Final Report
Volume I

A NEW SHORT-TERM TRAFFIC PREDICTION AND INCIDENT DETECTION SYSTEM ON I-4

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16. Abstract

One of the key elements for an effective on-line ATMIS is the ability to predict traffic congestion with reasonable accuracy. The rationale behind using predictive information in traffic diversion is that drivers' travel decisions are affected by future traffic conditions expected to be in effect when they reach downstream sections of the highway network on their way to their destinations. In order to build forecasts of traffic parameters, it is necessary to have a model that can process past values of the parameters and then dynamically respond to changing conditions on the network. One methodology that meets these criteria is the non-linear time series approach. This methodology was applied previously in the off-line traffic prediction model that was developed in the context of a previous research project for the FDOT. In this project, additional factors are investigated to improve the performance of the model such as decay factors and the inclusion of additional traffic parameters such as occupancy and volume. The first part of this report presented the research and development efforts to improve and validate the time-series short-term traffic prediction model on I-4. The traffic prediction system was developed as a stand-alone module using MS Visual Basic 6.0. The developed module is capable of running in both off-line and on-line modes. Extensive testing using the developed module was also conducted to explore the impact of the model parameters and the traffic conditions on the performance of the model. It was found that the model performed very well except under heavy traffic congestion, due primarily to the rapid change and instability in traffic conditions. However, the model performance during congested conditions may be improved by incorporating the historical traffic information. This will result in one hybrid model that predicts traffic conditions using historical data and the most recent data to improve the accuracy of prediction. This is one focus for the continued research project supported by the Florida Department of Transportation.

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DISCLAIMER

The opinions, findings, and conclusions in this publication are those of the authors' and not necessarily those of the Florida Department of Transportation of the US Department of Transportation. This report does not constitute a standard, specification, or regulation. This report is prepared in cooperation with the State of Florida Department of Transportation.

EXECUTIVE SUMMARY

The propagation of traffic congestion on the transportation infrastructure of our society has become a major concern for motorists and transportation officials. Travel time is an indirect measure of the travel cost and is the most perceived by travelers. Congestion occurs on a network when the demand on the facility exceeds the capacity of the network. Information and communication technologies, as well as advanced computers, electronics, and modeling techniques are used in ITS to better manage and improve the operation of the existing transportation infrastructure. The intelligent infrastructure is primarily based on Advanced Traffic Management and Information Systems (ATMIS). Such systems are driven by modern information technology to collect, process, and disseminate real time traffic information to travelers in order to improve traffic operations and safety. Such information is expected to influence traveler's choices of trip departure time, trip route, and possibly mode. Thus, by implementing ATMIS efficiently, it is expected that recurrent and incident congestion will be spread over time and space.

One of the key elements for an effective on-line ATMIS is the ability to predict traffic congestion with reasonable accuracy. The rationale behind using predictive information in traffic diversion is that drivers' travel decisions are affected by future traffic conditions expected to be in effect when they reach downstream sections of the highway network on their way to their destinations. It will be most effective, flexible, and useful if travelers learn about projected travel times before they start their trips (i.e., while they are still at their trip origins). Such information could be made available via the World Wide Web (WWW), Highway Advisory Radio (HAR), cable television stations, telephone services, and other forms of marketable media. In addition, travel time forecasts could be made available while motorists are en-route from their origins to their destinations. This could be accomplished through Changeable Message Signs (CMS), HAR, cellular phone services, onboard vehicle information systems, and car PCs.

In order to build forecasts of traffic parameters, it is necessary to have a model that can process past values of the parameters and then dynamically respond to changing

conditions on the network. One methodology that meets these criteria is the non-linear time series approach. This methodology was applied previously in the off-line traffic prediction model that was developed in the context of a previous research project for the FDOT. In this project, additional factors are investigated to improve the performance of the model such as decay factors and the inclusion of additional traffic parameters such as occupancy and volume. The first part of this report presented the research and development efforts to improve and validate the time-series short-term traffic prediction model on I-4. The traffic prediction system was developed as a stand-alone module using MS Visual Basic 6.0. The developed module is capable of running in both off-line and on-line modes. Extensive testing using the developed module was also conducted to explore the impact of the model parameters and the traffic conditions on the performance of the model. It was found that the model performed very well except under heavy traffic congestion, due primarily to the rapid change and instability in traffic conditions. However, the model performance during congested conditions may be improved by incorporating the historical traffic information. This will result in one hybrid model that predicts traffic conditions using historical data and the most recent data to improve the accuracy of prediction. This is one focus for the continued research project supported by the Florida Department of Transportation.

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1 INTRODUCTION

The objectives of this research project are twofold: First, to improve the short-term traffic prediction model and conduct sensitivity analysis to investigate the effect of various factors on the prediction accuracy; and second, to develop a neural network model (Fuzzy ART) for the automated detection of incidents on I-4. The tasks accomplished in each part are listed below:

<u>Volume I: Short-term traffic prediction on I-4</u>

1. Use Different decay factors such as half normal and exponential function to smooth detector data and improve on the performance of the existing off-line model.
2. Use additional traffic variable, e.g., occupancy, in addition to speed, to see if the accuracy of the existing prediction model will be improved.
3. Test the off-line prediction model using more incident-free days (recurring congestion) to examine the reliability of the prediction model and, most importantly, to avoid overestimation of traffic speed
4. Implement the on-line real time traffic prediction model.
5. Evaluate the performance of the on-line prediction model

<u>Volume II: Incident detection on I-4</u>

1. Filter all the loop detector data and the incident database collected on the central corridor of I-4 in 1993 and 1994. The filtering mechanism should be suitable for on-line implementation.

2. Collect a new set of incident and loop detector data on I-4 via the dial-up connection between UCF and FMC. The new data will also be subject to filtering.
3. Develop software to process the data and train the proposed ANN models. The programming effort will be conducted in MS Visual Basic 6.0. The development process involves debugging and testing the software.
4. Split the data set into two subsets: one for training and the other for testing.
5. Train the proposed ANN models using the training data subset.
6. Evaluate the performance of the trained models using incident detection performance measures.
7. Test the proposed models off-line using the testing data subset.
8. Conduct the on-line testing of the new trained models by incorporating a new module into the existing on-line module.

2 SHORT TERM TRAFFIC PREDICTION

2.1 INTRODUCTION

The propagation of traffic congestion on the transportation infrastructure of our society has become a major concern for motorists and transportation officials. Travel time is an indirect measure of the travel cost and is the most perceived by travelers. The user of a transportation facility will measure the cost of the congestion they encounter primarily by the additional travel time required to traverse from their origin to their destination. Congestion occurs on a network when the demand on the facility exceeds the capacity of the network to process vehicles. The U.S. Department of Transportation (1998) has quantified the annual cost of congestion to our nation to be over $48 billion in lost productivity, and this cost will continue to grow. Information and communication technologies, as well as advances in computers, electronics, and modeling are used in ITS to better manage and improve how transportation providers offers services to the public. The intelligent infrastructure contains the program area of Advanced Traffic Management and Information Systems (ATMIS). ATMIS are based on modern information technology to collect, process, and disseminate real time traffic information to travelers. The principle objective of ATMIS is to improve traffic flows and safety. By providing information to motorists, ATMIS are expected to influence traveler's choices of trip departure time, trip route, and possibly mode. Thus, by implementing ATMIS efficiently, it is expected that recurrent and incident congestion will be spread over time and space.

One of the key elements for an effective on-line ATMIS is the ability to predict traffic congestion with reasonable accuracy. Kaysi et al. (1993) and Ben-Akiva et al. (1991) argued that traffic routing strategies under recurring and non-recurring congestion should be based on forecasting of future traffic conditions rather than historical and/or current traffic conditions. The rationale behind using predictive information in traffic diversion is that drivers' travel decisions are affected by future traffic conditions expected to be in effect when they reach downstream sections of the highway network on their way to their destinations.

It will be most effective, flexible, and useful if travelers learn about projected travel times before they start their trips (i.e., while they are still at their trip origins). Such information could be made available via the World Wide Web (WWW), Highway Advisory Radio (HAR), cable television stations, telephone services, and other forms of marketable media. In addition, travel time forecasts could be made available while motorists are en-route from their origins to their destinations. This could be accomplished through Changeable Message Signs (CMS), HAR, cellular phone services, onboard vehicle information systems, and car PCs.

Currently, traffic operators lack a tool that can utilize the information received from loop detector stations to forecast traffic conditions in short time horizons. For instance, the operator would have the ability to use predicted speed, occupancy, and volume data for the next five, ten, or fifteen minutes to influence their management strategies. Since the loop detector stations are closely spaced, point estimates of these parameters can be used to forecast travel times for origin-destination pairs along the network. This information could then be disseminated through various types of media to those travelers who are both on the network and plan to use the network.

In order to build forecasts of traffic parameters, it is necessary to have a model that can process past values of the parameters and then dynamically respond to changing conditions on the network. One methodology that meets these criteria is the non-linear time series approach. A time series is composed of a time line of values that are spaced at equal intervals known as time steps. For example, if an operator had access to the speed values from a loop detector station for every minute, then this data would be a speed time series with a one-minute time step. The non-linear aspect to this methodology is rooted in the application of a non-linear transformation to the time series data. This type of transformation is applied to find trends within the time series. Once the trend has been established for the time series, then a forecast can be made about future time steps. The non-linear time series approach has been shown to be useful for predicting traffic volumes by Vojak (1994). This methodology was applied previously in the off-line traffic prediction model that was developed in the context of a previous research project for the FDOT. In this project, additional factors are investigated to improve the performance of the model such as decay factors and the inclusion of additional traffic parameters such as occupancy and volume. In addition, the model is implemented in real time and the results are presented in this report.

2.2 DATA COLLECTION PROCESS

The network studied is an 18 km (11.2 mile) freeway section known as the I-4 Central Corridor, in Orlando, Florida. The data is collected from double inductance loops on this freeway section which extends from Maitland Blvd. in east Orlando to John Young Parkway in the west side of the corridor. There are 25 loop detector stations numbered in a descending order in the westbound direction. Station 10 is an exception in that it is a communications hub without any loop detectors present. The loop detectors have a resolution of 30 seconds and are spaced approximately every 0.8 km (0.5 miles). Table 1 elucidates the exact spacing between the loop detector stations, as well as a description of the location of each station. Station 10 is not displayed in the list since no loop detectors are present at its location. Hence, distances along this subsection are taken from Station 9 to Station 11. Note that the naming convention used by the Florida Department of Transportation (FDOT) differs at Stations 23 through 25. FDOT uses the delineation of 23A for Station 23, 23B for Station 24, and 24 for Station 25. The FDOT naming convention for these three stations is not adopted since it is confusing to recognize Station 24 as the last loop detector station in the eastbound direction when there are 25 stations along the I-4 Central Corridor. Hence, all subsequent discussion will describe the loop detector stations as beginning with Station 25 and ending with Station 1 in the westbound direction.

Table 1: Loop Detector Stations on I-4 Central Corridor

STATION	LOCATION	MILE MARKER	STATION SUBSECTION	DISTANCE (km)	DISTANCE (miles)
1	John Young Pkwy	13.675	2-1	0.792	0.492
2	E of John Young Pkwy	14.167	3-2	0.855	0.531
3	Rio Grande Ave	14.698	4-3	0.383	0.238
4	Orange Blossom Trail	14.936	5-4	1.056	0.656
5	Michigan St	15.592	6-5	0.724	0.450
6	Kaley Ave	16.042	7-6	0.824	0.512
7	Gore Ave	16.554	8-7	0.814	0.506
8	East-West Expy	17.060	9-8	0.578	0.359
9	Church St	17.419	11-9	0.890	0.553
11	Robinson St	17.972	12-11	0.766	0.476
12	SR 50	18.448	13-12	0.853	0.530
13	Ivanhoe Blvd	18.978	14-13	0.763	0.474
14	Princeton St	19.452	15-14	0.792	0.492
15	Winter Park St	19.944	16-15	0.798	0.496
16	Par Ave	20.440	17-16	0.927	0.576
17	Minnesota Ave	21.016	18-17	0.652	0.405
18	SR 426	21.421	19-18	0.731	0.454
19	E of SR 426	21.875	20-19	0.809	0.503
20	Lee Rd	22.378	21-20	0.624	0.388
21	E of Lee Rd	22.766	22-21	0.731	0.454
22	Kennedy Blvd	23.220	23-22	0.855	0.531
23 (23A)‡	Maitland Blvd EB Ramp	23.751	24-23	0.731	0.454
24 (23B)‡	E of Maitland Blvd	24.205	25-24	0.835	0.519
25 (24)‡	Wymore Rd	24.724			

‡ Station Number Used by FDOT

Inductance loop data is processed at the I-4 Freeway Management Center (FMC), which also supports closed circuit TV cameras (CCTV) and a state-of-the-art surveillance system. In addition, there are several CMS in each direction of I-4 within the Central Corridor. Predicted travel times can be posted on the CMS along the I-4 Central Corridor to help drivers make their en-route switching decisions. A detailed map of the study section is displayed in Figure 1.

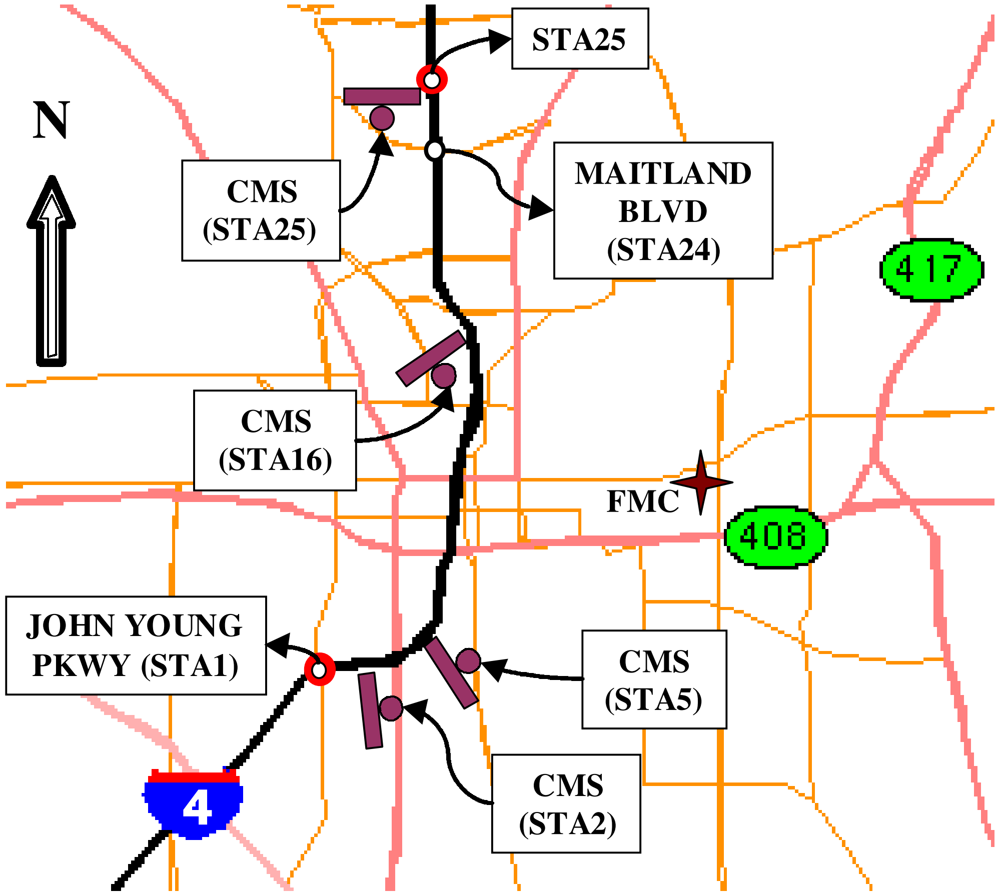


Figure 1: CMS on I-4 Central Corridor

Speed, volume, and occupancy data are available using the Loop Output and Verification Algorithm Testing System (LOVATS©) database developed by the University of Central Florida. This database contains traffic data (speed, volume, and occupancy) during incident free days and contains traffic and incident data during incident days for a total period of 15 months; see Al-Deek et al. (1996, 1995b). The study period of interest is the westbound morning peak period. This peak period begins at 6:00 am and concludes at 10:00 am. Throughout the morning peak period, the traffic composition is predominated by commuters and motorists on business related trips. These drivers are familiar with the network, which qualifies them as excellent candidates for route guidance and information dissemination.

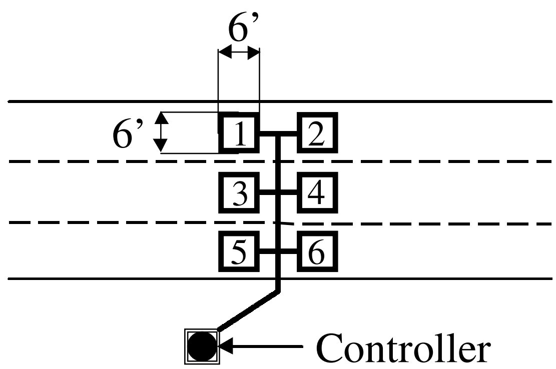


Figure 2: Typical Loop Detector Station

Data collection mandates an understanding of how the loop detectors measure each traffic parameter. Figure 2 displays the configuration of a typical loop detector station in one direction of travel. The I-4 Central Corridor is composed of three lanes of traffic in each direction. At each detector station on the mainline, there are two 6' x 6' loops embedded in the pavement per lane connected to a controller located in a cabinet adjacent to the roadside. Hence, there are six inductance loops per station in each direction. In order to directly measure the speed of a vehicle in one lane, two loops are required. Occupancy and volume measures are accomplished with a single loop. Therefore, for a single time slice of data, a loop detector station will report three speeds, six volumes, and six values for the time lane occupancy. Loop detector data from twenty incident free morning peak periods in the westbound direction is extracted from the LOVATS© database for this study. Speed, occupancy, and volume data are reported with a 30-second resolution. This data is used in the development and testing of the prediction schemes.

2.3 DATA FILTERING

Prior to the application of prediction models, the loop detector data must be filtered. The travel time prediction models will use a single traffic parameter per time slice at each station. Hence, the three speeds produced at a loop detector station must be reduced to a single speed value. In addition, the volumes and occupancies reported by the loop detector station must be reduced to a single input to the prediction model per time slice. All three parameters will report false values when the loop detector or the communications infrastructure between the loops and the FMC is not functioning. If there is an error in the data, it is identified by a -9xx value, -xx value, or zero. The procedures used to filter each parameter are summarized in the following sections.

2.3.1 Filtering Speeds

Each loop detector station on the I-4 Central Corridor provides three speed measures per time slice (one speed measure for each lane). A simple set of rules is used to filter out this data, given by the following:

1. If all three speeds are positive numbers, then average the three speed values to obtain a single speed value for the station.

2. If two of the speed values are positive numbers, then average the two positive speed values to obtain a single speed value for the station.

3. If one of the speed values is a positive number, then take the single positive speed value as the speed value for the entire station. A speed value from one loop detector is a valid estimation of the speed for all three lanes during recurrent congestion since all

vehicles are constrained by the capacity limits of the corridor. Hence, vehicles will be moving at approximately the same speed regardless of their lane.

4. If none of the speeds are positive numbers, then the station is down. If this station is not at the beginning or end of the study section, then take the average of the upstream and downstream station speeds for that time slice as the speed value for the station that is down. If the opposite is true, then use the speed value at the upstream station if the last station is down, and use the downstream station if the first loop detector station is down.

2.3.2 Filtering Occupancies

Each loop detector station on the I-4 Central Corridor provides six occupancy measures per time slice (two occupancy measures for each lane). Again, a simple set of rules is used to filter out this data, given by the following:

1. If all occupancies are positive numbers, then average the six occupancy values to obtain a single occupancy value for the station.

2. If one or more of the occupancy values are positive numbers, then average the positive occupancy values to obtain a single occupancy value for the station. Note that this rule will allow the use of a single loop detector to report occupancy values for the entire station. Using one loop detector to report occupancy is a valid estimation of the occupancy for all three lanes during recurrent congestion since all vehicles are constrained by the capacity limits of the corridor. Hence, vehicles will be covering the loop detectors approximately the same percentage of time regardless of their lane.

3. If none of the occupancy values are positive numbers, then the station is down. If this station is not at the beginning or end of the study section, then take the average of the

upstream and downstream station occupancies for that time slice as the occupancy value for the station that is down. If the opposite is true, then use the occupancy value at the upstream station if the last station is down, and use the downstream station if the first loop detector station is down.

2.3.3 Filtering Volumes

Each loop detector station on the I-4 Central Corridor provides six volume measures per time slice (two volume measures for each lane). More conditions exist with filtering volume data. For instance, the operator will be interested in the volume counts for all three lanes as an aggregate measure; averaging across lanes is not a correct procedure with volume data. Filtering volume data is broken down into two major procedures. First, the data from the two loop detectors in each lane must be reduced to a single value for the lane. Secondly, the volumes reported for each lane are summed to produce the total volume for the station. More constraints exist with the replacement of erroneous volume data with values from adjacent detectors. These constraints, and the rules used to filter the volume data are given as follows:

1. If the two detectors in a lane report positive volume values, then average these values to report a volume for that lane. If the values reported by the other detectors meet this rule or the constraints that follow, then sum the average volumes reported by each lane to obtain the total volume for the station.
2. If the only one detector in a lane reports a positive volume value, then use the working detector value as the volume for that lane. If the values reported by the other

detectors meet this rule or the constraints that follow, then sum the average volumes reported by each lane to obtain the total volume for the station.

3. If both detectors in a lane are down (i.e. volume ≤ 0), then use the average of the volumes for the other two lanes as the volume for that lane. If the values reported by the other detectors meet this rule or the constraints that follow, then sum the average volumes reported by each lane to obtain the total volume for the station.

4. If three or more detectors are down, then the entire station is considered to be down. This rule recognizes that lane volumes cannot be reasonably approximated if too much data is missing from a station. If this station is not at the beginning or end of the study section, then take the average of the upstream and downstream station volumes for that time slice as the volume value for the station that is down. If the opposite is true, then use the volume value at the upstream station if the last station is down, and use the downstream station if the first loop detector station is down.

2.4 ADDITIONAL TESTING OF THE MODEL

The purpose of this task is to test the prediction model off-line using additional incident-free days under recurrent congestion. The previous study, which was completed for the FDOT, used only 5 incident free days to develop and test the prediction model. In this project, we extended the number of days for testing purpose to a total of 20 days. All the results shown here are based on data collected from the selected 20 incident free days.

2.4.1 Single Variable Prediction Model

This section describes the development and testing of the single variable prediction model using speed only. The peak period under study is the westbound morning peak period (6:00 am to 10:00 am), in which the traffic composition is predominated by commuters and motorists on business. A 5-minute prediction interval is implemented to enable short-term forecasts of speeds across the westbound direction of the I-4 Central Corridor. Hence, the predictions are updated every five minutes. These conditions are well suited to the goal of predicting recurrent congestion on a short-term time horizon in real time. We first discuss speed prediction performance at discrete loop detector stations, which forms the backbone of travel time prediction. Subsequently, the discussion shifts to the topic of speed prediction across the entire 18.0-km (11.2-mile) study section. This will set the stage for travel time prediction for the I-4 Central Corridor. The travel time prediction model is calibrated through the application of decay factors to smooth the input speed data, as well as setting up a threshold on the minimum speed predictions. The combinations of refinements that produce the best prediction performance are elucidated through rigorous statistical testing, and this case is presented as the final calibrated single variable prediction model.

2.4.2 Speed Prediction at Discrete Stations

Speed predictions at discrete loop detector stations represent the fundamental level of corridor travel time prediction. A single loop detector station contributes data that is used to monitor approximately 0.8 km (0.5 miles) of the freeway corridor. It is important to note that the loop detector station provides a point estimate within that 0.8 km (0.5 miles) of space that is being monitored. Therefore, the information provided by a loop detector station is a spatial approximation of the freeway conditions. This limitation of the intelligent architecture introduces error into predictions of traffic parameters prior to the application of any prediction model.

For single variable prediction, the first question to answer is how many past values in the time series (H) should be used in the prediction model? This question is answered by considering the relevance of a history of speeds to the forecasted speed. The value of H will influence the conditional probabilities used to select the predicted α value. Recall that the predicted α value is used to find the predicted speed. Only recent past data is necessary in order to perform a prediction using non-linear time series. If H is too large, then the prediction model will slowly respond to changing traffic conditions because too much weight is being placed on the early history of speeds in the time series. At the same time, an H value that is too small will prompt the prediction scheme to overreact to the fluctuations within the traffic stream. Preliminary testing has shown that $H = 30$ (2 hr 30 min) past α values provide a suitable population of α values to generate predictions.

The behavior of the speed prediction model at a discrete loop detector station is characterized in Figure 3. These speed profiles are associated with station 23 in the westbound direction of the I-4 Central Corridor during the morning peak period. The predicted speed profile is generated using $H = 30$ past α values. This loop detector station becomes congested when the speed falls below 35 mph. Note that the predicted speed profile matches very closely with the actual speed profile during the non-congested time slices prior to 7:00 am. The close match results from small fluctuations in the speed values during the prior time slices. At approximately 7:00 am, a sharp drop in speed occurs that marks the beginning of the congestion period. It is evident that the prediction profile is lagging behind the actual speed profile. This lag is attributed to the fact that the prediction scheme is still placing enough weight on the earlier time slices to reduce the effect of the rapid drop in speed. The prediction profile then self-corrects during the congested period. Towards the end of the congestion period (approximately 9:00 am), the actual speeds increase rapidly as the level of service on the system improves. Once again, the prediction profile lags behind the actual speed profile by under predicting the true speed. The under predictions stem from the influence of the history of congested time slices. Note at the end of the study period that the prediction profile does not begin to follow the actual speed profile until the last three time slices. The model requires several uniform time slices of non-congested speeds to stabilize due to the fluctuations experienced at the end of the congestion period.

