Moving Smart in Rhode Island

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16. Abstract

Real-time transportation system information is a critical element in the development of Intelligent Transportation Systems (ITS). The Rhode Island Department of Transportation (RIDOT) is in the process of developing a fully integrated intelligent transportation system. This system is composed of the following: a transportation management center (TMC), dynamic messaging signs (DMS); closed-circuit television (CCTV) cameras accompanied by video imaging process systems; and highway advisory radio (HAR). RIDOT plans to have the capability in the near future of monitoring and controlling several closed loop signalization systems, particularly alternate routes during an incident. To make this a reality, research is needed to ensure that the appropriate transportation data is captured and developed, as well as an appropriate information system is developed. This project's goal was to ensure the following: (1) that appropriate real-time operating conditions data are captured and developed automatically into a user-friendly format stipulating travel time or speed; and (2) that a real-time information system prototype is developed that supports monitoring, warehousing/mining, and concurrent access of data via the web; and (3) that an integrated system combines and extends the existing stand-alone systems.

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SECTION 1. INTRODUCTION

Real-time transportation system information is the critical element in the development of intelligent transportation systems (ITS). With the rapid advancement of communications and electronic technology, tremendous possibilities are available to improve the way that information is provided to the traveling public about how to use the system effectively and efficiently. The management, integration, and presentation of the collected real-time information present the greatest challenge to a state Department of Transportation or municipality that is controlling traffic signals, dynamic message signs, audio advisories, et cetera. Ultimately, the transportation system operator wants to present quality information to all types of users of the system, from traveler to the analyst or researcher.

The types of information needed and sources available are the next critical pieces of the puzzle with respect to the types of information that can be provided. What the system operator wants to present is dependent on the types of devices that are in the system to be accessed. Traditionally, inductive loop detection (ILD) devices have been the backbone of the transportation system. These devices have the ability to provide traffic volumes, lane occupancy, speed, and vehicle classification.

Probes in the system provide the ability to measure performance over space, including the capture of information over multiple links or segments over various time periods. Using probes to measure travel time is a concept gaining more attention throughout the country. There are various methods of attempting to gain this information in real-time. The successful TRANSMIT [Mouskos, 1998], program in the NY/NJ area uses roadside toll tag readers to measure the travel time of tag holders between readers. Less successful was an attempt in Washington, D.C. [FHWA, 2002] to measure travel time by geo-locating cell phone users. Inaccuracies due to radio frequency reflections and obstructions to line of sight prevented the desired degrees of precision in locating vehicles. The AVL (autonomous vehicle location) devices normally use Global Positioning Systems (GPS) to locate vehicles in a fleet and convey information to a central dispatching point. These systems usually can assess current speeds of the vehicles equipped with these devices.

The data acquisition, management, and access goals of this research project were to provide the end users with a useful integrated view of the traffic situation. Ultimately, it is inherently difficult to do so when the data is coming from different sources. An additional challenge is to design and develop the computer systems in such a way that the data is available for dissemination in real-time and at the same time archived for later analysis and use in such efforts as travel-time prediction.

In this research effort, the desire is to capture traffic data from RIDOT ILDs, GPS, and “human-by-phone” sources, as well as work on the integration of database, real-time, web, and GIS (Geographic Information Systems) systems. The effort includes analyzing the data to work toward the development of a travel-time prediction framework as well as the development of real-time information system prototype that supports monitoring, warehousing/mining, and concurrent access via the web. These results have also been reported in the short paper [Peckham, 2002].

1.1 Research Objectives

The overall research objectives are as follows:

(1) To develop a system where appropriate real-time operating conditions data are captured and developed automatically into a user-friendly-format stipulating travel time or speed
(2) To develop a real-time information system prototype that supports monitoring, warehousing/mining, and concurrent access via the web; and
(3) To develop an integrated system that combines and extends the existing stand-alone systems.

1.2 Report Organization

The remainder of the report is organized to address the items involved in the overall research effort. Section 2 contains details on how the research was conducted. Section 3 provides results, and analysis of the data, while Section 4 gives details about applying the results to the development for a framework for travel time prediction and the prototype. Section 5 is devoted to the conclusions and recommendations for further work.

SECTION 2. METHODOLOGY

This section details the efforts involved in conducting the research. Included in this section is a discussion about site selection, data sources, analysis, and application of results. The principal goal for this project was to be able to gather and analyze data from various portions of the Rhode Island transportation system, as well as to be able to display the traffic performance information. One of the issues of particular interest in the research was to develop an open source prototype for the display, which would consist of GIS, database software, and a web interface.

2.1 Study Area

For the research effort, the area of concern was a portion of I-95. The study area boundaries stretch from West Greenwich to Providence because this area of Interstate 95 has field equipment devices and probe data sources. To analyze travel time, eight segments (4 NB/ 4 SB) between Exit 8 and Exit 23 along I-95 were chosen. The chosen segments were based on the ability to capture data from each section.

