clicking on Data|Reload Data (see Figure A1-56).

Figure A1-55. Data Warehouse Example Data Table (Bus Table)

Figure A1-56. Data Warehouse Example Data Table with a Query (Bus Table)

Running the Dynamic Traffic Assignment Module

The DTA and DTA-related modules used in the TSP project are listed in Table A1-1, along with lists of the parameters that must be defined and the functions performed by each module. The Cell Generation, Demand Profiler, Bus Assignment, Intersection Signal Optimization and Intersection Signal Coordination modules are run before DTA to ensure that network, demand, bus and signal data are in the format required by the DTA module. DTA is then run and RouteSim is called from within DTA. When DTA is complete, the vehicle path and travel time results are imported to the database, so that they can be used in reporting modules. Access to the modules through the web and client interfaces are also described in this section.

Table A1-1. DTA and DTA-related Modules

Module	Parameters	Module Function
Generate Cell File	Time Step Weather—clear, light rain, moderate rain, heavy rain	Creates a cell network based on the node and link network, with the length of each cell equal to the distance traveled in one time step at free flow speed. If rainy weather is selected, lower free flow speeds will be assumed, resulting in shorter cells.
Demand Profiler	Weightings Simulation Length (seconds) Use Zone IDs Use Dynamic Table Max OD Pairs	Assigns exact departure times to each vehicle. The weightings entered determine the proportion of vehicles to depart in each interval within the selected simulation length. The "Use Zone IDs" box should be selected if the origins and destinations in the static_od table are zone ids rather than node ids. The "Use Dynamic Table" box can be selected if the demand to be profiled is already in time-dependent rather than static format. A maximum number of OD pairs can be entered to limit the number of vehicle trips created in the demand table.
Bus Assignment	None	Assigns exact departure times to buses based on the data in the bus period and frequency tables.

Table A1-1. DTA and DTA-related Modules (continued)

Module	Parameters	Module Function
Intersection Signal Optimization	Node ID Minimum Cycle Length Minimum Phase Green Time Force Generation	Creates and optimizes signal at node selected, subject to the timing constraints entered. If "Force Generation" is selected, a signal will be created even if flows do not warrant it according to the NCUTCD rules.
Intersection Signal Coordination	Nodes	Coordinates the signals at the nodes selected.
DTA with TDSP	Iterations Ending Time (seconds) Time Step (seconds) Assignment Length (steps) Warm Up/Cool Down	Performs DTA with calculation of time dependent shortest paths (TDSP) at each iteration. The number of iterations, simulation length ("Ending Time"), time step and number of time steps ("Assignment Length") can be specified. If "Warm Up/Cool Down" is selected, the simulation will begin 15 minutes early to pre-load the network, and end 15 minutes late to allow vehicles to complete their trips.
DTA with Updates Only	Same parameters as DTA with TDSP	Performs DTA with updates of previously calculated paths at each iteration, instead of calculating the time dependent shortest paths (TDSP). This saves significant computational time, but can only be done if DTA has been previously performed, and a library of routes has already been created.
RouteSim	Simulation Length (seconds) Time Step (seconds)	RouteSim is automatically called from within DTA, but can also be run on its own.
Import Simulation Results to Database	none	After DTA has been run, this module is run to create vehicle path and travel time database tables based on the text file output created by the DTA module. The database tables will then be used to run reporting modules.

Running DTA Modules from the Web interface

The Modules page allows the user to run DTA and other utilities on the selected network. A scroll menu of modules appears on the left side of the page, and the right side lists any parameters that must be entered for the selected module (see Figure A1-57).

The status of a module can be tracked by checking the "Task History" page (see Section 2). This page lists all the tasks that are in process and complete and also provides links to log files for each task.
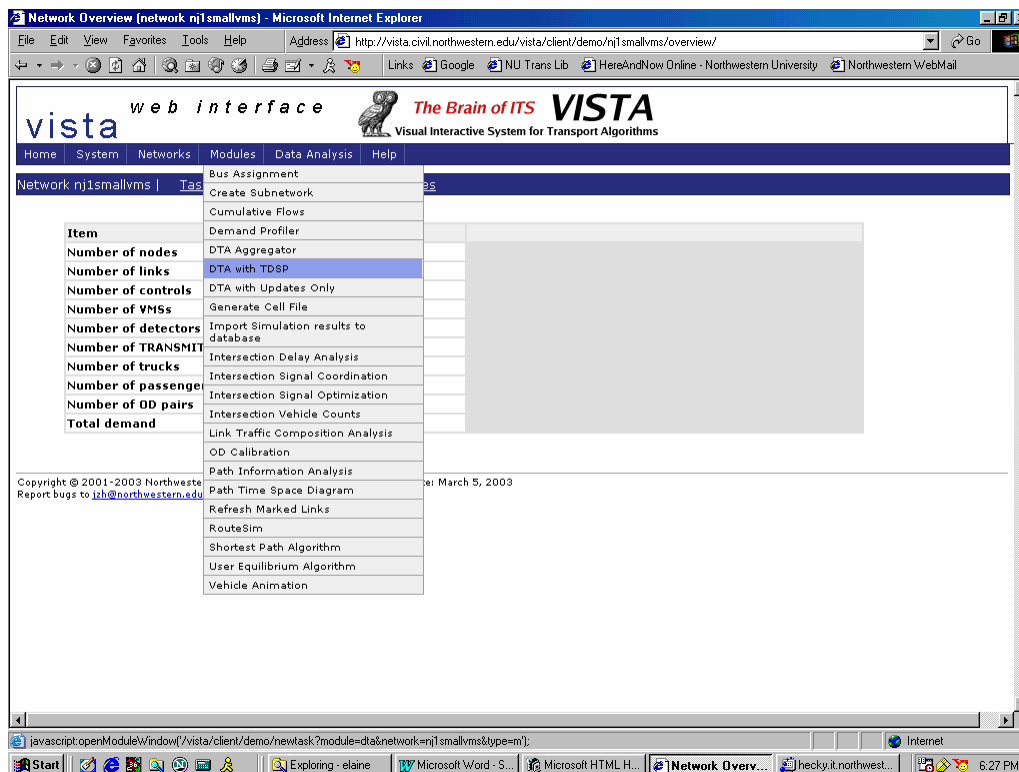
Figure A1-57. Web Interface Modules Page

Running DTA Modules from the Client interface

The Modules menu allows the user to run DTA and other utilities on the selected network (see Figure A1-58).
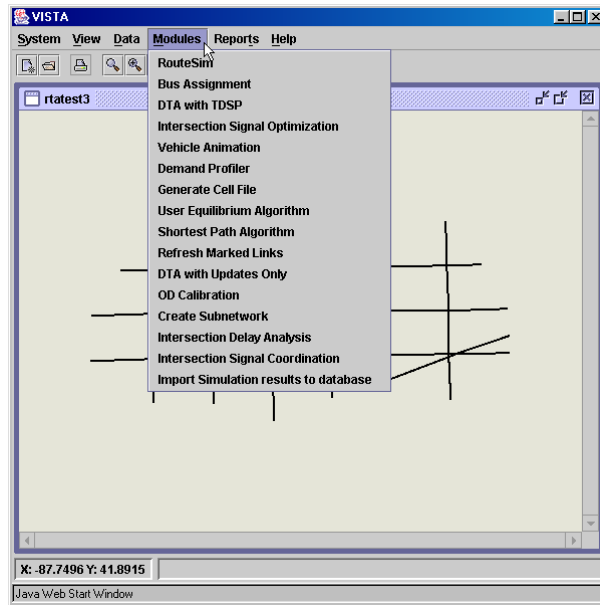
Figure A1-58. Client Interface Modules Menu

Running Reporting Modules

The reporting modules used in the TSP project are listed in Table A1-2, along with lists of the parameters that must be defined and the functions performed by each module. In each case, "Table Name" indicates the name of the database table to which the report results should be written. Access to the reporting modules through the web and client interfaces are also described in this section.