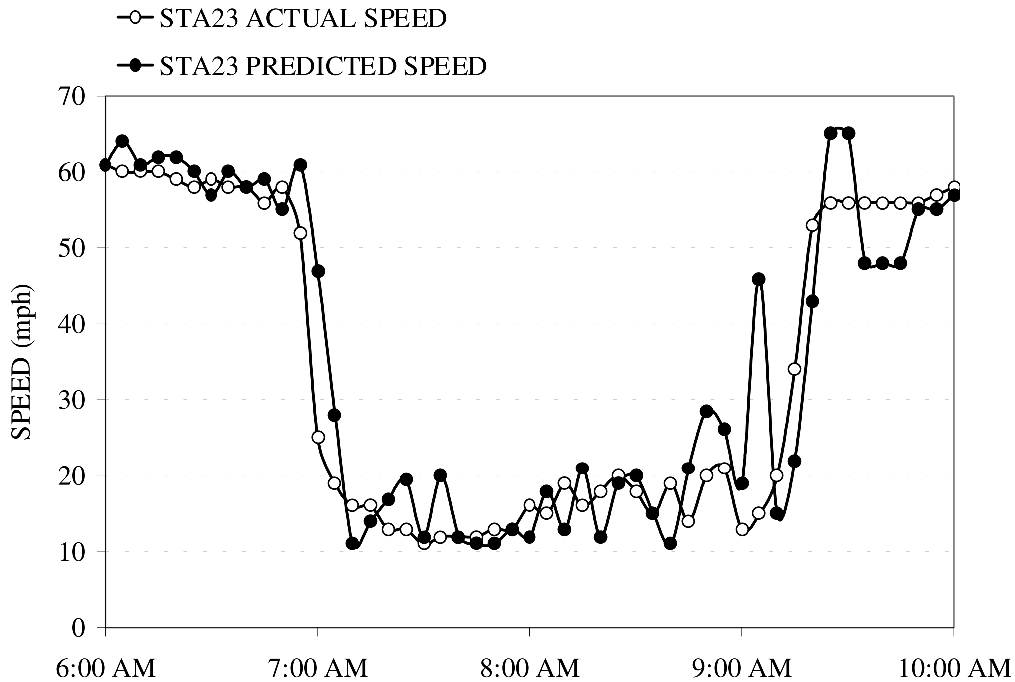


Figure 3: Speed Profiles for Station 23 (02/09/93, WB, H = 30)

Many insights are gained with statistical analysis of the prediction results through box plots. Figure 4 is a box plot analysis performed on two sets of three contiguous stations along the I-4 Central Corridor for predictions on speed data collected on 02/09/93. Stations 1-3 are downstream of the bottleneck, so these detectors do not experience congestion characterized by speeds less than 35 mph. The bottleneck for incident free days is located at station 18, hence stations 18-20 exhibit congested conditions. The solid dividers at the center of each box represent the median of the data. Note from Figure 4 that the median error in prediction is approximately zero for each station. The boxes represent 50% of the data points captured, and Figure 4 reveals that the boxes are all condensed. So, the plurality of the instantaneous errors is small. Figure 4 demonstrates that the errors are symmetric, evidenced by the nearly equidistant tails on the box plots. Therefore, the non-linear time series operation proves to be unbiased. A final note regarding Figure 4 is that the lines outside of the tailed boxes are outliers, or at least three standard deviations away from the median. The sensitivity of the single variable prediction model to abrupt changes in input data is manifested in Figure 5 where the actual speed (input data) is plotted against the instantaneous percent error for the speed predictions at station 23 on 2/9/93.

The largest speed prediction errors occur when the actual speed changes significantly. These sudden drops or increases occur at approximately 7:00 am and 9:00 am. Bounded by these times are congested traffic conditions exhibited by the actual speed falling below 35 mph. During the congested time slices found between the boundaries, there is less variation in actual speed. As a result, the errors in speed predictions are considerably smaller around 8:00 am. Hence, the model performs worst at the temporal boundaries to congestion, while it performs qualitatively well during the congested time slices of the peak period. Similar results are found on other stations tested.

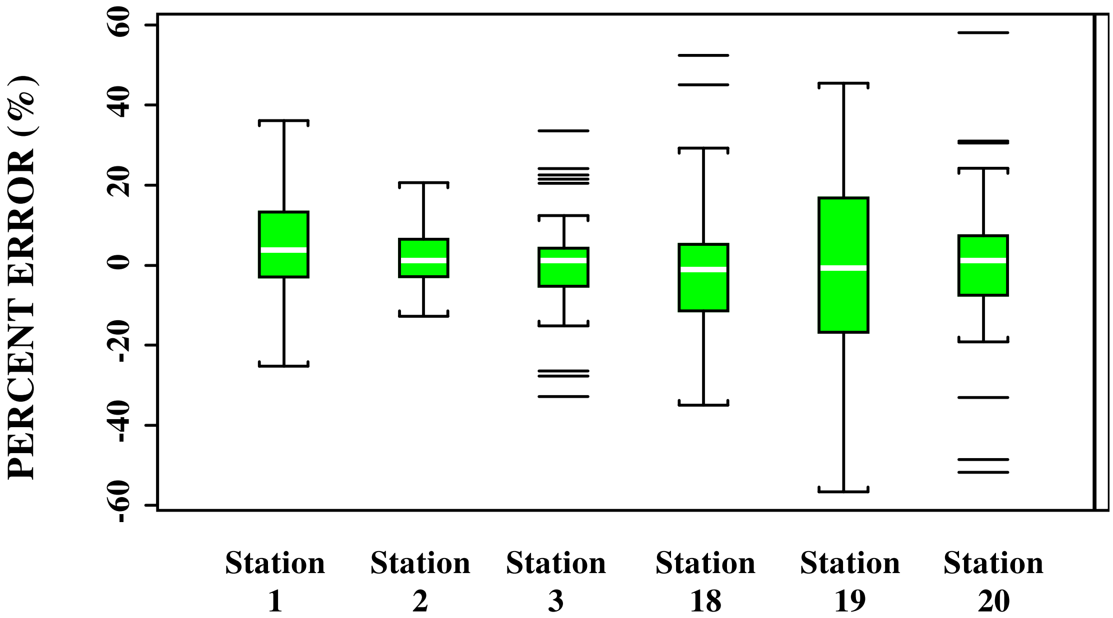


Figure 4: Box Plot Analysis of Speed Prediction Errors

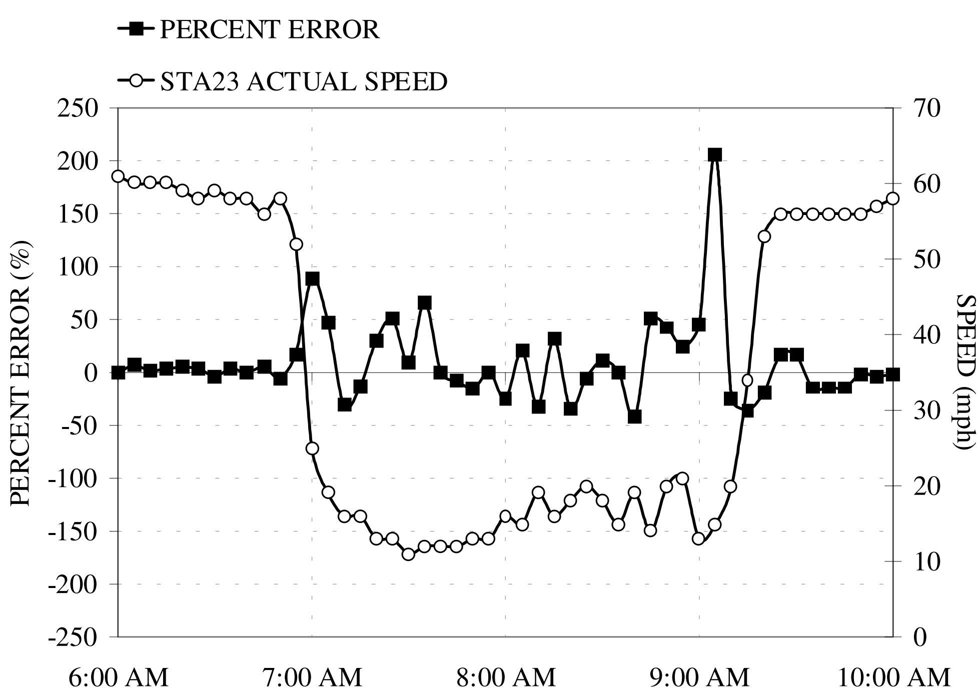


Figure 5: Sensitivity of Speed Prediction Errors to Actual Speeds at Station 23

2.4.3 Speed Prediction across the Study Section

The next stage of complexity in prediction modeling is to consider the entire system of loop detectors along the study section. This is initiated by examining the speeds that are predicted at each loop detector station for the entire study period. Therefore, a spatial dimension has been added to the temporal analysis. Predictions over space are far more interesting than individual point estimates. Route guidance and trip planning decisions are made using spatial considerations. For instance, the driver will consider the performance of competing networks between the origin and destination of travel, and select the network with the least resistance, i.e. congestion. The performance of a network is not measured by a point estimate. It is measured across the network, or spatially. The intelligent infrastructure of loop detectors will act as the spatial approximation for the I-4 network. The approximation comes from the use of a collection of point estimates as a seamless monitoring system.

Speed predictions are generated for twenty incident free days across the westbound direction of the I-4 Central Corridor for the morning peak period (6:00 am to 10:00 am) every five minutes using 30 past α values. Two performance measures are examined for predictions with spatial and temporal dimensions. The average predicted spatial speed is determined for each time slice. The average spatial speed for a time slice is obtained by averaging the speeds predicted for stations 1-25 at each time slice. For example, the average spatial speed for 6:00 am would be the average of all speeds that are predicted at each loop detector station at 6:00 am. Therefore, the average spatial speed can be described as the corridor speed. In addition, the average temporal speed is determined for each station. The average temporal speed is measured as the average of all speeds predicted for a station during the morning peak period. So, the average temporal speed for station 25 would be the average of all speeds predicted for the loop detectors at station 25 from 6:00 am to 10:00 am. Building on earlier findings of the algorithm's affinity for symmetry, the hypothesis that the errors in speed predictions would cancel out each other temporally and spatially is tested.

In order to access the corridor performance of speed predictions, a comparison of actual and predicted corridor speeds is necessary. Figure 6 juxtaposes the actual and predicted corridor speed profiles for the westbound morning peak period on 02/09/93, a typical day. The most striking characteristic of the plot is the likeness of the corridor speed profiles. The predicted corridor speed remains in close proximity to the actual profile throughout the study period. Note that the largest deviations can be found near the temporal congestion boundaries at approximately 7:00 am and 9:00 am. Given the results of Figure 6, a negligible error would be expected in the corridor speed predictions.

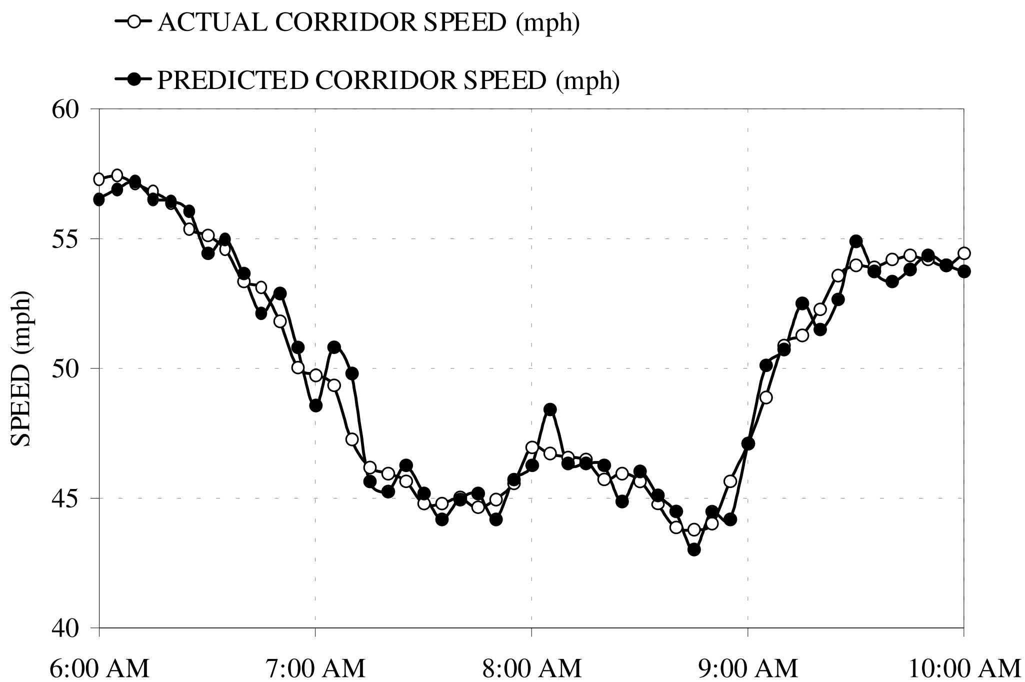


Figure 6: Actual and Predicted Corridor Speeds (02/09/93, WB, H = 30)

In order to quantify and visually depict the corridor speed errors, Figure 7 is constructed below. This plot details the average spatial error for speed predictions on a typical day (02/09/93) that is tested. Note that all spatial speed errors are within ±10%, and 96% of all time slices contained less than 5% error. Hence, the hypothesis that the corridor speed errors cancel spatially is confirmed. The implication is that if you are attempting to predict a corridor speed, then the error in that prediction would be negligible using this prediction model. These results are very encouraging for the application of the prediction model as a spatial analysis tool.

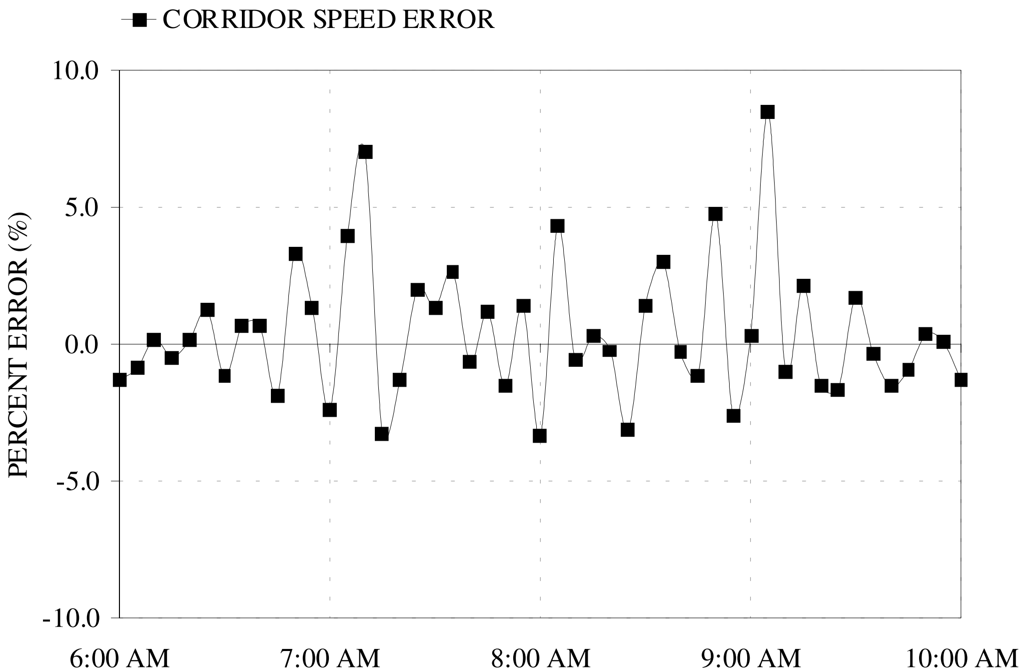


Figure 7 Corridor Speed Error (02/09/93, WB, H = 30)

The average temporal errors in speed predictions for the westbound morning peak direction on 02/09/93 are plotted in Figure 8. The impetus behind this investigation is to examine the performance of speed predictions over time. From this figure, all 25 loop detector stations report temporal speed errors that are less than 10%. The temporal errors with the greatest magnitude occur between stations 25 and 22. These stations are at the beginning of the study section, and experience heavy congestion relative to the other stations in the corridor. Larger temporal errors are expected at these stations since they experience more fluctuations in speed with the onset and relief of congestion. With the results displayed in Figure 8, it can be concluded that the prediction errors cancel temporally along the time slices during the morning peak period (6:00 am to 10:00 am).

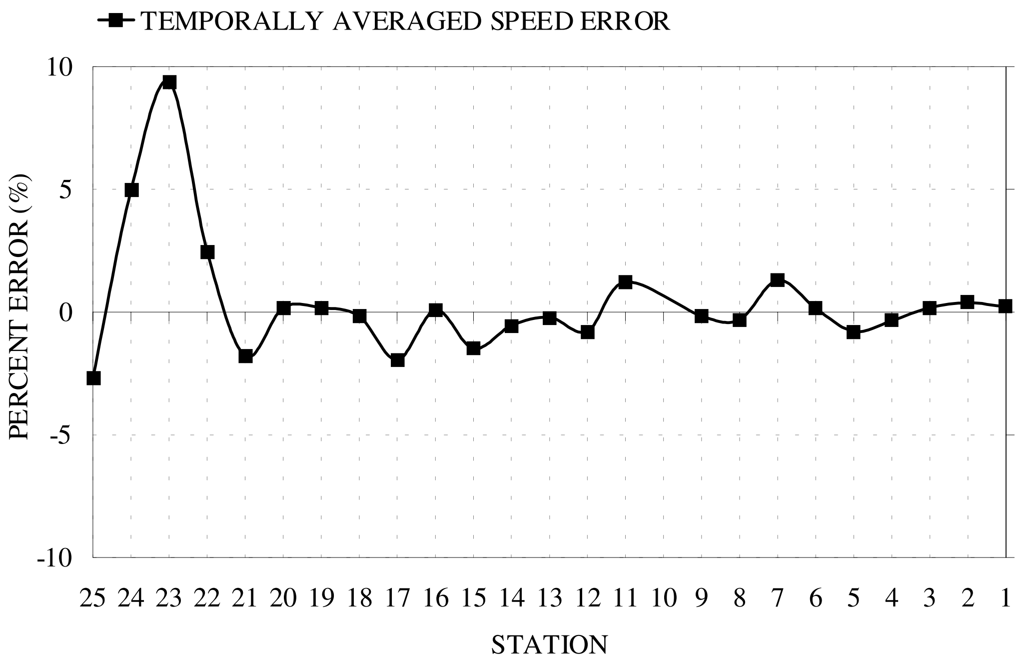


Figure 8 Temporal Speed Error (02/09/93, WB, $H = 30$)

The implication of the temporal errors negating each other over time is that it is desirable to predict a parameter over a study period with multiple time slices. In other words, a prediction horizon composed of several time steps produces favorable results.

2.4.4 Travel Time Prediction across the Study Section

The parameter of interest in this investigation is the travel time across the I-4 Central Corridor. This is the spatial parameter that will be used by motorists to make route choice decisions. In addition, predicted travel times are the most intelligent forecasts available for route guidance media such as CMS, HAR, car PCs, and onboard information systems. While the motorist can garner information from a corridor speed prediction, the travel time forecast is far more useful because it allows the user to translate the information directly into their trip schedules.

The travel time predictions are derived directly from the speed predictions. A subsection is defined by looking at two consecutive loop detector stations that provide point speed estimates. Figure 9 displays the first subsection in the westbound direction of the I-4 Central Corridor, bounded by stations 25 and 24.

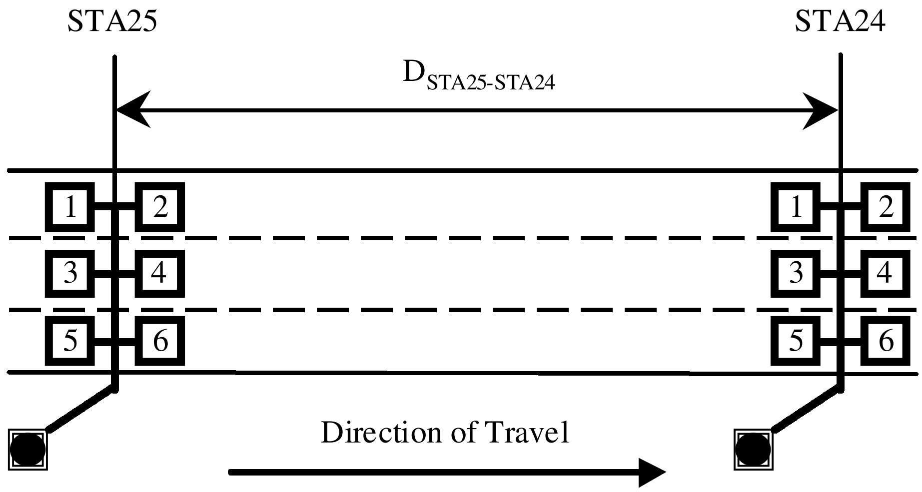


Figure 9: Station 25 to Station 24 Subsection

Given that the loop detectors provide point estimates of speeds on freeway segments, it is reasonable to assume that the speed changes linearly between two stations. As such, travel time predictions are derived from the speed predictions using the following methodology: the travel time between two consecutive stations is the average of the travel times calculated from speeds at these two consecutive stations. For example, the following formula is used to calculate the travel times between stations 25 and 24.

$$TT_{STA\,25-STA\,24} = \frac{1}{2}\left(\frac{DISTANCE_{\;STA\,25-STA\,24}}{SPEED_{\;STA\,25}} + \frac{DISTANCE_{\;STA\,25-STA\,24}}{SPEED_{\;STA\,24}}\right) \qquad [1]$$

Given equation 15, travel times can be predicted for any pair of loop detector stations. The loop detector stations along the I-4 Central Corridor are located near the exits to arterials in the adjacent grid network. Thus, origin-destination travel time pairs can be forecasted for any of the entry and exit ramp combinations. Note that if all of the subsection travel times are summed, then the travel time for the entire corridor is found. Equation 16 summarizes this operation.

$$TT_{STA25-STA1} = \sum_{i=1}^{24}\left(TT_{STA(i+1)-STA(i)}\right) \qquad [2]$$

The corridor travel time is used as the predicted traffic parameter of interest throughout the remainder of this analysis. As before, corridor profiles for a typical day reveal the behavior of the single variable non-linear prediction model. The corridor profiles for the actual corridor travel time and the predicted corridor travel time are described in Figure 10. The plot clearly shows that the predicted travel times closely follow the propagation of the actual travel times over the entire morning peak period. For the non-congested time slices prior to 7:00 am and following 9:00 am, the predictions match precisely. Throughout the congested region, the travel time predictions oscillate closely around the actual corridor travel time values.

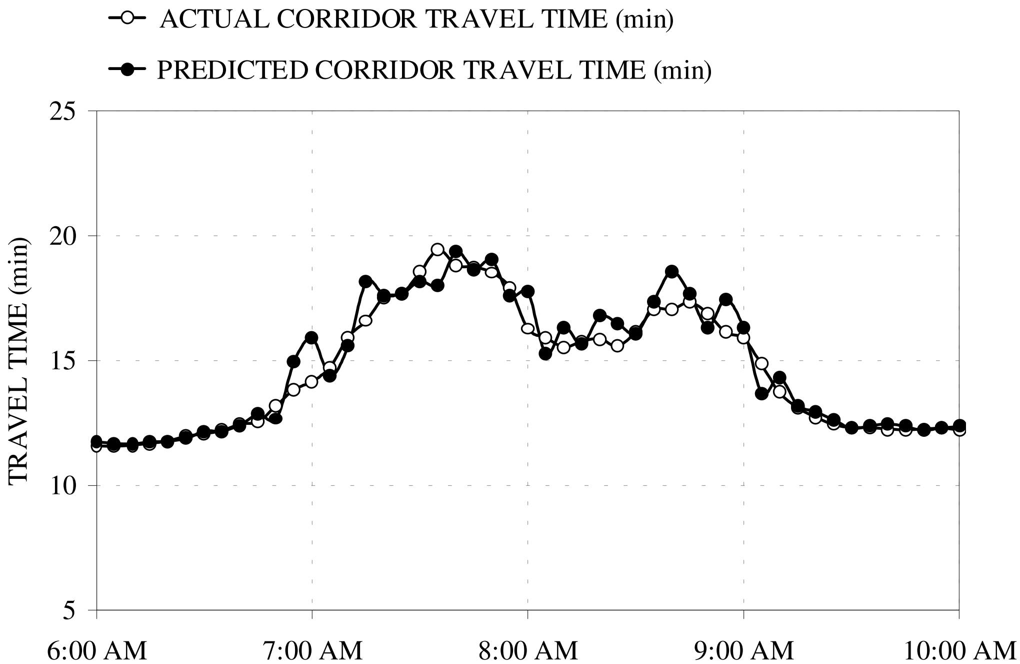


Figure 10: Corridor Travel Time Profiles (02/09/93, WB, *H* = 30)

As in the case for speed predictions, the condition that the spatial errors in travel time cancel is tested. Figure 11 shows that 98% of all predictions of corridor travel times fell within 10% of the actual travel times. Also note the dashed curve on the plot, which represents the average corridor travel time error for the morning peak period. In other words, if all of the corridor travel time errors for the peak period are examined, then this quantity is the average of them. From the plot, the value of the average corridor travel time error is 1.3%. Since this value is very close to zero, the travel time predictions are unbiased. So, the model tended not to consistently over or under-predict the corridor travel times. This demonstrates that the model remained unbiased in the conversion from point speed estimates to spatial travel time forecasts.