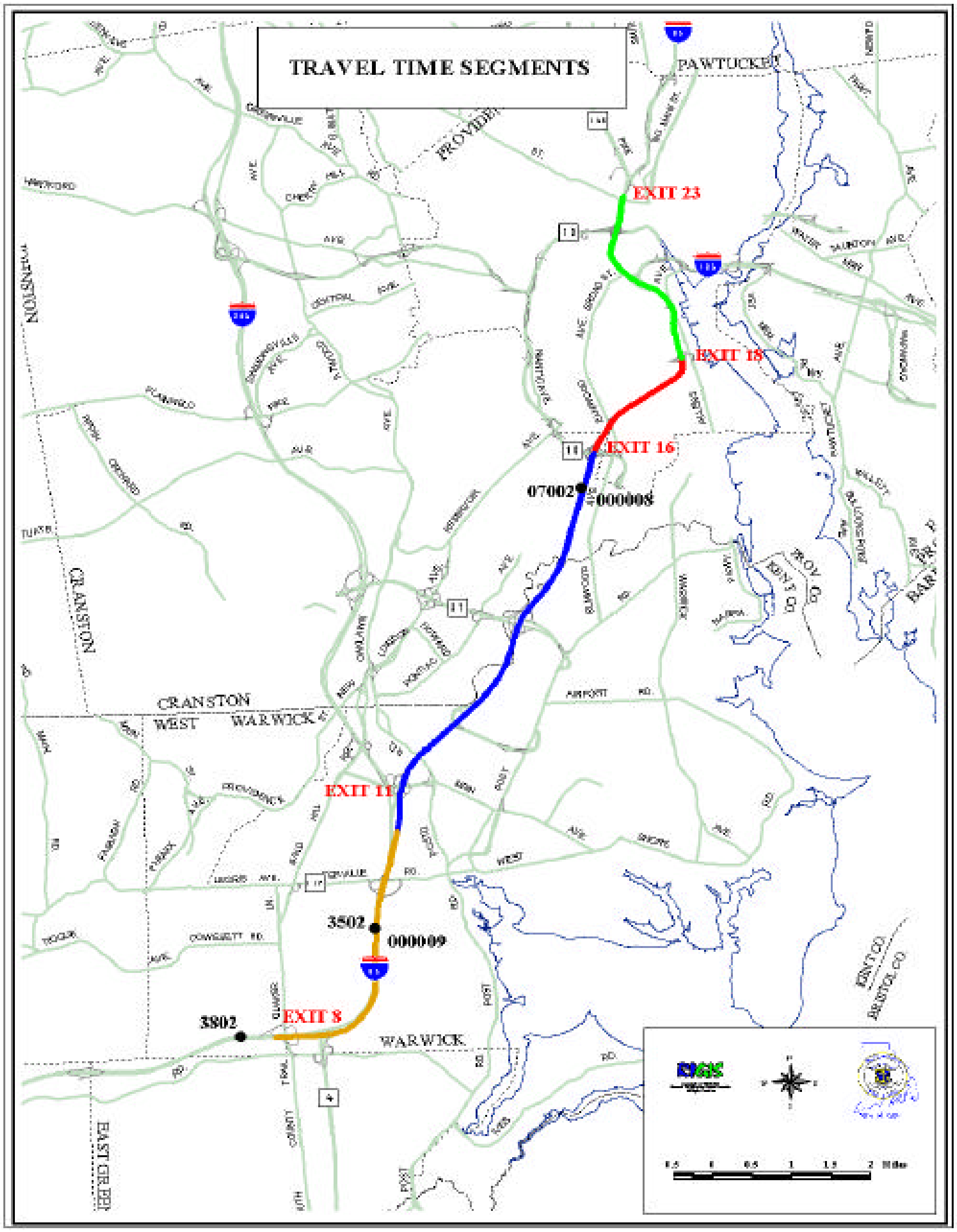


Figure 1. Study Area Along I-95

The study area ranges from Route 2 in West Greenwich (Exit 8) to the State Offices located in Providence (Exit 23) along I-95. Figure 1 provides an illustration of this. The various colors represent the various segments, and they represent a northbound and southbound segment respectively. This segment of I-95 serves as the backbone of travel to all major cities and attractions throughout Rhode Island.

As with typical freeway segments, entrance and exit ramps provide merging or diverging problems for the mainline, resulting in bottlenecks at various points. Segment 1 begins in West Greenwich (Exit 8 NB – Exit 11 NB) and is subject to excessive delays due to the presence of major merging sections at the beginning (Route 4/ I-95) and end of the segment (I-295/I-95). Segment 2 enters the Warwick/Cranston area (Exit 11 NB – Exit 16 NB) and experiences periods of stop & go conditions due to the presence of Route 37, Route 10, and Jefferson Boulevard entrance/exit ramps. Segment 3 (Exit 16 NB – Exit 18 NB) borders Providence and features Thurbers Avenue, which is a dangerous curve that causes motorists to reduce speed drastically, while the presence of Route 10 also leads to increasing congestion levels. Segment 4 runs through the heart of the Providence metropolitan area (Exit 18 NB– Exit 23 NB) and is dominated by weaving sections, as is common in many metropolitan areas near the CBD (central business district), as entrance and exit ramps are closely spaced. The southbound segments begin with Segment 5 (Exit 23 SB – Exit 18 SB), which experiences heavy congestion levels due to the I-195 on-ramp. Segment 6 (Exit 18 SB – Exit 16 SB) sustains periods of delay due to the Thurbers Avenue curve. Segment 7 (Exit 16 SB – Exit 10B) is the longest of the test sections. There is no Exit 11 in the southbound direction. This segment experiences pockets of congestion due to the Route 37 interchange and the influx of vehicles entering via I-295 South. Segment 8 (Exit 10B SB – Exit 8 SB) is characterized by the Route 4 southbound on-ramp (Exit 9 SB), which causes a bottleneck situation from vehicles trying to access the route from all four lanes. The flow of traffic is much smoother after Exit 9. This area converges rather quickly, from four lanes to three lanes and finally two for travelers who are not familiar with the area. An underlying factor with respect to congestion is that the middle lane serves as the low speed travel lane for travelers on Route 4 and the high-speed lane for motorists continuing on I-95. Signs in the area provide travelers with information of the upcoming segment 1.5 miles in advance. Table 1 displays segment information for the study area.

Table 1. Segment Identification and Lengths

Segment ID	I-95 Boundaries	Segment Length (mi.)	Direction
1	Exit 8 – Exit 11	3.86	NB
2	Exit 11 – Exit 16	5.55	NB
3	Exit 16 – Exit 18	1.82	NB
4	Exit 18 – Exit 23	2.83	NB
5	Exit 23 – Exit 18	2.46	SB
6	Exit 18 – Exit 16	1.29	SB
7	Exit 16 – Exit 10B	6.95	SB
8	Exit 10B – Exit 8	3.26	SB

2.2 Data Sources

One of the desires of the research was to develop a travel time prediction technique. To do this, various kinds and sources of data are required, including travel time, vehicle speeds, traffic volumes, lane occupancy, and roadway capacity. Travel time is not readily captured by traditional data capture sources, as most devices that are deployed by state or local transportation agencies use point source detection or monitoring. In this instance, there were two things that the researchers really wanted to accomplish: (1) to capture travel time along segments; and (2) to capture traffic flow characteristics associated with those segments during the time of travel time monitoring.

To capture travel time data, a global positional systems (GPS) device was used, as well as the reporting of data via a group called "Rhode Watchers" [Harris, 2002]. The GPS device was capable of collecting vehicle occupancy, trip purpose, location data (latitude, longitude), travel speed, vehicle ignition state, and a time stamp. The "RhodeWatchers" were mobile employees in the system equipped with Nextel two-way/cellular phones and who were to report incidents, roadway debris, disabled motorists, and severe congestion during their morning and afternoon commutes. RhodeWatchers served as traffic probes and they relayed their position at designated checkpoints to provide researchers with travel time data.

Inductive loop detectors (ILDs) provided the third source of data within the designated study area. They provided researchers with traffic flow characteristic data in 15-minute intervals (a compromise interval determined between RIDOT and URI). Table 2 displays where each loop detector station is located within the study area. Some limitation on detector numbers and locations was due to certain detectors in the system not working at the time of the data capture period.

Table 2. Loop Detector Locations within Segments

Station #	Segment ID	Segment Boundary	Direction
8	2	Exit 8 – Exit 11	NB
9	1	Exit 11 – Exit 16	NB
3502	8	Exit 16 - Exit 10B	SB
7002	7	Exit 10B – Exit 8	SB
3802	1	Exit 8 – Exit 11	NB
3802	8	Exit 10B – Exit 8	SB

2.3 Data Capture

The data collection process began in early April 2001 and continued through mid June of 2001. The RhodeWatcher data was collected during the morning commute and afternoon commute on Tuesdays, Wednesdays, and Thursdays. The amount of data was limited due to the number and availability of volunteers, which led to choosing certain days (i.e. Tuesday, Wednesday, Thursday). These three days are the most reliable and represent typical travel patterns, and the researchers wanted to identify typical characteristics. Monday, Friday, and the weekend tend to show much more fluctuation in traffic. RIDOT provided loop detector data as could be sustained for their program during the months of April, May, and June. The GPS probe collected travel speed and location information for the designated peak travel periods.

The RhodeWatcher and GPS probe data were analyzed to determine average travel times per designated segment and travel times for the entire study area. The loop detectors provided traffic flow characteristics. All three devices were used to determine if any correlation among them exists to determine how the various devices can be accurately used together or alternatively in a reporting system to most accurately predict travel time for RIDOT. Standard descriptive statistical measures such as mean travel time and standard deviation were used. Other statistical techniques, as merited were used as well, such as regression analysis (single or multi-variable) [Cannamela, 2001].