Table A1-2: Reporting Modules

Module	Parameters	Report Output
General Report	Time Intervals	Aggregate system-wide travel time report
Path Time Space Diagram	Link IDs Table Name	Plot of the average travel time through the corridor.
Origin Destination Travel Time Report	none Table Name	Listing of average travel time, travel time variance and number of vehicles for each OD pair.
Path Information Analysis	Table Name Origin Node Destination Node Use Zone	Table listing all paths used between the origin and destination selected. If "Use Zone" is selected, the "Origin Node" and "Destination Node" values will be taken as zone ids instead of node ids.
Link Traffic Composition Analysis	Link ID Table Name	For the selected link, the origins and destinations of all vehicles that travel on that link will be reported.
Bus Travel Time Report	Bus Route Table Name	For the selected bus route, the travel time for each run completed during the simulation will be reported, along with the travel time average and variance for that route.
Bus Path Time Space Report	Link IDs Table Name	For the selected links, the bus travel time average and variance are reported.
Schedule Adherence Report	Bus Route Table Name	For the selected bus route, the schedule adherence of each run at each time point will be reported.
Signal Report	Node Table Name	For a selected intersection, the total green time and proportion of green time over the whole simulation period will be reported. Also, maximum, minimum, average and variance of green times per cycle will be listed.
Intersection Vehicle Counts	Table Name Node Time Interval	For the selected intersection, the number of vehicles making each movement is listed for each time interval of the specified length.

Table A1-2: Reporting Modules (continued)

Module	Parameters	Report Output
Cumulative Flows	Link ID	For the selected link, a plot showing cumulative in-flow and out-flow is produced.
VMS Report	Time Interval VMS ID	For the selected VMS, the vehicle counts and travel times on the all route alternatives are shown for each time interval.
Detector Report	Time Interval Detector ID	For the selected detector, the average and standard deviation of the vehicle occupancy, flow and travel time for each time interval are shown in both table and plot format.
TRANSMIT Detector Report	Time Interval TRANSMIT Detector ID	A table listing the number of vehicles detected by the selected detector for each time interval is shown. A second table lists all other TRANSMIT detectors that detected vehicles that had passed through the selected detector, and shows the number of vehicles that passed through those detectors.
DTA Aggregator	none	The DTA Aggregator reports link travel times averaged over each minute of simulation.
Link Plots	Link ID	Travel time, density flow in or flow out curves are reported for the selected link.

Running Reports from the Web interface

In the web interface, all of the reports can be run from the "Reports" page (see Figure A1-59), except for the Intersection Movement Counts and the Link Traffic Composition Analysis, which are found on the "Modules" page. A list of previously run reports appears in the "Reports History" section of the "Reports" page. Further, the progress and completion of a report can be tracked through the web interface "Tasks" page (see Figure A1-58). Examples of the report results are shown below.
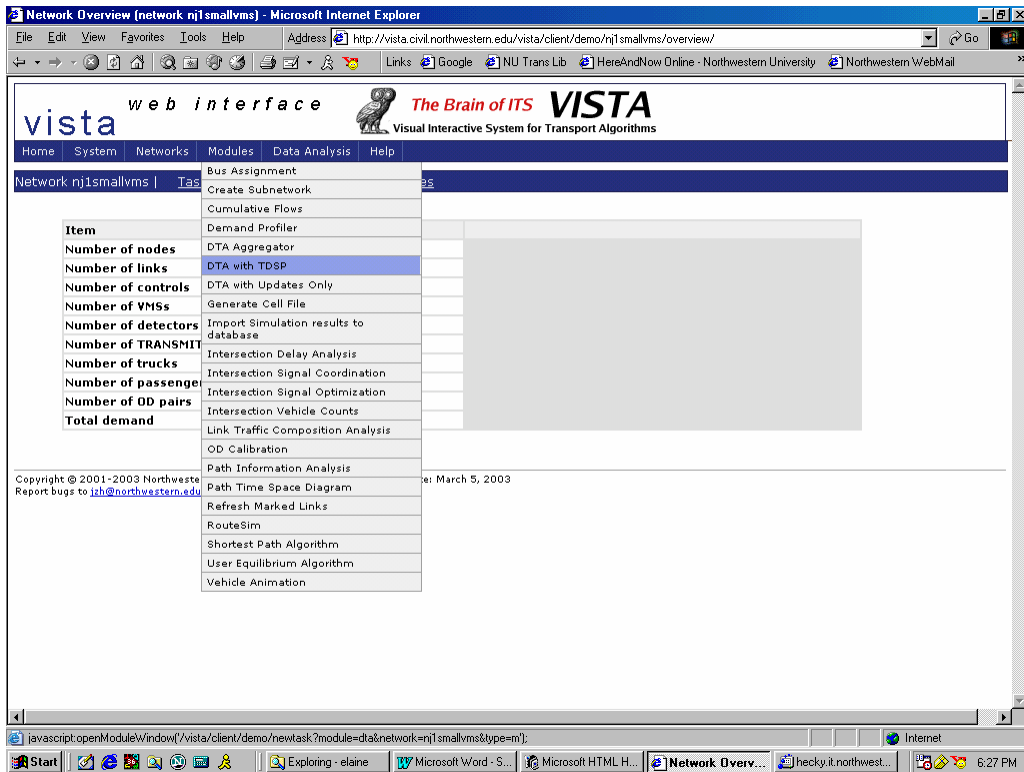
Figure A1-59. Web Interface Reports Page

General Report

The General Report gives general network statistics, such as number of nodes, links, controls and OD pairs. It also gives aggregate travel statistics, including total system travel time and average, maximum and minimum OD travel times. Further, the distributions of OD travel times and vehicles departure times are shown. The level of detail of the distributions can be increased by setting a smaller "Time Interval" value at the top of the General Report page and clicking on "Update". An example of a portion of the General Report is shown in Figure A1-60.