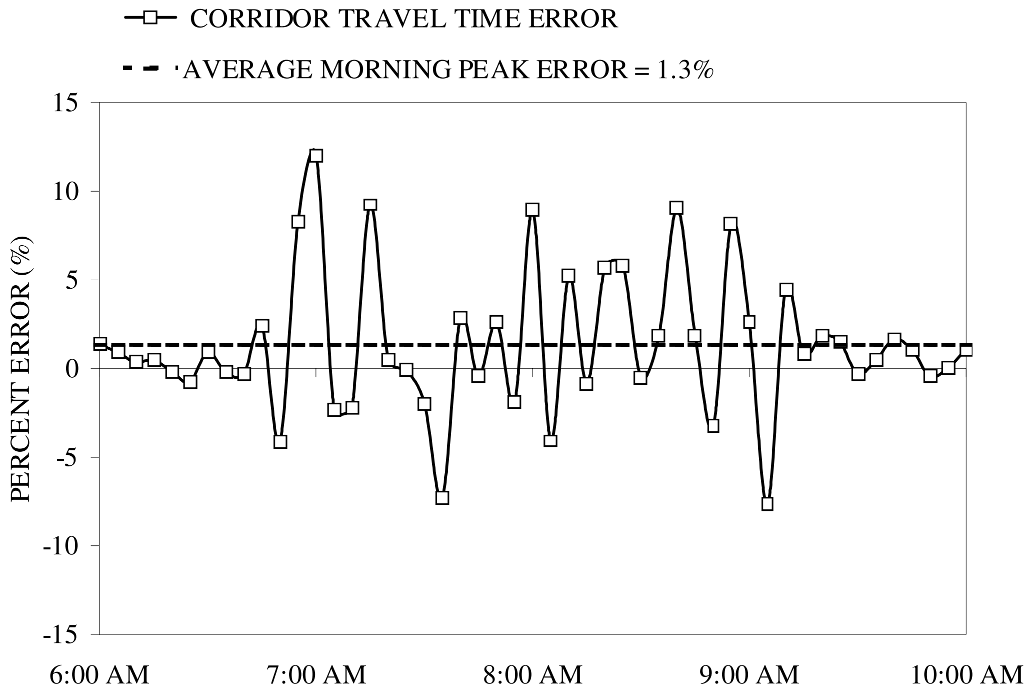


Figure 11: Corridor Travel Time Errors (02/09/93, WB, *H* = 30)

In addition, the travel time errors with the most magnitude occur at the temporal boundaries of congestion. This trend, which is also found in speed errors at discrete stations, is displayed in Figure 12. Here, the actual corridor speed is superimposed over the corridor travel time errors. Note that the largest corridor travel time prediction errors correspond to where the rate change in corridor speed has the greatest magnitude. These changes in corridor speed occur at the temporal congestion boundaries, or the times when congestion sets in and when congestion is relieved. In order to improve the single variable prediction model, it is desirable to find ways to reduce this sensitivity.

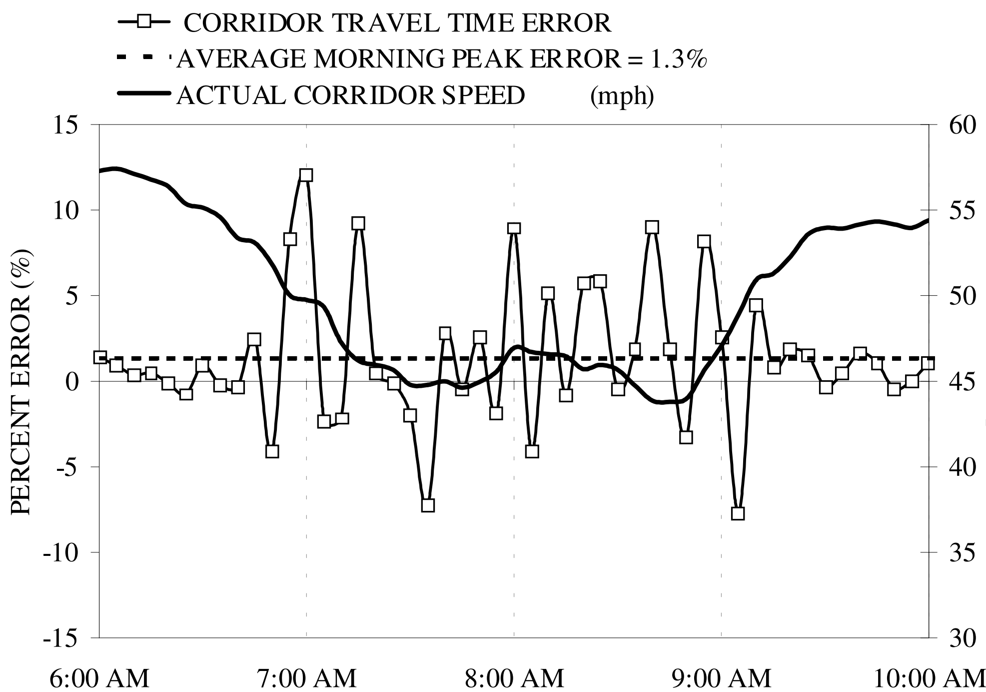


Figure 12: Corridor Travel Time Sensitivity to Actual Speeds (02/09/93, WB, *H* = 30)

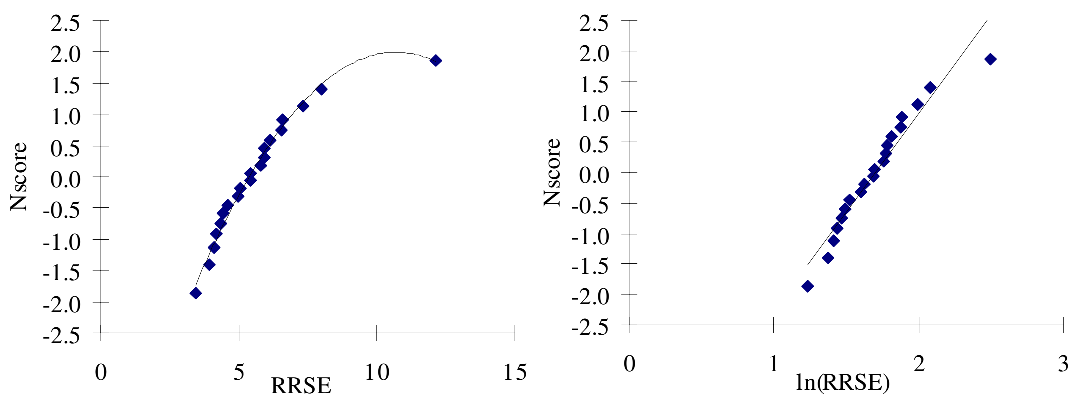


Figure 13: Normal Probability Plots of RRSE and ln(RRSE) for Case (a) Data

2.4.5 Summary

In this section, we explained the development and testing procedures used in the single variable prediction model. An examination of predicted speeds at discrete loop detector stations revealed that errors in speed predictions were unbiased, and that the model is most sensitive at the temporal congestion boundaries. Examination of corridor speeds demonstrated that the errors in the predictions cancelled over space and time. Corridor travel time predictions using the single variable prediction model closely followed the trend of actual corridor travel times throughout the study period. The single variable prediction model was calibrated through the application of two refinements: a threshold on the minimum predicted speed, and smoothing the 30-second input data with decay factors from statistical distributions. With the aid of the testing procedures in SAS®, a clear winner was selected among the combination of refinements. The combination of a 10 mph threshold and uniform smoothing of the input data produced the best performance.

2.5 EFFECT OF DECAY FACTORS

The objective of this task is to explore the effect of applying different decay factors on the performance of the previously developed prediction model. The main purpose of this task is to calibrate the prediction model by adjusting the factors that are likely to affect its performance. Given the promising results attained thus far, the development of a calibrated model for single variable prediction is warranted. Two classes of refinements are tested in this discourse. The first calibration technique attempts to remove noise elements from the raw 30-second input data through the use of decay factors. Applying a threshold on the minimum speed predictions permitted composes the second class of refinements. With extensive testing of these calibration techniques, a final calibrated model is presented for corridor travel time prediction using a single variable in the non-linear time series prediction methodology.

2.5.1 Smoothing Input Data

The loop detector stations along the I-4 Central Corridor have a resolution of 30 seconds. Hence, they provide speed values at 30-second intervals. All of the prediction schemes utilize 5-minute prediction horizons since there is a little practical value in a 30-second prediction. If raw 5-minute speed values are obtained through the averaging of ten 30-second speed values, then noisy data is generated. Noisy data produces fluctuating trends that are difficult to predict. As a result, smoothing the input data with decay factors is tested. The smoothing takes place by replacing each 30-second speed value with a weighted 30-second speed value. The weights, or decay factors, are determined from three statistical distributions: a uniform distribution, an exponential distribution, and a half-normal distribution. The uniform distribution places equal weight on each of the 10 speed values used to calculate the weighted 30-second speed values. By contrast, the exponential and half-normal distributions place more emphasis on the more recent 30-second speed values.

Table 2 displays the decay factors that are used to produce the weighted 30-second data. These decay factors are used in conjunction with equation 1 to produce the weighted speed values. If t is the current time slice and the weighted speed is generated from i+1 30-second speed values, then the decay factor for each 30-second speed is δ_i.

$$s'(t) = \sum_{i=0}^{9} \delta_i \cdot s(t-i) \qquad [3]$$

Table 2: Decay Factors for Smoothing Input Data

	Decay Factors		
i	Uniform	Exponential	Half-Normal
0	0.1	0.27276	0.26041
1	0.1	0.20207	0.22752
2	0.1	0.14969	0.18168
3	0.1	0.11090	0.13259
4	0.1	0.08215	0.08843
5	0.1	0.06086	0.05391
6	0.1	0.04509	0.03003
7	0.1	0.03340	0.01529
8	0.1	0.02474	0.00712
9	0.1	0.01833	0.00303

These decay factors are moving weights; they are applied to each 30-second time slice in the time series. Therefore, all 30-second speed data will be replaced by a 30-second speed value weighted with one of the above distributions. The 5-minute speeds used in the prediction schemes are determined by taking an average of 10 weighted 30-second speed points.

2.5.2 Thresholds

The second refinement to test is setting an appropriate threshold for the minimum predicted speed. The non-linear time series model utilizing the local Hölder exponent, α, has the mathematical capability to produce speeds less than 5 mph. However, a five-minute average speed less than 5 mph is unreasonable on incident free days on the I-4 Central Corridor. For instance, in the 02/09/93 LOVATS© database, the lowest actual speed in a five-minute time slice is 8 mph. As a result, two thresholds for the minimum predicted speed are tested: a 5-mph threshold, and a 10-mph threshold. The minimum threshold speed calibration is applied in the following manner: any predicted speed less than the threshold speed is replaced with the average of the predicted speeds at the upstream and downstream stations during the same time slice. If the loop detector station is located at the endpoints of the study section, then any predicted speeds less than the threshold speed are replaced with the predicted speed at the downstream or upstream station for the beginning and end points of the study section respectively. Note that this methodology preserves the on-line characteristics of the prediction approach since only data from the current time slice is used to supplant violations of the threshold rule.

2.5.3 Calibrated Model

The calibrated model is determined from the six possible combinations of smoothing methods and thresholds. These combinations are elucidated in Table 3.

Table 3: Calibrated Model Cases for Single Variable Prediction

	Smoothing Method		
Threshold	Uniform	Exponential	Half-Normal
10-mph	case (a)	case (b)	case (c)
5-mph	case (d)	case (e)	case (f)

For simplicity of identification, these cases are given the letter designations of case "a" through case "f." In order to compare these cases, a statistical yardstick for time series analysis is needed. An appropriate measure is the Root Relative Square Error (RRSE). This measure is typically used in time series analysis. It has the property of penalizing large prediction errors; thereby providing an accurate assessment of the model's performance, see Harvey (1992). The RRSE has the following form:

$$RRSE = \frac{\sqrt{\sum_{t=1}^{48} (\hat{x}_t - x_t)^2}}{\sqrt{\sum_{t=1}^{48} (x_t)^2}} \qquad [4]$$

Where $\hat{x}_t$ is the predicted parameter at time slice *t*, and x_t is the actual value of the parameter at time slice *t*. There are forty-eight (48) 5-minute time slices in the four-hour peak period tested, so the terms are summed over 48 elements.

The RRSE calculations for the corridor travel times corresponding to each case are presented in Table 4. The test days are arranged by weekday, and the average and standard deviation are presented for each case over the twenty days tested. When the cases are compared via the average RRSE for each case, several trends are noted. First of all, the cases with the 10 mph threshold (cases (a) through (c)) have smaller average RRSE values than those cases with the 5 mph threshold (cases (d) through (f)). When cases (a) through (c) are compared, case (b) has the smallest corridor travel time RRSE for five of the twenty days tested: 01/22/93, 09/03/93, 10/07/93, 01/27/93, and 03/23/94. Case (c) has the smallest corridor travel time RRSE on one day (08/09/93). For the remaining 14 days, case (a) has the smallest corridor travel time RRSE. In Figure 14, the average corridor travel time RRSE values for the six cases are plotted. Once again, it is readily seen that case (a), which is calibrated with uniform smoothing and a 10 mph threshold, has the smallest average RRSE.

Table 4: RRSE (%) for Single Variable Prediction Cases

		CASES					
		(a)	(b)	(c)	(d)	(e)	(f)
TEST DAY	WEEKDAY	Uniform Smoothing and 16 kph (10 mph) Threshold	Exponential Smoothing and 16 kph (10 mph) Threshold	Half-Normal Smoothing and 16 kph (10 mph) Threshold	Uniform Smoothing and 8 kph (5 mph) Threshold	Exponential Smoothing and 8 kph (5 mph) Threshold	Half-Normal Smoothing and 8 kph (5 mph) Threshold
01/22/93	Friday	5.439	4.889	5.040	6.019	6.048	7.403
09/03/93	Friday	3.427	3.183	3.651	3.427	3.482	3.651
10/01/93	Friday	4.115	4.607	4.906	5.373	7.845	7.390
11/12/93	Friday	4.589	6.889	6.773	10.061	10.725	9.506
01/25/93	Monday	4.204	5.325	4.870	7.059	6.356	5.925
08/09/93	Monday	6.138	6.183	3.951	6.391	10.399	7.269
08/16/93	Monday	3.944	5.259	3.951	6.399	6.718	7.269
09/13/93	Monday	8.000	9.389	9.630	10.000	12.489	12.649
01/21/93	Thursday	5.806	7.424	6.927	8.010	9.257	8.977
02/04/93	Thursday	5.915	7.122	6.354	8.125	8.456	9.387
10/07/93	Thursday	6.578	6.183	7.398	9.280	10.399	10.620
04/14/94	Thursday	5.068	6.113	6.661	6.188	8.880	10.096
01/19/93	Tuesday	5.416	6.032	6.868	8.566	7.928	8.270
02/09/93	Tuesday	4.454	5.198	5.597	6.816	7.503	7.863
08/03/93	Tuesday	4.358	4.828	4.513	6.162	5.837	7.449
10/05/93	Tuesday	4.972	5.487	6.392	6.548	8.365	9.325
01/27/93	Wednesday	5.943	4.570	4.871	8.845	8.179	8.538
02/03/93	Wednesday	6.552	8.975	8.574	14.487	16.549	16.835
08/04/93	Wednesday	7.349	7.654	7.352	14.854	13.295	13.767
03/23/94	Wednesday	12.154	10.077	10.457	13.192	10.220	11.252
AVERAGE		5.721	6.269	6.237	8.290	8.946	9.172
STD. DEV.		1.921	1.760	1.867	3.019	2.933	2.901

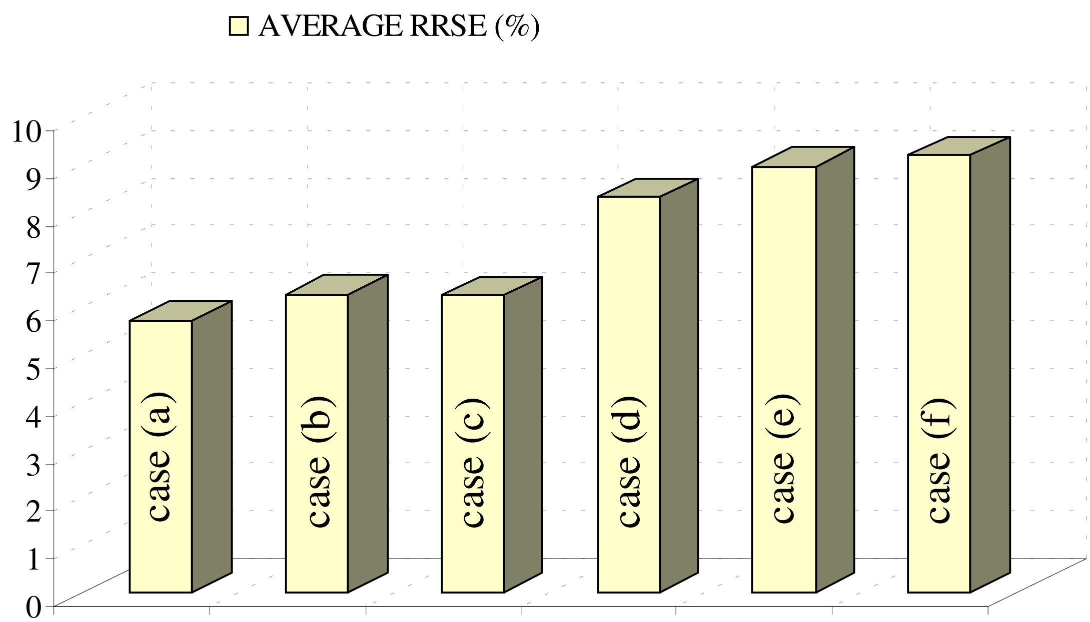


Figure 14: Average RRSE (%) for Single Variable Prediction Cases

In order to determine a winner among the six cases, a comprehensive statistical analysis is performed using the SAS® software. The details of the three statistical procedures used to determine the winning case are presented in Table 5. The first step in the determination of the winner is the ANOVA procedure that is performed using PROC GLM in SAS®. PROC GLM is a procedure that analyzes General Linear Models such as regression, analysis of variance (ANOVA), analysis of covariance, multivariate analysis of variance, and partial correlation, see *SAS/STAT User's Guide* (1990). ANOVA techniques are generally used for data following a normal distribution. However, the RRSE measure follows a chi-square distribution. In order to normalize the RRSE data, a transformation must be applied. The appropriate transformation for this data is to take the natural log of the response variable, or RRSE. This transformation tends to normalize the data since it “pulls” the observations in the tail of the distribution back toward the mean, see Mendenhall and Sincich (1992). Figure 15 contrasts the normal probability plot of the RRSE data for case (a) with the normal probability plot of the ln(RRSE) data for case (a). A clear curvilinear trend is shown in the first plot in the figure in which the raw RRSE data is used. However, the trend becomes linear after the application of the transformation to the RRSE data in the adjacent plot. In a normal probability plot, a linear trend is indicative of normality of the data set.

Table 5: Determination of Single Variable Prediction Calibrated Case

Step 1: SAS ANOVA

Source	DF	Type I SS	Mean Square	F Value	Pr > F	SIGNIFICANT @ α=.05
THRE	1	3.8433	3.8433	53.46	0.0001	YES
METHOD	2	0.2456	0.1228	1.71	0.1870	NO
THRE*METHOD	2	0.0079	0.0040	0.06	0.9463	NO
DOW	4	4.4280	1.1070	15.4	0.0001	YES
THRE*DOW	4	0.1094	0.0273	0.38	0.8221	NO
METHOD*DOW	8	0.2597	0.0325	0.45	0.8865	NO
THRE*METHOD*DOW	8	0.0211	0.0026	0.04	1.0000	NO

Step 2: Adjusted ANOVA (Combine Experimental Error)

Source	DF	Type I SS	Mean Square	F Value	Fcrit @ α=.05	SIGNIFICANT @ α=.05
THRE	1	3.8433	3.8433	196.9986	4.35	YES
METHOD	2	0.2456	0.1228	6.2953	3.49	YES
THRE*METHOD	2	0.0079	0.0040	0.2037	3.49	NO
DOW	4	4.4280	1.1070	56.7415	2.87	YES
THRE*DOW+METHOD*DOW +THRE*METHOD*DOW	20	0.3902	0.0195			

Step 3: Contrast Test (Contrast Uniform with Average of Exponential and Half-Normal)

Contrast	DF	Contrast SS	Mean Square	F Value	Fcrit @ α=.05	SIGNIFICANT @ α=.05
uniform v.s. others	1	0.2437	0.2437	12.4932	4.35	YES

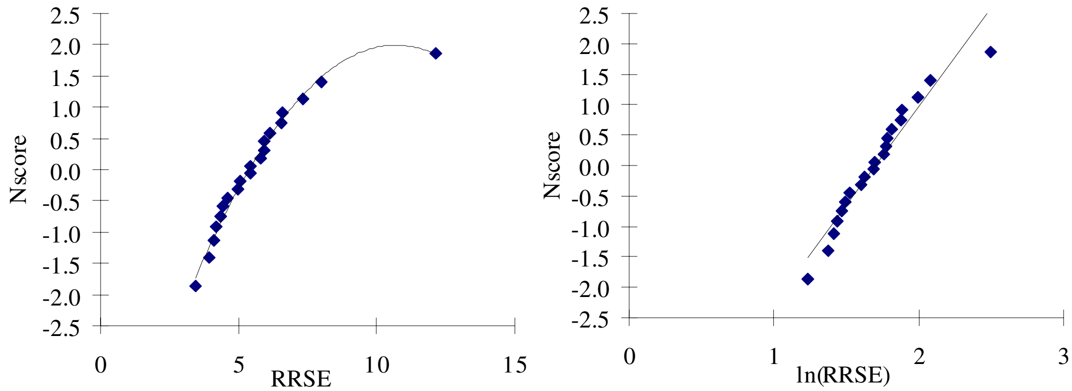


Figure 15: Normal Probability Plots of RRSE and ln(RRSE) for Case (a) Data

In step one of Table 5, ANOVA is performed on the ln(RRSE) data for all of the single variable prediction cases using SAS®. Three classes are included in the model: (1) THRE: the threshold on predictions; (2) METHOD: the smoothing method applied to the input data; and (3) DOW: the day of the week of the peak period tested. THRE has two levels (5 mph and 10 mph), METHOD has three levels (Uniform, Exponential, and Half-Normal), and DOW has five levels (Monday, Tuesday, Wednesday, Thursday, Friday). The interaction terms between the classes are separated in the model. Note that the only two significant variables in the model are THRE and DOW. Since threshold is significant, it is concluded that there is a significant difference between the 5 mph and 10 mph threshold. Thus, the winning threshold is the 10 mph threshold. DOW is also significant in step one, leading to the conclusion that a difference exists in prediction performance for the different weekdays.

DOW is an uncontrollable factor in the model. Hence, it contributes to the experimental error in the design. As a result, all of the interaction terms that involve DOW are included in one experimental error term in the adjusted ANOVA found in step 2 of Table 5. METHOD is a significant factor in this model since its F-value exceeds the critical F value for a design with a 0.05 level of significance, 2 degrees of freedom in the numerator of the F statistic, and 20 degrees of freedom in the denominator of the F statistic. As a result, it can be concluded that there is a difference in the performance of the prediction model due to the smoothing method selected.

The final step in the selection of the calibrated model is the contrast procedure elucidated in step 3 of Table 5. The CONTRAST statement of SAS® provides a mechanism for obtaining custom hypothesis tests, see *SAS/STAT User's Guide* (1990). In the hypothesis test of step 3, ln(RRSE) for the uniform smoothing method is contrasted with the average of the ln(RRSE) for the exponential and half-normal smoothing methods. The average of these latter measures is used in the test because it is assumed that the uniform smoothing method differs qualitatively the same as the other smoothing methods. As seen in Table 5, the F value for the uniform smoothing method exceeded the critical F value for a design with a 0.05 level of significance, 1 degree of freedom in the numerator of the F statistic, and 20 degrees of freedom in the denominator of the F statistic. The 20 degrees of freedom are associated with the experimental error calculated in step 2 of Table 5. As a result, a statistically significant difference is detected between the uniform smoothing method and the average of the other smoothing methods. Given the results of the statistical tests discussed above, the calibrated single variable prediction model is case (a), which utilizes a 10 mph threshold and uniform smoothing of the input data.