Examination of the entire study area as a whole was used to determine the overall travel time for travelers heading from West Greenwich to Providence. The overall travel time is useful for comparing average individual segment travel times versus expected times. The expected travel time based on the speed limit for each segment was used as a base case for comparison. Distances between exits were calculated using video footage from RIDOT and software was used to determine the accuracy of the video. Tables 3 & 4 on the following page display the baseline calculations for I-95 northbound and southbound.

Table 3. I-95 Northbound Calculated Travel Times According to Speed Limits

Segment ID	Segment Distance (miles)	Speed Limit (mph)	Calculated Travel Time (min)	Calculated Travel Time (sec)
Exit 8A –Exit 8B	0.19	65	0.2	11
Exit 8B – Exit 10	2.58	55	2.8	169
Exit 10 – Exit 11	1.09	55	1.2	71
Exit 11 – Exit 12	0.26	55	0.3	17
Exit 12 – Exit 13	1.18	55	1.3	78
Exit 13 – Exit 14	1.44	55	1.6	94
Exit 14 – Exit 16	2.67	55	2.9	175
Exit 16 – Exit 18	1.82	55	2.0	119
Exit 18 – Exit 20	1.38	50	1.7	99
Exit 20 – Exit 21	0.44	50	0.5	31
Exit 21 – Exit 22	0.23	50	0.3	16
Exit 22 – Exit 23	0.78	50	0.9	56
	14.06		**15.6**	**937**

Table 4. I-95 Southbound Calculated Travel Times According to Speed Limits

Segment ID	Segment Distance (miles)	Speed Limit (mph)	Calculated Travel Time (min)	Calculated Travel Time (sec)
Exit 23 - Exit 22	0.52	50	0.6	37
Exit 22 - Exit 21	0.27	50	0.3	20
Exit 21 - Exit 20	0.49	50	0.6	36
Exit 20 - Exit 19	0.45	50	0.5	32
Exit 19 - Exit 18	0.73	50	0.9	52
Exit 18 - Exit 17	1.04	55	1.1	68
Exit 17 - Exit 16	0.25	55	0.3	16
Exit 16 - Exit 15	2.45	55	2.7	161
Exit 15 - Exit 14	0.47	55	0.5	31
Exit 14 - Exit 13	1.45	55	1.6	95
Exit 13 - Exit 12B	1.24	55	1.4	81
Exit 12B – Exit 12A	0.30	55	0.3	20
Exit 12A – Exit 10B	1.04	55	1.1	68
Exit 10B- Exit 10A	0.27	55	0.3	18
Exit 10A – Exit 9	2.29	55	2.5	150
Exit 9 –Exit 8	0.70	50	0.8	50
	13.96		**15.5**	**934**

The results show that northbound and southbound trips are fairly close in distance, measuring 14.06 miles and 13.96 miles, respectively. If travelers are moving according to the speed limit, travel times should be about 15.6 minutes for the northbound trip and 15.5 minutes for the southbound trip. The figures provide a baseline to determine the efficiency and performance of the highway.

Tables 3 and 4 display the designated segments for I-95 northbound and southbound travel indicating expected travel times based on present speed limits. The longest segment constitutes Exit 11 to Exit 16 and thus has the longest travel time. The calculated travel times provide a measure to compare recorded travel times from the RhodeWatchers and the GPS device.

2.4 Data Archival and Information System Development [Liu, 2001]

In this part of the project, the development of a prototype system, capable of collecting real-time sensor and probe information and displaying travel speeds for selected highway segments on the web is described. Since the researchers did not have direct access to the probes and sensors, simulated data in the same format as was collected during the first part of the project was used here. This data was placed in flat files of the same format that would be collected from live sensors. This is a viable technique for a prototype development of this magnitude even with access to the live sensors. This permitted focus upon the design and development of the software prototype without the distractions of working with field equipment (which is more of an implementation challenge). RIDOT already knows how to collect the data, our challenge was to develop the archival and web -based display of the data.

The spatial display of road information for travelers is probably the most efficient means of displaying the road speeds. This is already done in such locations as Seattle, WA (see http://www.smarttrek.org/). Finding information about how to develop such a system for an individual intelligent transportation facility was not as readily available. Systems such as the Navigator software that has been developed by GADOT provide multi and integrated functionality, but probably at too steep a price for a small state such as Rhode Island. The primary goal of this part of the project was to determine how to receive data of the sort that was collected by the first part of the project using equipment and procedures that were already available or evolving in Rhode Island and then show how this could be displayed using integrated software technology. A particularly difficult piece of this work was to learn how to integrate database, GIS, and web technology to provide a coherent display of the data.

The database was needed to archive the data for future use in detecting anomalies and predicting travel times (future projects). As such we also considered the flat files containing the real-time sensor and probe data as a real-time extension of the database. GIS technology is needed to spatially display the road segments with a color-coded display of the real-time travel speeds. RIDOT already uses GIS technology for other tasks, so this is an extension of their already evolving software expertise. The web was chosen as the most available source of travel-time information and is consistent with what other states are choosing. We also suggest the use of audio (radio) advisories for travel time information, especially during anomalous situations.

Although not consistent with the technology at RIDOT, open source packages and environments for development were employed here. In a previous project, one PI experienced difficulty with the prevalent commercial GIS product in that it was not straightforward to configure a website around the GIS maps. It was possible, but the software modules required to accomplish the task were costly as well as the training needed to learn how to use them. The group decided that this was prohibitively expensive considering the budget of the project.

The software technology used was as follows:

- GRASS - an open source GIS (http://www.Baylor.edu/grass/index2.html) now maintained by Baylor University, but originally developed by the US Army Construction Engineering Research Laboratories.

- PostgreSQL - an open source object relational database management system (DBMS) (http://www.postgresql.org). This system was developed at the University of California at Berkeley and is widely considered to be a robust alternative to expensive commercial DBMS products.
- Apache, a commonly used open source web server.
- Perl and C (programming languages to implement the control program and glue (or script) the various applications together.

A special challenge in this portion of the project was learning how to use the GRASS GIS software. In the process of integrating this into the system, the team learned that GRASS did not support some of the fundamental functionalities of the commercial system, so these features were programmed into the software. This included the following:

- Software to get traffic information from the relational database; no relational database access procedures were available in GRASS or the accompanying scripting software GRASSLinks.
- Software to display color on the various road segments. This software was originally developed for natural resources researchers. Thus, various textures and shadings are used for regions of the maps, but transportation modules for distinguishing and displaying segments of roads were not available.
- Software to permit periodic update of the road information based upon real-time information. Previous developers of the software only required one access to files of data and then provided only one display. We needed a continuous loop of real-time display.
- Software to permit the user to click on the map and zoom into a particular location for more detailed information.

The primary functionalities that were coded into the system were first captured in use case text and diagrams, common notations used in the software engineering process. A short sample use case diagram and use case are given below in figures 2 and 3. More can be found in [Peckham, 2001]. Here is a list of these functionalities.

- Receive data from loop detectors (and other detection devices)
- Extract valid data from the raw data - This includes determining the locations, dates and times of the collected data and then deducing such information as the highway segment numbers.
- Populate the database - A database was designed and implemented and then populated to store the real-time and historical data.
- Calculate the average speed for each road segment
- Display the information for users who wish to access it via the web. A web interface was designed and developed to permit this access and color coded map display.
- Provide the ability for users to directly access the historical database with ad hoc queries.