Figure A1-60. The General Report

The image content (browser window):

General Information about Network njws_base

Table of Contents

Basic Network Information

Table 1. Network Overview

Item	Counts in network njws_base
Nodes	557
Links	1166
Controls	54
VMS panels	17
Detectors	167
TRANSMIT Detectors	25
O-D pairs	3956
Demand	122919
Passenger Vehicles	94566
Heavy Vehicles	28353
Buses	0
Bus Routes	0
Simulation Length (s)	3600

Table 2. Vehicle counts

	Total	Non-entering	Non-exiting
All Vehicles	122919	23782	46198
Passenger Veh.	94566	18284	35491
Heavy Veh.	28353	5498	10707

Travel Time information (Moving Vehicles only)

Table 3. All Vehicles Travel Time

Assignment	Start	End	No. Veh.	Total TT (H)	AVG (M)	STD (M)	MAX (M)	MIN (M)
0	00:00:00	00:15:00	30704	11904.0	23.26	22.6	60.0	0.0
1	00:15:00	00:30:00	24868	7623.0	18.39	17.15	45.0	0.0
2	00:30:00	00:45:00	22537	4972.0	13.24	10.87	30.0	0.0
3	00:45:00	01:00:00	20844	1772.0	5.1	4.74	15.0	0.0
Total	00:00:00	01:00:00	98953	26273.0	15.93	17.57	60.0	0.0

Table 4. Passenger Vehicle Travel Time

Assignment	Start	End	No. Veh.	Total TT (H)	AVG (M)	STD (M)	MAX (M)	MIN (M)
0	00:00:00	00:15:00	23617	9129.0	23.19	22.58	60.0	0.0
1	00:15:00	00:30:00	19153	5866.0	18.38	17.13	45.0	0.0
2	00:30:00	00:45:00	17343	3816.0	13.2	10.84	30.0	0.0
3	00:45:00	01:00:00	16006	1355.0	5.08	4.73	15.0	0.0
Total	00:00:00	01:00:00	76119	20167.0	15.9	17.55	60.0	0.0

Table 5. Heavy Vehicle Travel Time

Assignment	Start	End	No. Veh.	Total TT (H)	AVG (M)	STD (M)	MAX (M)	MIN (M)
0	00:00:00	00:15:00	7087	2775.0	23.5	22.67	59.0	0.0
1	00:15:00	00:30:00	5715	1757.0	18.45	17.19	45.0	0.0
2	00:30:00	00:45:00	5194	1155.0	13.35	10.96	30.0	0.0
3	00:45:00	01:00:00	4838	416.0	5.17	4.77	15.0	0.0
Total	00:00:00	01:00:00	22834	6105.0	16.04	17.64	59.0	0.0

Travel Time information (With Non-entering Vehicles)

Table 6. All Vehicles Travel Time

Assignment	Start	End	No. Veh.	Total TT (H)	AVG (M)	STD (M)	MAX (M)	MIN (M)
0	00:00:00	00:15:00	30704	11904.0	23.26	22.6	60.0	0.0
1	00:15:00	00:30:00	30706	13461.0	26.3	22.46	60.0	0.0
2	00:30:00	00:45:00	30719	13154.0	25.69	22.67	60.0	0.0
3	00:45:00	01:00:00	30606	11534.0	22.61	25.88	60.0	0.0
Total	00:00:00	01:00:00	122735	50055.0	24.47	23.5	60.0	0.0

Table 7. Passenger Vehicle Travel Time

Assignment	Start	End	No. Veh.	Total TT (H)	AVG (M)	STD (M)	MAX (M)	MIN (M)
0	00:00:00	00:15:00	23617	9129.0	23.19	22.58	60.0	0.0
1	00:15:00	00:30:00	23622	10335.0	26.25	22.44	60.0	0.0
2	00:30:00	00:45:00	23632	10105.0	25.66	22.67	60.0	0.0
3	00:45:00	01:00:00	23532	8881.0	22.65	25.91	60.0	0.0
Total	00:00:00	01:00:00	94403	38451.0	24.44	23.5	60.0	0.0

Table 8. Heavy Vehicle Travel Time

Assignment	Start	End	No. Veh.	Total TT (H)	AVG (M)	STD (M)	MAX (M)	MIN (M)
0	00:00:00	00:15:00	7087	2775.0	23.5	22.67	59.0	0.0
1	00:15:00	00:30:00	7084	3126.0	26.48	22.53	60.0	0.0
2	00:30:00	00:45:00	7087	3048.0	25.81	22.67	60.0	0.0
3	00:45:00	01:00:00	7074	2652.0	22.5	25.8	60.0	0.0
Total	00:00:00	01:00:00	28332	11603.0	24.57	23.51	60.0	0.0

Vehicle Miles Traveled (VMT) Information

Table 9. All Vehicles VMT

Assignment	Starting Time	Ending Time	Vehicle Count	Total VMT (Miles)
0	00:00:00	00:15:00	30704	59287.27
1	00:15:00	00:30:00	30706	36545.84
2	00:30:00	00:45:00	30719	25080.08
3	00:45:00	01:00:00	30606	11061.47
Total	00:00:00	01:00:00	122735	131974.66

Figure A1-60. The General Report (continued)

Table 10. Passenger Vehicle VMT

Assignment	Starting Time	Ending Time	Vehicle Count	Total VMT (Miles)
0	00:00:00	00:15:00	23617	45631.32
1	00:15:00	00:30:00	23622	28091.7
2	00:30:00	00:45:00	23632	19296.27
3	00:45:00	01:00:00	23532	8542.23
Total	00:00:00	01:00:00	94403	101561.52

Table 11. Heavy Vehicles VMT

Assignment	Starting Time	Ending Time	Vehicle Count	Total VMT (Miles)
0	00:00:00	00:15:00	7087	13655.95
1	00:15:00	00:30:00	7084	8454.14
2	00:30:00	00:45:00	7087	5783.81
3	00:45:00	01:00:00	7074	2519.24
Total	00:00:00	01:00:00	28332	30413.14

Table 14. Heavy Vehicle Delay

Assignment	Starting Time	Ending Time	Vehicle Count	AVG Delay (M/Veh)	Delay STD (M)
0	00:00:00	00:15:00	7087	20.76	22.83
1	00:15:00	00:30:00	5715	16.27	16.65
2	00:30:00	00:45:00	5194	11.67	10.54
3	00:45:00	01:00:00	4838	4.28	4.67
Total	00:00:00	01:00:00	22834	14.08	17.25

Congestion Index Information (With Non-entering Vehicles)

Table 15. All Vehicles Delay

Assignment	Starting Time	Ending Time	Vehicle Count	AVG Delay (M/Veh)	Delay STD (M)
0	00:00:00	00:15:00	30704	20.52	22.78
1	00:15:00	00:30:00	24868	16.23	16.62
2	00:30:00	00:45:00	22537	11.56	10.44
3	00:45:00	01:00:00	20844	4.2	4.62
Total	00:00:00	01:00:00	122735	22.88	23.87

Table 16. Passenger Vehicle Delay

Assignment	Starting Time	Ending Time	Vehicle Count	AVG Delay (M/Veh)	Delay STD (M)
0	00:00:00	00:15:00	23617	20.45	22.77
1	00:15:00	00:30:00	23622	24.5	22.75
2	00:30:00	00:45:00	23632	24.42	23.21
3	00:45:00	01:00:00	23532	22.03	26.31
Total	00:00:00	01:00:00	94403	22.85	23.86

Table 17. Heavy Vehicle Delay

Assignment	Starting Time	Ending Time	Vehicle Count	AVG Delay (M/Veh)	Delay STD (M)
0	00:00:00	00:15:00	7087	20.76	22.83
1	00:15:00	00:30:00	7084	24.72	22.85
2	00:30:00	00:45:00	7087	24.58	23.21
3	00:45:00	01:00:00	7074	21.89	26.19
Total	00:00:00	01:00:00	28332	22.99	23.87