Recall from the analysis of Table 5 that a difference in prediction performance was detected for the different weekdays. Now that a calibrated single variable prediction case has been selected, an estimate test will be performed on the case (a) data to ascertain patterns in prediction performance. The ESTIMATE statement in SAS® is used to estimate linear functions of the parameters by multiplying the class variable by an estimate vector, see *SAS/STAT User's Guide* (1990). In essence, estimates are the averages of the differences of the ln(RRSE) between the pairs, or a pairwise t-test. Table 6 details the steps in the estimate test. Step 1 consists of an ANOVA test on a model where the day of the week (DOW) is the only parameter in the ln(RRSE) model. This test affirms that the weekday is significant to the model. The estimate calculations follow in step 2 of Table 6 to determine if differences exist between the boundary days of the week (Monday and Friday) and the middle weekdays (Tuesday, Wednesday, Thursday) as well as all of the unique combinations of weekday pairs. Only three significant cases are detected: Monday vs. Wednesday (estimate = -0.36301), Tuesday vs. Wednesday (estimate = -0.47380), and Wednesday vs. Friday (estimate = 0.57266). In all of these cases, the estimate reveals that prediction performance on Wednesdays is below that of Monday, Tuesday, and Friday. Hence, Wednesdays provide the most difficult day to predict corridor travel times using the calibrated single variable prediction model. This occurs because there is more noise in the actual speed data reported by the loop detector stations. The noise is attributed to the absence of a well-defined congestion region spanning several time slices. In other words, traffic loads are such that they exceed the capacity of the roadway for a short duration, causing sharp changes in the speed profiles.

Table 6: Weekday Prediction Performance Using the Estimate Test

Step 1: SAS ANOVA

Dependent Variable: LGRRSE

Source	DF	Type I SS	Mean Square	F Value	Pr > F	SIGNIFICANT @ α=.05
DOW	4	0.76799845	0.19199961	3.54	0.0317	YES

Step 2: ESTIMATE Test

Parameter	Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate	SIGNIFICANT @ α=.05
MF v.s. TWR	-0.2173027	-2.04	0.0588	0.1627606	NO
M v.s. F	0.20964774	1.27	0.2223	0.16464216	NO
M v.s. T	0.11079422	0.67	0.5112	0.16464216	NO
M v.s. W	-0.3630087	-2.2	0.0435	0.16464216	YES
M v.s. R	-0.085222	-0.52	0.6123	0.16464216	NO
T v.s. W	-0.4738029	-2.88	0.0115	0.16464216	YES
T v.s. R	-0.1960162	-1.19	0.2523	0.16464216	NO
T v.s. F	0.09885352	0.6	0.5572	0.16464216	NO
W v.s. R	0.27778665	1.69	0.1122	0.16464216	NO
W v.s. F	0.57265639	3.48	0.0034	0.16464216	YES
R v.s. F	0.29486974	1.79	0.0935	0.16464216	NO

2.6 EFFECT OF ADDITIONAL TRAFFIC VARIABLES

This task investigates the effect of using additional traffic variables such as lane occupancy in addition to speed to improve the performance of the prediction model. The loop detector stations on the I-4 Central Corridor provide the parameters of speed, time lane occupancy, and volume. Hence, the operator has three sources of information to judge prevailing traffic conditions. The relevance of these parameters to traffic prediction is tested. The first testing procedure involves the application of the non-linear time series model to the occupancy and volume time series independently, and comparison of prediction performance with the speed time series. The findings of this testing endeavor are then applied so that multivariable prediction schemes can be defined. These prediction schemes are divided into two classes to be defined later: the POST class and the PRE class. Finally, the prediction performances of the POST and PRE class schemes are compared against the performance of the calibrated single variable prediction model developed earlier. All comparisons are based upon the corridor travel time during the morning peak period of the westbound direction of the I-4 Central Corridor. In this section we will illustrate how the other traffic parameters can be incorporated into the traffic prediction models. Different schemes have been also suggested for testing the model's performance and are shown in this section.

2.6.1 Prediction of Lane Occupancy and Traffic Volume

Before multivariable prediction schemes can be developed, it is necessary to examine the prediction performance of the occupancy and volume time series. In other words, occupancy predictions are generated from occupancy data and volume predictions are generated from volume data. Recall that speed prediction performance was found to be sensitive to the magnitude of the fluctuations in the input data. If occupancy and volume data experience less fluctuation, then the prediction performance of these parameters will be more precise than speed predictions. In addition, the volume and occupancy data could be used to detect changes in traffic conditions since they would not experience the same degree of lagging found in speed predictions. This information could then be used to modify the speed predictions. On the other hand, prediction performance will suffer if there is more variation in these parameters; they will lag to an even greater extent in detecting changes in traffic conditions. In this case, multivariable prediction schemes would involve some combination of the time series data to produce a new time series with meaningful characteristics.

Figure 16 displays the actual and predicted occupancy profiles for station 23 on 02/09/93 in the westbound direction of the I-4 Central Corridor during the morning peak period. The occupancy data is smoothed with the uniform decay factors discussed before. The non-congested time slices (before 7:00 am and after 9:00 am) show that the predicted profile is oscillating around the actual profile with relative accuracy. During the congested period, however, the occupancy predictions never stabilize or track well with the actual profile. The large amplitudes in the predicted occupancy profile evidence this. These results are not encouraging for the use of occupancy data as a flag for changing traffic conditions. The volume profiles for station 23 on 02/09/93 are displayed in Figure 17. The volume data is also smoothed with the uniform decay factors discussed before.

The data points in the actual volume time series represent 5-minute averages of the uniformly smoothed 30-second volume data. It is important to note that this volume is for all three lanes on the mainline. The trends in the volume profiles are considerably different from those seen in the speed and occupancy profiles. The congestion region is not located as easily in this display. Also, the predicted volume profile is oscillating around the actual profile with relatively large amplitudes. This pattern is not indicative of a regime that can be used to flag changing traffic conditions for travel time prediction.

Table 7 quantifies the RRSE calculated for the parameters. The prediction performance of corridor speeds, occupancies, and volumes are compared for twenty incident free morning periods for the westbound direction of the I-4 Central Corridor.

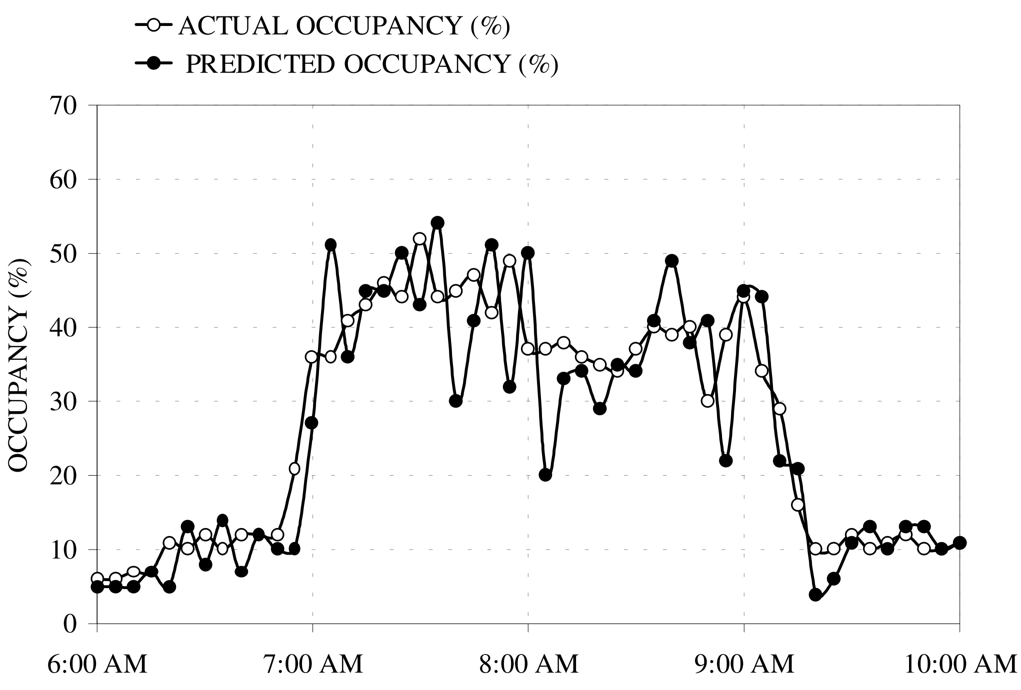


Figure 16: Occupancy Profiles for Station 23 (02/09/93, WB, *H* = 30)

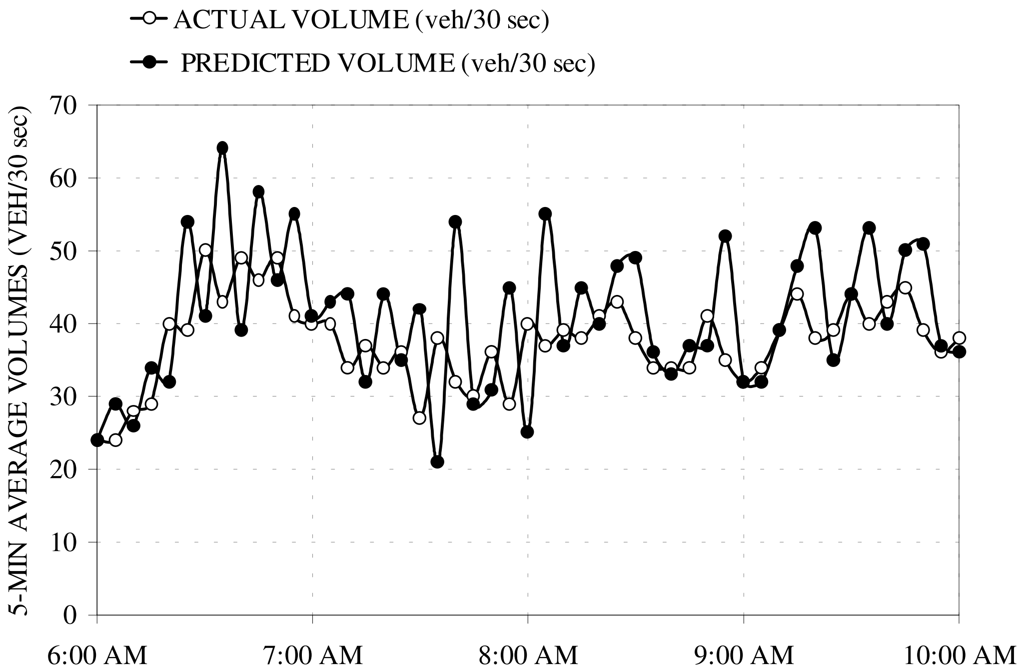


Figure 17: Volume Profiles for Station 23 (02/09/93, WB, $H = 30$)

Table 7: RRSE (%) for Corridor Parameters

TEST DAY	WEEKDAY	Corridor Speeds	Corridor Occupancies	Corridor Volumes
01/22/93	Friday	1.550	6.006	5.316
09/03/93	Friday	1.259	5.792	6.852
10/01/93	Friday	1.625	5.983	6.909
11/12/93	Friday	1.926	6.180	5.715
01/25/93	Monday	1.510	4.597	5.645
08/09/93	Monday	1.860	4.821	4.928
08/16/93	Monday	1.808	5.908	6.447
09/13/93	Monday	2.434	7.847	5.594
01/21/93	Thursday	2.340	5.845	5.683
02/04/93	Thursday	1.259	5.821	5.863
10/07/93	Thursday	1.770	5.654	6.177
04/14/94	Thursday	1.511	5.717	5.649
01/19/93	Tuesday	1.610	5.792	6.164
02/09/93	Tuesday	1.632	6.307	5.236
08/03/93	Tuesday	1.602	5.279	6.539
10/05/93	Tuesday	1.337	6.002	6.230
01/27/93	Wednesday	1.919	5.906	5.035
02/03/93	Wednesday	2.495	5.142	6.855
08/04/93	Wednesday	2.481	5.403	6.214
03/23/94	Wednesday	2.586	5.727	6.659
AVERAGE		1.826	5.786	5.986
STD. DEV.		0.426	0.650	0.612

The summary statistics at the bottom of the table reveal that the corridor occupancy and corridor volumes have poorer prediction performance and more variation than corridor speed predictions. As a result, occupancy and volume time series cannot be used as a reliable flag for changing traffic conditions. Multivariable prediction schemes, therefore, should seek to find a logical combination of the time series parameters.

2.6.2 *Multivariable Prediction Schemes*

The results shown above limit the schemes available for multivariable prediction. However, the information provided by occupancy and volume time series can be combined through traffic flow fundamental relationships to produce additional speed time series. The relationship between speed, time lane occupancy, and volume is derived below.

$$\bar{v} = \bar{l} \cdot \left(\frac{\bar{q}}{\bar{r}} \right) \qquad [5]$$

Where

$\bar{v}$ = The average speed

$\bar{l}$ = The average vehicle length

$\bar{q}$ = The average flow rate

$\bar{r}$ = The time lane occupancy

The speed time series derived with the above equation can be used independently to generate speed predictions, or be combined with the predictions from the speeds provided by loop detectors. While there is a plethora of possible prediction schemes that can be generated in this manner, the most relevant schemes are presented in Table 8. Note that the case label (a) is reserved for the calibrated single variable model developed earlier. This case will serve as the base case which all of the other cases will be compared against. The case names differentiate the prediction schemes. The multivariable prediction schemes belong to one of two classes: POST or PRE. The POST and PRE classes refer to whether equation 3 is used after or before the prediction methodology outline is applied. The POST class refers to those schemes where the predictions of occupancy and volume are combined using equation 3. In other words, occupancy and volume values are predicted first, and then they are substituted into equation 3. By contrast, the PRE class includes those schemes where the occupancy and volume data are substituted into equation 3 to form a new speed time series, and that new speed time series is predicted. The details of each prediction scheme are presented below.

Table 8: Corridor Travel Time Prediction Schemes

Label	Case Name	Class	Number of Variables
(a)	Calibrated	Single Variable	1
(b)	SOV POST	POST	2
(c)	SPDHATAVG SOV POST	POST	3
(d)	SPDHAT MOD A SOV POST	POST	2
(e)	SPDHAT MOD B SOV POST	POST	3
(f)	SOV PRE	PRE	2
(g)	SOV PRE SPD	PRE	3
(h)	SPDHATAVG SOV PRE	PRE	3
(i)	SPDHATAVG SOV PRE SPD	PRE	3
(j)	SPDHAT MOD A SOV PRE	PRE	3
(k)	SPDHAT MOD B SOV PRE	PRE	3

2.6.2.1 <u>Case (b): SOV POST</u>

The steps involved in the SOV POST prediction scheme are summarized as follows:

1. Predict the volume and occupancy at each station using the prediction methodology outlined before.
2. Calculate the derived predicted speed (sov_post_{n+1}) using equation 3.

$$sov\_post_{n+1} = 15.1515\left(\frac{q_{n+1}}{r_{n+1}}\right) \qquad [6]$$

The conversion factor of 15.1515 accounts for an assumed average vehicle length ($\bar{l}$) of 20 feet. Hence, the conversion factor for equation 3 is 0.757576. This conversion factor is derived as follows:

$$\bar{v}[\text{mph}] = 0.757576(\bar{l}[\text{ft}]) \cdot \frac{q\left[\dfrac{\text{veh} - 3\text{ lanes}}{0.5\text{ min}}\right]}{r[\%]}$$

where, [7]

$$0.757576 = \left(\frac{1\text{ mile}}{5280\text{ ft}}\right)\left(\frac{1\text{ station}}{3\text{ lanes}}\right)\left(\frac{60\text{ min}}{1\text{ hr}}\right)\left(2 \cdot \frac{0.5\text{ min}}{\text{min}}\right)(100)$$

3. Calculate the predicted corridor travel time using the derived speeds at each station.

Two variables (volume and occupancy) are used in this prediction scheme to derive the corridor travel time. The flow chart for the Case (b) prediction scheme is displayed in Figure 18.

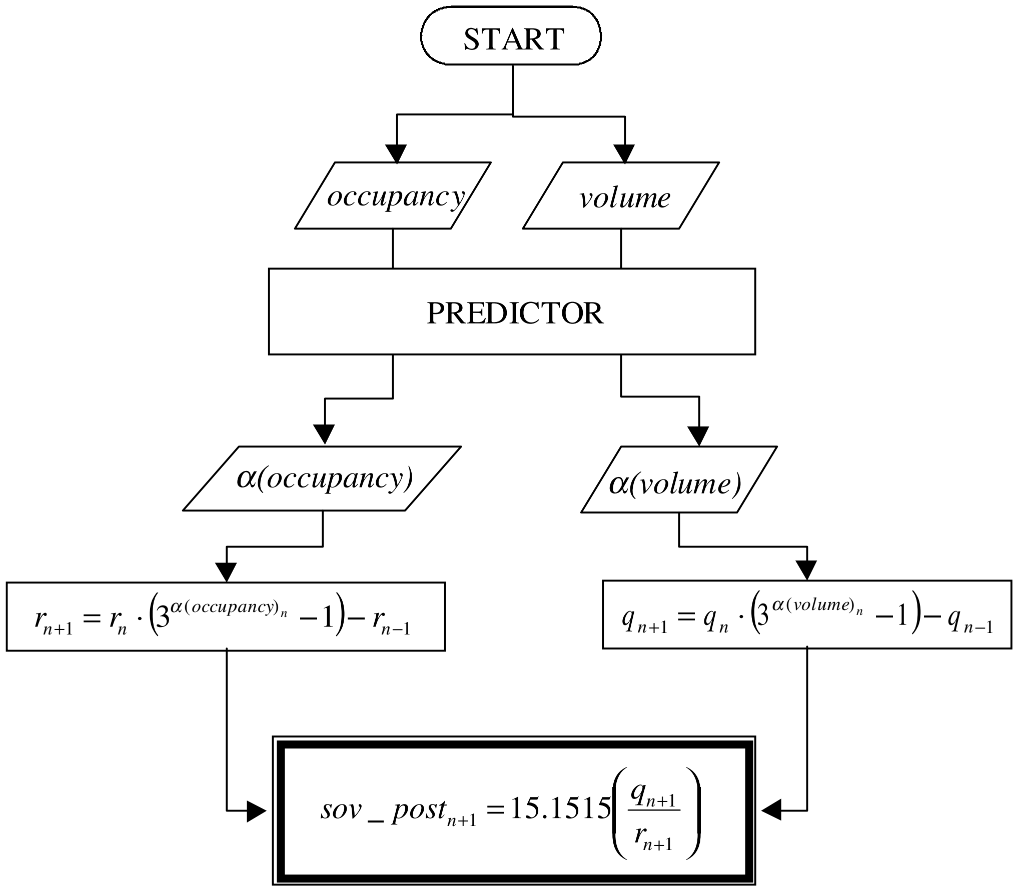


Figure 18: Flow Chart for Multivariable Prediction Case (b)

2.6.2.2 Case (c): SPDHATAVG SOV POST

The steps involved in the SPDHATAVG SOV POST prediction scheme are summarized as follows:

1. Predict the speed, volume, and occupancy at each station using the prediction methodology outlined before.
2. Calculate the derived predicted speed (sov_post_{n+1}) using equation 3.
3. Average the derived speed from step 2 with the predicted speed from the speed time series to obtain *spdhatavg_sov_post*, as indicated below:

$$spdhatavg\_sov\_post = \frac{S_{n+1} + sov\_post_{n+1}}{2} \qquad [8]$$

4. Calculate the predicted corridor travel time using the average speeds from step 3.

Three variables (volume, occupancy, and speed) are used in this prediction scheme to derive the corridor travel time. The flow chart for the Case (c) prediction scheme is displayed in Figure 19.

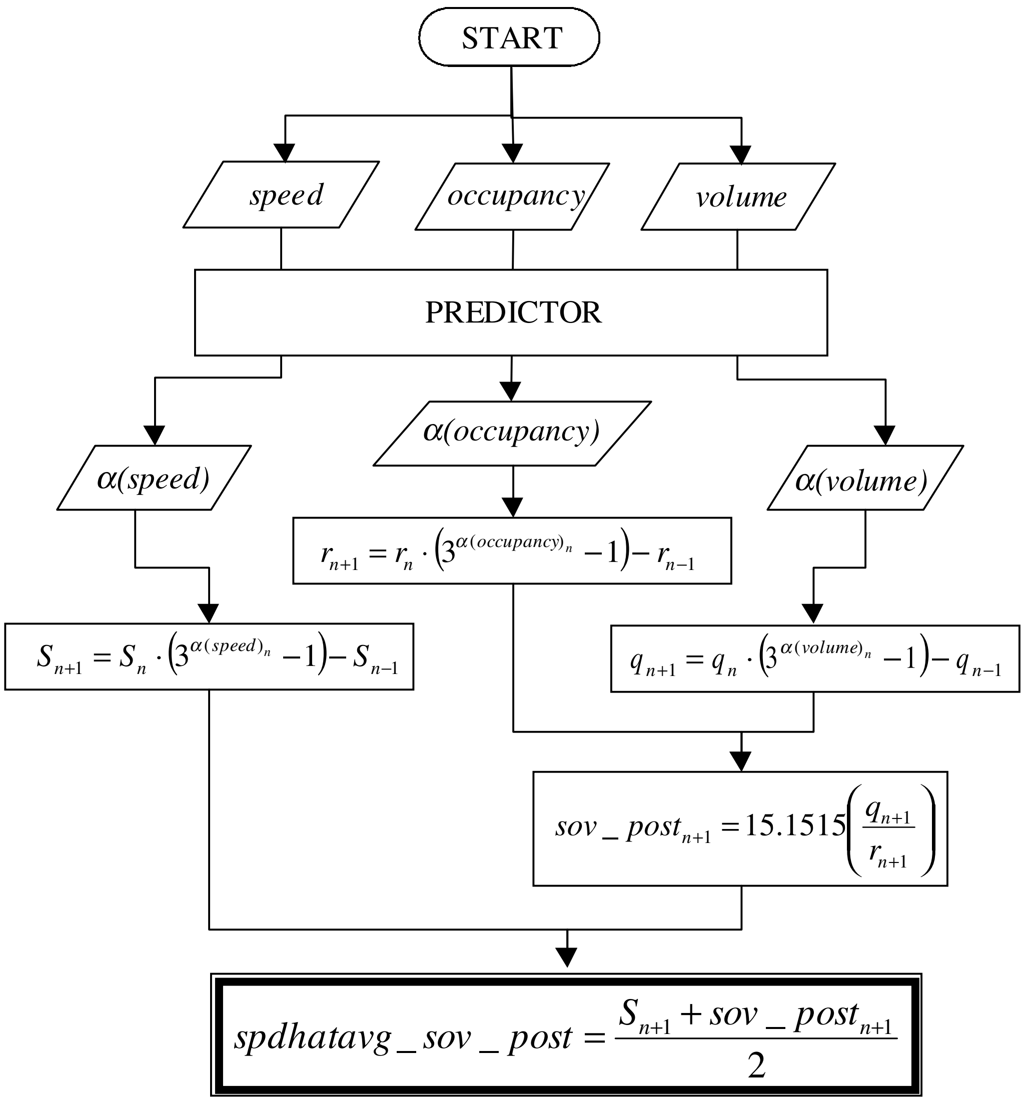


Figure 19: Flow Chart for Multivariable Prediction Case (c)

2.6.2.3 Case (d): SPDHAT MOD A SOV POST

The steps involved in the SPDHAT MOD A SOV POST prediction scheme are summarized as follows:

1. Predict the volume and occupancy at each station using the prediction methodology outlined before.
2. Calculate α(*mod_post)* as the ratio of the predicted α for volume to the predicted α for occupancy.

$$\alpha(mod\_post) = \frac{\alpha(volume)}{\alpha(occupancy)} \quad [9]$$

3. Calculate the predicted speed ($spdhat\_mod\_a\_post_{n+1}$) using α(*mod_post)*, actual volumes, and actual occupancies as follows:

$$spdhat\_mod\_a\_post_{n+1} = 15.1515\left(\frac{q_n}{r_n}\right)\cdot\left(3^{\alpha(mod\_post)_n} - 1\right) - 15.1515\left(\frac{q_{n-1}}{r_{n-1}}\right) \quad [10]$$

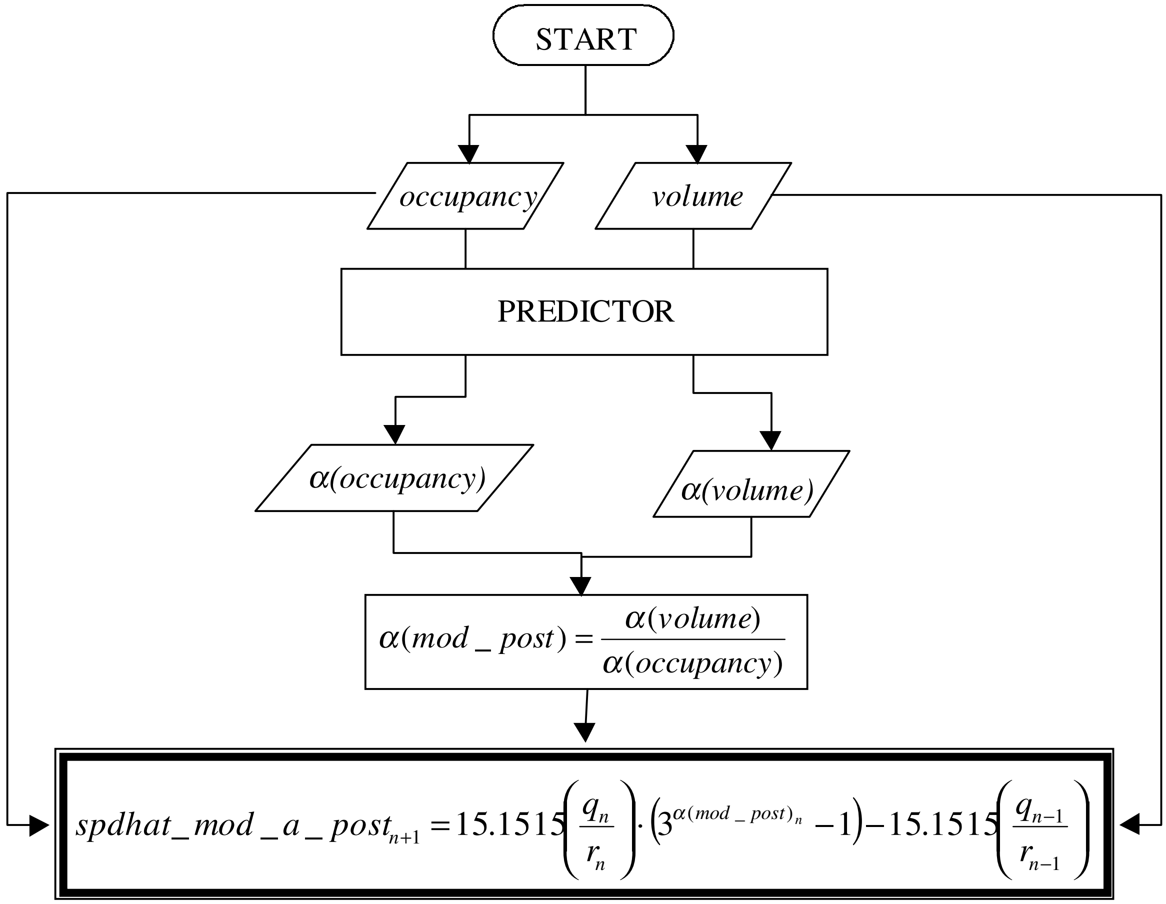


Figure 20: Flow Chart for Multivariable Prediction Case (d)

4. Calculate the predicted corridor travel time using the predicted speeds found in step 3.

Two variables (volume and occupancy) are used to derive the corridor travel time. The flow chart for the Case (d) prediction scheme is displayed in Figure 20.