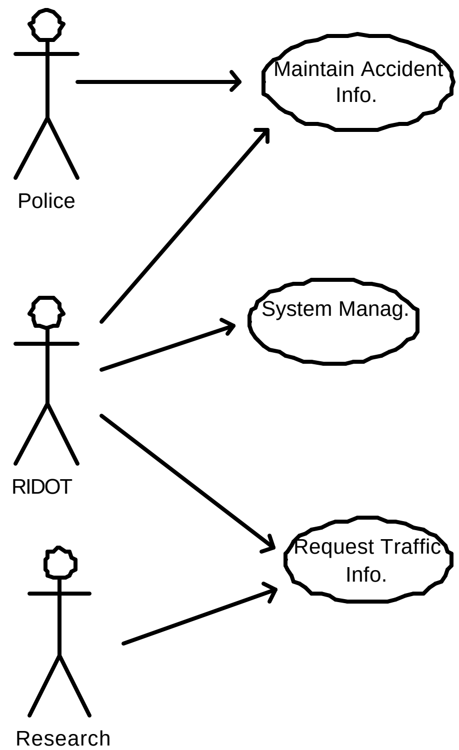


Figure 2. Use Case Diagram

Overview: The purpose of this use case is to write accident information into the database.

Actors: Police Department/Watcher

Starting Point: This use case begins when actor gets information about a new accident.

Ending Point: This use case ends when system notifies actor about successful writing data into database.

Measurable Results: Appropriate information appears in the database tables.

Flow of Events:

1. The actor selects the Add Accident option on the specific screen.
2. The system presents the Add Accident screen to the actor.
3. The actor enters the information.
4. The actor presses the submit button.
5. If the system is unable to add the accident, the system executes alternate flow E1 or alternate flow E2.
6. The system validates and accepts the new accident.
7. The actor is presented with a message indicating a successful accident addition.

Alternate Flow E1: The system is unable to add an accident

1. The system is unable to post the accident to the accident table.
2. The system responds with a message indicating the reason.

Alternate Flow E2: Existence of similar information

1. The system has the similar information (location and time of accident).
2. The system responds with a message indicating presence of similar information by showing found similar information and asks actor whether continue or abort transaction.
3. The actor verifies his information with the existed information and continues or aborts transaction.

Alternative Flow of Events: The actor exits.

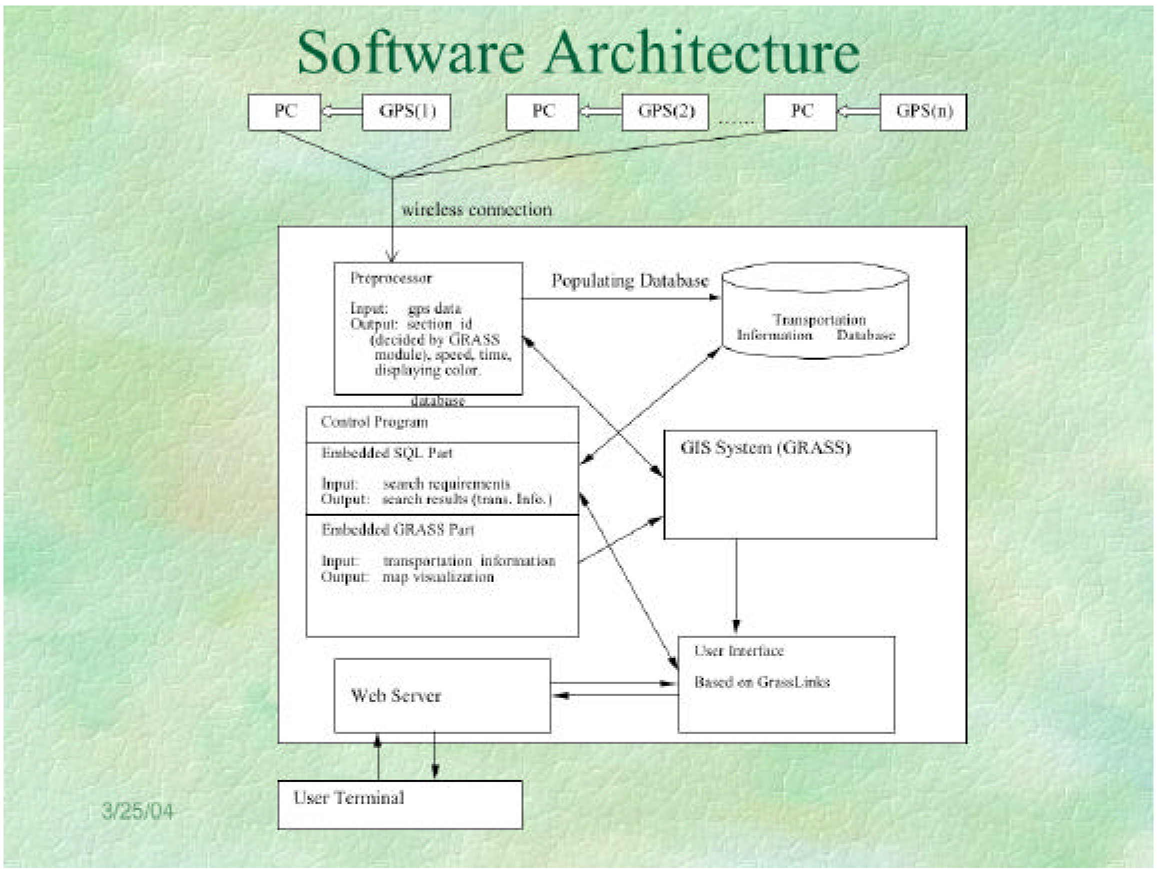
Business Rules:

1. The following fields cannot be blank: AccidentID, AccidentTIme, AccidentLocation,RoadCondition, Visibility, Traffic.

Figure 3. Use Case: Maintain Accident Info.

For the system design, a three -tier client server software architecture was chosen. This is the architecture that is used for most web environments with a database backend because it provides good performance under heavy request loads and is a design that permits easy modifiability and extensibility. The three tiers are the web interface, the database server, and a separate layer of application logic in the middle. A high level diagram of the whole system architecture is shown in Figure 4. Information about the problems and solutions encountered and used in this project can be found in greater detail in [Liu, 2002]. Some screen shots of the prototype are shown in Section 4.

Figure 4: High Level System Diagram



SECTION 3. RESULTS

3.1 Findings from Traffic Data Capture

Various data was captured to gain an understanding of the performance in the system. The data came from inductive loop detectors, a GPS device, and from "probe" reporters ("Rhode Watchers"). The intent was to look at multiple sources to understand how they can provide some level of understanding of the system, where there were limited data stations.

3.1.1 Inductive Loop Data

One of the interesting outcomes of this work is the capture of volume and speed data with the regression equations modeling the situation on the interstate highway in Rhode Island. If speed is plotted against time of day, we find a drop in speed during the commute times. If volume and speed are plotted on a two-dimensional graph, it exhibits a traditional speed versus volume relationship in that the curve takes on a parabolic tendency. As it is, one notices that the speed decreases slowly with volume until volume is high, and then speed drops off precipitously for a significant subset of the data. A graphic of speed versus volume is provided in Figure 5. The "weighted" speed is provided, since the effort was to look at the entire roadway segment, versus just providing a lane-by-lane speed. In Figure 5, one notices that a regression fit was attempted, but it only really fits a portion of the curve fairly well. Attempts were also made to segment the curve into two portions—non-peak periods and peak periods. Figure 6 is a graphic of time-of-day vs speed. The time periods are reported every 15-minutes with the first period reported at 5:30AM. The important aspect of this work for the second part of the project was the illustration of the types of data, the frequency of collection, and the data formats to be used in a real-time system. As the reader will see, at the time of this study there still was a disconnect between the ability of the technology as employed in Rhode Island and the need for frequent data collection.

