Multimodal ITS Data Integration and Performance Measurement in Portland, Oregon

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ABSTRACT

Performance measures for a multimodal corridor are developed and implemented in the Portland, Oregon Interstate 5 test bed. With the implementation of Intelligent Transportation Systems (ITS), extensive disaggregate transportation data sets are now available and can be used as the basis for generating transportation performance measures along on the existing roadway infrastructure, particularly freeways and major arterials. These measures are increasingly available to state and regional transportation agencies implementing performance-based systems planning. In this study, the benefits of nationally used performance measures are reviewed, and several were selected for application to the corridor study test bed, using archived loop detector and bus dispatch system (BDS) data. The results are presented visually and described quantitatively. DOTs already collecting or archiving large amounts of ITS data can automate the data conversion process and have data available for these performance measures for use in making future planning and policy decisions. Potential benefits of integrating freeway and BDS data are revealed at the end of this paper towards a better understanding and visualizing freeway performance measures.

BACKGROUND

For decades transportation agencies have relied on manual counts and limited data for monitoring system performance. The Oregon Department of Transportation (ODOT), the City of Portland, the Tri-County Metropolitan Transportation District of Oregon (TriMet--the regional transit provider), and other regional partners have implemented a comprehensive advanced transportation management system (ATMS) including inductive loop detectors and video surveillance along freeways and arterials. This has made it possible for these agencies to consider real-time traffic conditions when making operational decisions. The ITS strategies have included a broad-based data sharing program, so that one agency can benefit from using another agency's data sources. This project continues this successful collaboration by leveraging traffic surveillance data (from video, loop detector and BDS) along a freeway/arterial corridor to generate performance indicators that can communicate with and "inform" the freeway TMOC, TriMet's TMOC, other agencies and the public.

The increase in data availability and interest in performance measurement based on these data requires development of data visualization techniques that provide quick visual inspection of these measures. Data visualization is a logical extension of advances in data collection, archiving, and analysis.

The objective of this project reported here is to establish a test bed for evaluating and testing innovative uses of archived ITS data in a multimodal corridor. Using archived transit and traffic flow information, this project is showcasing the benefits of advanced transportation information technologies to improve the understanding of traffic flow through analyzing and displaying performance measures that can benefit various transportation operations agencies, as well as short and long term planning. Methods are being developed to warehouse, integrate and validate relevant transportation- and traffic-related data from diverse sensors and sources along a corridor study test bed in Portland, Oregon.

PERFORMANCE MEASURES

Performance measures provide systematic targets for improving the efficiency and equity of person and freight movement over time. ITS deployments make it possible to transform vast amounts of data into information needed for adjusting operating strategies, evaluating system performance, and making decisions about future transportation investments (*1,2,3,4,5*). Thus, new systems-oriented performance measures can be used to communicate the dynamics of system performance and to assess the opportunities for improving traveler safety and mobility, system efficiency, economic productivity, and reducing energy consumption and pollution.

This project is a part of a larger study along a multimodal corridor using advanced technologies to improve transportation planning, analysis and evaluation. Along with a parallel study for transit, this study identifies measures using data from freeway sensors, and from TriMet's BDS-equipped "smart" buses, meeting the multimodal objective of the study.

LITERATURE REVIEW

Performance measures are usually linked to specified goals and objectives for one mode, but some have multimodal applications. A generally-accepted performance measure typology applicable to a multimodal planning process includes (*6*):

- *Efficiency*: Measures such as volume to capacity ratio, delay, level of service (LOS), and travel time express facility use of the system capacity from the supply perspective.
- *Effectiveness*: Indicators reflecting user perceptions, including mobility, reliability, and accessibility.

- *Externality*: Measures associated with pollution, emissions, accidents reflect the system supply perspective.

A new era of multimodal federal, state and regional transportation planning includes frameworks for application of performance measures (*1, 2, 3, 4, 5, 6, 7, 8, 9, 10*). Highway performance is also tracked at a nationwide level (*3, 4, 11*), and statewide ITS data can be used to report important statistics (3, 4, *6, 9*). To help promote the use of performance measures a national Performance Measures Library (*6*) offers a concise look-up guide for typical measures used, as shown in Table 1.

Recently, performance measures were synthesized from 35 nationwide Departments of Transportation (DOTs) and Metropolitan Planning Organizations (MPOs) for monitoring and operations management of highway systems (*12*). Based on an evaluation of best practices, several key measures were recommended to serve as foundations for other commonly reported measures:

1. Quantity of travel
   - (i) Person-miles traveled
   - (ii) VMT
2. Quality of travel Average speed weighed by PMT
   - (i) Average travel time
   - (ii) Travel time reliability
   - (iii) Average delay
   - (iv) LOS
3. Utilization of the system
   - (i) Percent of system at LOS X
   - (ii) Density
   - (iii) Percentage of travel congested
   - (iv) V/C ratio
   - (v) Percent of miles operating in desired speed range
   - (vi) Vehicle occupancy
   - (vii) Lane-mile-hours at LOS E or F
4. Safety
   - (i) Crash severity
   - (ii) Crash type
   - (iii) Incidents induced delay
   - (iv) Evacuation clearance time

In Oregon, the transportation system performance is monitored as part of its congestion management system (CMS) (*13*). Congestion indicators used in Oregon include per capita VMT, V/C ratio, and auto occupancy. ODOT is in the process of adding several other mobility and safety indicators recommended by NCHRP (*6, 14*) into their systems performance reporting (*5*). Most previous studies relied on data from one source to calculate performance measures that were presented in a tabular format. These efforts have not focused on the development of visualization tools that can present relevant measures in an easy to understand manner for the appropriate audience. In addition, the integration of data from various heterogeneous sources was not common in these previous studies.

CORRIDOR PERFORMANCE ANALYSIS

Interstate 5 is the major north-south transportation corridor through Oregon and is the most significant segment of ODOT's ATMS. A 22-mile (35.2 km) corridor was selected for analysis between Jantzen Beach and Stafford Road, as shown in Figure 1. This corridor includes inductive loop detectors (in 2- and 3-lane cross-sections) at 25 northbound and 15 southbound locations. These detectors support the region's comprehensive ramp metering program. In addition to the freeway, TriMet provides regular and express bus service that operates the freeway and on parallel arterials.

Data Description

The freeway analysis used archived loop detector data collected on five days in January 2002, and during three weeks in November 2002. The raw data from January 2002 included vehicle counts, occupancy and average speed for each lane and on-ramp, recorded over 20-second intervals. The raw archived loop detector file obtained from ODOT contains approximately 180 MB per day, including more than 1.8 million records for all the detectors installed in the region. Data for the studied corridor were extracted and screened for outliers and errors. The raw data included errors due to misreporting of time intervals during which no vehicles were counted (reported as -999 rather than zero), as well as malfunctioning of southbound Stations 1, 10, and the ramp at southbound Station 9 and northbound Station 20 during all five days of analysis. Southbound Station 9 and northbound Station 4 reported no data between 14:25 and 16:56 and 0:00 to 16:16 respectively on two separate days, and is thus listed as a partial malfunction.

The freeway data from November 2002 contained fewer errors when compared to the January data. In this study only one day from the November 2002 was used in parallel with archived BDS data. The choice of these periods was made based on the availability of various data sources (spatial and temporal reasons) along the study corridor. For example during the three week period in November 2002 TriMet coded pseudo bus stops along the freeway specifically for this study. During the five days in January 2002, ODOT was performing tube counts at the same locations for validation purposes. The November 2002 counts were also chosen to represent typical weekday conditions and to control for the variation that might occur based daily changes.

Average Daily Traffic (ADT)

Figure 2(a) shows the mean study corridor ADT calculated over the five study days in January 2002 for both freeway directions, and the ADT reported by ODOT from tube counts at the same locations. Figure 2(b) shows the difference between the ADT measured using the two data sources. As shown, the ADT calculated from the detector data varies somewhat from that measured by ODOT. Using the archived detector data to estimate the corridor ADT over many days would be more reliable than the 48-hour road-tube counts used to derive annual ADT volumes. Since the detectors can transmit data all day, every day, ADT calculated from this source can provide more accurate temporal statistics using data already being collected.

Travel Time (Method I)

Travel time is a principal measure of transportation system performance used by traffic engineers, planners, and analysts and can be easily understood by the public (*15*). Travel time was calculated in the literature using two different methods. The total corridor travel time (referred to as Method I) was calculated by summing the estimated travel time for each freeway segment represented by each detector. The midpoints between each pair of detectors were used to delineate the segments and travel times were estimated for each day studied. For example, Figure 3 shows travel time versus time for January 24 for both north- and southbound directions. Figure 3 also illustrates the cumulative travel time and free-flow travel time throughout the day. As the cumulative line deviates from the cumulative free-flow travel time the travel time increases can be clearly observed. At 7:05 the travel time increased from 23 min. to 28 min. Similarly, at 19:42 the travel time decreased from 49 min. to 24 min. The free-flow travel time on this day was approximately 24 min.