2.6.2.4 Case (e): SPDHAT MOD B SOV POST

The steps involved in the SPDHAT MOD B SOV POST prediction scheme are summarized as follows:

1. Predict the volume and occupancy at each station using the prediction methodology outlined before.

2. Calculate $\alpha(mod\_post)$ as the ratio of the predicted α for volume to the predicted α for occupancy, see equation 7 above.

3. Calculate the predicted speed ($spdhat\_mod\_b\_post_{n+1}$) using $\alpha(mod\_post)$ and the actual speeds as follows:

$$spdhat\_mod\_b\_post_{n+1} = S_n \cdot \left(3^{\alpha(mod\_post)_n} - 1\right) - S_{n-1} \qquad [11]$$

4. Calculate the predicted corridor travel time using the predicted speeds found in step 3.

Three variables (volume, occupancy, and speed) are used in this prediction scheme to derive the corridor travel time. The flow chart for the Case (e) prediction scheme is displayed in Figure 21.

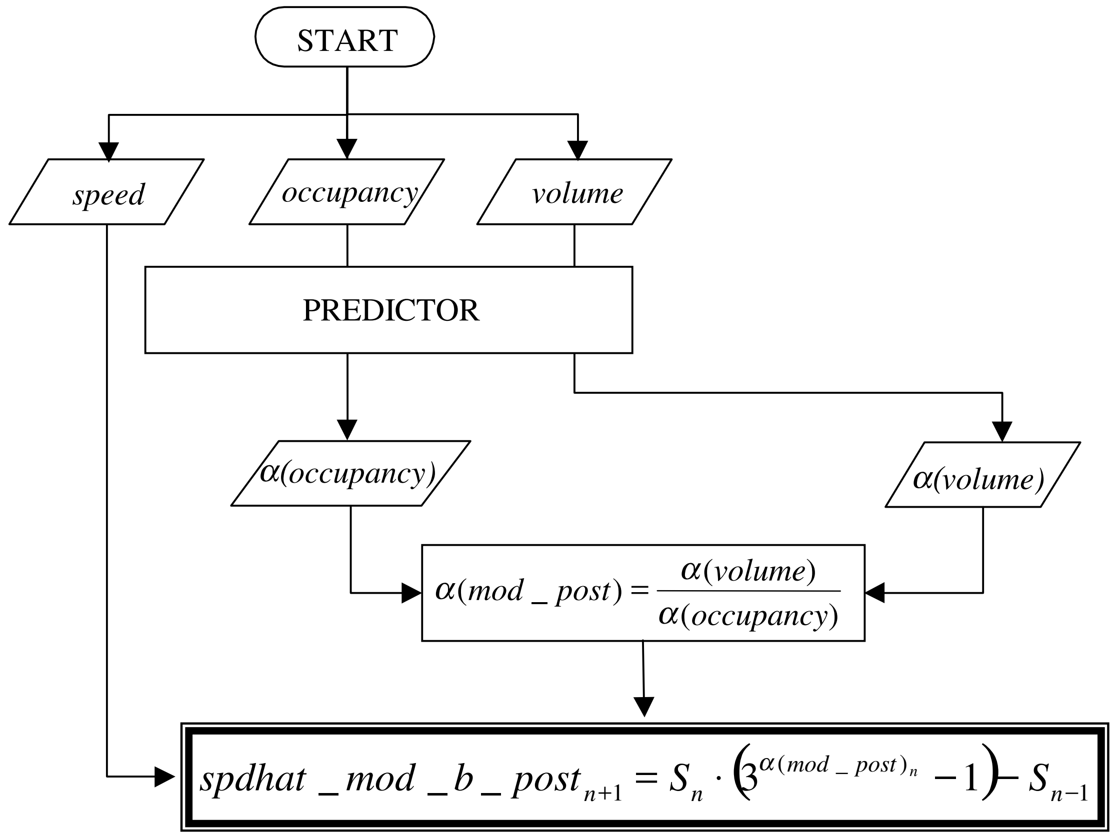


Figure 21: Flow Chart for Multivariable Prediction Case (e)

2.6.2.5 Case (f): SOV PRE

The steps involved in the SOV PRE prediction scheme are summarized as follows:

1. Calculate the derived speed using equation 1.

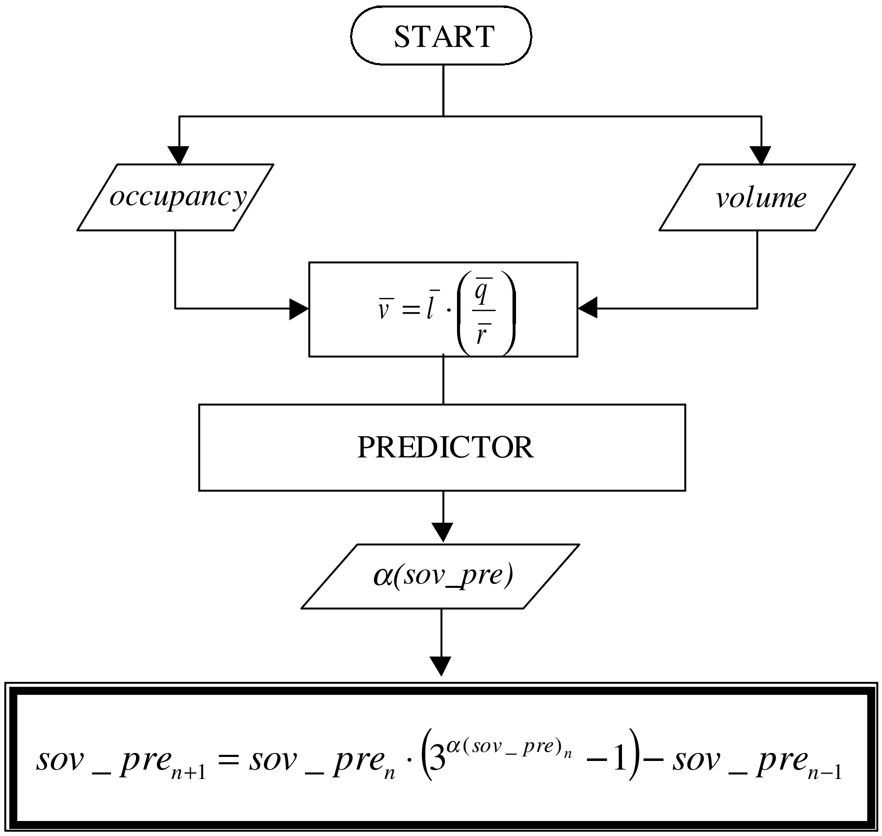


Figure 22: Flow Chart for Multivariable Prediction Case (f)

2. Predict the derived speed (*sov_pre*) at each station using the prediction methodology outlined before. The α values used in these predictions are given the name α(*sov_pre)* to distinguish them from the α values associated with the speeds from the loop detectors. The following relation describes the procedure:

$$sov\_pre_{n+1} = sov\_pre_n \cdot \left(3^{\alpha(sov\_pre)_n} - 1\right) - sov\_pre_{n-1} \qquad [12]$$

3. Calculate the predicted corridor travel time using the predicted derived speeds (*sov_pre*) at each station.

Two variables (volume and occupancy) are used in this prediction scheme to derive the corridor travel time. The flow chart for the Case (f) prediction scheme is displayed in Figure 22.

2.6.2.6 Case (g): SOV PRE SPD

The steps involved in the SOV PRE SPD prediction scheme are summarized as follows:

1. Calculate the derived speed using equation 3.

2. Calculate the predicted speed (*sov_pre_spd*) using the predicted α for the derived speed time series (*α(sov_pre)*), and the actual speeds as follows:

$$sov\_pre\_spd_{n+1} = S_n \cdot \left(3^{\alpha(sov\_pre)_n} - 1\right) - S_{n-1} \qquad [13]$$

3. Calculate the predicted corridor travel time using the predicted derived speeds at each station.

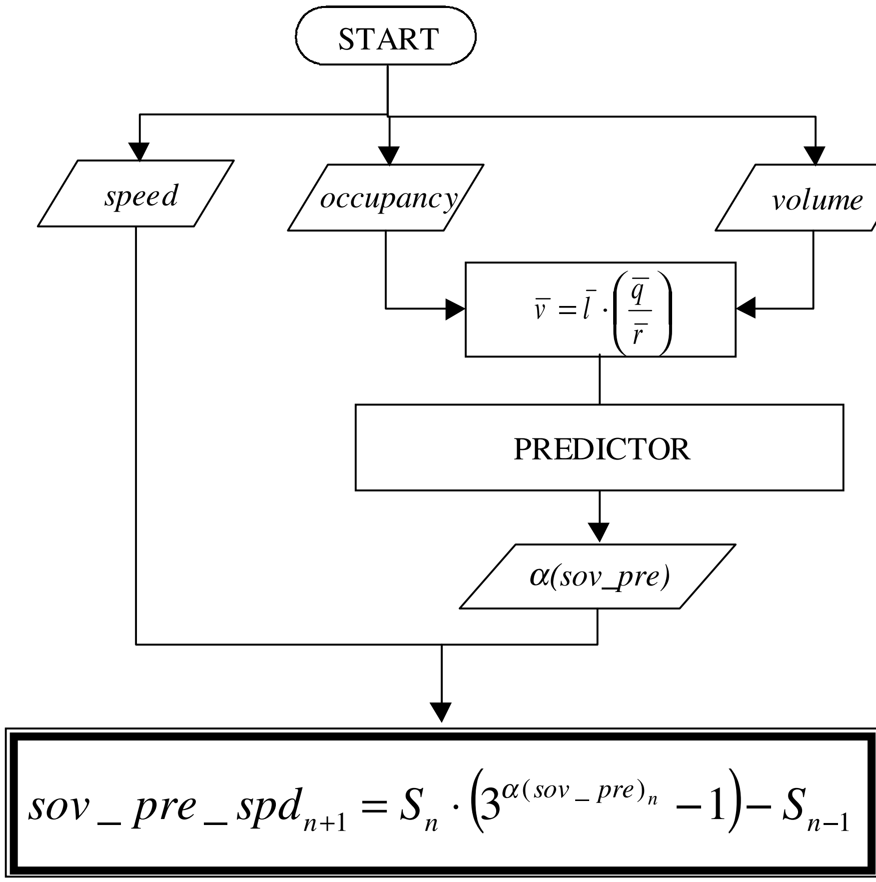


Figure 23: Flow Chart for Multivariable Prediction Case (g)

Three variables (volume, occupancy, and speed) are used in this prediction scheme to derive the corridor travel time. The flow chart for the Case (g) prediction scheme is displayed in Figure 23.

2.6.2.7 <u>Case (h): SPDHATAVG SOV PRE</u>

The steps involved in the SPDHATAVG SOV PRE prediction scheme are summarized as follows:

1. Calculate the derived speed using equation 3.
2. Predict the derived speed (*sov_pre*) at each station using the prediction methodology outlined before. The α values used in these predictions are given the

name α(*sov_pre)* to distinguish them from the α values associated with the speeds from the loop detectors.

3. Average the derived speed from step 2 with the predicted speed from the speed time series to obtain *spdhatavg_sov_pre*. Equation 12 describes the operation:

$$spdhatavg\_sov\_pre = \frac{S_{n+1} + sov\_pre_{n+1}}{2} \qquad [14]$$

4. Calculate the predicted corridor travel time using the predicted derived speeds (*spdhatavg_sov_pre*) at each station.

Three variables (volume, occupancy, and speed) are used in this prediction scheme to derive the corridor travel time. The flow chart for the Case (h) prediction scheme is displayed in Figure 24.

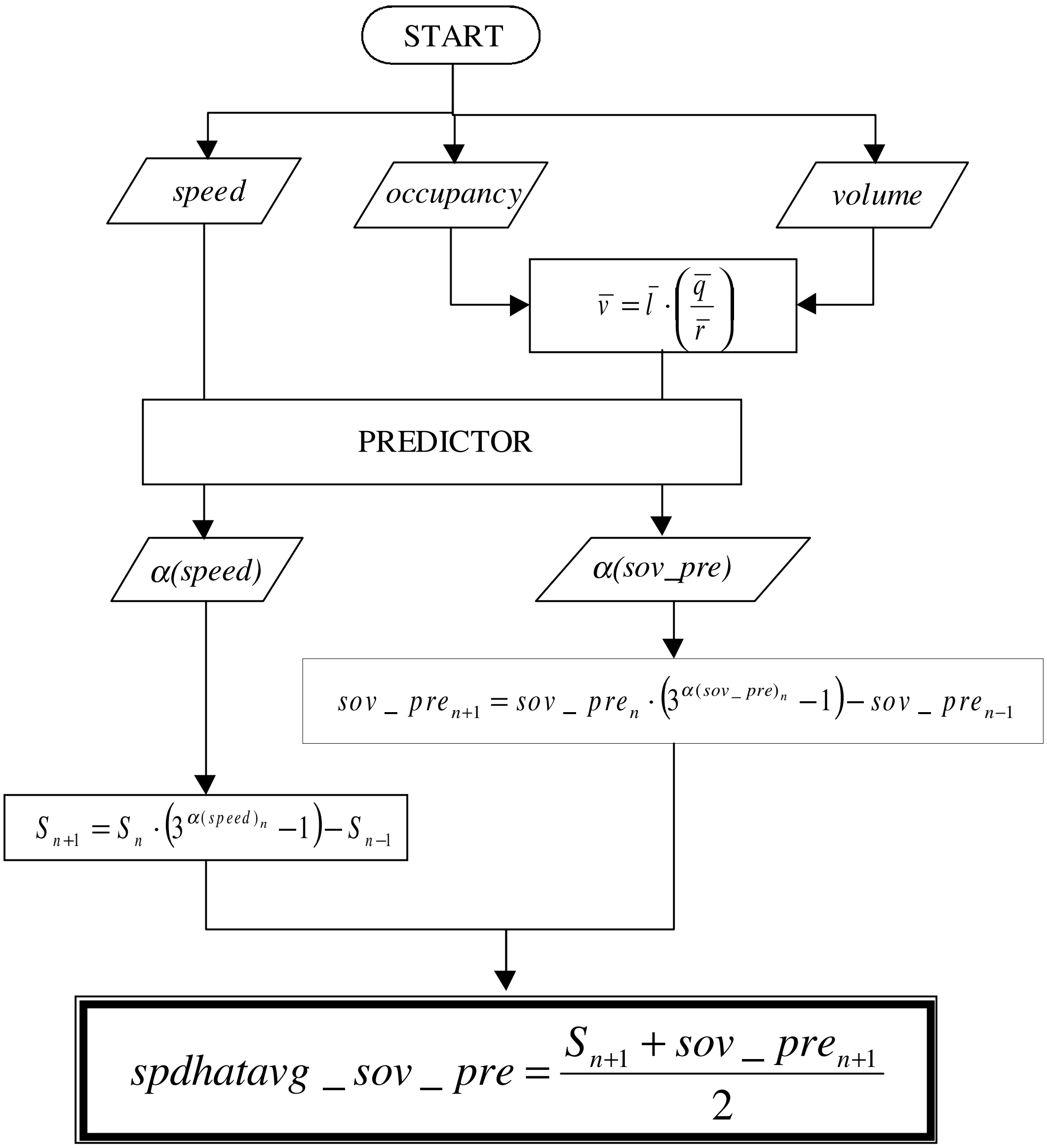


Figure 24: Flow Chart for Multivariable Prediction Case (h)

2.6.2.8 Case (i): SPDHATAVG SOV PRE SPD

The steps involved in the SPDHATAVG SOV PRE SPD prediction scheme are summarized as follows:

1. Calculate the derived speed using equation 3.
2. Calculate the predicted speed (*sov_pre_spd*) using the predicted α for the derived speed time series (α(*sov_pre*)), and the actual speeds.

3. Average the derived speed from step 2 (*sov_pre_spd*) with the predicted speed from the speed time series to obtain *spdhatavg_sov_pre_spd*. Equation 13 describes the operation:

$$spdhatavg\_sov\_pre\_spd = \frac{S_{n+1} + sov\_pre\_spd_{n+1}}{2} \qquad [15]$$

4. Calculate the predicted corridor travel time using the predicted derived speeds (*spdhatavg_sov_pre_spd*) at each station.

Three variables (volume, occupancy, and speed) are used in this prediction scheme to derive the corridor travel time. The flow chart for the Case (i) prediction scheme is displayed in Figure 25.

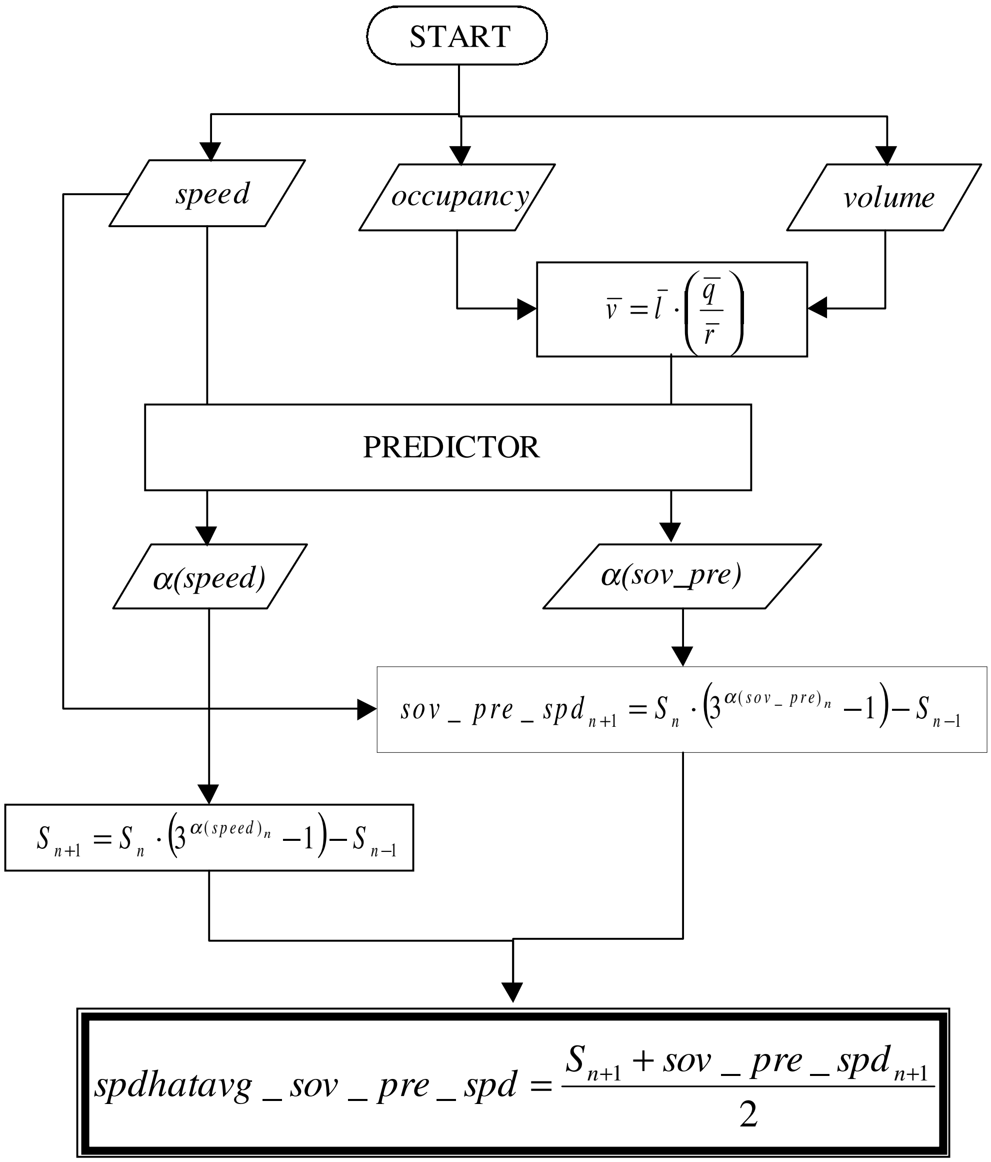


Figure 25: Flow Chart for Multivariable Prediction Case (i)

2.6.2.9 Case (j): SPDHAT MOD A SOV PRE

The steps involved in the SPDHAT MOD A SOV PRE prediction scheme are summarized as follows:

1. Calculate the derived speed using equation 3.

2. Calculate $\alpha(mod\_pre)$ as the average of the α from the loop detector speed time series and the α for the derived speeds ($\alpha(sov\_pre)$).

$$\alpha(mod\_pre) = \frac{\alpha(speed) + \alpha(sov\_pre)}{2} \qquad [16]$$

3. Calculate the predicted speed ($spdhat\_mod\_a\_pre_{n+1}$) using $\alpha\ (mod\_pre)$, and the derived speeds (sov_pre) from step 1 as follows:

$$spdhat\_mod\_a\_pre_{n+1} = sov\_pre_n \cdot \left(3^{\alpha(mod\_pre)_n} - 1\right) - sov\_pre_{n-1} \qquad [17]$$

4. Calculate the predicted corridor travel time using the predicted speeds found in step 3.

Three variables (volume, occupancy, and speed) are used in this prediction scheme to derive the corridor travel time. The flow chart for the Case (j) prediction scheme is displayed in Figure 11.

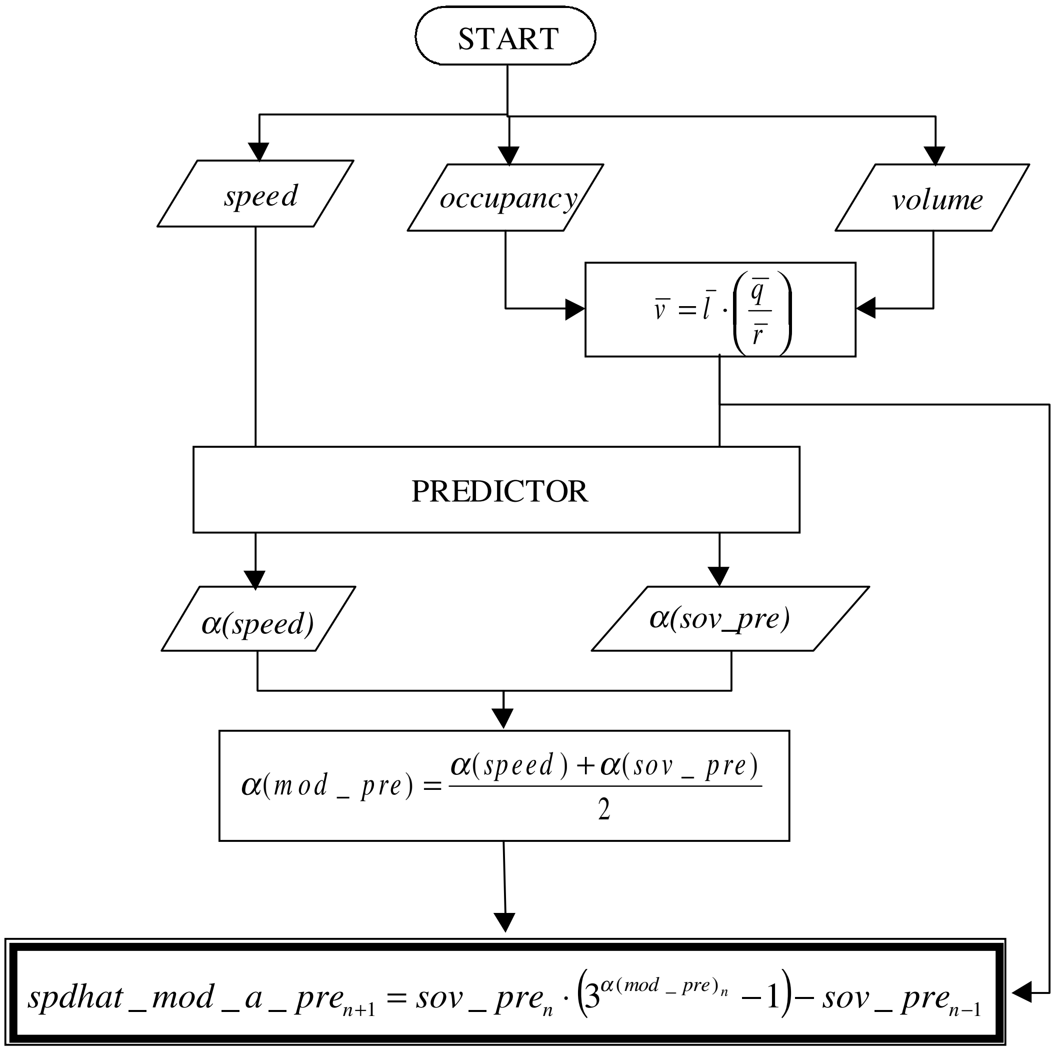


Figure 26: Flow Chart for Multivariable Prediction Case (j)

2.6.2.10 Case (k): SPDHAT MOD B SOV PRE

The steps involved in the SPDHAT MOD B SOV PRE prediction scheme are summarized as follows:

1. Calculate the derived speed using equation 3.

2. Calculate α*(mod_pre)* as the average of the α from the loop detector speed time series and the α for the derived speeds α*(sov_pre)* as in equation 14.