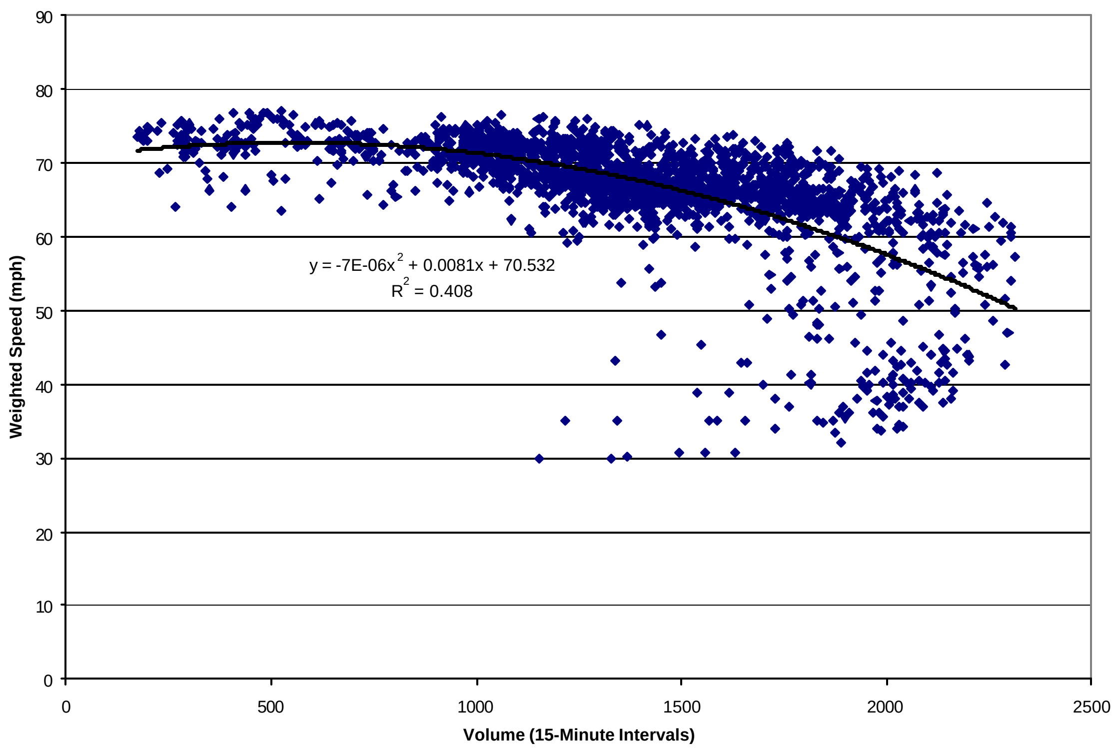


Figure 5. Speed Versus Volume

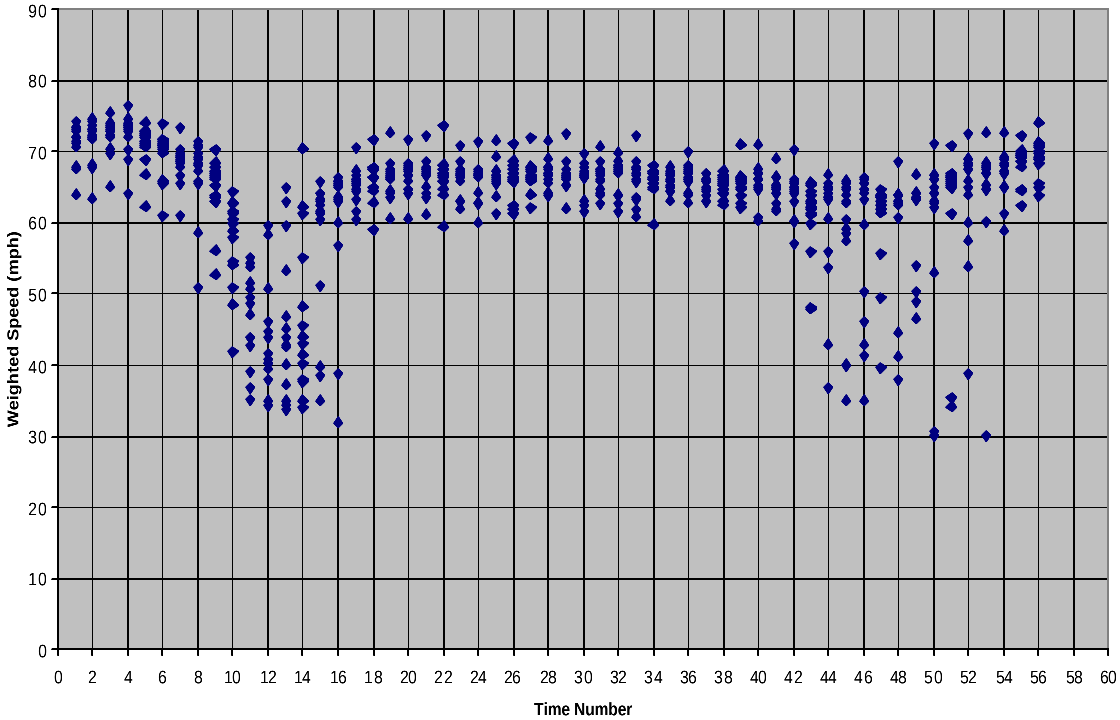


Figure 6. Speed Versus Time of Day

3.1.2 Rhode Watcher Data

A complete summary analysis for April, May, and June of average travel times was performed with standard deviations for each segment of the Rhode Watchers data. See Tables 5 and 6 for a summary.

Table 5. Average A.M. Travel Times Collected for RhodeWatchers

Segment	Average Travel Time (min)	Standard Deviation (min)	N
Exit 8 – Exit 11	4.6	0.7	20
Exit 11 – Exit 16	5.8	1.8	67
Exit 16 – Exit 18	2.6	1.0	67
Exit 18 – Exit 23	3.8	1.5	91

Table 6. Average P.M. Travel Times Collected for RhodeWatchers

Segment	Average Travel Time (min)	Standard Deviation (min)	N
Exit 23 – Exit 18	6.0	3.4	40
Exit 18 – Exit 16	2.5	1.8	40
Exit 16 – Exit 10B	7.3	3.4	40
Exit 10B – Exit 8	3.3	0.4	18

A comparison of RhodeWatcher data shows that on average, the travel time is within a minute of the calculated travel time except for segment 5 (Exit 23 SB – Exit 18 SB). The calculated travel time for Segment 5 is 2.9 minutes while the average RhodeWatcher travel time is 6.0 minutes. A contributing factor to these conditions is the presence of the I-195 on-ramp located near Exit 20. This stretch of highway converges from four lanes in one direction into two lanes for I-95 southbound and two lanes for I-195, shown in Figure 1. Travelers tend to occupy three of the four travel lanes while trying to access the on-ramp causing a queue to develop. Table 7 below displays a comparison of RhodeWatcher data versus the calculated travel times.