Travel Time (Method II)

A second travel time estimation method was also examined. The previous estimation used the sum of the estimated travel time across each segment for every 20-second interval. The location-time method (Method II) considers the movement of a hypothetical reference vehicle as it moved through the corridor. It was assumed that traffic conditions would change as vehicles moved through the corridor. The difference in travel time between the two methods was found to be negligible in this case.

Average Speed

Average speed, the analogue of travel time, is another principal parameter that describes the state of a given traffic stream. Decreased vehicle speed reflects the reduction in mobility people experience during congestion. The duration of congestion can also be determined by observing the periods during which reduced speeds are experienced. For this study, the 20-sec speed data were plotted versus time using the right-hand axis as shown in Figure 4. In order to magnify the speed reductions, oblique cumulative plots were constructed where the difference between the cumulative speed curve and a line $V= v_0 t'$ was plotted on the left-hand axis. The rescaling rate v_0 was chosen arbitrarily to maximize visual resolution and t' was the elapsed time from the beginning of the curve. Further details describing the use of oblique plots are available in (*15*). Figure 4(a) clearly depicts the times at which notable speed changes occurred.

Vehicle Miles Traveled (VMT)

VMT is an aggregate indicator of traffic volume. Even though VMT is not a direct measure of congestion, it is useful for monitoring trends over time and for planning purposes. In this study, the corridor VMT was calculated using segment counts from mainline and on-ramp detectors. The VMT for each 20-second period for which loop data was available is a product of the segment length and the number of vehicles counted by the detector in that interval. It was assumed that once the vehicles were on the freeway, they would travel the length of the entire downstream segment. The corridor VMT was summed over 24 hours for each day and further converted to a VMT measured for each successive 1-mile segment (to account for variations in loop detector spacing).

Figure 5 shows a box plot of the VMT measured for each one mile segment over the five study days. The box plot captures the minima and maxima for each dataset (limited to five days in this example) as well as the median and the boundaries of the first and third quartiles. As shown, the VMT varies somewhat throughout the I-5 corridor. This measure can help in planning maintenances and assigning traffic response vehicles along heavily used segments on freeways.

Vehicle Hours Traveled (VHT)

VHT is a measure that reflects mobility and quality of travel at the system or facility level. Its advantage over VMT is that VHT also includes the amount of delay that occurs, better representing the impacts of congestion. VHT for the corridor is shown in Figure 5. To calculate VHT, freeway and ramp counts were multiplied by the travel time (location-time method). The average VHT for five days was calculated and normalized to facilitate comparison. ODOT can base their VHT calculations upon data collected over many days, thus accounting for seasonal and day-of-week variations in traffic flow.

Vehicle Miles Traveled by Congestion Level

Congestion level and LOS can be determined from detector occupancy data. Occupancy is the fraction of time that vehicles are present over the loop during each measurement interval. Higher occupancy reflects longer vehicle travel times across the detectors, indicating congested conditions. Figure 6 shows VMT classified by LOS. This figure highlights how traffic quality of service changes along the corridor. This figure can be used in planning and operations to direct future capital investments along the corridor towards improving LOS along segments with lower performance.

Volume to Capacity Ratio (V/C)

The V/C ratio measures a facility's capacity utilization by the current or projected traffic (*11*). A link-based measure, the V/C ratio reflects mobility and quality of travel and is widely used due to the availability of volume and capacity values for transportation links. Capacity can be defined as the maximum sustainable throughput for a facility. For this study the capacity of the freeway was assumed to be 2000 veh/hr/lane. The mean V/C ratio for five days for the southbound direction is shown as a surface plot in Figure 7. Since certain sections along I-5 change from 3 lanes to 2, the V/C ratio was adjusted accordingly. As seen in the figure, stations operating at LOS above "D" in the southbound direction included Stations 3 (Columbia Blvd.) and 8 (Going St.) in the morning peak period and Station 13 (Upper Boones Ferry Rd.) during the evening peak period. A LOS greater than "D" indicates that operations are taking place at near capacity and flow breakdowns can occur. Sites at this level should be candidates for remedial measures. The V/C measure should be based on many days' data, in order to consider variations across days of the week, seasons and multiple years.

Delay

One of the costs of congestion is delay, defined as the excess time required to traverse a section of roadway compared to the free flow travel time. For this study, delay was calculated for the freeway mainline volumes excluding on-ramps for all five study days. The estimation of freeway delay was based on the difference between actual travel time and the free-flow travel time on the freeway segments. Delay was calculated by segment of the study corridor for all 5 days using the following equation:

$$\text{Delay (veh-hours)} = \frac{\text{Distance (VMT)}}{\text{Average Speed (mph)}} - \frac{\text{Distance (VMT)}}{\text{Freeflow Speed (mph)}}$$

Total delay (veh-hr.) for each station was defined as the sum of all delay at that station throughout the day. Figure 8 shows the average delay due to congestion for the southbound direction. For locations that indicate higher delays, as an example, a DOT can focus its incident response efforts to reduce further delays. Figure 8 also shows average delay per station for all 5 days. From this plot one can see several spikes of delay that occur at key bottlenecks along the corridor.

Person Miles Traveled (PMT)

Person miles traveled is an aggregate quantity of travel used to identify mobility performance. Person-miles are usually computed by the summation of the products of Average Annual Daily Traffic (AADT) multiplied by the length of the roadway segment and the average vehicle occupancy depending on the traffic composition. The PMT was calculated by multiplying the VMT by the average vehicle occupancy. The traffic composition, comprised of the percentages of passenger cars, buses and trucks, was obtained by vehicle count at a random location on I-5 using traffic surveillance video available at the Portland State University ITS Laboratory. Vehicle occupancies were estimated to be: 1.4 for passenger cars; 25 for buses; and 1.1 for trucks (*15*); these values were applied to generate the total PMT for this corridor.

Q-Ratio

The Q-ratio, equal to the total VMT divided by total VHT, is a measure of the quality of travel (*4*). This measure is a proxy for the average travel speed in the sense that larger Q-ratios indicate higher speeds and better quality of travel. Figure 9 shows a box plot of the Q-ratio, also calculated per one mile segment along the corridor. As seen in, the figure, average Q-ratio for southbound I-5 remained in the range of 45 mph (72.5 km/h) to 55 mph (88.6 km/h) on all days of analysis.

Mobility Index (MI)

The mobility index measures the person flow in the transportation system and is calculated by multiplying average speed by the average vehicle occupancy, or the PMT divided by VMT. The mobility index provides a multimodal cross-comparison since it is independent of vehicle type (*16*). The index is applicable at the route, segment, corridor, regional or statewide levels in that higher values indicate better performance. Figure 10 shows the mobility index for northbound and southbound I-5 by station. It was observed that northbound I-5, Station 1 (Stafford) and Station 15 (Macadam) and southbound I-5, Stations 11 (Hood River Ave.), 13 (Upper Boons Ferry) and 14 (Lower Boons Ferry) showed better passenger movements as compared to other locations.

DATA INTEGRATION

The previous discussion has focused on means for reporting corridor performance based on freeway surveillance data only. The next phase of this project integrates bus Automatic Vehicle Location (AVL) data (a component of the BDS installed on all TriMet buses) data with that from the freeway in order to leverage greater levels of information for corridor management and information systems. TriMet operates two express bus routes on a sub-section of the I-5 corridor. Route 95X provides morning peak service between Sherwood and Downtown Portland on the I-5 freeway Similarly, Route 96X is a morning and evening peak only service and runs between Sherwood and Downtown Portland on the I-5 freeway. Neither route includes any stops along the freeway. The TriMet BDS is set up to record arrival and departure time data at stop locations. Therefore, for Routes 95X and 96X the database includes the departure time from the last stop before each bus enters the freeway and at the first stop after each bus leaves the freeway in Downtown Portland. In order to capture bus movements on the freeway, TriMet established a set of pseudo-stops for this experiment. Figure 11 shows the locations of the pseudo-stops along the freeway (numbered between 11371 and 11388) as well as the 7 loop detector stations along the same segment. This is a 4.2 mile corridor between the Haines St. on-ramp and the Terwilliger Blvd. on-ramp. Generally this corridor includes three lanes in each direction and becomes heavily congested in the morning peak period as a major commute route into Downtown Portland. This delay was clear in Figure 8.

Using BDS data from 20 northbound buses on Thursday, November 7, 2002, Figure 12 shows a time space diagram that includes trajectories of buses traveling between 6:30 and 9:00 a.m. as solid lines. As with any trajectory (where the x-axis is time and the y-axis is distance), the slope is the speed and the horizontal distance between the two end points is the travel time. It is easy to observe how travel times varied throughout this peak period. Note that in Figure 12, the Route 96X buses traveled between pseudo stops 11374 and 11384, while the 95X buses traveled between pseudo stops 11377 to 11384.

In this section two key performance measures will be used to demonstrate the possibility of integrating data from various heterogeneous sources that can add value toward better understand these measures. The fusion of different data sources will illustrate how gaps that are present in one data source are filled when integrating one data source with another.