Figure A1-60. The General Report (continued)

Path Time Space Diagram

When a series of link IDs representing a corridor is entered, the Path Time Space Diagram report plots the average vehicle travel time against distance traveled along the selected links. The report results include a table listing the distance traveled under column "x" and the cumulative travel time required under column "y" for each link. These results are also shown in graphical format as a plot of travel time against distance. An example of a Path Time Space Diagram for seven links is shown in Figure A1-61.
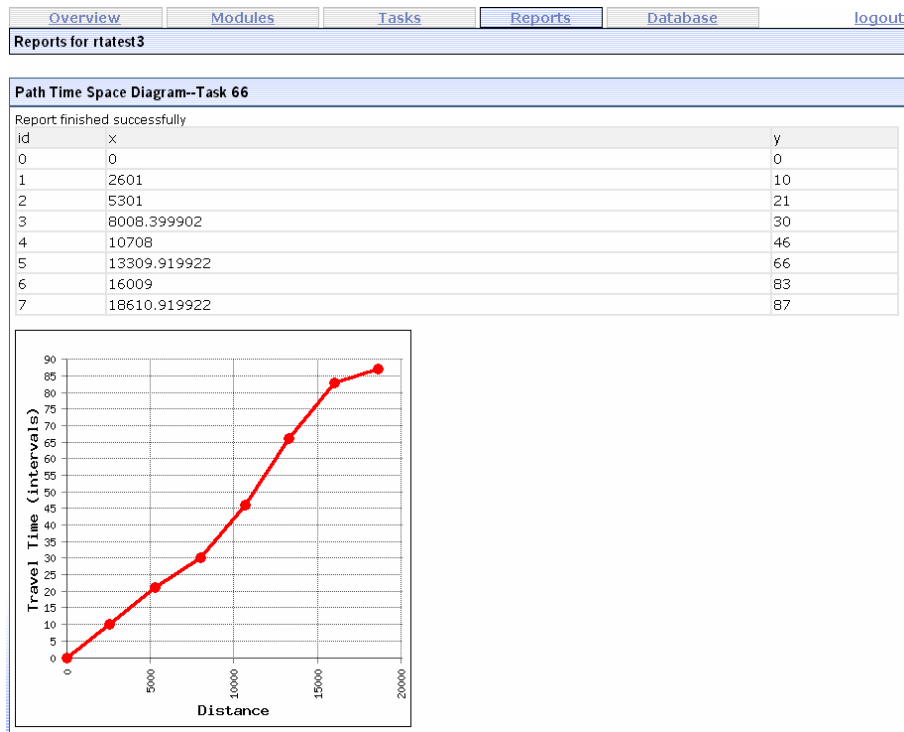
Figure A1-61. The Path Time Space Diagram

Origin Destination Travel Time Report

The Origin Destination Travel Time Report lists the average travel time and travel time variance for each OD pair in the network, as well as the number of vehicles that traveled between each OD pair. An example of an Origin Destination Travel Time Report is shown in Figure A1-62. (The origins and destinations are listed as centroid node IDs.) This report will allow for convenient comparison of OD travel times for different TSP scenarios.

Figure A1-62. The Origin Destination Travel Time Report

Path Information Analysis

For a selected OD pair, the Path Information Analysis report lists all the paths used by vehicles that traveled between that origin and that destination. The results are stored in a database table, and can be accessed through the Database web page. An example of a Path Information Analysis result table is shown in Figure A1-63. The first column, "id", shows the ids of the paths listed, and the paths are then listed in the path column. The "vehno" column shows the number of vehicles that used each path during the simulation period, and the "stepv" column shows the number of vehicles that started on each path during different time intervals within the simulation period. The "tratime" column shows

the average travel time of path for each time intervals within the simulation period. The first row, with id=0, does not correspond to a path, but exists simply to show the number of intervals used in the "stepv" and "tratime" columns. The example in Figure A1-63 shows two different paths used to travel from node 111208 to node 6051.

Table pia in network rtatest3				
Data in table pia				
|< << <		0 to 3 records of 3	> > > >|	
id path		vehno stepv	tratime	
0 {0}		0 {0,1,2,3,4}	{0,1,2,3,4}	
1 {11208,32877,6011,7627,11218,32883,6051}		3447 {1060,941,789,505,152,0}	{1548,1358,1048,749,483,0}	
2 {11208,3702,5325,7627,11218,32883,6051}		327 {100,102,67,35,23,0}	{1550,1358,1048,750,490,0}	

Figure A1-63. The Path Information Analysis Table

Link Traffic Composition Analysis

For a selected link, the Link Traffic Composition Analysis report lists the OD pairs of the vehicles that traveled along that link. The results are stored in a database table, and can be accessed through the Database web page. An example of a Link Traffic Composition Analysis result table is shown in Figure A1-64. The first column, "id", shows the ids of each entry. The "source" column shows the origin zone, and the "destination" column shows the destination zone. The "interval" column indicates a time interval within the simulation period, and the vehno column shows the number of vehicles that traveled on the selected link to travel between the given OD pair during the given time interval. The first row, with id=0, does not correspond to a link traffic composition entry, but instead shows origin node (in the "source" column), destination node (in the "destination" column) and link id (in the "interval" column) of the link.

Table ltca in network rtatest3			
Data in table ltca			
|< << <	0 to 4 records of 4	> > > >|	
id source	destination	interval	vehno
0 6956	6957	7627	
1 6989	6944	0	2001
2 6989	6944	1	1294
3 6989	6944	2	705

Figure A1-64. The Link Traffic Composition Analysis Table

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Bus Travel Time Report

The Bus Travel Time Report lists the departure time and total travel time of each run made for a selected route (only runs completed before the end of the simulation period are included). The average travel time and standard deviation and variance of the travel time for the bus route are then shown. An example of a Bus Travel Time Report is shown in Figure A1-65.

Figure A1-65. The Bus Travel Time Report

Bus Path Time Space Report

For a selected set of links representing a corridor, the Bus Path Time Space Report shows the average travel time and travel time variance for each link. The number of buses included in the calculations is also listed for each link. An example of a Bus Path Time Space Report is shown in Figure A1-66.

Figure A1-66. The Bus Path Time Space Report

Schedule Adherence Report

For a selected bus route, the Schedule Adherence Report shows the scheduled arrival time, actual arrival time and the difference between the two for each bus run and time point on that route. The scheduled arrival time is derived from data in the bus_time_stamps table and the actual arrival time is determined from the simulation output. An example of a Schedule Adherence Report is shown in Figure A1-67.