Table 7. Average RhodeWatcher Travel Time vs. Calculated Travel Time

Segment ID	Segment Boundary	Direction	Average RhodeWatcher Travel Time (min)	Calculated Travel Time (min)	Average Difference in Travel Time (min)
1	Exit 8 – Exit 11	NB	4.6	4.2	+0.4
2	Exit 11 - Exit 16	NB	5.3	6.1	-0.8
3	Exit 16 - Exit 18	NB	2.6	2.0	+0.6
4	Exit 18 - Exit 23	NB	3.8	3.4	+0.4
5	Exit 23 - Exit 18	SB	6.0	2.9	+3.1
6	Exit 18 - Exit 16	SB	2.5	1.4	+1.1
7	Exit 16 – Exit 10B	SB	7.3	7.6	-0.3
8	Exit 10B - Exit 8	SB	3.3	3.6	-0.3

3.1.3 GPS Analysis

Table 8. A.M. Peak Hour GPS Travel Time Summary

Segment ID	Exit Number	Average Travel Time (sec)	Standard Deviation (sec)	Average Speed (mph)	Standard Deviation (mph)	N
Segment 1	Exit 8 - Exit 11	260	44	55	9	14
Segment 2	Exit 11 – Exit 16	457	180	49	14	13
Segment 3	Exit 16 – Exit 18	152	45	42	12	13
Segment 4	Exit 18 – Exit 23	260	34	41	5	13

Table 9. P.M. Peak Hour GPS Travel Time Summary

Segment ID	Exit Numbers	Average Travel Time (sec)	Standard Deviation (sec)	Average Speed (mph)	Standard Deviation (mph)	N
Segment 5	Exit 23 – Exit 18	405	212	35	11	15
Segment 6	Exit 18 – Exit 16	99	21	60	9	15
Segment 7	Exit 16 - Exit 10B	430	187	60	14	15
Segment 8	Exit 10B – Exit 8	162	19	65	6	15

The analysis shows the average travel times and speeds for each segment along with standard deviations and the number of observations. The average travel times for the entire trip were longer for both AM & PM peak-hour travel.

When average travel times from the GPS data collection are compared with base line calculated travel times, the observation is that all of the segments for the I-95 northbound trip produce an average travel time that is longer than the base line travel time. These results indicate that traffic flow is moving slower than posted speed limits. A large discrepancy occurs for northbound travel in segment 2 (Exit 11 – Exit 16) and segment 4 (Exit 18 – Exit 23), which on average, take 93 seconds and 58 seconds longer to travel through, respectively. The southbound trip on I-95 shows that it takes longer to traverse segments 5 & 6 and a shorter time period while traveling through segments 7 & 8. Segment 5 (Exit 23 – Exit 18) on average takes an additional 221 seconds for travel, while Segment 8 (Exit 10B – Exit 8) takes approximately 59 seconds less to traverse. These values indicate that traffic flow is much smoother and faster than the posted speed limit of 55 mph for segments 7 & 8. Table 10 shows the variation of calculated travel times versus average GPS travel times.

Table 10. Average GPS Travel Time vs. Calculated Travel Time.

Segment ID	Segment Boundary	Direction	Avg GPS Travel Time (sec)	Calculated Travel Time (sec)	Avg Difference in Travel Time (sec)	Standard Deviation (sec)
1	Exit 8 - Exit 11	NB	260	251	+9	42
2	Exit 11 - Exit 16	NB	457	364	+93	173
3	Exit 16 - Exit 18	NB	151	119	+32	43
4	Exit 18 - Exit 23	NB	259	202	+57	33
5	Exit 23 - Exit 18	SB	398	177	+221	195
6	Exit 18 - Exit 16	SB	97	84	+13	19
7	Exit 16 - Exit 10B	SB	411	455	-44	172
8	Exit 10B - Exit 8	SB	159	218	-59	19

The analysis was, for the most part, very similar for the average RhodeWatcher results. The trend for segments 7 and 8 show that the typical average speed is faster than the 55 mph posted speed limit. The standard deviations show the rather large differences in travel time, especially for segments 2, 5, & 7. These deviations can range anywhere from 20 seconds to 3 minutes, which is very significant with respect to overall travel time. The differences in travel time appear to be smaller when compared to the GPS data, however this can be attributed to the accuracy of time measurement between the two sources of data. The GPS travel time data was recorded to the nearest second, while the RhodeWatcher data was recorded to the nearest minute.

In summary, probe travel times were longer than the calculated travel times for most segments due to the fact that data was collected during peak periods. These results were expected based on increased traffic volumes from the system being under duress (i.e. peak period travel). Segments 7 & 8 experience a much smoother flow of traffic and higher speeds than other segments. Table 11 shows a complete summary of the GPS and RhodeWatcher data versus the baseline assumption of vehicles traveling at the posted speed limit.

Table 11. Comparison of RhodeWatcher, GPS, and Calculated Travel Times

Segment ID	Segment Boundary	Direction	Avg. Rhode-Watcher Travel Time (sec)	Avg. Diff. in Calc. Travel Time (sec)	Calc. Travel Time (sec)	Avg. GPS Travel Time (sec)	Avg. Diff. in Calc. Travel Time (sec)
1	Exit 8 - Exit 11	NB	276	*25*	251	260	*9*
2	Exit 11 - Exit 16	NB	318	*-46*	364	457	*93*
3	Exit 16 - Exit 18	NB	156	*37*	119	151	*32*
4	Exit 18 - Exit 23	NB	228	*26*	202	259	*57*
5	Exit 23 - Exit 18	SB	360	*183*	177	398	*221*
6	Exit 18 - Exit 16	SB	150	*66*	84	97	*13*
7	Exit 16 - Exit 10B	SB	438	*-17*	455	411	*-44*
8	Exit 10B - Exit 8	SB	198	*-20*	218	159	*-59*

SECTION 4. APPLICATION OF RESULTS

4.1 Framework for Travel Time Prediction

This portion of the research effort is devoted to the development of a framework to apply to travel time prediction. The researchers outlined the steps to take in designing the process for accurate calculations and targeted it to intelligent transportation experts in the field. The outline includes such matters as deciding applicability of the regression equations to types of highway segments, how to determine and break down the highway of interest into segments, what type of data to collect, how to select the data collection periods, how often to collect and transmit the data, what types of field data sources to consider (loop detectors, GPS probes, VIPSs, tag readers, and radar detectors), how to disseminate the data, and how to perform the average speed and travel time calculations. The outline below sketches the steps that should be taken in such a study. (In some cases details about this study are given.)