Travel Time

Referring to Figure 11, it is shown that the pseudo stops were co-located with loop detectors as well as between the fixed detectors. In Portland, loop detectors are typically located only where there is an on-ramp, thus providing limited information between interchanges. It was thus possible to construct artificial trajectories from the loop detectors only, using the location-time method (Method II) described above. These trajectories are shown as dashed lines on Figure 12. This figure shows how fusion can be performed between freeway loop data that have limited spatial resolution with data recorded by buses traveling through the corridor with lower temporal resolution. The integration between these two data sources can now be used to validate a key performance measure, which is the segment and corridor-level travel times (and/or speeds) reported to motorists or freeway managers. As shown in the figure, when traffic conditions are un-congested, the two trajectories are nearly coincident; however, when the bus travel times increase, the loop detectors tend to misreport travel time by several minutes. Merging the two data sources is a useful tool for providing enhanced traffic management and traveler information and toward improving travel time estimation and forecasting. Such integration can substantially improve the reliability of reported speeds and travel times that are posted on variable message signs that are installed along the corridor.

Average Speed

Figure 13 displays a speed plot for northbound I-5 on November 7, where the color variation represents the average speeds measured at 20-second intervals by the six loop detector stations between Haines St. and Terwilliger Blvd. The 20 bus trajectories have been superimposed over the speed plot, indicating that the loop detectors can provide a good indication of mean travel time for a corridor. The slope of trajectories has changed almost at the same location where the freeway speed declined (darker red color). This method can be used to show how accurately the speed is reported by the loops and represents the movement along the corridor. More statistical analysis was used to validate such information. The statistical analysis revealed that there was no evidence of difference between the means at the 95% level of confidence.

CONCLUSIONS

This project established a test bed for evaluating and testing innovative uses of ITS data in a multimodal corridor in Portland, Oregon. Techniques were tested using loop sensor data in order to improve traffic operations and maximize person-throughput, and ultimately enhance customer satisfaction in the corridor. This project is a part of ongoing research at Portland State University. The next phase of this project is to integrate and compare archived ITS data obtained from parallel corridors to similar ITS data used in this paper aiming at a better understanding of performance along a multimodal corridor.

Currently such performance measures are being automated at the Portland State University Intelligent Transportation Systems Laboratory at a basic level. These efforts are moving towards automating the generation of performance measures to save time for researchers and practitioners so they can begin implementation at the point where this paper ends.

The integration between loop detector data and BDS data is still an opportunity that can be further explored for generating and validating performance measures widely used and rarely tested due to the lack of sufficient data sources. This paper has revealed the possibility of this kind of integration and future research is ongoing in this area.

The operational efficiency of I-5, an important interstate that passes through the heart of Oregon, was examined. Several performance measures were selected based on a literature review and evaluated using loop detector data from I-5 and BDS data. The use of visualization tools in this paper has revealed the power of visual representation of such measures and fills in a present gap in the literature. Most DOTs that collect this data do not use it for generating statistics relevant for policy analysis. Most of the ITS data from freeways is used for traveler information and then discarded. With access to large data sets, DOTs can automate the process of converting it into useful performance measures for use in making future planning and policy decisions without additional data collection costs.

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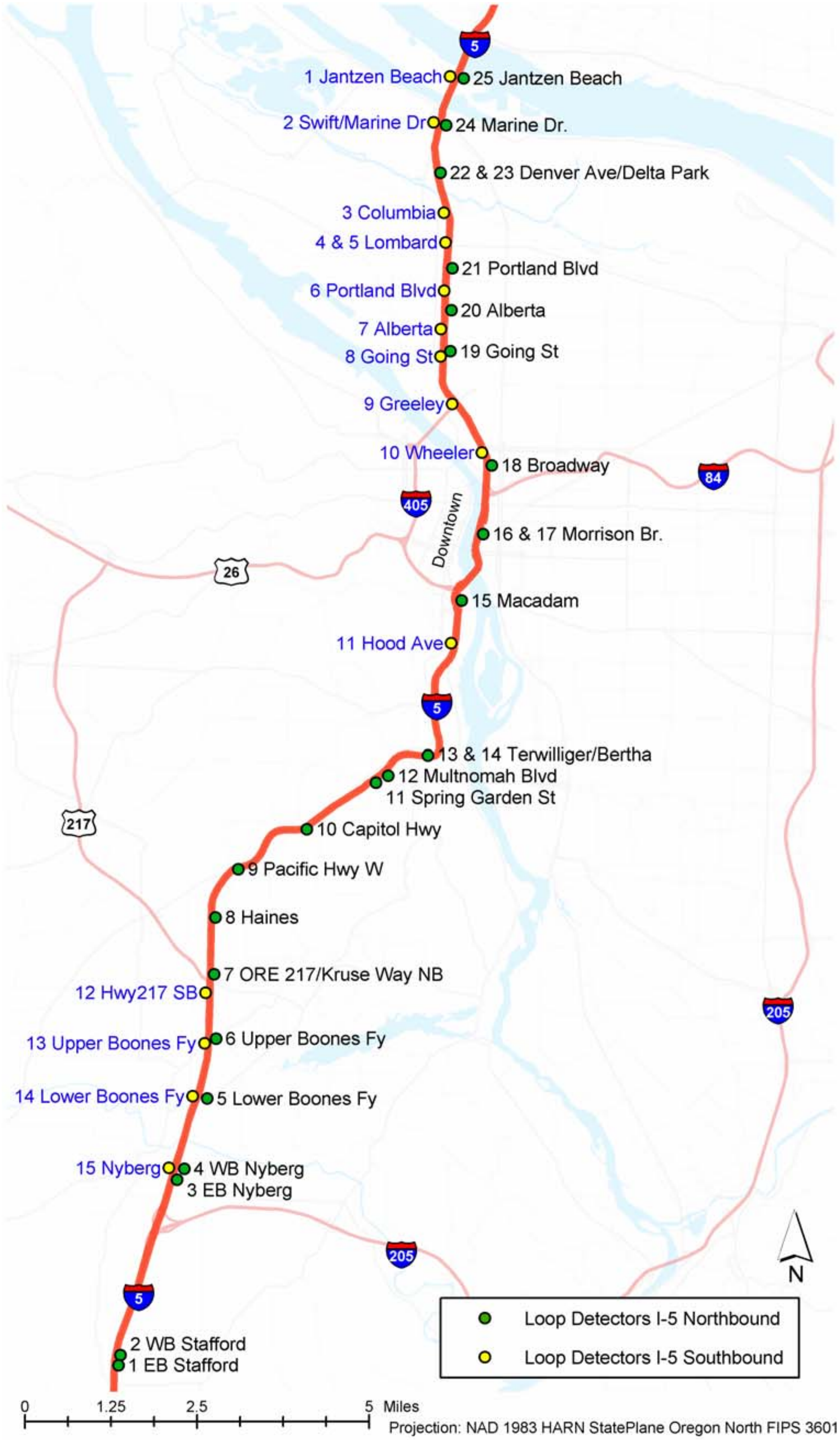
TABLE 1 Performance Measures Based on Literature

Goal Category	Identified Performance Measures
Accessibility	Travel Time Distance Roadway Condition, Capacity Population Access to Destinations
Mobility	Travel time, Speed Delay, Congestion Amount of travel Reliability, Variability Multimodal - travel time, Delay Multimodal - Amount of Travel Multimodal – Other
Economic Development	Economic cost of pollution Economic cost of accidents Economic cost of fatalities Economic cost of lost time Economic cost of congestion Property damage accidents/VMT Direct jobs supported or created Percent of state gross product Economic indicator for People movement Percent of employers that cite difficulty in accessing desired labor supply due to transportation. Employee-related percent of employers who have relocated for transportation reasons
Quality of Life	Accessibility, Mobility Related: Air Quality Related Noise Related Environmental and Resource Conservation
Safety	Number of Incidents Related Motorist Behavior Related
Operational Efficiency	Time, Speed Measures - Vehicle, Traveler Operations Operational Measures - Vehicle, Traveler Operations Passenger Specific - Roadway Cost per vehicle for parking fees Percent of workers who have paid parking at employment sites Percent of workers who have free parking at employment sites VMT/PMT (Q-ratio) Average vehicle occupancy Percent of vehicles using high-occupancy lanes.