Figure A1-67. The Schedule Adherence Report

Signal Report

For a selected node, the Signal Report shows the amount of time granted to each phase. An example of a Signal Report is shown in Figure A1-68. The "Total Green" column shows the number of seconds of green and yellow time allocated to each phase during the simulation period. The "Proportion Green" column shows the proportion of the simulation period that is allocated to each phase. The "Max Green" column indicates shows the longest continuous period of green granted to each phase and the "Min Green" column indicates shows the shortest continuous period of green granted to each phase. The "Avg Green" column shows the average continuous period of green granted to each phase, with the variance shown in the "Variance" column.
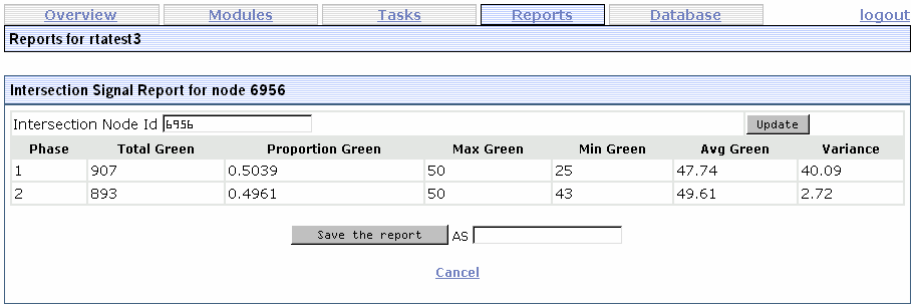
Figure A1-68. The Signal Report

Intersection Vehicle Count

For a selected intersection, the Intersection Vehicle Count creates a table that shows the number of vehicles that make each possible movement at the intersection. An example of an Intersection Vehicle Count result table is shown in Figure A1-69. The "id" column gives each record a line identification label. The "time interval" column indicates the assignment interval within the simulation period, where the 0th interval refers to the whole simulation period. The remainder of the columns indicate by link id all the possible movements at the selected intersection; for example, movement (6011,7627) refers to the movement from link 6011 to link 7627. The values in those columns

indicate the number of vehicles that make the given movement in the indicated assignment interval.

Figure A1-69. The Intersection Vehicle Count Table

Cumulative Flows

The Cumulative Flow report produces a plot of the cumulative flow in and flow out over the simulation period for the selected link. An example of a cumulative flow report plot is shown in Figure A1-70.
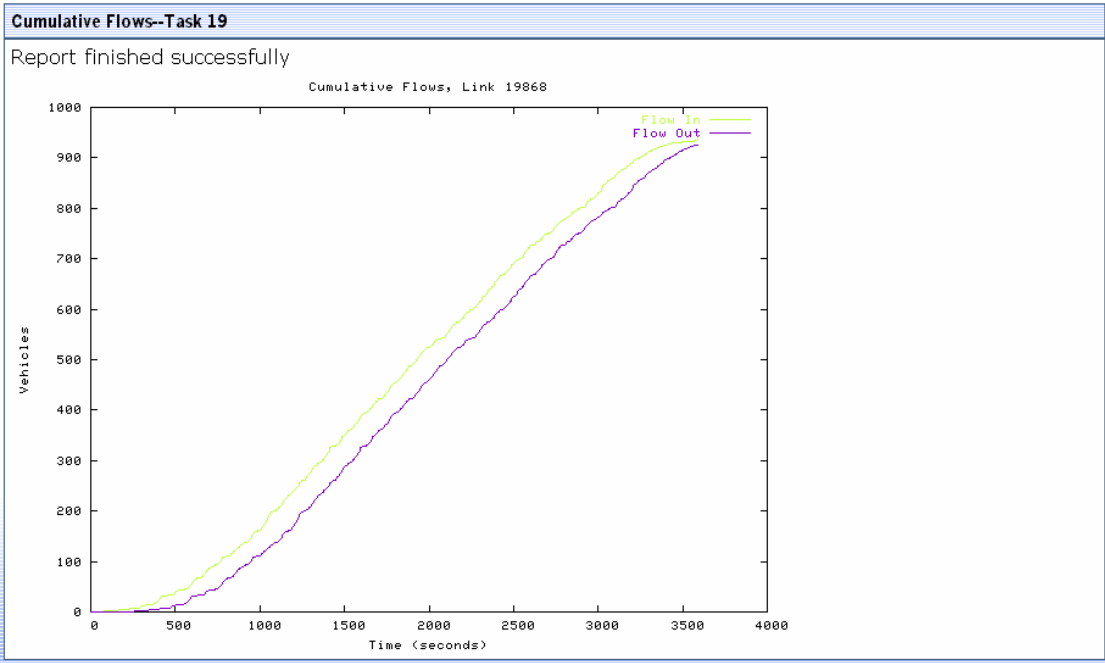
Figure A1-70. Cumulative Flow Curve

VMS Report

The variable message sign (VMS) report shows the vehicle count and average travel times for each of the route alternatives associated with a VMS. An example of a VMS report is shown in Figure A1-71. First, the report describes the location of the VMS and then shows the link ids of the links associated with each route alternative. Next, the report shows a table listing the average travel time and number of vehicles for each time interval on the first route alternative is shown along with a plot of the average travel time on the route. (The time interval is selected by the report user.) A similar table and plot are then shown for the second route alternative.

VMS Report

Time Interval (minute): 5

VMS ID 2

Update

VMS 2 Location: **50** feet downstream on link **9** in lane **0**
Total Number of Vehicles Passed This VMS: 2810
Compliance Rate: 0.5
Strategy: 2

2 Routes attached:
Freeway -- Link id: 3 12 22 23 24 25
Number of vehicles went through this route: 2412
State Route -- Link id: 13 42 10 43 38 34 33
Number of vehicles went through this route: 51

Route 5 Freeway

Start	Average Travel Time (seconds)	Vehicle Count
0	73	200
300	75	284
600	79	281
900	81	278
1200	87	286
1500	88	298
1800	91	284
2100	95	276
2400	93	278
2700	92	274
3000	77	281
3300	101	220