3. Calculate the predicted speed (*spdhat_mod_b*$_{n+1}$) using α *(mod_pre)*, and the actual speeds (*S)* from the loop detectors:

$$spdhat\_mod\_b_{n+1}\_pre = S_n \cdot \left(3^{\alpha(mod\_pre)_n} - 1\right) - S_{n-1} \qquad [18]$$

4. Calculate the predicted corridor travel time using the predicted speeds found in step 3.

Three variables (volume, occupancy, and speed) are used in this prediction scheme to derive the corridor travel time. The flow chart for the Case (k) prediction scheme is displayed in Figure 27.

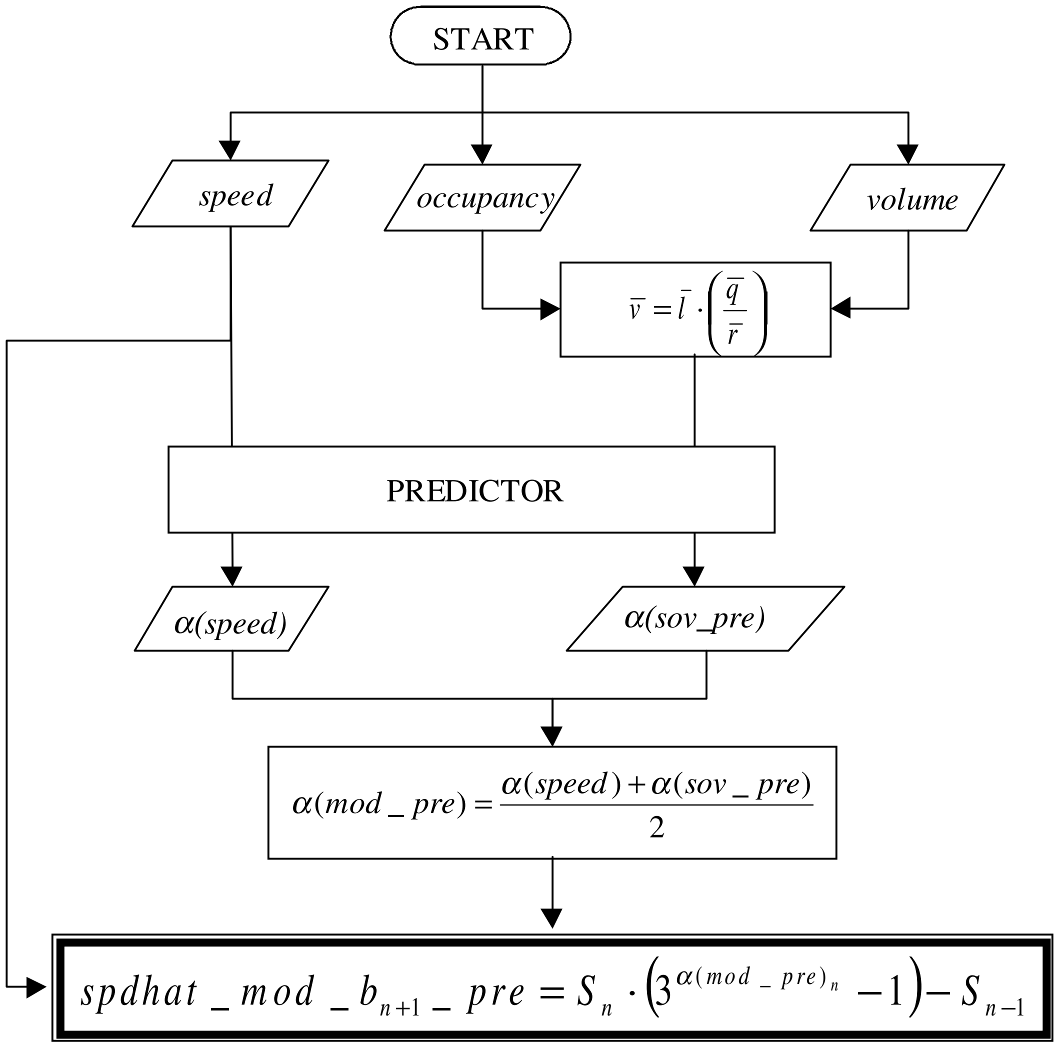


Figure 27: Flow Chart for Multivariable Prediction Case (k)

2.6.3 Multivariable Prediction Performance

The RRSE statistic is used to compare the corridor travel time prediction performance. The ten multivariable prediction schemes are compared against the calibrated single variable prediction model, case (a). The RRSE statistics corresponding to each of the corridor travel time prediction cases for twenty incident-free morning peak periods are given in Table 9. The test days are grouped by weekday, and summary statistics are provided for each case. For each day tested, there is a shaded value. This value is the case with the smallest RRSE for the test day. Note that the single variable prediction model described by case (a) has the smallest RRSE on 12 of the 20 days tested. Among the multivariable cases, no case has more than three days of superior prediction performance. Also note the average summary statistic provided for each case in the second to last row of the table. Case (a) produced the smallest average RRSE for the twenty incident free days.

Table 10 summarizes the testing procedures performed using SAS® on the multivariable prediction schemes. A significant ANOVA model with two factors (scheme and weekday) is constructed in Step 1. Estimates of the average difference between cases are found in Step 2. The t-tests shown in Step 2 are pair-wise t-tests on the estimates. Note that only the comparisons which yield a p-value smaller that 0.05 indicate a significant difference. In total, there are 55 possible pair-wise comparisons. The estimate test combinations found in Table 10 are also displayed in Figure 28 in a combination chart for facile observation. Rows indicate the first case in the comparison, and columns indicate the second case such that the estimate tests are read "case(row) vs. case(column)". The shaded cells represent null (e.g. case (a) vs. case (a)) or duplicate comparisons. YES or NO indicate whether or not the estimate is significant at a 0.05 level of confidence. The value of the estimate is appended to the significance of each comparison.

Recall from Table 9 that case (a) has the smallest average RRSE over the twenty days tested. Case (a) is the base case to compare the multivariable prediction performance for predicting corridor travel times. Hence, the first row in Figure 28 is the most important.

All other rows in the table consist of inclusive comparisons among multivariable prediction strategies. Note first that all of the estimate values in the first row are negative values. Hence, the case (a) RRSE values are smaller in magnitude than the multivariable prediction schemes. Also note that all but two of the estimate tests in the first row are significant. The two tests that are not statistically different from the calibrated single variable prediction model are case (i) and case (k). Both of these belong to the PRE class of predictions, so these schemes use a predicted derived speed time series. It is not surprising that these schemes are performing very closely to the single variable case since these strategies are designed so that the volume and occupancy data contribute marginally to the speed predictions. Therefore, more emphasis is placed on the speed time series in these strategies than the volume and occupancy time series. While these two cases are not found to be significantly different from the single variable prediction case, they are also not performing better than the calibrated single variable model. The inclusion of multiple variables in a prediction strategy adds to the complexity and computational demands of the model. Given this and the results attained, the calibrated single variable prediction model is recommended over the multivariable strategies.

Table 9: RRSE (%) for Multivariable Prediction Cases

		CASES										
		(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)
TEST DAY	WEEK DAY	Single Variable	SOV POST	SPDHAT AVG SOV POST	SPDHAT MOD A SOV POST	SPDHAT MOD B SOV POST	SOV PRE	SOV PRE SPD	SPDHAT AVG SOV PRE	SPDHAT AVG SOV PRE SPD	SPDHAT MOD A SOV PRE	SPDHAT MOD B SOV PRE
01/22/93	Fri.	5.434	7.739	6.266	9.715	6.423	9.563	5.776	6.130	5.598	9.785	5.575
09/03/93	Fri.	3.427	31.797	9.633	36.182	6.757	35.921	6.509	9.868	3.840	35.179	3.933
10/01/93	Fri.	4.113	8.375	6.315	9.329	7.010	8.003	7.643	5.598	5.318	7.284	5.319
11/12/93	Fri.	4.586	8.011	5.662	9.208	6.622	10.595	6.533	6.710	5.213	10.000	5.263
01/25/93	Mon.	4.204	6.607	4.570	5.870	6.460	7.750	6.237	5.291	5.038	7.218	5.040
08/09/93	Mon.	6.138	8.349	6.224	9.070	8.585	9.353	5.909	5.431	6.110	9.198	6.125
08/16/93	Mon.	3.944	9.500	5.793	8.171	5.414	9.198	5.408	4.702	4.260	8.919	4.278
09/13/93	Mon.	7.133	8.870	6.293	8.819	8.176	10.776	9.068	7.424	7.669	9.866	7.705
01/21/93	Thur.	5.807	8.888	6.835	11.831	8.802	10.399	6.380	7.068	5.926	10.477	5.938
02/04/93	Thur.	3.427	16.781	5.582	20.717	7.598	19.529	6.431	7.411	4.070	19.136	4.028
10/07/93	Thur.	6.577	11.956	8.063	12.934	7.884	11.592	6.272	7.138	6.441	11.441	6.456
04/14/94	Thur.	5.084	7.766	6.390	10.228	9.273	8.548	7.218	5.776	4.390	8.337	4.457
01/19/93	Tues.	5.416	9.122	5.522	9.569	8.436	10.691	6.999	6.733	6.805	9.420	6.808
02/09/93	Tues.	4.454	8.193	6.812	8.678	5.711	9.449	5.826	5.079	5.610	9.235	4.483
08/03/93	Tues.	4.364	6.728	4.181	8.831	6.974	9.268	4.978	4.778	4.460	8.936	4.475
10/05/93	Tues.	4.972	8.500	6.977	9.624	5.861	9.537	7.797	6.170	6.081	10.172	6.104
01/27/93	Wed.	5.943	10.663	7.120	9.148	7.326	7.690	5.848	4.802	5.655	7.385	5.668
02/03/93	Wed.	6.552	10.686	8.106	14.001	8.963	13.502	8.605	9.749	7.720	12.662	7.715
08/04/93	Wed.	7.349	7.456	7.208	9.711	8.566	10.877	9.240	7.062	7.920	9.438	7.963
03/23/94	Wed.	12.154	16.815	14.403	17.301	14.895	14.489	12.710	12.323	12.109	14.970	12.128
AVERAGE		5.554	10.640	6.898	11.947	7.787	11.837	7.069	6.762	6.012	11.453	5.973
STD. DEV.		1.941	5.718	2.150	6.625	2.028	6.289	1.774	1.954	1.870	6.234	1.899

Table 10: ANOVA and Estimate Tests for Multivariable Prediction Schemes

Step 1: SAS ANOVA

Dependent Variable: LGRRSE

Source	DF	Type I SS	Mean Square	F Value	Pr > F	SIGNIFICANT @ α=.05
SCHEME	10	15.3634351	1.53634351	18.01	0.0001	YES
DOW	4	3.17583827	0.79395957	9.31	0.0001	YES
SCHEME*DOW	40	2.40227992	0.060057	0.70	0.9037	NO

Step 2: ESTIMATE Test

Parameter	Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate	SIGNIFICANT @ α=.05
case(a) v.s. case(b)	-0.61276	-6.63	0.0001	0.09236616	YES
case(a) v.s. case(c)	-0.22697	-2.46	0.015	0.09236616	YES
case(a) v.s. case(d)	-0.72145	-7.81	0.0001	0.09236616	YES
case(a) v.s. case(e)	-0.35818	-3.88	0.0002	0.09236616	YES
case(a) v.s. case(f)	-0.72523	-7.85	0.0001	0.09236616	YES
case(a) v.s. case(g)	-0.26257	-2.84	0.005	0.09236616	YES
case(a) v.s. case(h)	-0.20906	-2.26	0.0249	0.09236616	YES
case(a) v.s. case(i)	-0.08734	-0.95	0.3458	0.09236616	NO
case(a) v.s. case(j)	-0.68807	-7.45	0.0001	0.09236616	YES
case(a) v.s. case(k)	-0.07946	-0.86	0.3909	0.09236616	NO
case(b) v.s. case(c)	0.38579	4.18	0.0001	0.09236616	YES
case(b) v.s. case(d)	-0.10869	-1.18	0.241	0.09236616	NO
case(b) v.s. case(e)	0.25458	2.76	0.0065	0.09236616	YES
case(b) v.s. case(f)	-0.11247	-1.22	0.2251	0.09236616	NO
case(b) v.s. case(g)	0.35019	3.79	0.0002	0.09236616	YES
case(b) v.s. case(h)	0.40370	4.37	0.0001	0.09236616	YES
case(b) v.s. case(i)	0.52542	5.69	0.0001	0.09236616	YES
case(b) v.s. case(j)	-0.07531	-0.82	0.416	0.09236616	NO
case(b) v.s. case(k)	0.53330	5.77	0.0001	0.09236616	YES
case(c) v.s. case(d)	-0.49448	-5.35	0.0001	0.09236616	YES
case(c) v.s. case(e)	-0.13121	-1.42	0.1573	0.09236616	NO
case(c) v.s. case(f)	-0.49826	-5.39	0.0001	0.09236616	YES
case(c) v.s. case(g)	-0.03560	-0.39	0.7004	0.09236616	NO
case(c) v.s. case(h)	0.01791	0.19	0.8465	0.09236616	NO
case(c) v.s. case(i)	0.13963	1.51	0.1325	0.09236616	NO
case(c) v.s. case(j)	-0.46110	-4.99	0.0001	0.09236616	YES
case(c) v.s. case(k)	0.14751	1.60	0.1122	0.09236616	NO
case(d) v.s. case(e)	0.36327	3.93	0.0001	0.09236616	YES
case(d) v.s. case(f)	-0.00378	-0.04	0.9674	0.09236616	NO
case(d) v.s. case(g)	0.45888	4.97	0.0001	0.09236616	YES
case(d) v.s. case(h)	0.51238	5.55	0.0001	0.09236616	YES
case(d) v.s. case(i)	0.63411	6.87	0.0001	0.09236616	YES
case(d) v.s. case(j)	0.03337	0.36	0.7183	0.09236616	NO

Parameter	Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate	SIGNIFICANT @ α=.05
case(d) v.s. case(k)	0.64199	6.95	0.0001	0.09236616	YES
case(e) v.s. case(f)	-0.36705	-3.97	0.0001	0.09236616	YES
case(e) v.s. case(g)	0.09561	1.04	0.3021	0.09236616	NO
case(e) v.s. case(h)	0.14912	1.61	0.1083	0.09236616	NO
case(e) v.s. case(i)	0.27084	2.93	0.0038	0.09236616	YES
case(e) v.s. case(j)	-0.32989	-3.57	0.0005	0.09236616	YES
case(e) v.s. case(k)	0.27872	3.02	0.003	0.09236616	YES
case(f) v.s. case(g)	0.46266	5.01	0.0001	0.09236616	YES
case(f) v.s. case(h)	0.51617	5.59	0.0001	0.09236616	YES
case(f) v.s. case(i)	0.63789	6.91	0.0001	0.09236616	YES
case(f) v.s. case(j)	0.03716	0.40	0.688	0.09236616	NO
case(f) v.s. case(k)	0.64577	6.99	0.0001	0.09236616	YES
case(g) v.s. case(h)	0.05350	0.58	0.5632	0.09236616	NO
case(g) v.s. case(i)	0.17523	1.90	0.0596	0.09236616	NO
case(g) v.s. case(j)	-0.42551	-4.61	0.0001	0.09236616	YES
case(g) v.s. case(k)	0.18311	1.98	0.0491	0.09236616	YES
case(h) v.s. case(i)	0.12173	1.32	0.1894	0.09236616	NO
case(h) v.s. case(j)	-0.47901	-5.19	0.0001	0.09236616	YES
case(h) v.s. case(k)	0.12961	1.40	0.1624	0.09236616	NO
case(i) v.s. case(j)	-0.60074	-6.50	0.0001	0.09236616	YES
case(i) v.s. case(k)	0.00788	0.09	0.9321	0.09236616	NO
case(j) v.s. case(k)	0.60862	6.59	0.0001	0.09236616	YES

	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)
(a)		YES -0.61276	YES -0.22697	YES -0.72145	YES -0.35818	YES -0.72523	YES -0.26257	YES -0.20906	NO -0.08734	YES -0.68807	NO -0.07946
(b)			YES 0.38579	NO -0.10869	YES 0.25458	NO -0.11247	YES 0.35019	YES 0.40370	YES 0.52542	NO -0.07531	YES 0.53330
(c)				YES -0.49448	NO -0.13121	YES -0.49826	NO -0.03560	NO 0.01791	NO 0.13963	YES -0.46110	NO 0.14751
(d)					YES 0.36327	NO -0.00378	YES 0.45888	YES 0.51238	YES 0.63411	NO 0.03337	YES 0.64199
(e)						YES -0.36705	NO 0.09561	NO 0.14912	YES 0.27084	YES -0.32989	YES 0.27827
(f)							YES 0.46266	YES 0.51617	YES 0.63789	NO 0.03716	YES 0.64577
(g)								NO 0.05350	NO 0.17523	YES -0.42551	YES 0.18331
(h)									NO 0.12173	YES -0.47901	NO 0.12961
(i)										YES -0.60074	NO 0.00788
(j)											YES 0.60862
(k)											

Figure 28: Estimate Test Results for Multivariable Prediction Schemes

If single loop detectors are used to monitor a network, then multivariable prediction schemes that only use volume and occupancy data must be used because single loop detectors do not provide direct measures of speeds. Three of the multivariable schemes meet these criteria: case (b), case (d), and case (f). Based upon the testing between the multivariable cases with two variables, case (b) or SOV POST, has the smallest average RRSE (10.640%). In addition, case (b) has the estimate (-0.61276) that is closest to zero among the two variable models. Therefore, case (b) is performing the closest to the calibrated single variable prediction model, case (a). Recall that case (a) has the best performance among all models. Hence, case (b) is recommended to predict corridor travel times along a network with single loop detectors.

2.6.4 Summary

The testing and evaluation of the multivariable prediction schemes was presented. Corridor volumes and occupancies were tested, and both were found to have poorer corridor prediction performance than corridor speeds. As a result, these loop detector parameters were not suitable as timely indicators of changing traffic conditions. Ten multivariable prediction schemes were set up based upon the derivation of a speed time series using occupancy and volume data. These schemes differed in their treatment of the derived time series. Hence, the contribution of volume and occupancy data to the travel time predictions was varied. Rigorous testing revealed that the calibrated single variable prediction model was significantly superior to eight of the ten multivariable schemes. The other two multivariable schemes were found not to be statistically different from the single variable case. Hence, the additional information provided by the volume and occupancy values did not improve upon corridor travel time prediction. Finally, case (b) was recommended for implementation on networks with single loop detectors that do not provide direct measurements of speeds.

2.7 REAL TIME TRAFFIC PREDICTION MODEL

This task involves full real time implementation of the traffic prediction model based on the results and calibration efforts previously presented earlier. The real time implementation is developed in a MS Visual Basic 6.0 and has been tested extensively. The underlying mechanism of establishing a real time short-term traffic prediction model requires real time access to the loop detector data since they represent the main input to the developed model. The traffic prediction model is invoked from the main window by clicking the 'Traffic Prediction' menu shown in Figure 29. The submenu contains the option to set up the model parameters. By clicking on the 'Setup' item in the submenu a new dialog window appears as shown in Figure 30. All the parameters in this window will be explained in the next section.

The performance evaluation of the traffic prediction model requires continuous monitoring of the prediction error in real time. The prediction error is expressed in terms of the difference between the observed and predicted values using the formula presented in earlier. Using the loop data collected in the last few months, the performance of the model was evaluated from the calculated errors and the relevant statistical tests.

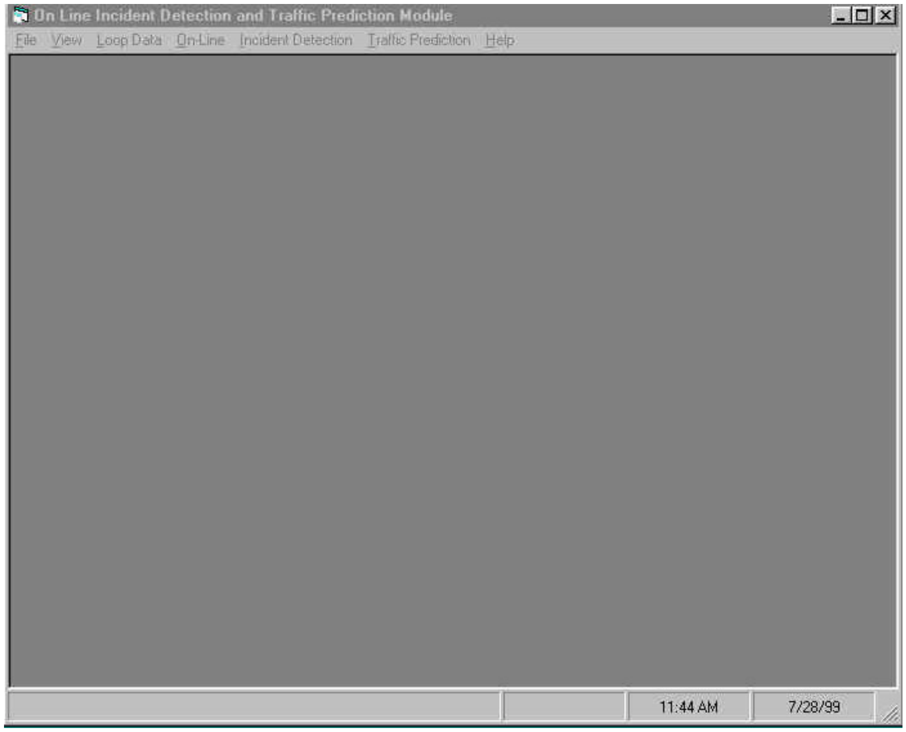


Figure 29: A snapshot of the online incident detection and traffic prediction main module

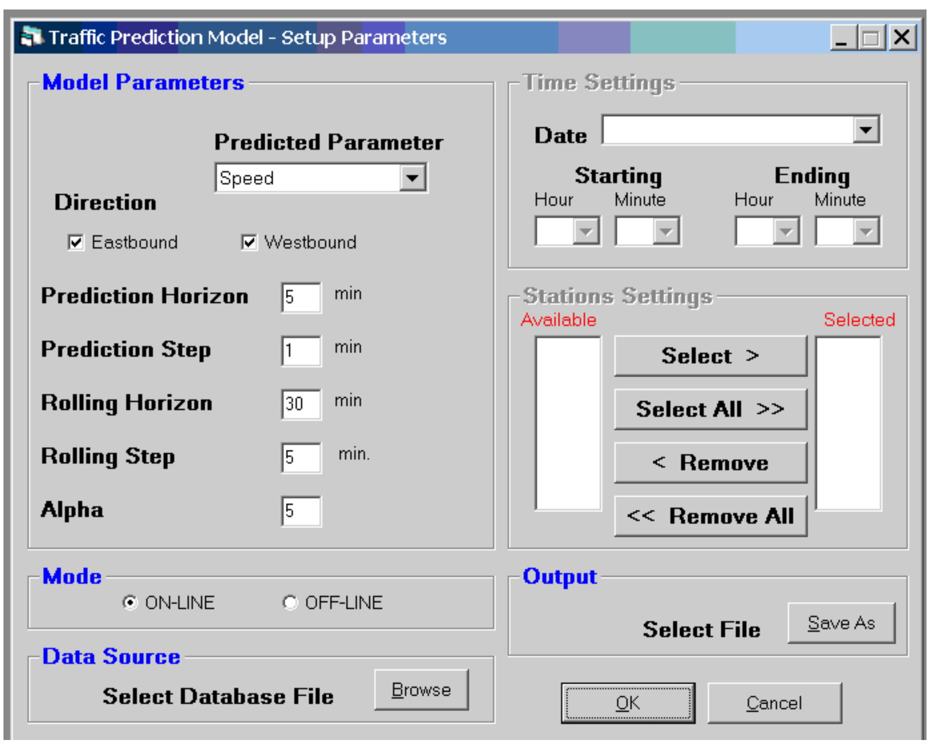


Figure 30: A snapshot of the traffic prediction model setup dialog

The setup parameters of the traffic prediction model are grouped as follows:

2.7.1 *Model Parameters*

- Predicted parameter: This option lets the user select the predicted parameter from one of the three traffic parameters: Speed, Volume, or Occupancy. At this time, only the speed parameter is functional. The other parameters will be enabled in the future.
- Predictors: The time series model allows the user to base the prediction on one or more of the three traffic parameters. By default, the predicted parameters must be one of the predictors. For instance, to predict speed you must include the speed parameter in the time series model. At this time, the real time model is based on speed data only. Multi-variable models are not yet implemented.
- Direction: This option allows the user to select the direction of travel along which prediction is to be made. The available options on I-4 are eastbound and westbound.
- Prediction Horizon: This defines the time period after which prediction is made. If we set the prediction horizon to 5 minutes, then predictions are made 5 minutes away from the present time.
- Prediction Step: This defines the prediction frequency or how often prediction is updated on the system. For instance, a 1-min prediction step results in refreshing the predicted values once every one minute for the same prediction horizon.
- Rolling Horizon: This is the basis for prediction since it defines the prediction history or the past values upon which prediction is based. If we select a 30-min

rolling horizon, then only values from the past 30 minutes will be incorporated in the time series model. The level of aggregation depends on the length of the prediction horizon. In this example, if the prediction horizon is selected as 5 minutes, then rolling horizon will be composed of 6 five-minute averages of the predictors' values.