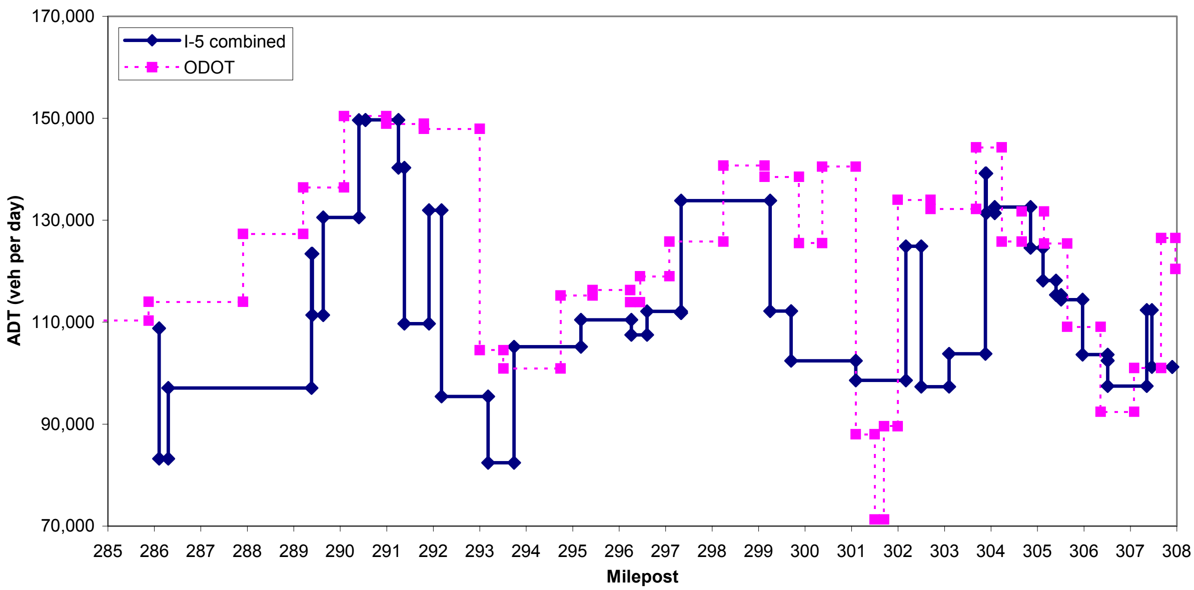
A complete version of Table 1 can be found online at: http://www.gcu.pdx.edu/modules/hwyper_table1.htm



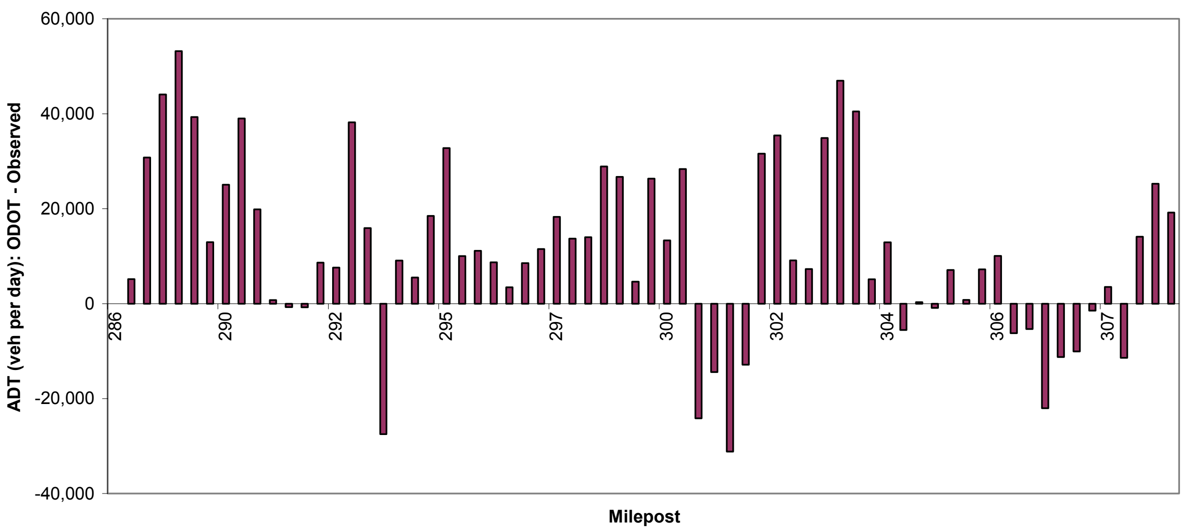
Southbound I-5	
Station	MP
1	307.90
2	307.35
3	305.97
4	305.51
5	305.40
6	304.85
7	304.08
8	303.90
9	303.10
10	302.17
11	299.25
12	291.91
13	291.25
14	290.40
15	289.38

Northbound I-5	
Station	MP
1	286.10
2	286.30
3	289.40
4	289.63
5	290.54
6	291.38
7	292.18
8	293.18
9	293.74
10	295.18
11	296.26
12	296.60
13	297.33
14	297.33
15	299.70
16	301.09
17	301.09
18	302.50
19	303.88
20	304.40
21	305.12
22	306.51
23	306.51
24	307.46
25	307.90

FIGURE 1 Loop Detector Location Map for I-5.

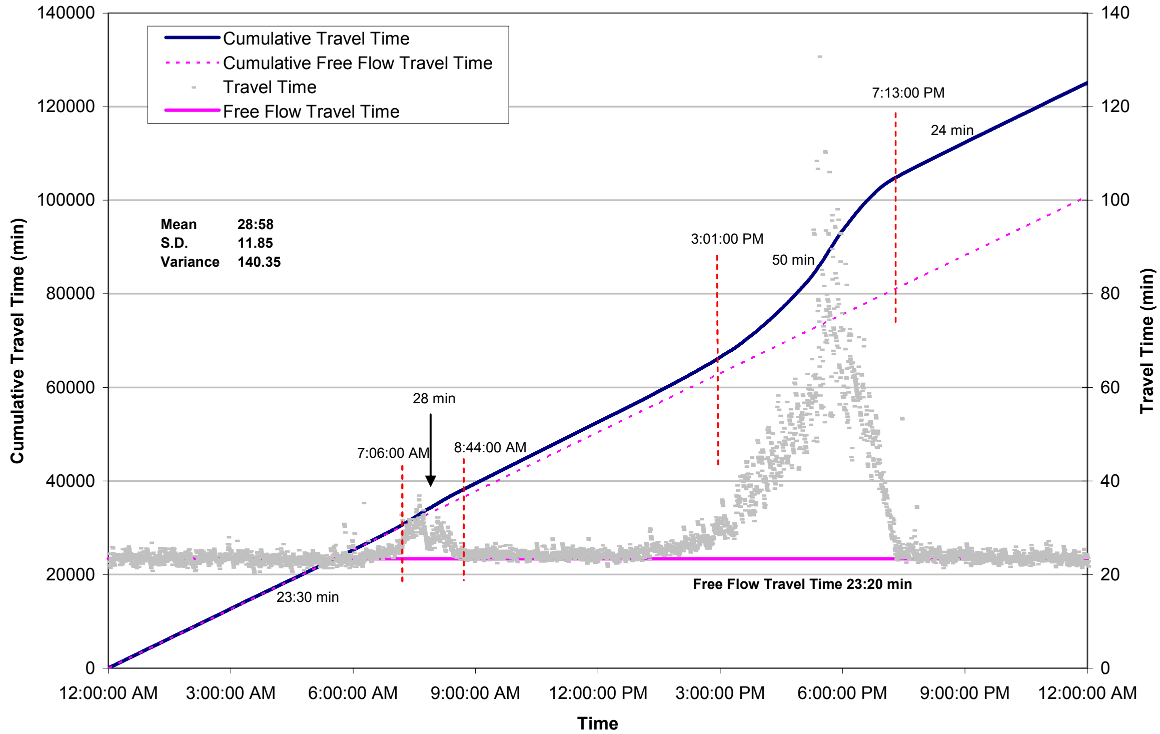


(a)

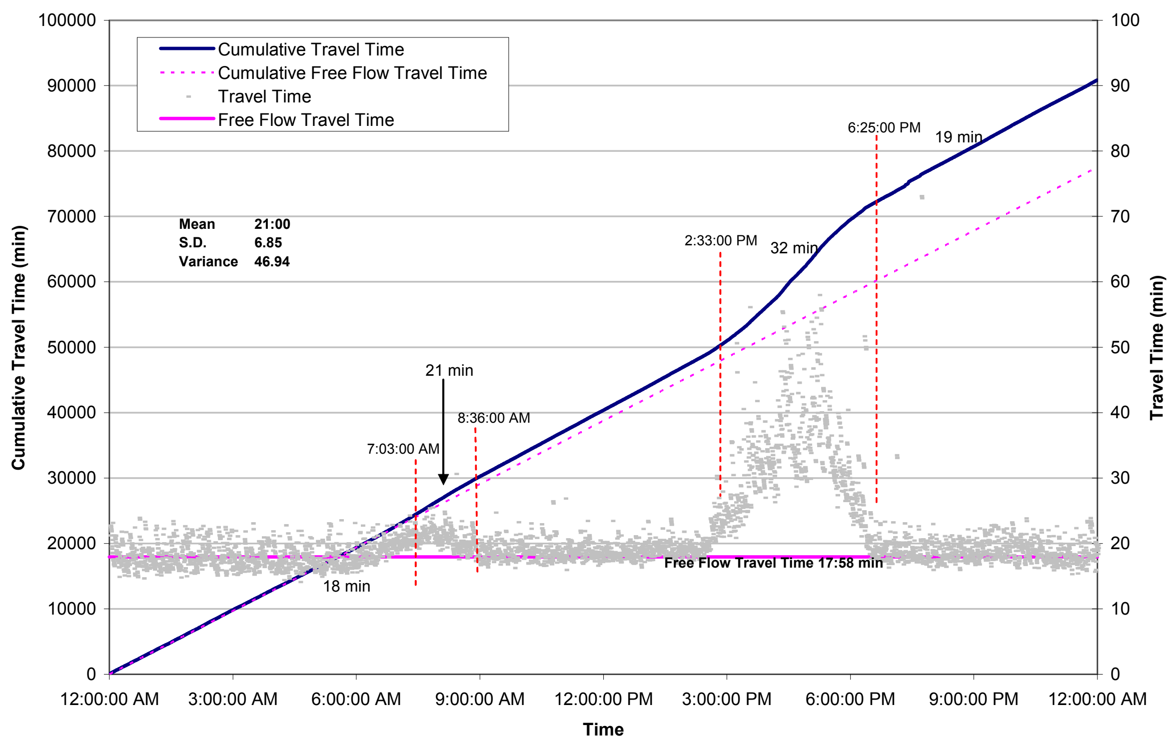


(b)

FIGURE 2 Average Daily Traffic (ADT) Comparison.