Figure A1-71. VMS Report

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Route 6 State Route

Start	Average Travel Time (seconds)	Vehicle Count
2100	47	11
2400	153	27
2700	162	35
3000	281	26
3300	210	23
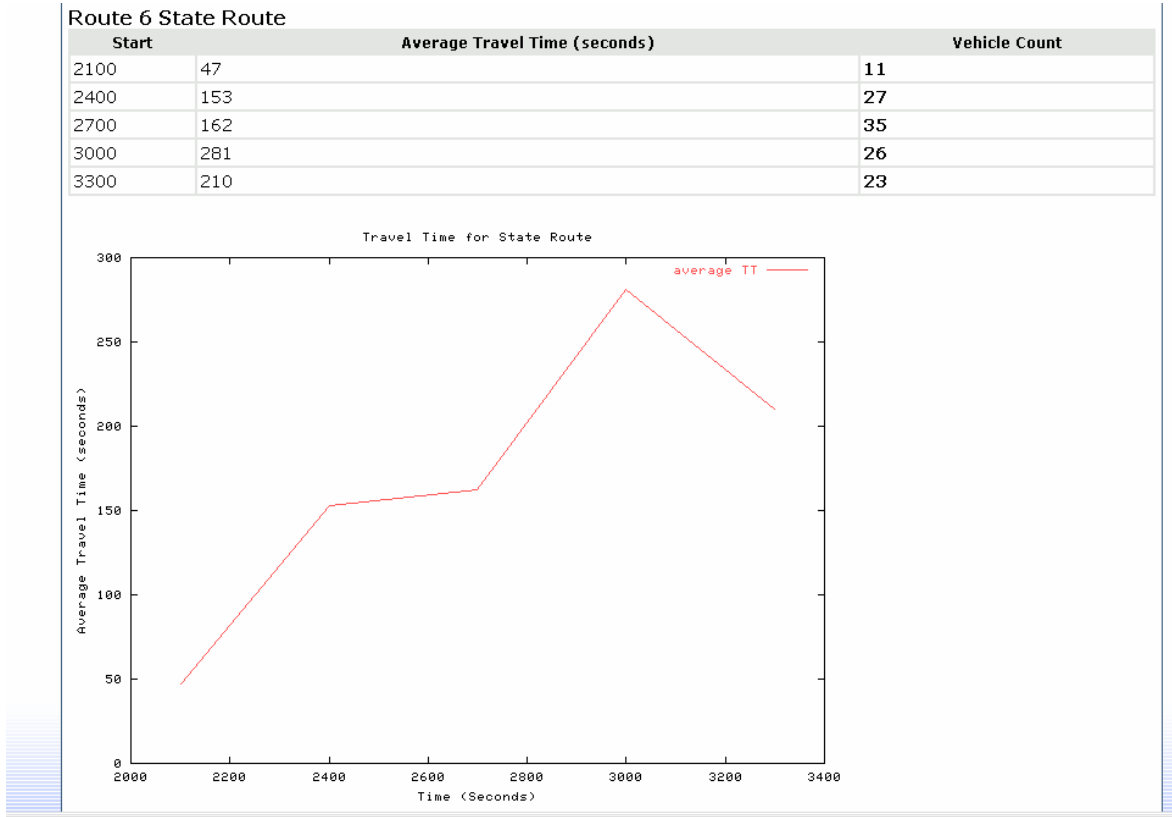
Figure A1-71. VMS Report (continued)

Detector Report

The detector report shows the flow, occupancy and speed detected by a selected detector in the simulator. An example of a Detector Report is shown in Figure A1-72. First, report describes the location of the detector. Next, the report shows a table listing the average and standard deviation of vehicle flow detected for each time interval, along with a plot of flow detected throughout the simulation period. (The time interval is selected by the report user.) A similar table and plot are then shown for the speed detected by the detector. The detector used in the example was set to detect only flow and speed, and not occupancy; therefore, the report shows a message stating that no occupancy data was found for the occupancy report.

Detector Report for detector 155

Time Interval (minute): 5

Detector ID 148 ▾

Update

Detector 155 Location: 1583 feet downstream on link 4465 in lane 3

No data found for Occupancy Report

Flow Report

| Period | | Flow (vehicles/hour) | |
Start	End	Average	Standard Deviation
0	300	0.00	0
300	600	10.62	9
600	900	24.18	3
900	1200	57.26	14
1200	1500	118.60	11
1500	1800	144.26	10
1800	2100	164.52	3
2100	2400	160.90	3
2400	2700	176.82	10
2700	3000	202.86	5
3000	3300	203.32	2
3300	0	201.41	1
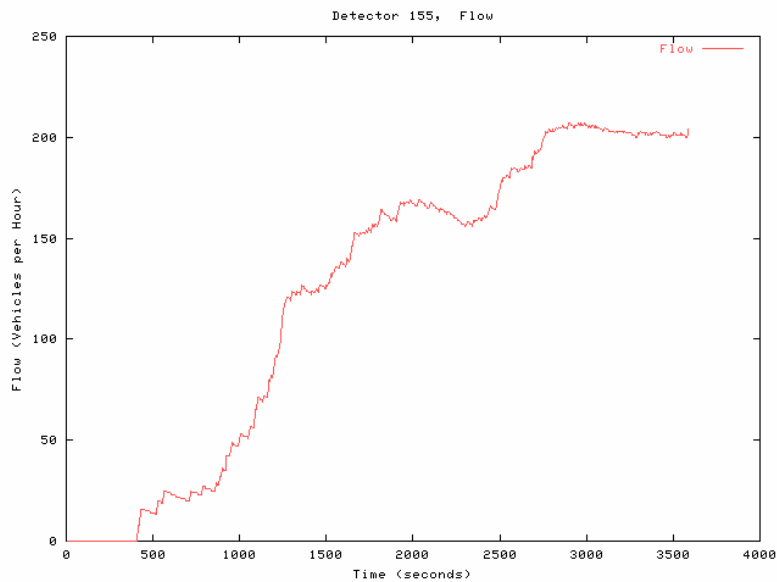
Figure A1-72. Detector Report

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Speed Report

| Period | | Speed (mph) | |
Start	End	Average	Standard Deviation
0	300	7.00	0
300	600	7.00	0
600	900	7.00	0
900	1200	7.00	0
1200	1500	7.00	0
1500	1800	7.00	0
1800	2100	7.00	0
2100	2400	7.00	0
2400	2700	7.00	0
2700	3000	7.00	0
3000	3300	7.00	0
3300	0	7.00	0
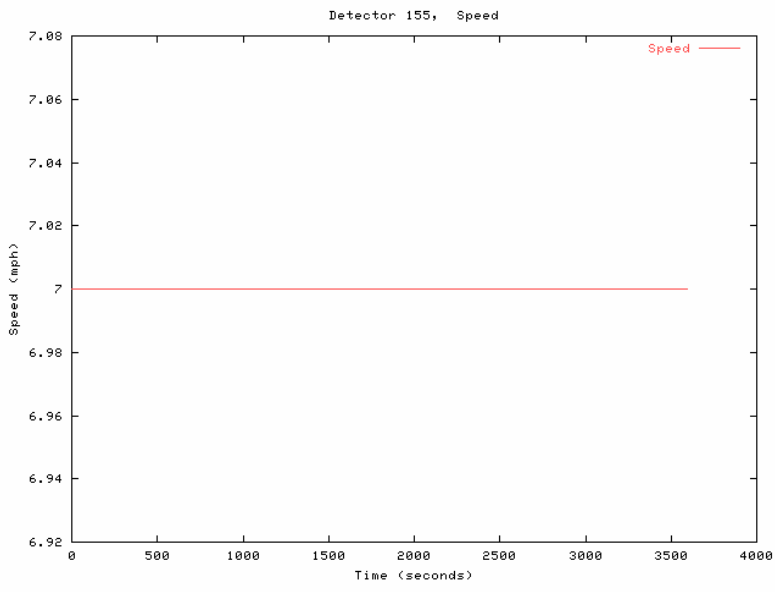
Figure A1-72. Detector Report (continued)

TRANSMIT Detector Report

The TRANSMIT detector report shows the number of vehicles detected by a selected TRANSMIT detector in the simulator. An example of a TRANSMIT Detector Report is shown in Figure A1-73, where the detector of interest is number 6147022, as shown in the title bar of the window. First, the report describes the location of the detector. Next, the report shows a table listing the number of vehicles detected for each time interval. (The time interval is selected by the report user.) The total, average, standard deviation and variance of the number of vehicles detected are listed at the end of the table. A second table lists all other TRANSMIT detectors that detected vehicles that had passed through the detector 6147022, and shows the number of vehicles that passed through those detectors.