- Rolling Step: This variable determines if the values derived from the rolling horizon are independent or overlapping. If the rolling step is smaller than the prediction horizon, then the rolling horizon values will represent moving averages.
- Number of Alpha Intervals: This represents the number of intervals used to construct the histogram for Alpha values.

2.7.2 Mode

The traffic prediction model can be run in two modes: Offline and Online. The offline mode allows the user to conduct analysis of the model performance using a set of data previously collected from I-4. The model requires that loop data be available for the time period during which prediction is made. When run online, the model will be fed with real time data from I-4 over a dial-up connection between the user's PC and the FMC. In either case, prediction is only available at stations with operational traffic controllers.

2.7.3 Data Source

In order to run the traffic prediction model offline the user must select the data source from which the loop detector data is to be retrieved. The loop data is compiled in real time into a database access file on a monthly basis. By clicking the Browse button, the user will be prompted to select the database file.

2.7.4 Time Settings

This option is only available in offline mode and permits the user to define the time period during which the prediction model is run. The user must also select the date of month from the list of available dates. It should be noted here that prediction is contingent upon the availability of loop data during the day and time period selected.

2.7.5 Station Settings

Whether the prediction model is run online or offline, the user should select the stations at which prediction is desired. The user has the option selecting a group of stations or the entire corridor.

An example is shown in Figure 31 for a model to predict speed values in both directions of I-4. Speed is predicted only from past speed values in offline mode. The time period selected was from 6:00 AM to 10:00 AM on April 8th, 1999. Prediction was requested for all 69 stations using a 5-min prediction horizon with a 30-min rolling horizon of nonoverlapping averages. Prediction is updated every 5 minutes and the number of alpha intervals is chosen as 5. Clicking 'OK' in the dialog window starts the prediction model.

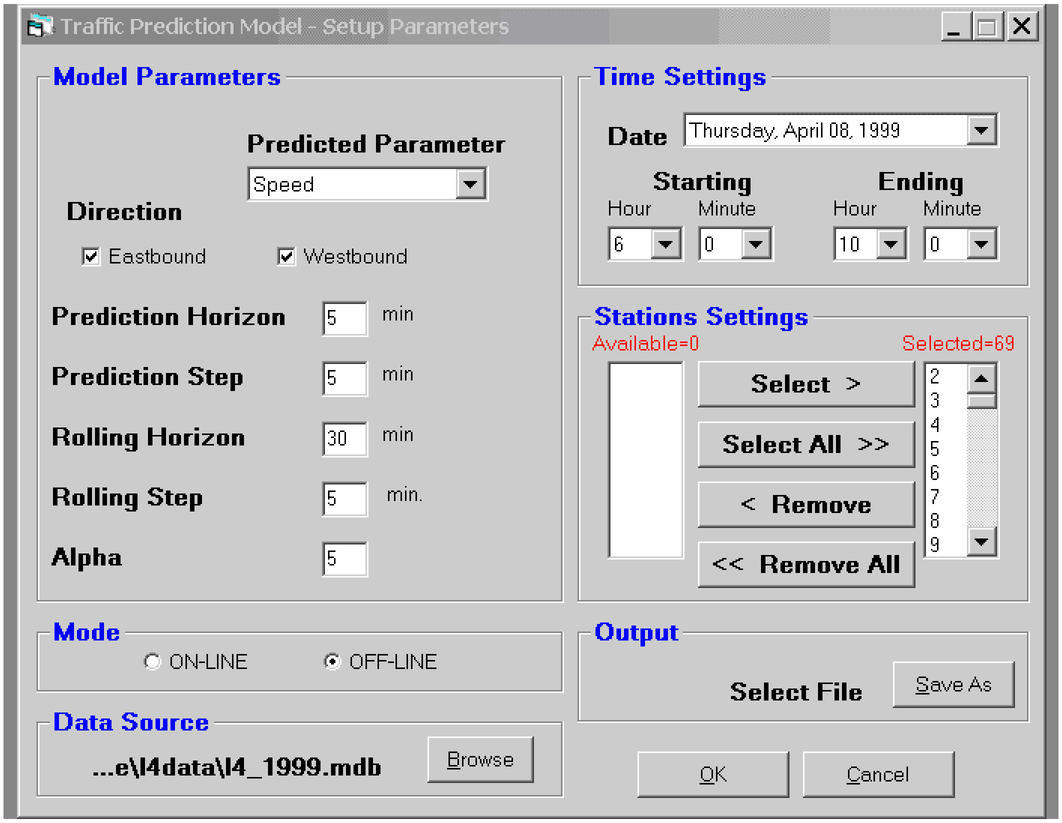


Figure 31: A snapshot of the setup dialog with a selected set of parameters

2.7.6 *Running the model*

It takes a few seconds to initialize the model before the dialog window shown in Figure 32 appears. The window shows that the first predicted speed values are at 6:05 AM using a rolling horizon from 5:30 AM to 6:00 AM. The outcome is presented to the user in a spreadsheet format. The first column shows the station numbers and a brief description of their locations. The next 6 columns show the 5-min speed averages taken during the 30-min rolling horizon. This is followed by the alpha values, the predicted values (shown in bold), and the observed values. The observed and predicted values are used to calculate the error shown in the last column. The error equation used here is the RRSE and can be expresses as follows:

$$RRSE = \frac{\sqrt{\sum_{t=1}^{N} (\hat{x}_t - x_t)^2}}{\sqrt{\sum_{t=1}^{N} (x_t)^2}}$$

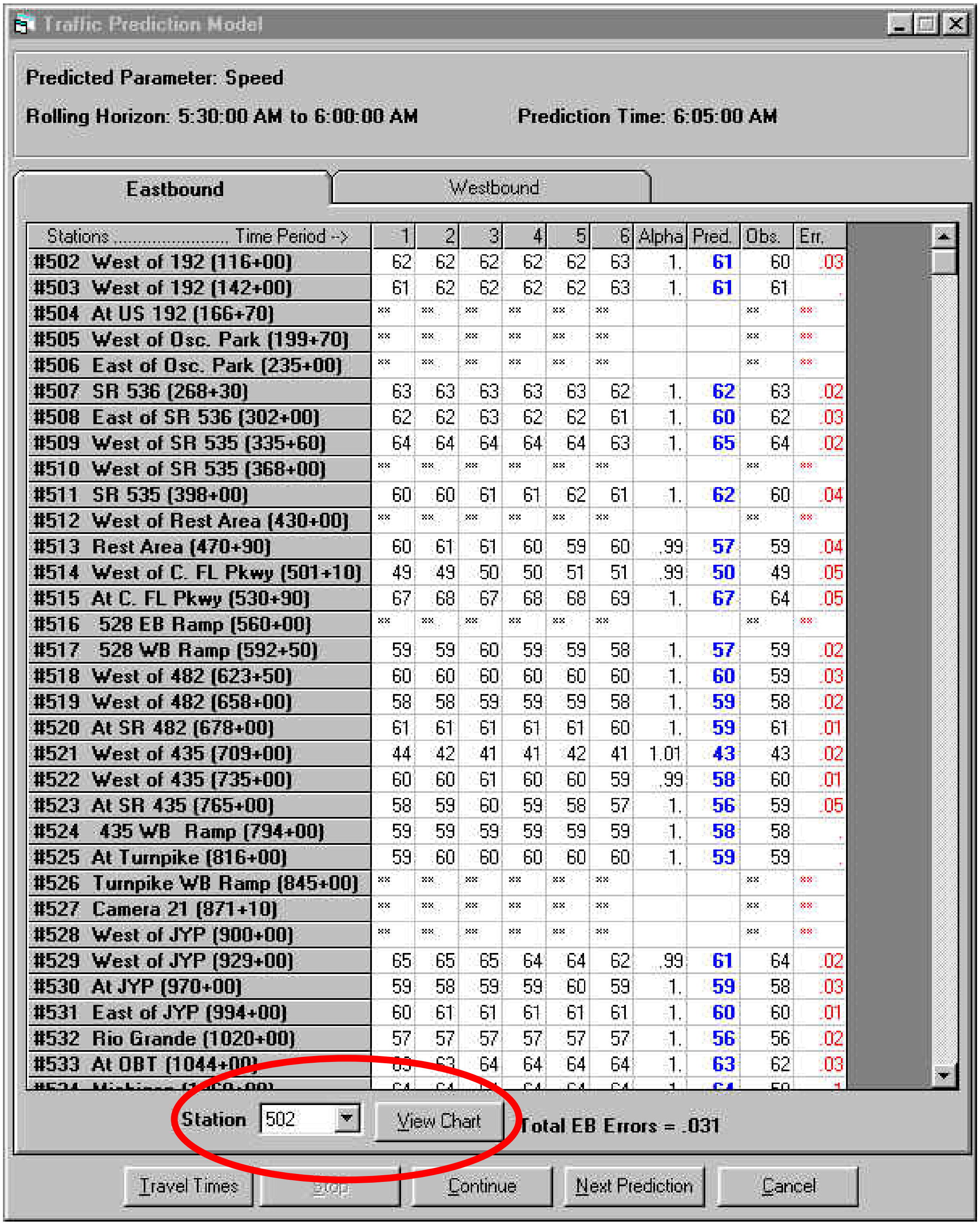
Where,

$\hat{x}_t$ = The predicted value at time t

x_t = The observed value at time t

N = The total number of observations

The user can step through the prediction process one step at a time by clicking the "Next Prediction" button. In this example, the next 5-min prediction will be carried out and the rolling horizon will slide forward by 5 min. All values will be updated accordingly. In order to continue executing the traffic prediction model to the end of the specified time period, the user may hit the "Continue" button. It should be noted here that the errors column is updated with every prediction made and reflects the cumulative error since the onset of the prediction period. The sum of errors over all selected stations is also presented to the user at the bottom of the spreadsheet. This represents the overall error computed over time and space.



Stations .... Time Period -->	1	2	3	4	5	6	Alpha	Pred.	Obs.	Err.
#502 West of 192 (116+00)	62	62	62	62	62	63	1.	61	60	.03
#503 West of 192 (142+00)	61	62	62	62	62	63	1.	61	61	.
#504 At US 192 (166+70)	**	**	**	**	**	**			**	**
#505 West of Osc. Park (199+70)	**	**	**	**	**	**			**	**
#506 East of Osc. Park (235+00)	**	**	**	**	**	**			**	**
#507 SR 536 (268+30)	63	63	63	63	63	62	1.	62	63	.02
#508 East of SR 536 (302+00)	62	62	63	62	62	61	1.	60	62	.03
#509 West of SR 535 (335+60)	64	64	64	64	64	63	1.	65	64	.02
#510 West of SR 535 (368+00)	**	**	**	**	**	**			**	**
#511 SR 535 (398+00)	60	60	61	61	62	61	1.	62	60	.04
#512 West of Rest Area (430+00)	**	**	**	**	**	**			**	**
#513 Rest Area (470+90)	60	61	61	60	59	60	.99	57	59	.04
#514 West of C. FL Pkwy (501+10)	49	49	50	50	51	51	.99	50	49	.05
#515 At C. FL Pkwy (530+90)	67	68	67	68	68	69	1.	67	64	.05
#516 528 EB Ramp (560+00)	**	**	**	**	**	**			**	**
#517 528 WB Ramp (592+50)	59	59	60	59	59	58	1.	57	59	.02
#518 West of 482 (623+50)	60	60	60	60	60	60	1.	60	59	.03
#519 West of 482 (658+00)	58	58	59	59	59	58	1.	59	58	.02
#520 At SR 482 (678+00)	61	61	61	61	61	60	1.	59	61	.01
#521 West of 435 (709+00)	44	42	41	41	42	41	1.01	43	43	.02
#522 West of 435 (735+00)	60	60	61	60	60	59	.99	58	60	.01
#523 At SR 435 (765+00)	58	59	60	59	58	57	1.	56	59	.05
#524 435 WB Ramp (794+00)	59	59	59	59	59	59	1.	58	58	.
#525 At Turnpike (816+00)	59	60	60	60	60	60	1.	59	59	.
#526 Turnpike WB Ramp (845+00)	**	**	**	**	**	**			**	**
#527 Camera 21 (871+10)	**	**	**	**	**	**			**	**
#528 West of JYP (900+00)	**	**	**	**	**	**			**	**
#529 West of JYP (929+00)	65	65	65	64	64	62	.99	61	64	.02
#530 At JYP (970+00)	59	58	59	59	60	59	1.	59	58	.03
#531 East of JYP (994+00)	60	61	61	61	61	61	1.	60	60	.01
#532 Rio Grande (1020+00)	57	57	57	57	57	57	1.	56	56	.02
#533 At OBT (1044+00)	63	63	64	64	64	64	1.	63	62	.03

Figure 32: A snapshot of the traffic prediction model output

Another way to view the prediction process is a graphical plot as shown in Figure 33. The plot is invoked by selecting a station and clicking the "View Chart" button. In this example station 502 was selected for illustration. The plot shows the rolling horizon as a solid line preceding the predicted value, shown as an X marker. The plot window allows the user to navigate through all selected stations backward and forward. The plot will be also refreshed with every new prediction. Another example is given in Figure 34, which shows the plot for station 508 in the westbound direction.

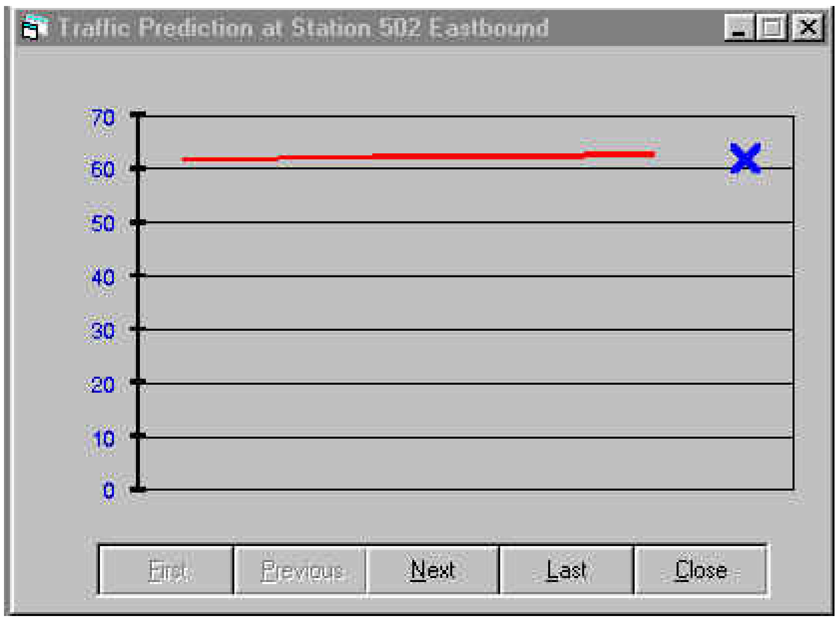


Figure 33: A snapshot of the traffic prediction plot for station 502 in the eastbound direction

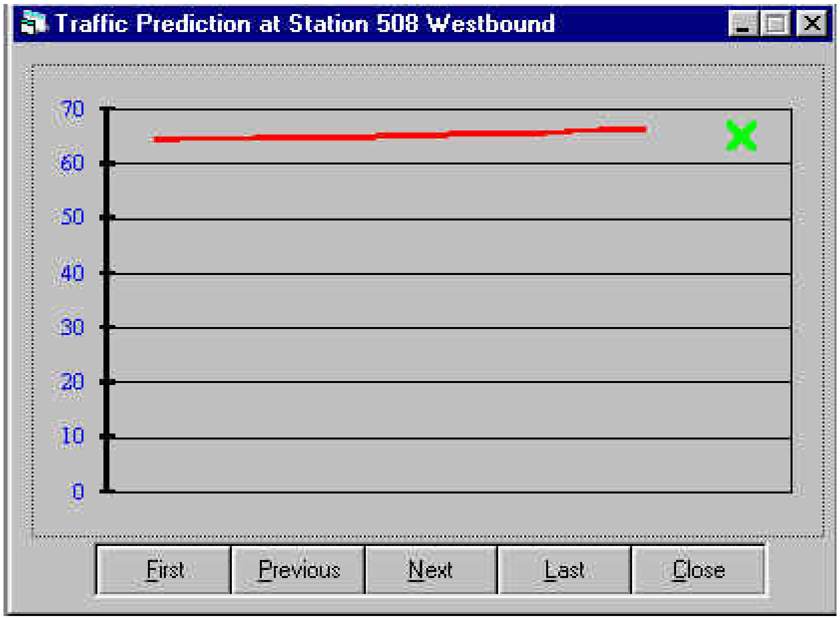


Figure 34: A snapshot of the traffic prediction plot for station 508 in the westbound direction

2.7.7 Travel times

Another useful feature in the traffic prediction model is its ability to predict travel times from predicted speeds. The predicted travel times are based on the average speed of two adjacent stations and the distance between them. Travel times are invoked by clicking the "Travel Times" button. An origin/destination matrix is displayed as shown in Figure 35. The matrix shows the travel times from each station to all other stations in both directions. The upper triangle shows the travel times in the eastbound direction, while the lower triangle shows the westbound direction. Travel times are shown in minutes and are also updated with every new prediction.

Travel Times between stations in minutes

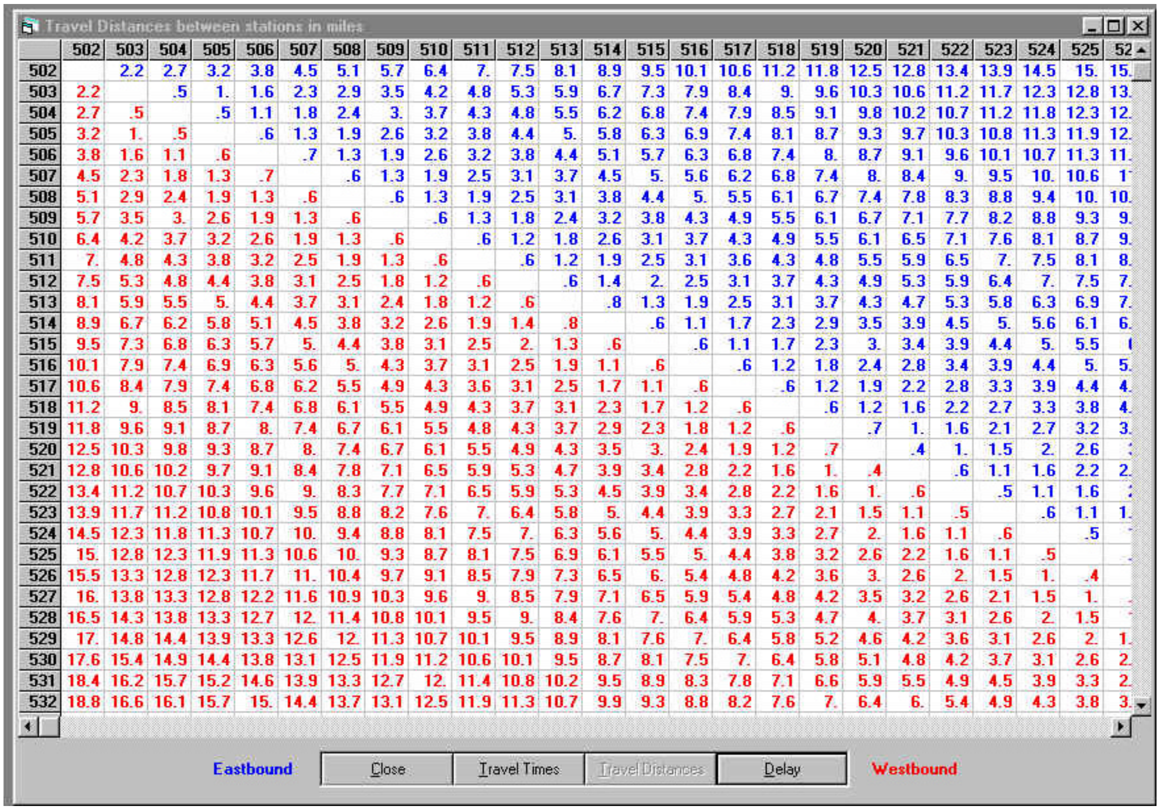
	502	503	504	505	506	507	508	509	510	511	512	513	514	515	516	517	518	519	520	521	522	523	524	525	52
502		.5	.9	1.3	1.7	2.3	2.9	3.5	4.1	4.6	5.2	6.	6.7	7.2	7.7	8.4	9.	9.6	10.	10.7	11.3	11.9	12.4	12.9	13.
503	.5		.5	.7	1.	1.6	2.2	2.8	3.4	3.9	4.5	5.3	6.	6.5	7.	7.7	8.3	8.9	9.3	10.	10.6	11.2	11.7	12.2	12.
504	1.	.5		.5	.8	1.4	2.	2.7	3.2	3.8	4.3	5.2	5.8	6.4	6.9	7.5	8.1	8.7	9.1	9.8	10.4	11.	11.6	12.	12.
505	1.6	1.	.5		.6	1.2	1.8	2.4	3.	3.5	4.1	4.9	5.6	6.1	6.6	7.3	7.8	8.5	8.9	9.6	10.1	10.7	11.3	11.7	12.
506	1.9	1.4	.8	.6		.6	1.2	1.8	2.4	2.9	3.5	4.3	5.	5.6	6.	6.7	7.3	7.9	8.3	9.	9.6	10.2	10.7	11.2	11.
507	2.2	1.6	1.1	.8	.6		.6	1.2	1.8	2.3	2.9	3.7	4.4	4.9	5.4	6.1	6.7	7.3	7.7	8.4	9.	9.6	10.1	10.6	11.
508	2.9	2.4	1.9	1.5	1.1	.6		.6	1.2	1.7	2.3	3.1	3.7	4.3	4.8	5.4	6.	6.7	7.1	7.8	8.3	8.9	9.5	9.9	10.
509	3.6	3.1	2.6	2.2	1.7	1.2	.6		.6	1.1	1.7	2.5	3.1	3.7	4.2	4.8	5.4	6.1	6.5	7.2	7.7	8.3	8.9	9.3	9.
510	4.2	3.7	3.2	2.8	2.3	1.7	1.1	.6		.5	1.1	1.9	2.6	3.2	3.6	4.3	4.9	5.5	5.9	6.6	7.2	7.8	8.3	8.8	9.
511	4.8	4.3	3.8	3.3	2.8	2.3	1.7	1.1	.5		.6	1.4	2.	2.6	3.1	3.7	4.3	5.	5.4	6.	6.6	7.2	7.8	8.2	8.
512	5.4	4.9	4.4	3.9	3.4	2.8	2.3	1.7	1.1	.6		.8	1.4	2.	2.5	3.1	3.7	4.4	4.8	5.5	6.	6.6	7.2	7.6	8.
513	6.3	5.8	5.3	4.7	4.2	3.6	3.1	2.5	1.9	1.4	.8		.6	1.2	1.7	2.3	2.9	3.6	4.	4.6	5.2	5.8	6.4	6.8	7.
514	6.9	6.4	5.9	5.3	4.8	4.2	3.6	3.1	2.5	2.	1.4	.6		.6	1.1	1.7	2.3	3.	3.3	4.	4.6	5.2	5.8	6.2	6.
515	7.5	6.9	6.4	5.9	5.3	4.8	4.2	3.6	3.1	2.5	1.9	1.1	.6		.5	1.1	1.7	2.4	2.8	3.4	4.	4.6	5.2	5.6	6.
516	8.	7.5	7.	6.4	5.9	5.3	4.7	4.1	3.6	3.1	2.5	1.7	1.1	.5		.6	1.2	1.9	2.3	2.9	3.5	4.1	4.7	5.1	5.
517	8.6	8.1	7.6	7.	6.5	5.9	5.3	4.8	4.2	3.7	3.1	2.3	1.7	1.1	.6		.6	1.2	1.6	2.3	2.9	3.5	4.1	4.5	[illegible]
518	9.2	8.7	8.2	7.7	7.1	6.5	5.9	5.4	4.8	4.3	3.7	2.9	2.3	1.7	1.2	.6		.7	1.	1.7	2.3	2.9	3.5	3.9	4.
519	10.	9.4	8.9	8.4	7.8	7.2	6.6	6.	5.5	4.9	4.4	3.6	3.	2.4	1.9	1.3	.7		.4	1.1	1.6	2.2	2.8	3.2	3.
520	10.4	9.8	9.3	8.8	8.2	7.6	7.	6.4	5.9	5.3	4.8	4.	3.4	2.8	2.3	1.7	1.1	.4		.7	1.3	1.9	2.4	2.9	3.
521	11.3	10.8	10.3	9.7	9.1	8.5	7.9	7.3	6.8	6.2	5.7	4.9	4.3	3.7	3.2	2.6	2.	1.3	.9		.6	1.2	1.7	2.2	2.
522	12.1	11.6	11.1	10.4	9.8	9.2	8.7	8.1	7.5	7.	6.4	5.6	5.	4.5	3.9	3.3	2.7	2.	1.6	.7		.6	1.2	1.6	2.
523	12.7	12.2	11.7	11.1	10.4	9.8	9.3	8.7	8.1	7.6	7.	6.2	5.6	5.1	4.5	3.9	3.3	2.6	2.2	1.4	.6		.6	1.	1.
524	13.3	12.7	12.2	11.6	11.	10.4	9.8	9.3	8.7	8.2	7.6	6.8	6.2	5.6	5.1	4.5	3.9	3.2	2.8	1.9	1.2	.6		.4	[illegible]
525	13.7	13.2	12.7	12.	11.4	10.8	10.2	9.7	9.1	8.6	8.	7.2	6.6	6.1	5.5	4.9	4.3	3.6	3.2	2.3	1.6	1.	.4		[illegible]
526	14.2	13.7	13.2	12.6	11.9	11.3	10.8	10.2	9.6	9.1	8.5	7.7	7.1	6.6	6.	5.4	4.8	4.1	3.7	2.9	2.1	1.5	.9	.5	
527	14.6	14.1	13.6	13.	12.3	11.8	11.2	10.6	10.1	9.5	8.9	8.1	7.6	7.	6.5	5.9	5.3	4.6	4.2	3.3	2.5	1.9	1.4	.9	[illegible]
528	14.9	14.3	13.8	13.2	12.6	12.	11.5	10.9	10.3	9.8	9.2	8.4	7.8	7.3	6.7	6.1	5.5	4.8	4.4	3.5	2.8	2.2	1.6	1.2	[illegible]
529	15.1	14.6	14.1	13.5	12.9	12.3	11.8	11.2	10.6	10.1	9.5	8.7	8.1	7.6	7.	6.4	5.8	5.1	4.7	3.8	3.1	2.5	1.9	1.5	[illegible]
530	16.1	15.6	15.1	14.5	13.9	13.3	12.7	12.2	11.6	11.1	10.5	9.7	9.1	8.5	8.	7.4	6.8	6.1	5.7	4.8	4.1	3.5	2.9	2.5	[illegible]
531	16.7	16.1	15.6	15.	14.4	13.8	13.2	12.7	12.1	11.6	11.	10.2	9.6	9.	8.5	7.9	7.3	6.6	6.2	5.3	4.6	4.	3.4	3.	2.
532	17.2	16.6	16.1	15.5	14.9	14.3	13.7	13.2	12.6	12.1	11.5	10.7	10.1	9.6	9.	8.4	7.8	7.1	6.7	5.8	5.1	4.5	3.9	3.5	[illegible]