(a) Northbound I-5



(b) Southbound I-5

FIGURE 3 Travel Time (Method I).

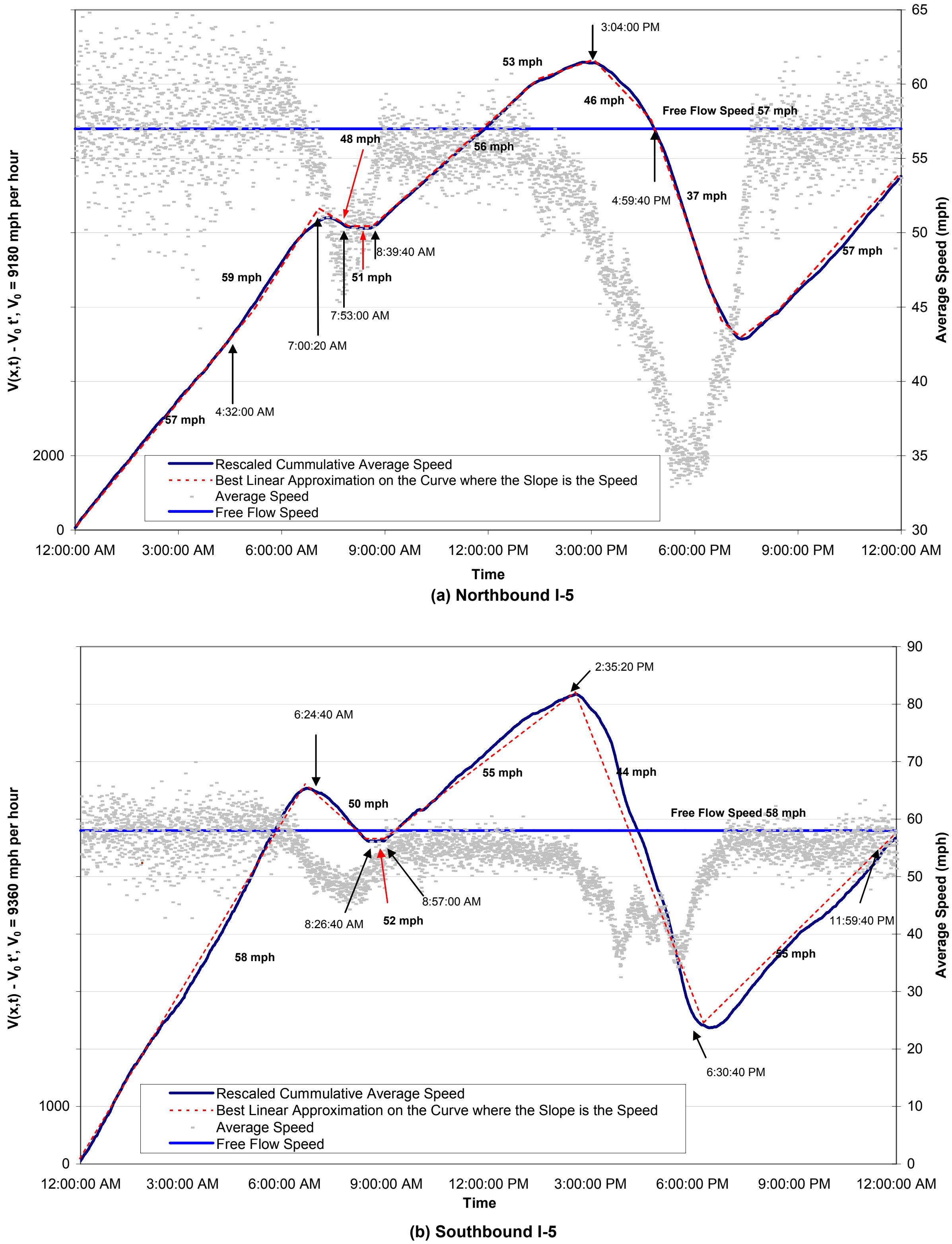


FIGURE 4 Speed Analysis with Oblique Cumulative Speed Curve.

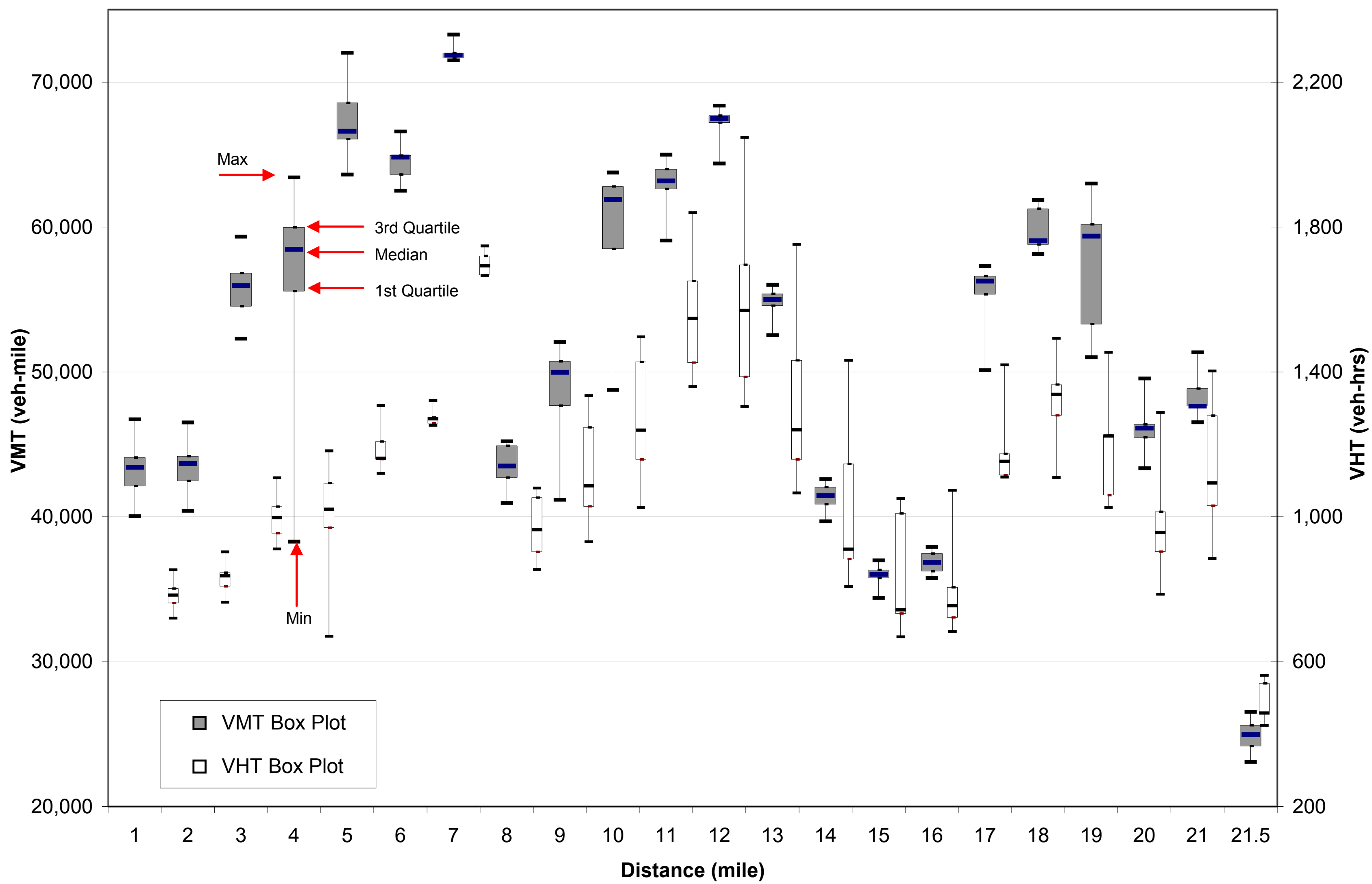


FIGURE 5 Vehicle Miles and Hours Traveled.