TRANSMIT Detector Reports for detector 6147022

Time Interval (minute): 5   Detector ID 6147016 ▼   Update

Detector 6147022 Location: 2000 feet downstream on link 21402130 in lane 1

Period Start	Period End	Vehicles
00:00:00	00:05:00	23
00:05:00	00:10:00	43
00:10:00	00:15:00	61
00:15:00	00:20:00	64
00:20:00	00:25:00	77
00:25:00	00:30:00	54
Total		322
Average		54
Standard Deviation		19
Variance		352

Detector	Vehicles
6147032	315
6147042	1
Total	315
Exclusive	7

Figure A1-73. TRANSMIT Detector Report

Running Reports from the Client interface

The Reports menu allows the user to run reports on the selected network (see Figure A1-74). Most of the reports output their results to tables, which can be viewed in the Data Warehouse or the web interface. Results that are not outputted to tables can be viewed in the web interface. The DTA Aggregator and link plots are described in this section. See Section 1.5.1 on Running Reports from the Web interface for detailed explanations and examples of the Path Information Analysis, Link Traffic Composition Analysis, Path Time Space Diagram, Cumulative Flows, General Report and Intersection Vehicle Count reports.
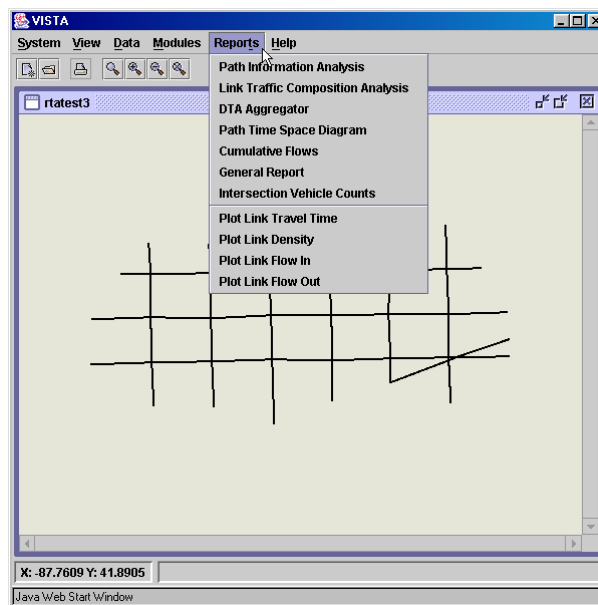
Figure A1-74. Client Interface Reports Menu

DTA Aggregator

The DTA Aggregator reports link travel times averaged over each minute of simulation. The results are stored in a table named traveltime_min, which can be accessed either through the GIS client's Data Warehouse, or through the Database page in the web interface. Figure A1-75 shows the traveltime_min table as viewed through the GIS client's Data Warehouse. The link ids are shown in the "id" column, the link types are

shown in the "type" column, and the average link travel times for each minute of simulation are shown in array format in the "time" column.

Figure A1-75. DTA Aggregator – Traveltime_min Output Table

Link Plots

Travel time, density flow in and flow out curves can also be reported for user-selected links. The reports show the respective measures plotted over the simulation period. For example, Figure A1-76 shows the density plot of link 19868. A Data tab is available in the top left of the window, and allows the density data to be viewed in table format, as shown in Figure A1-77. The Preferences tab provides display options for the plot, as shown in Figure A1-78.
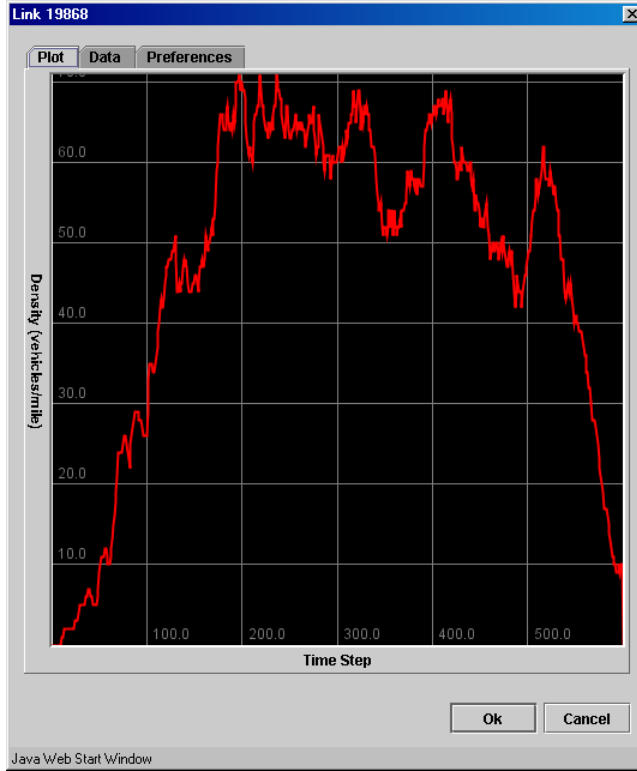
Figure A1-76. Link Density Plot

Figure A1-77. Link Density Plot – Data

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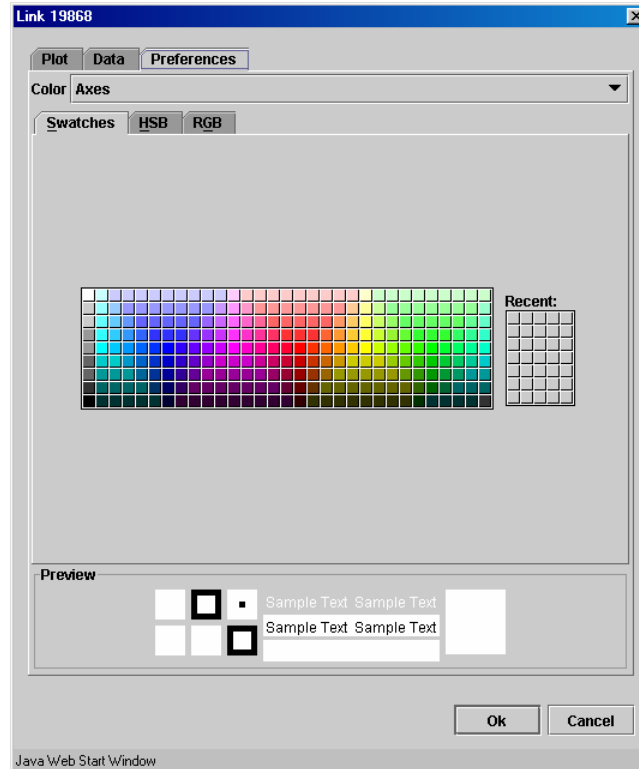
Figure A1-78. Link Density Plot – Preferences

Running Simulation Animation

Animation is a convenient method of performing an initial verification of whether or not the results of a simulation are reasonable. Since animation is inherently graphic, it cannot be viewed in the web interface, and instead must be viewed in the GIS client interface.