1. Determine types of roads to which the work can be applied: In this study unsignalized roadways such as I-295, I-195, and Rt. 10 in Rhode Island were targeted.
2. Determine the study area: Once the study area is selected, it should be broken down into appropriate segments for travel-time analysis.
3. Determine types of data desired:
    a. Speed-flow, density-flow, and speed-density relationships should be established. To do so, the following three types of data are needed.
        i. Volume data
        ii. Average speeds
        iii. Density
    b. Roadway capacity
    c. Peak hour volumes
4. Determine data collection period: This will vary for the different research needs. The more data, the more accurate the predictions will be. A three to six month period will be sufficient for most predictions (unless seasonal variations are expected). Data collected on Tuesdays, Wednesdays, and Thursdays tend to show the most typical travel periods.
5. Determine the real-time transmission techniques: Real-time transmission is most convenient. For volume, density, and speed, collection can be done in intervals from 30 seconds to 15 minutes. The shorter collection intervals give more accuracy but increase the volume of data.
6. Determine the types of field data sources applicable: Some choices are:
    a. Loop detection
    b. GPS probes
    c. Video image processing system (VIPS) from a CCVE system
    d. Tag readers for vehicles
    e. Radar detection

7. Determine the location of data sources: Data dissemination can be accomplished for almost any distance. The more closely and regularly spaced sources are best, although geometry may be a factor in some situations (such as stretches of highway with very few or many branches, merges, exits, entrances).
8. Determine the means for the dissemination of the data: Once data is collected, it needs to be aggregated, cleaned, and presented for use in the prediction model selected. The data can be separated into two categories: real-time and historical. Both may be needed for prediction. Historical data is essential for validation and calibration of the prediction model.
9. Determine the means for establishing the "ground truths". For example, GPS devices or humans utilizing timing devices in vehicular probes can be used. In both cases, the floating car technique should be used whenever possible (drive so that the same number of vehicles on the highway are traveling faster than the probe as are traveling slower than the probe.)
10. Formulate the prediction model: Average speed is the underlying requirement for the determination of travel time, but volume is needed to infer this. For example, speed bins were used in this study to infer average speed. Also volume is needed in the prediction process. As volume and density increase, the average speed is expected to eventually decrease. A combination of a theoretical model of the relationship between density and speed, and archived historical information can be used to determine the expected average speed for the highway segment of interest. Additional parameters such as seasonal variations, presence of an anomalous situation (planned and unplanned) can also influence travel time calculation. In this project, prediction equations were formulated using polynomial regression relating volume to average speed. This provided a good fit in this preliminary study
11. Calculate the travel time based on the archived and real-time data: In this study, a simple "time = distance / speed " calculation was used for each segment. The total travel time for a given route was summed over the segments.
12. Validate and calibrate using the archived data and "ground truth" data.

4.2 Display of Prototype Traffic Information

Figures 7 and 8 show how the real-time traffic information would be displayed for a person viewing a website. Data was simulated with a time-stamp to replicate what would be provided in real-time. The legends within the figures designate how the aggregated real-time data (specified time interval) would be interpreted.