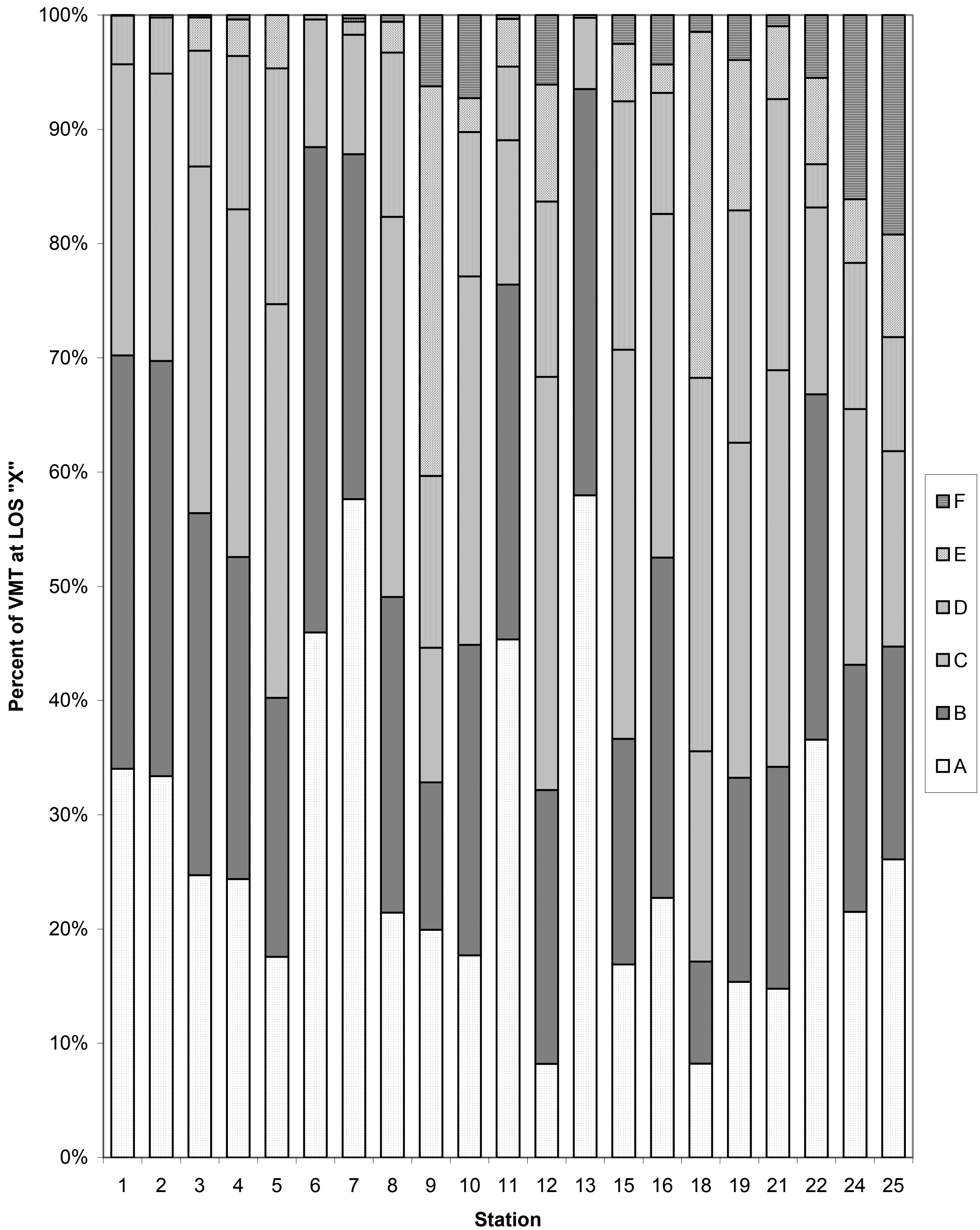


FIGURE 6 Percent Vehicle Miles Traveled by LOS.

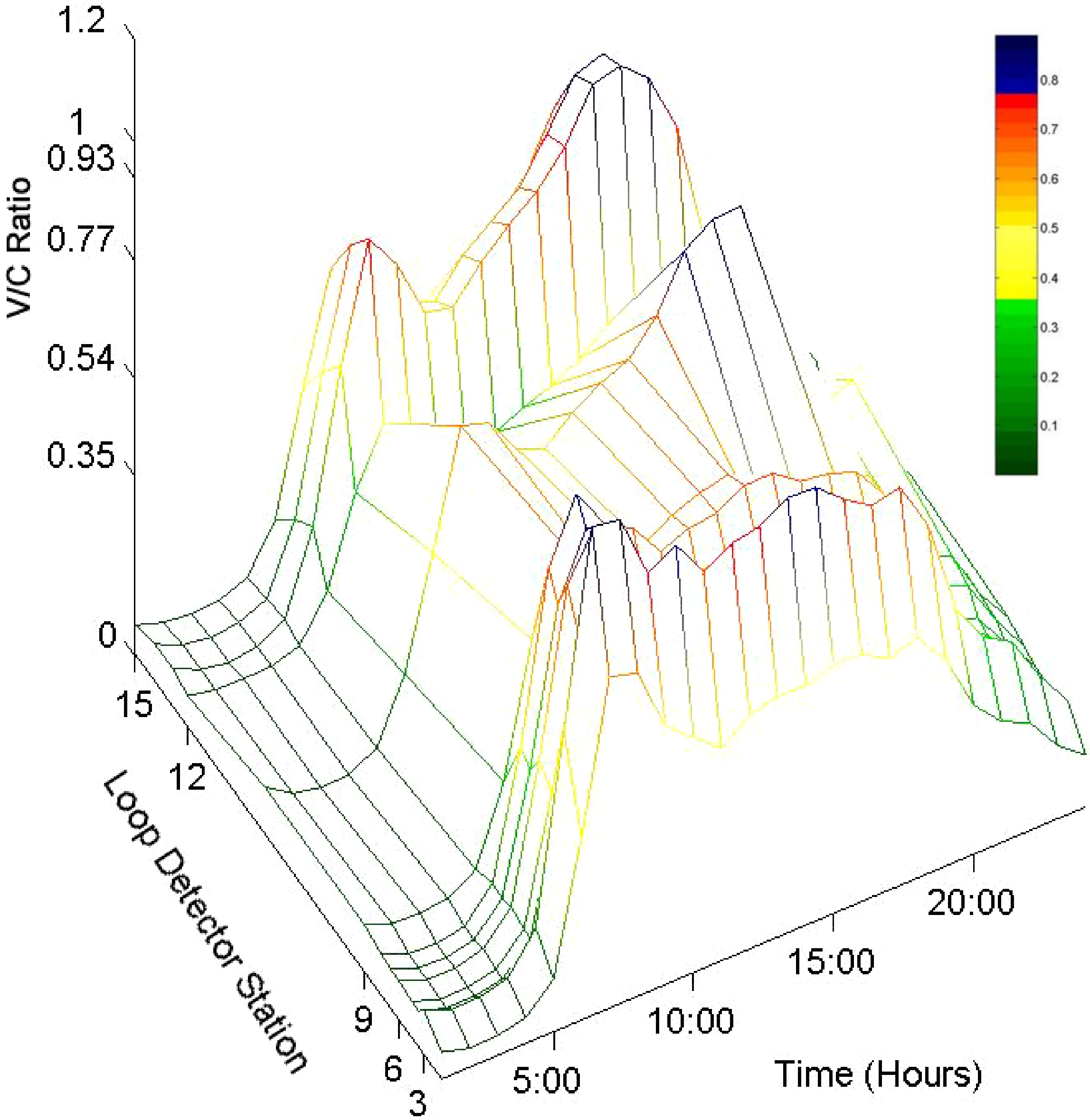
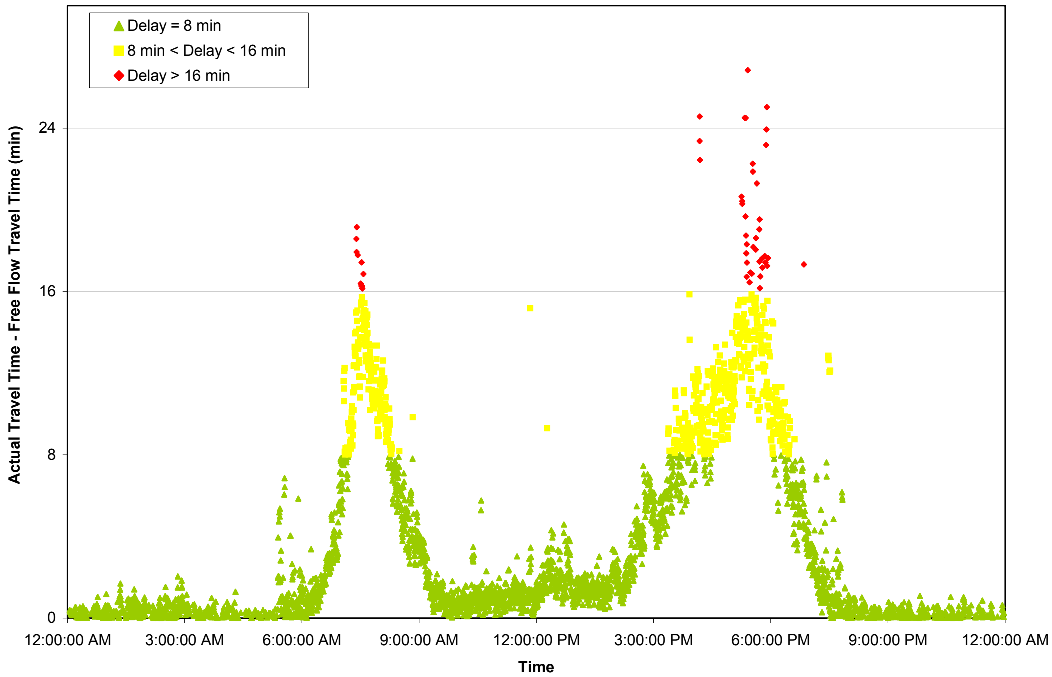


FIGURE 7 Average V/C Ratio.