After DTA has been run on a network, the simulation animation can be viewed by selecting Data Animation from the Data menu (see Figure A1-79). The Configure Animation window then appears to prompt the user to select the data that is to be animated (see Figure A1-80). Specifically, the user can select to have links color-coded by density, travel time, inflow or outflow (see Figure A1-81). During animation, a color-code legend will appear to show the values associated with each color. If the animation is by density, the colors indicate the proportion of jam density associated on each link (the legend is shown in Figure A1-82). If the animation is by travel time, the colors

indicate the link travel time as a multiple of free flow travel time on each link (the legend is shown in Figure A1-83). If animation is by inflow or outflow, the colors indicate the number of vehicles entering or leaving the link during each time step (the legend is shown in Figure A1-84). Figure A1-85 shows an example of what a network looks like during animation.
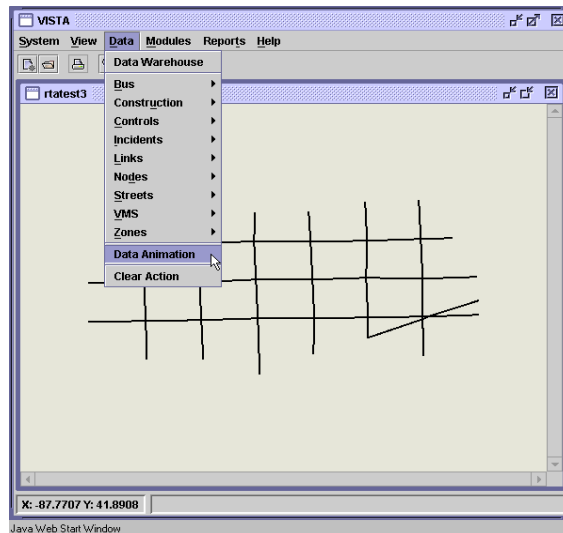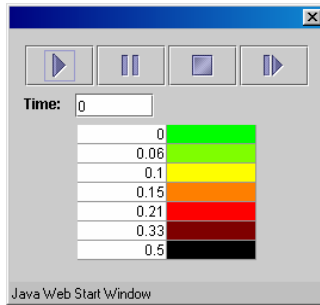

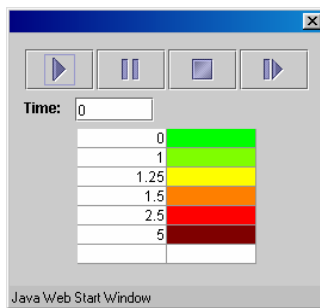**Figure A1-79. Client Interface Data Animation Menu Option**
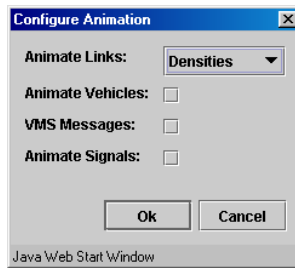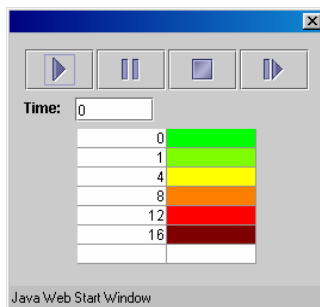

Figure A1-80. Configure Animation Window
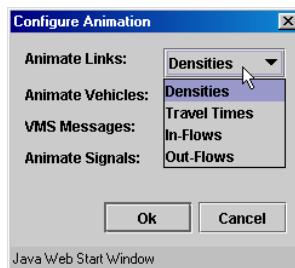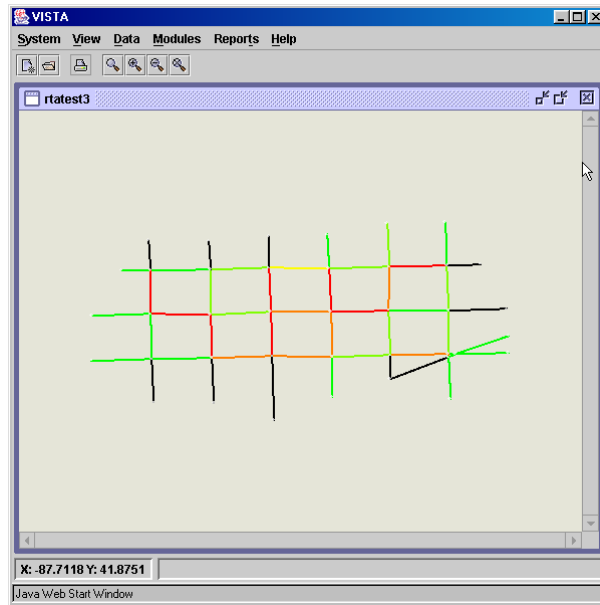

Figure A1-81. Animation Options

Figure A1-82. Color Codes for Animation by Density

**Figure A1-83. Color Codes for Animation by Travel Time**

**Figure A1-84. Color Codes for Animation by Inflow or Outflow**

Figure A1-85. Example of Network Animation

For more detail, individual vehicles and signals can also be animated. Before running the Data Animation, the Vehicle Animation module must be run from the Modules menu. This module will prompt the user for the percentage of vehicles to animate (see Figure A1-86). When the Vehicle Animation module has finished, Data Animation can be selected from the Data menu, then in the Configure Data Animation window, Animate Vehicles and Animate Signals can be selected. (There are no VMS's in the Chicago network, so this option is irrelevant.) The data animation will then appear as shown in Figure A1-87. The small dark circles represent cars, and the large circles represent buses. The small light colored circles represent bus stops.
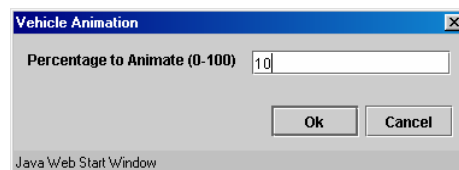
Figure A1-86. Vehicle Animation window
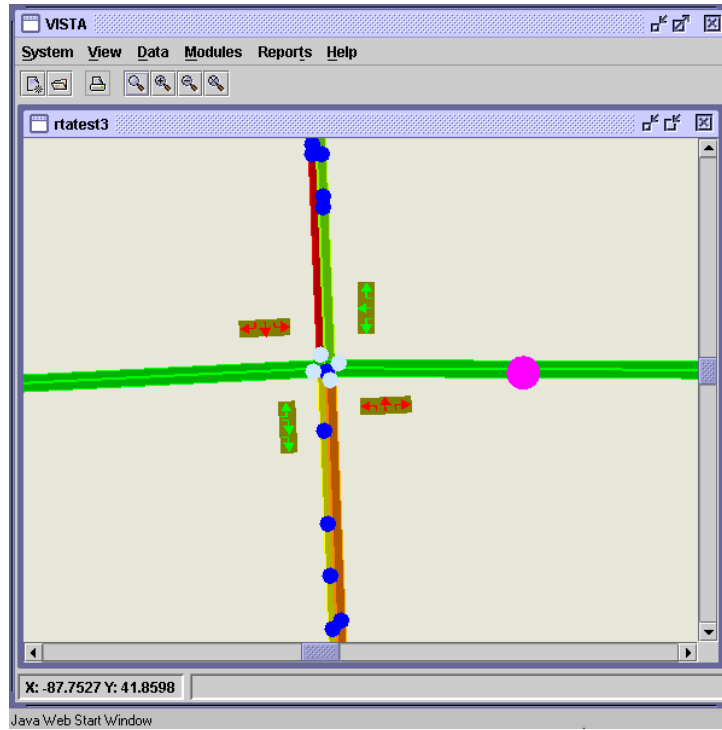
Figure A1-87. Example of vehicle and signal animation