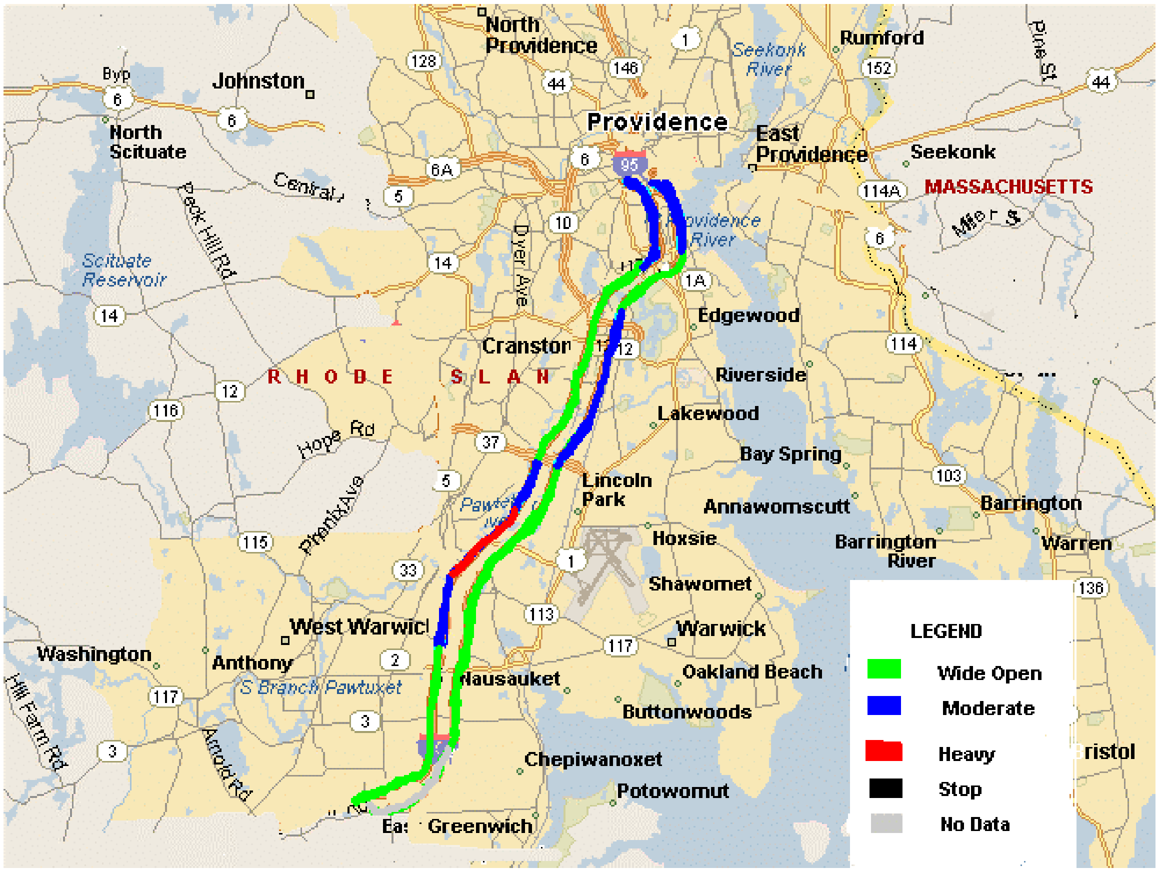


Figure 7. GIS Map with Color Code Showing the Real-time Speeds on the Highway

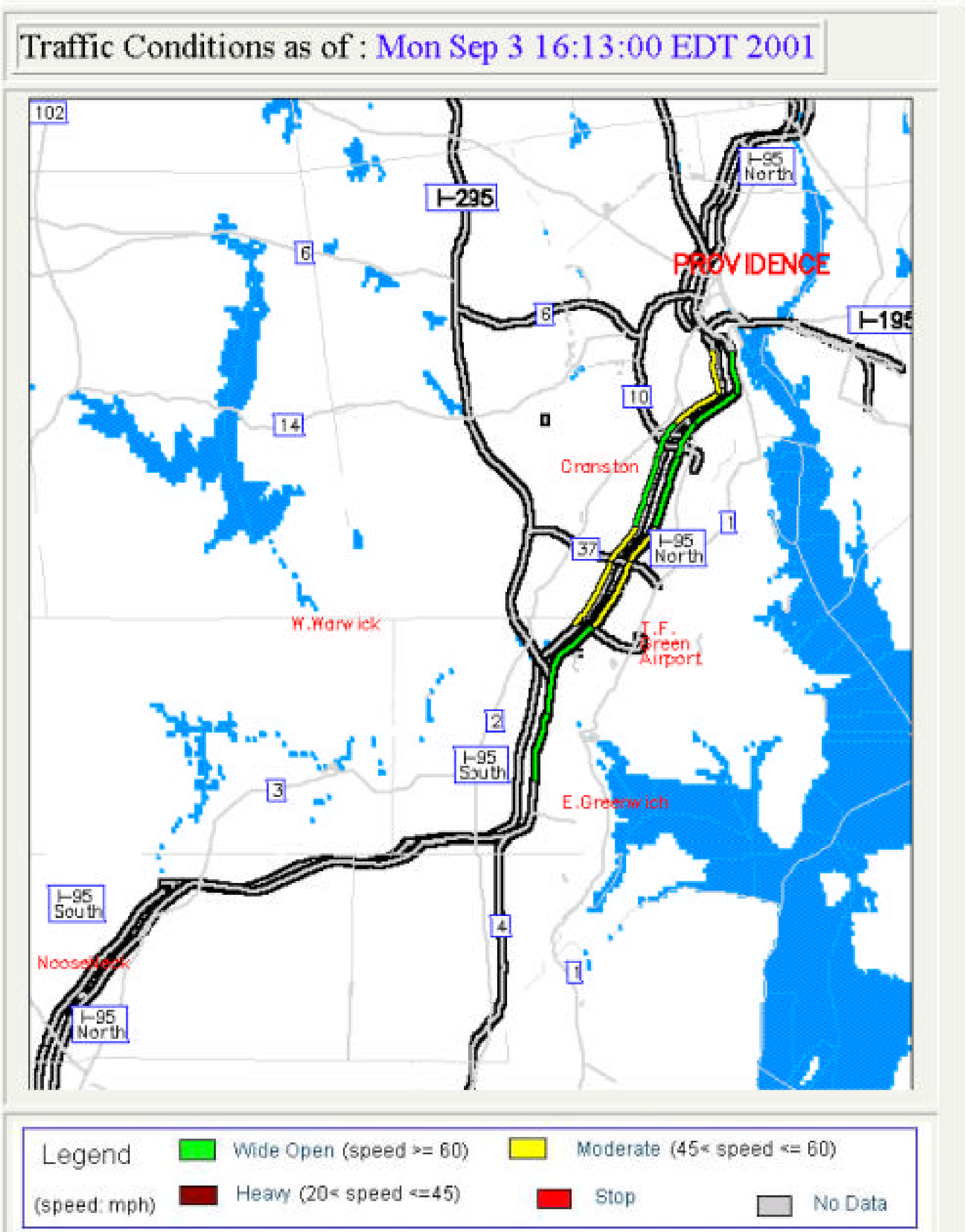


Figure 8. Screenshot of Another View of a GIS Map Depicting Color-Coded Highway Speeds

SECTION 5. CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER WORK

5.1 Conclusions

The collection of real-time traffic data and its management for integration, as well as its archiving, mining, and dissemination is a major challenge. When there are multiple databases or systems that capture or store transportation data, it becomes imperative that there be some capability data-sharing if not full integration. These items are vital importance as transportation system operators seek to improve the efficiency and effectiveness of their system. This helps in providing quality information to all types of users of the system from tourist to commuter, from transportation agency operators and administrators, to analysts and researchers. This research effort provided an initial investigation in looking at these types of issues.

The overall research objectives were as follows:

- To develop a system where appropriate real-time operating conditions data are captured and developed automatically into a user-friendly-format stipulating travel time or speed
- To develop a real-time information system prototype that supports monitoring, warehousing/mining, and concurrent access via the web; and
- To develop an integrated system that combines and extends the existing stand-alone systems.

The accomplishments of this project include the following.

- Collection of traffic data from various locations using different modes of collection (loop detectors, GPS and human RhodeWatchers)
- Analysis of the data collected
- Creation of a data analysis and systems development background for anomaly detection and travel time algorithms
- Experimentation with open source GIS and database systems (GRASS and Postgres respectively)
- Development of a prototype systems integrating GIS, database and web interface to display the current travel times of segments of selected Rhode Island highways

The conclusions of this work vary with respect to the different issues that arose during the research time period.

- The initial conclusion is that there were not enough data stations in the transportation system (working or in-place) to provide real-time data that would be meaningful to segments of the roadway in a timely fashion. More detectors were needed to better characterize the system in reasonably close intervals, and the data needed to be captured or reported in shorter time intervals, especially during the peak periods or during times of an incidence. This would allow better understanding for the operator and user of the system in "real-time" and better understanding for the analyst/researcher for a post-analysis in a manner that allows for characterization through model development.

- There needs to be standardization of "probe" data in that it can be and has been shown to be an effective measuring device of movement through the system. The GPS data was consistent, but for persons who are calling in to report location or travel time, there should be a specific level of reporting that is consistent. For example, the GPS data can provide specifics on time travel to fractions of a second (which may be more than necessary), whereas human reporting is given in a less exact fashion, which could exaggerate the travel results (lower or higher).

- Open source GIS and databases and interfaces can be used to effectively display the current travel times of segments of selected Rhode Island highways.

5.2 Future Work Recommendations

Most of the original goals of the project were accomplished in this project. There were some additional outcomes and due to lack of time and resources, some goals were postponed. This section outlines the future work that is planned in this ongoing effort.

- Other data sources -The integration of different types of information is one of the goals of this project. A future area of attack for the research is to use probe vehicles such as the RhodeWatchers or RIPTA buses or general fleet vehicles to provide the real-time information on roadways where other sources are not available. Ultimately, the tie-in is to use this data to provide better origin-destination data and to provide real-time traveling conditions. Since, these vehicles will only provide information randomly special attention will have to be paid to the prediction algorithms.

- Traffic anomaly detection - If traffic speed information is archived, this can be used in conjunction with incoming real-time data to detect anomalous traffic situations. Anomalous situations can be detected if the real-time speeds are compared to archived information for different days of the week and times of the day. Incoming information via phone reporting accidents and schedules for road maintenance can also be integrated to provide travelers up to date information about the traffic situations. Other efforts include [Smith, 2000] and [Smith, no date].

- Travel time prediction- Preliminary techniques for travel-time detection were outlined in Cannamela's work. The travel time algorithm development will be an effort based initially on capturing operating conditions on specific roadways that are identified by RIDOT. Once, these conditions are specified, the travel algorithm development can take place directly. Data from the various components of the system, such as the VIPS and the probes will provide the starting point for the analysis. Additional floating car analyses may be performed as well as a validation technique. This data will allow the research to develop some predictive times initially, and then as more data is provided, a more robust set of models and algorithms can be developed. One point of departure as an application for this data is the use of traffic assignment, User Equilibrium and System Optimal traffic assignment models, capacity restraint, and diversion models to help automatically determine the best diversion scenario for RIDOT to employ**.**

- Emerging technologies - - Future work should also include investigation into emerging technologies for collecting traffic information, such as vehicle identification tags [TXDOT, 2001]

- As for the other modes of transportation, this research envisions being able to ensure the provision of real-time data on rail and bus modes as well. Although we did not have the time to collect this information and integrate it into this project, the travel time collection techniques will be similar and in fact more reliable due to dealing with more regularly scheduled modes of travel. The difficulty will be in the desire to provide travelers with a coherent intermodal travel time information. Algorithms to support such an effort will be inherently different from those used in one transportation modal environment.

Currently, the authors of this report have begun and will continue to work with others in the area of anomaly detection and travel time reporting and prediction [Peckham, 2003]

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[Smith, nodate] http://www.gmupolicy.net/its/newprojects.html Abnormal event traffic forecasting now in progress. Principal Investigator: Dr. Brian L. Smith, University of Virginia, 804-243-8585, briansmith@virginia.edu External contact. Stephany Hanshaw, VDOT, Hampton Roads Smart Traffic Center, Virginia Beach, VA. 757.424.9907 Project objective. To improve nonparametric regression forecasting approach during abnormal traffic events (such as incidents**)**

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