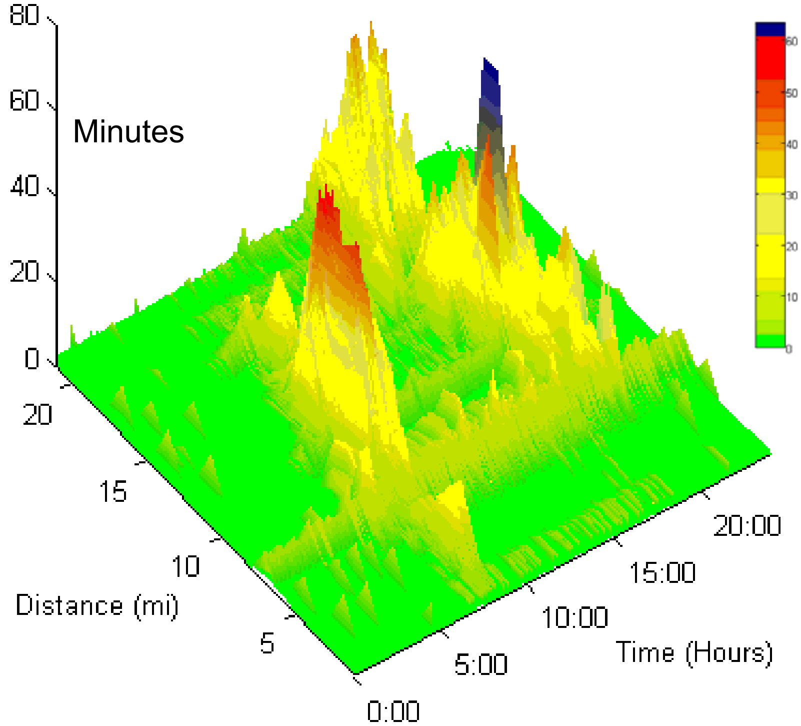


FIGURE 8 Delay and Average Delay

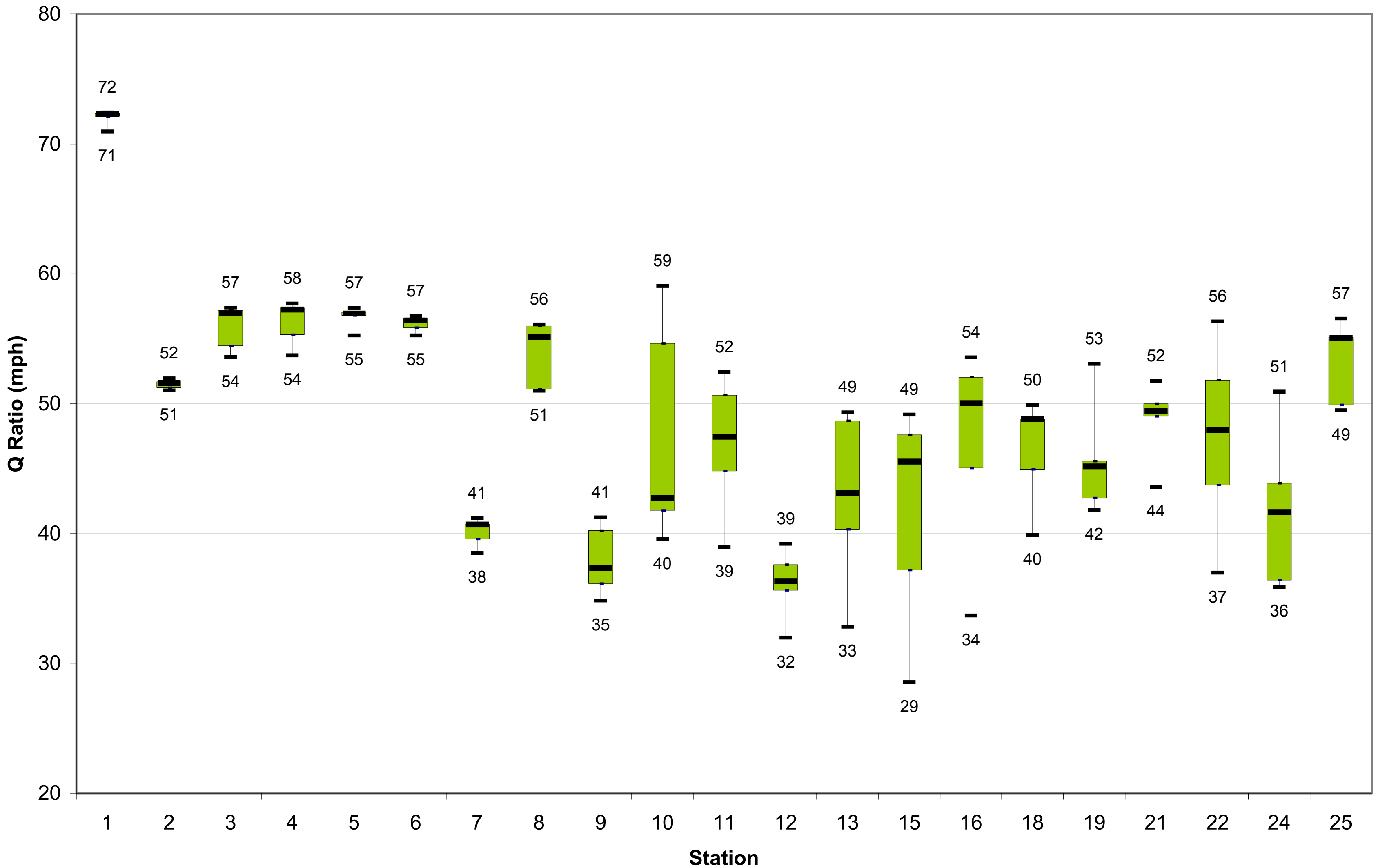


FIGURE 9 Q Ratio.

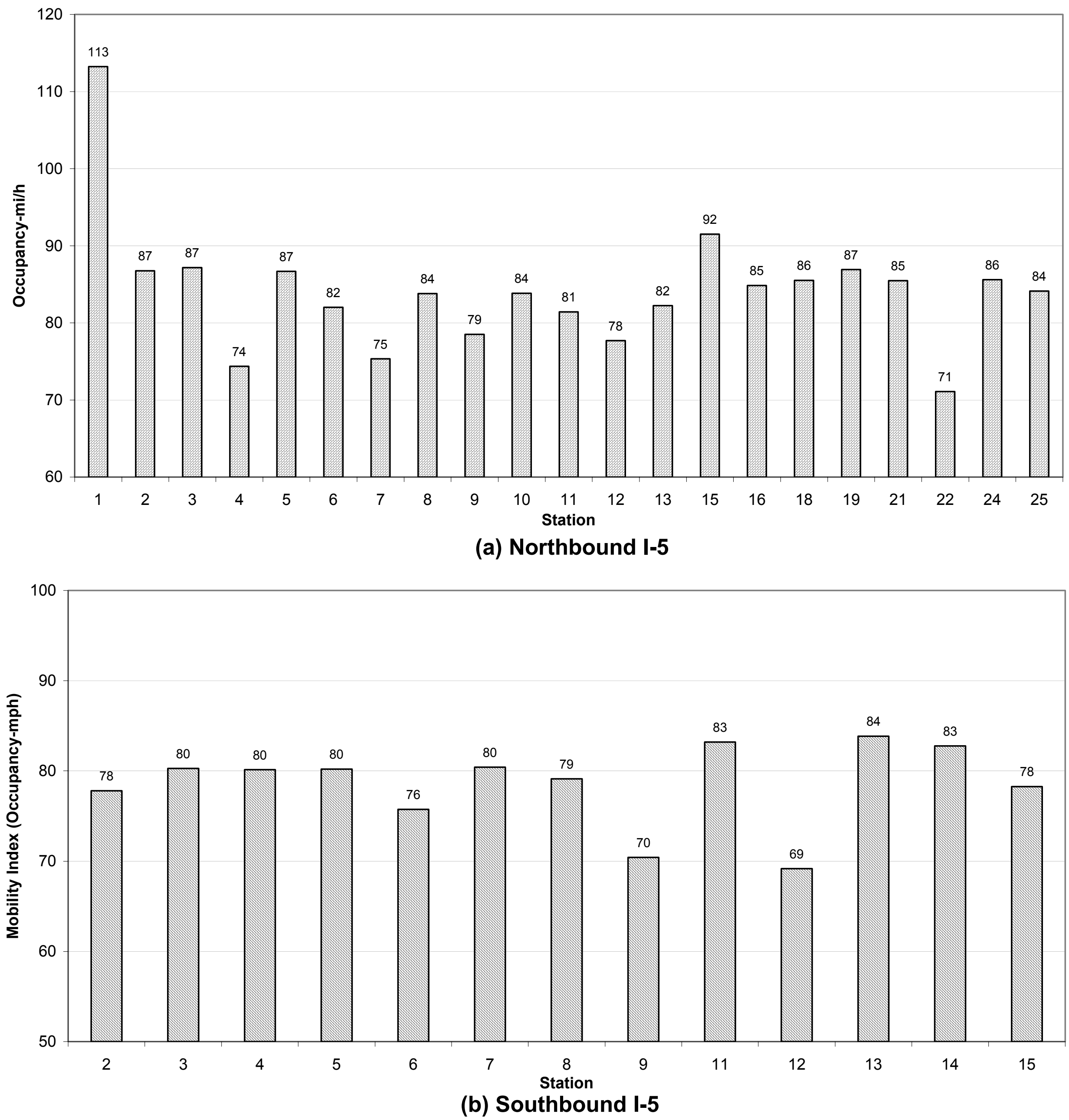


FIGURE 10 Mobility Index.

FIGURE 11 Express Bus Experiment Site Map

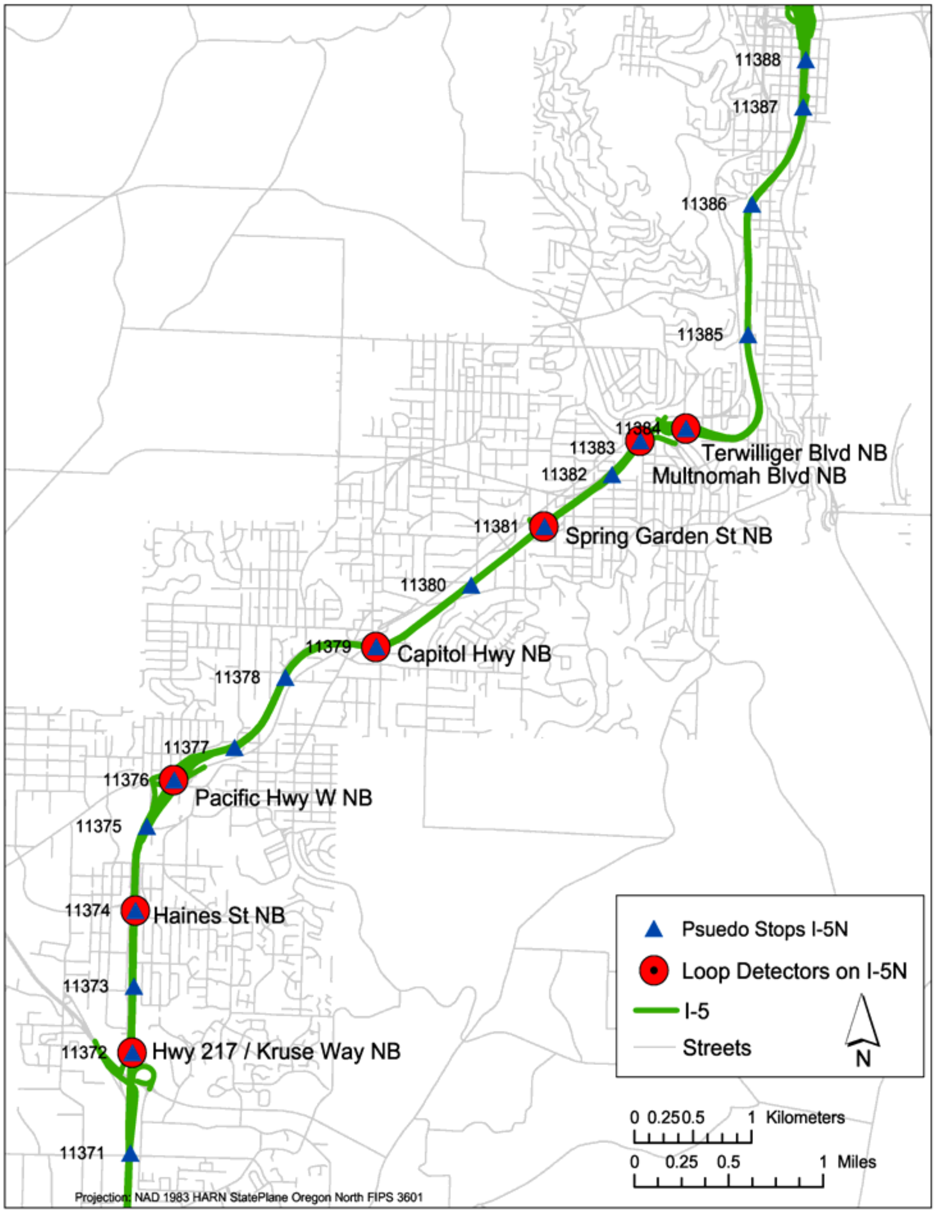


FIGURE 12 Bus Trajectories and Predicted Trajectories for November 7

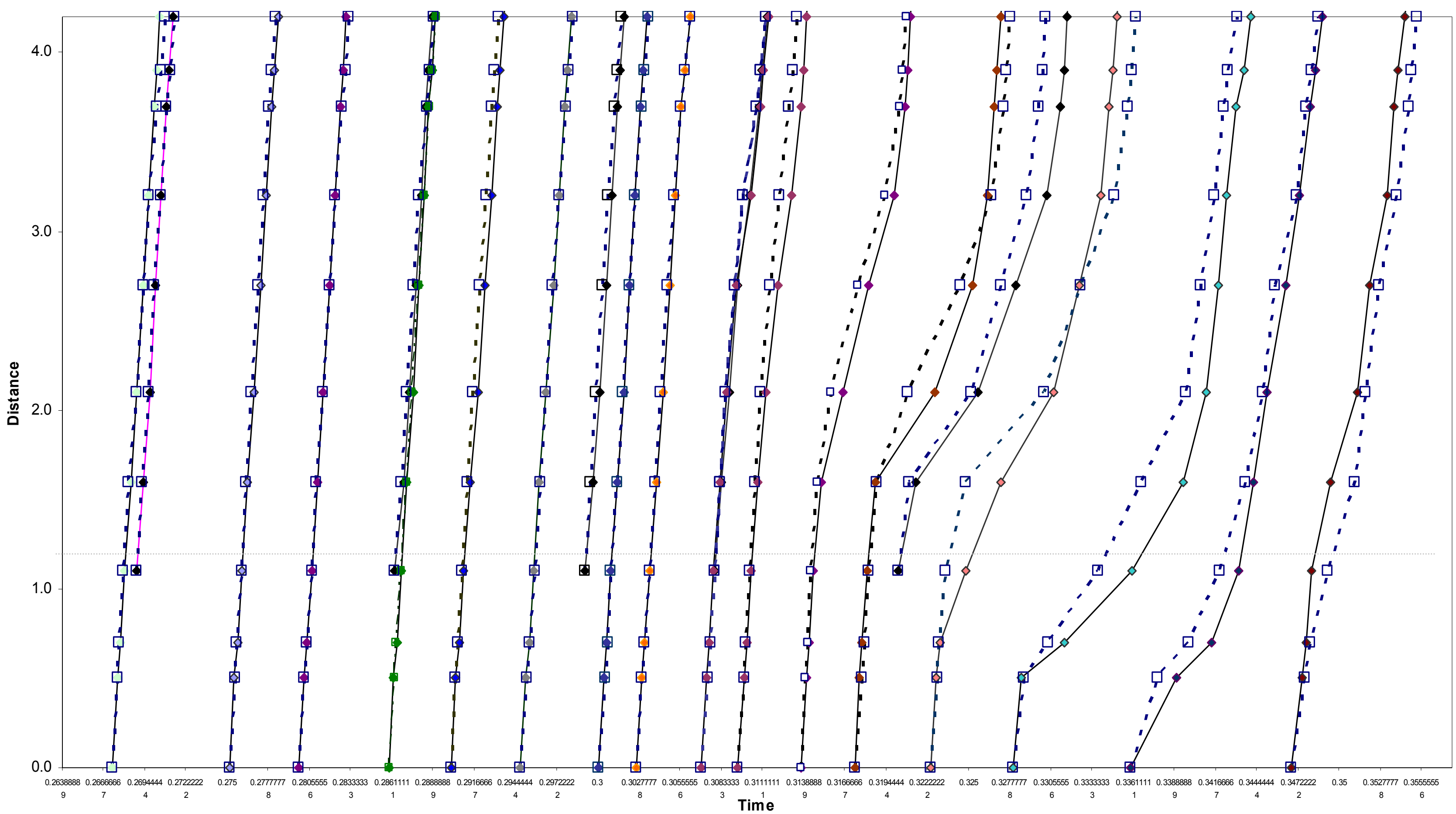


FIGURE 13 Contour Plot of Sensor Data (Raw) with Bus Trajectories November 7