Eastbound Close Travel Times Travel Distances Delay Westbound

Figure 35: A snapshot of the predicted travel times between all stations of I-4 in both directions

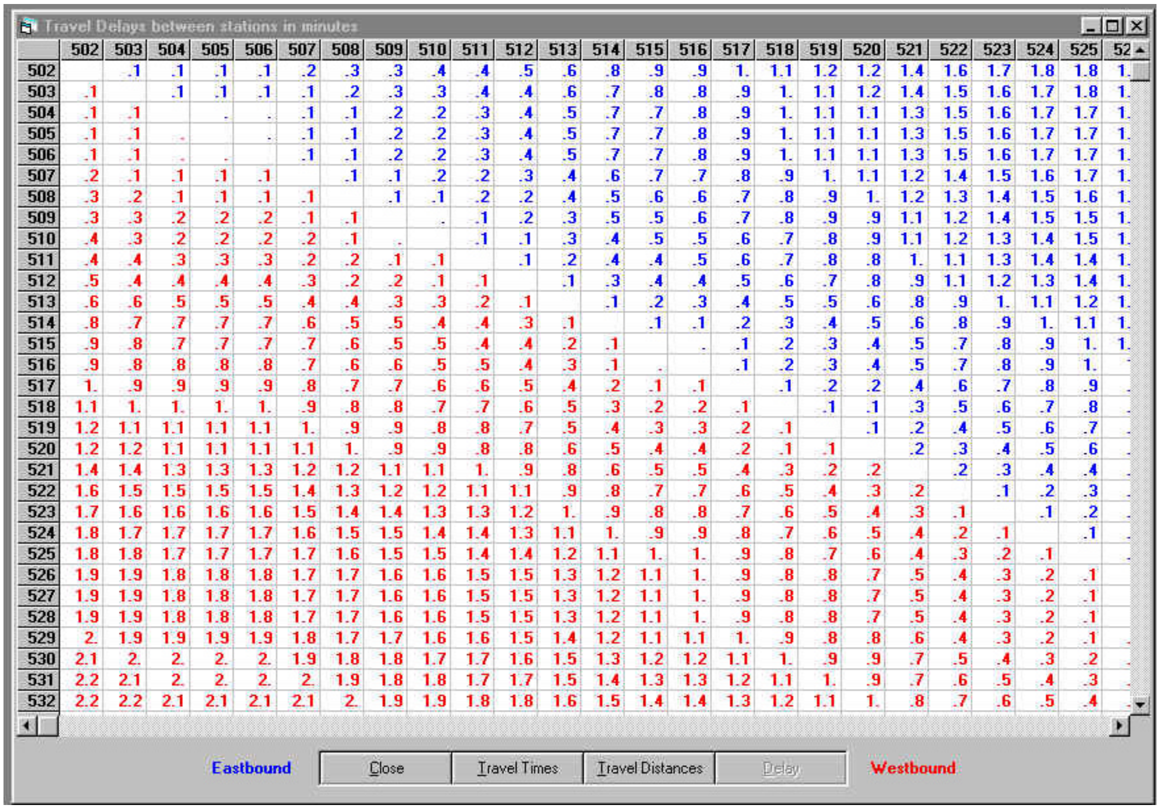
Also, available to the user is the travel distance and travel delay matrices. The user may switch to the travel distance matrix among stations by clicking the "Travel Distances" button. This action will replace the travel time values with the travel distance values as shown in Figure 36.

One of the most important information to the freeway motorists is the expected travel delay ahead. Such information is usually posted on the changeable message signs to alert the drivers of the anticipated delay. Since the freeway has several entry and exit points, it would be practically impossible to post travel delay among them to satisfy all motorists with various destinations. Therefore, it would be left to the traffic operators to restrict the delay information to the major exit points on the freeway or sections with heavy congestion or bottlenecks. Delay among stations is based on the difference between the travel times under actual and free-flow conditions. The expected delay matrix is shown in Figure 37.



	502	503	504	505	506	507	508	509	510	511	512	513	514	515	516	517	518	519	520	521	522	523	524	525	52
502		2.2	2.7	3.2	3.8	4.5	5.1	5.7	6.4	7.	7.5	8.1	8.9	9.5	10.1	10.6	11.2	11.8	12.5	12.8	13.4	13.9	14.5	15.	15.
503	2.2		.5	1.	1.6	2.3	2.9	3.5	4.2	4.8	5.3	5.9	6.7	7.3	7.9	8.4	9.	9.6	10.3	10.6	11.2	11.7	12.3	12.8	13.
504	2.7	.5		.5	1.1	1.8	2.4	3.	3.7	4.3	4.8	5.5	6.2	6.8	7.4	7.9	8.5	9.1	9.8	10.2	10.7	11.2	11.8	12.3	12.
505	3.2	1.	.5		.6	1.3	1.9	2.6	3.2	3.8	4.4	5.	5.8	6.3	6.9	7.4	8.1	8.7	9.3	9.7	10.3	10.8	11.3	11.9	12.
506	3.8	1.6	1.1	.6		.7	1.3	1.9	2.6	3.2	3.8	4.4	5.1	5.7	6.3	6.8	7.4	8.	8.7	9.1	9.6	10.1	10.7	11.3	11.
507	4.5	2.3	1.8	1.3	.7		.6	1.3	1.9	2.5	3.1	3.7	4.5	5.	5.6	6.2	6.8	7.4	8.	8.4	9.	9.5	10.	10.6	1
508	5.1	2.9	2.4	1.9	1.3	.6		.6	1.3	1.9	2.5	3.1	3.8	4.4	5.	5.5	6.1	6.7	7.4	7.8	8.3	8.8	9.4	10.	10.
509	5.7	3.5	3.	2.6	1.9	1.3	.6		.6	1.3	1.8	2.4	3.2	3.8	4.3	4.9	5.5	6.1	6.7	7.1	7.7	8.2	8.8	9.3	9.
510	6.4	4.2	3.7	3.2	2.6	1.9	1.3	.6		.6	1.2	1.8	2.6	3.1	3.7	4.3	4.9	5.5	6.1	6.5	7.1	7.6	8.1	8.7	9.
511	7.	4.8	4.3	3.8	3.2	2.5	1.9	1.3	.6		.6	1.2	1.9	2.5	3.1	3.6	4.3	4.8	5.5	5.9	6.5	7.	7.5	8.1	8.
512	7.5	5.3	4.8	4.4	3.8	3.1	2.5	1.8	1.2	.6		.6	1.4	2.	2.5	3.1	3.7	4.3	4.9	5.3	5.9	6.4	7.	7.5	7.
513	8.1	5.9	5.5	5.	4.4	3.7	3.1	2.4	1.8	1.2	.6		.8	1.3	1.9	2.5	3.1	3.7	4.3	4.7	5.3	5.8	6.3	6.9	7.
514	8.9	6.7	6.2	5.8	5.1	4.5	3.8	3.2	2.6	1.9	1.4	.8		.6	1.1	1.7	2.3	2.9	3.5	3.9	4.5	5.	5.6	6.1	6.
515	9.5	7.3	6.8	6.3	5.7	5.	4.4	3.8	3.1	2.5	2.	1.3	.6		.6	1.1	1.7	2.3	3.	3.4	3.9	4.4	5.	5.5	[illegible]
516	10.1	7.9	7.4	6.9	6.3	5.6	5.	4.3	3.7	3.1	2.5	1.9	1.1	.6		.6	1.2	1.8	2.4	2.8	3.4	3.9	4.4	5.	5.
517	10.6	8.4	7.9	7.4	6.8	6.2	5.5	4.9	4.3	3.6	3.1	2.5	1.7	1.1	.6		.6	1.2	1.9	2.2	2.8	3.3	3.9	4.4	4.
518	11.2	9.	8.5	8.1	7.4	6.8	6.1	5.5	4.9	4.3	3.7	3.1	2.3	1.7	1.2	.6		.6	1.2	1.6	2.2	2.7	3.3	3.8	4.
519	11.8	9.6	9.1	8.7	8.	7.4	6.7	6.1	5.5	4.8	4.3	3.7	2.9	2.3	1.8	1.2	.6		.7	1.	1.6	2.1	2.7	3.2	3.
520	12.5	10.3	9.8	9.3	8.7	8.	7.4	6.7	6.1	5.5	4.9	4.3	3.5	3.	2.4	1.9	1.2	.7		.4	1.	1.5	2.	2.6	[illegible]
521	12.8	10.6	10.2	9.7	9.1	8.4	7.8	7.1	6.5	5.9	5.3	4.7	3.9	3.4	2.8	2.2	1.6	1.	.4		.6	1.1	1.6	2.2	2.
522	13.4	11.2	10.7	10.3	9.6	9.	8.3	7.7	7.1	6.5	5.9	5.3	4.5	3.9	3.4	2.8	2.2	1.6	1.	.6		.5	1.1	1.6	[illegible]
523	13.9	11.7	11.2	10.8	10.1	9.5	8.8	8.2	7.6	7.	6.4	5.8	5.	4.4	3.9	3.3	2.7	2.1	1.5	1.1	.5		.6	1.1	1.
524	14.5	12.3	11.8	11.3	10.7	10.	9.4	8.8	8.1	7.5	7.	6.3	5.6	5.	4.4	3.9	3.3	2.7	2.	1.6	1.1	.6		.5	[illegible]
525	15.	12.8	12.3	11.9	11.3	10.6	10.	9.3	8.7	8.1	7.5	6.9	6.1	5.5	5.	4.4	3.8	3.2	2.6	2.2	1.6	1.1	.5		[illegible]
526	15.5	13.3	12.8	12.3	11.7	11.	10.4	9.7	9.1	8.5	7.9	7.3	6.5	6.	5.4	4.8	4.2	3.6	3.	2.6	2.	1.5	1.	.4	
527	16.	13.8	13.3	12.8	12.2	11.6	10.9	10.3	9.6	9.	8.5	7.9	7.1	6.5	5.9	5.4	4.8	4.2	3.5	3.2	2.6	2.1	1.5	1.	[illegible]
528	16.5	14.3	13.8	13.3	12.7	12.	11.4	10.8	10.1	9.5	9.	8.4	7.6	7.	6.4	5.9	5.3	4.7	4.	3.7	3.1	2.6	2.	1.5	[illegible]
529	17.	14.8	14.4	13.9	13.3	12.6	12.	11.3	10.7	10.1	9.5	8.9	8.1	7.6	7.	6.4	5.8	5.2	4.6	4.2	3.6	3.1	2.6	2.	1.
530	17.6	15.4	14.9	14.4	13.8	13.1	12.5	11.9	11.2	10.6	10.1	9.5	8.7	8.1	7.5	7.	6.4	5.8	5.1	4.8	4.2	3.7	3.1	2.6	2.
531	18.4	16.2	15.7	15.2	14.6	13.9	13.3	12.7	12.	11.4	10.8	10.2	9.5	8.9	8.3	7.8	7.1	6.6	5.9	5.5	4.9	4.5	3.9	3.3	2.
532	18.8	16.6	16.1	15.7	15.	14.4	13.7	13.1	12.5	11.9	11.3	10.7	9.9	9.3	8.8	8.2	7.6	7.	6.4	6.	5.4	4.9	4.3	3.8	3.

Figure 36: A snapshot of the travel distances between all stations on I-4 in both directions



	502	503	504	505	506	507	508	509	510	511	512	513	514	515	516	517	518	519	520	521	522	523	524	525	52
502		.1	.1	.1	.1	.2	.3	.3	.4	.4	.5	.6	.8	.9	.9	1.	1.1	1.2	1.2	1.4	1.6	1.7	1.8	1.8	1.
503	.1		.1	.1	.1	.1	.2	.3	.3	.4	.4	.6	.7	.8	.8	.9	1.	1.1	1.2	1.4	1.5	1.6	1.7	1.8	1.
504	.1	.1		.	.	.1	.1	.2	.2	.3	.4	.5	.7	.7	.8	.9	1.	1.1	1.1	1.3	1.5	1.6	1.7	1.7	1.
505	.1	.1	.		.	.1	.1	.2	.2	.3	.4	.5	.7	.7	.8	.9	1.	1.1	1.1	1.3	1.5	1.6	1.7	1.7	1.
506	.1	.1	.	.		.1	.1	.2	.2	.3	.4	.5	.7	.7	.8	.9	1.	1.1	1.1	1.3	1.5	1.6	1.7	1.7	1.
507	.2	.1	.1	.1	.1		.1	.1	.2	.2	.3	.4	.6	.7	.7	.8	.9	1.	1.1	1.2	1.4	1.5	1.6	1.7	1.
508	.3	.2	.1	.1	.1	.1		.1	.1	.2	.2	.4	.5	.6	.6	.7	.8	.9	1.	1.2	1.3	1.4	1.5	1.6	1.
509	.3	.3	.2	.2	.2	.1	.1		.	.1	.2	.3	.5	.5	.6	.7	.8	.9	.9	1.1	1.2	1.4	1.5	1.5	1.
510	.4	.3	.2	.2	.2	.2	.1	.		.1	.1	.3	.4	.5	.5	.6	.7	.8	.9	1.1	1.2	1.3	1.4	1.5	1.
511	.4	.4	.3	.3	.3	.2	.2	.1	.1		.1	.2	.4	.4	.5	.6	.7	.8	.8	1.	1.1	1.3	1.4	1.4	1.
512	.5	.4	.4	.4	.4	.3	.2	.2	.1	.1		.1	.3	.4	.4	.5	.6	.7	.8	.9	1.1	1.2	1.3	1.4	1.
513	.6	.6	.5	.5	.5	.4	.4	.3	.3	.2	.1		.1	.2	.3	.4	.5	.5	.6	.8	.9	1.	1.1	1.2	1.
514	.8	.7	.7	.7	.7	.6	.5	.5	.4	.4	.3	.1		.1	.1	.2	.3	.4	.5	.6	.8	.9	1.	1.1	1.
515	.9	.8	.7	.7	.7	.7	.6	.5	.5	.4	.4	.2	.1		.	.1	.2	.3	.4	.5	.7	.8	.9	1.	1.
516	.9	.8	.8	.8	.8	.7	.6	.6	.5	.5	.4	.3	.1	.		.1	.2	.3	.4	.5	.7	.8	.9	1.	.
517	1.	.9	.9	.9	.9	.8	.7	.7	.6	.6	.5	.4	.2	.1	.1		.1	.2	.2	.4	.6	.7	.8	.9	.
518	1.1	1.	1.	1.	1.	.9	.8	.8	.7	.7	.6	.5	.3	.2	.2	.1		.1	.1	.3	.5	.6	.7	.8	.
519	1.2	1.1	1.1	1.1	1.1	1.	.9	.9	.8	.8	.7	.5	.4	.3	.3	.2	.1		.1	.2	.4	.5	.6	.7	.
520	1.2	1.2	1.1	1.1	1.1	1.1	1.	.9	.9	.8	.8	.6	.5	.4	.4	.2	.1	.1		.2	.3	.4	.5	.6	.
521	1.4	1.4	1.3	1.3	1.3	1.2	1.2	1.1	1.1	1.	.9	.8	.6	.5	.5	.4	.3	.2	.2		.2	.3	.4	.4	.
522	1.6	1.5	1.5	1.5	1.5	1.4	1.3	1.2	1.2	1.1	1.1	.9	.8	.7	.7	.6	.5	.4	.3	.2		.1	.2	.3	.
523	1.7	1.6	1.6	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.	.9	.8	.8	.7	.6	.5	.4	.3	.1		.1	.2	.
524	1.8	1.7	1.7	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.1	1.	.9	.9	.8	.7	.6	.5	.4	.2	.1		.1	.
525	1.8	1.8	1.7	1.7	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.2	1.1	1.	1.	.9	.8	.7	.6	.4	.3	.2	.1		.
526	1.9	1.9	1.8	1.8	1.8	1.7	1.7	1.6	1.6	1.5	1.5	1.3	1.2	1.1	1.	.9	.8	.8	.7	.5	.4	.3	.2	.1	
527	1.9	1.9	1.8	1.8	1.8	1.7	1.7	1.6	1.6	1.5	1.5	1.3	1.2	1.1	1.	.9	.8	.8	.7	.5	.4	.3	.2	.1	
528	1.9	1.9	1.8	1.8	1.8	1.7	1.7	1.6	1.6	1.5	1.5	1.3	1.2	1.1	1.	.9	.8	.8	.7	.5	.4	.3	.2	.1	
529	2.	1.9	1.9	1.9	1.9	1.8	1.7	1.7	1.6	1.6	1.5	1.4	1.2	1.1	1.1	1.	.9	.8	.8	.6	.4	.3	.2	.1	.
530	2.1	2.	2.	2.	2.	1.9	1.8	1.8	1.7	1.7	1.6	1.5	1.3	1.2	1.2	1.1	1.	.9	.9	.7	.5	.4	.3	.2	.
531	2.2	2.1	2.	2.	2.	2.	1.9	1.8	1.8	1.7	1.7	1.5	1.4	1.3	1.3	1.2	1.1	1.	.9	.7	.6	.5	.4	.3	.
532	2.2	2.2	2.1	2.1	2.1	2.1	2.	1.9	1.9	1.8	1.8	1.6	1.5	1.4	1.4	1.3	1.2	1.1	1.	.8	.7	.6	.5	.4	.

Figure 37: A snapshot of the predicted travel delays between stations on I-4

2.8 RESULTS OF THE SENSITIVITY ANALYSIS

This section presents the results of the sensitivity analysis. The real time traffic prediction module developed in this project was used to conduct a comprehensive sensitivity analysis of the effect of various factors on the performance of the model. Several factors were considered and resulted in wide range of prediction errors. The effect of the following variables was studied.

- Prediction Horizon (PH): '5 Minute', '10 Minute', and '15 Minute'
- Prediction Step (PS): '5 Minute', '10 Minute', and '15 Minute'
- Rolling Horizon (RH): '15 Minute', '20 Minute', '25 Minute', and '30 Minute'
- Rolling Step (RS): '1 Minute', '3 Minute', and '5 Minute'

- Predicted Period (PP): 'Afternoon Peak', 'Morning Peak', and 'Off Peak'
- Traffic Direction (DIRECTION): 'East Bound' and 'West Bound'
- Observed Speed (OBSSPEED)
- Day (DAY)
- Month (MONTH)
- Year (YEAR)
- Time Prediction Made (TIMEPRD)

The performance of the traffic prediction model was evaluated using the following measures:

- Absolute Error (ABSERROR)
- Relative Error (RELERROR)

Influential Variables:

- Main Effects: (Significant at 5% level)
  - Observed Speed (OBSSPEED)
  - Predicted Period (PP): 'Afternoon Peak', 'Morning Peak', and 'Off Peak'
  - Traffic Direction (DIRECTION): 'East Bound' and 'West Bound'
  - Prediction Horizon (PH): '5 Minute', '10 Minute', and '15 Minute'
  - Prediction Step (PS): '5 Minute', '10 Minute', and '15 Minute'

- Two-Way Interaction: (Significant at 5% level)
  - OBSSPEED*PP
  - OBSSPEED*DIRECTION
  - OBSSPEED*RH

- OBSSPEED*RS
- OBSSPEED*PH
- OBSSPEED*PS
- DIRECTION*PP
- DIRECTION*RH
- DIRECTION*RS
- DIRECTION*PH
- DIRECTION*PS
- PP*RH
- PP*RS
- PP*PH
- PP*PS
- OBSSPEED*OBSSPEED

Effects of Influential Variables

The relative prediction error is less than 3% for both "Eastbound" and "Westbound" directions on I4 as shown in Table 11. The relative prediction error is less than 3% for all the three prediction periods as shown in Table 11. The prediction error is smaller in East Bound in the morning. The prediction error in the westbound direction was less in the afternoon period.

Table 11: Traffic Prediction Error (Relative) vs. Prediction Period and Traffic Direction

Prediction Period	Traffic Direction	Relative Error (%)
Afternoon Peak	East Bound	-3.03
	West Bound	-1.11
Morning Peak	East Bound	-0.58
	West Bound	-1.55
Off Peak	East Bound	-1.74
	West Bound	-0.43

For all the three prediction steps considered, the model has less than 2% of relative error as shown in Table 12. However, the "15 Minute" prediction step has the smallest relative error.

Table 12: Traffic Prediction Error (Relative) vs. Prediction Step

Prediction Step	Relative Error (%)
5 Minute	-1.49
10 Minute	-1.55
15 Minute	-1.37

For all the three rolling steps considered, the model has shown good performance. The prediction error for the "5 Minute" rolling step was the smallest as shown in Table 13.

Table 13: Traffic Prediction Error (Relative) vs. Rolling Step

Rolling Step	Relative Error (%)
1 Minute	-1.59
3 Minute	-1.59
5 Minute	-1.34

For all the four rolling horizons, the model performs well with less than 2% error as shown in Table 14. However, the smallest error corresponded to a rolling horizon of 15 minutes.

Table 14: Traffic Prediction Error (Relative) vs. Rolling Horizon

Rolling Horizon	Relative Error (%)
15 Minute	-1.16
20 Minute	-1.29
25 Minute	-1.55
30 Minute	-1.74

The relative prediction error can exceed 10% during congested conditions, especially in the off peak period. Table 15 shows the frequency of error observations under different traffic conditions ranging from free-flow to heavy congestion in the afternoon peak period.

Table 16 and Table 17 also show the frequency of observations in the morning peak and the off-peak periods, respectively. Similarly, Figure 38 through Figure 43 show the statistical characteristics of the prediction errors and the factors affecting their magnitude.

Table 15: Traffic Prediction Error (Relative) in the Afternoon Peak

Relative Prediction Error	Observed Speed			Total
	Heavy Congested	Mild Congested	Free Flow	
Below 0.05	1464 (46.64%)	20528 (65.88%)	217867 (96.21%)	239859
0.05 - 0.10	193 (6.15%)	2936 (9.42%)	5758 (2.54%)	8887
Above 0.10	1482 (47.21%)	7696 (24.70%)	2835 (1.25%)	12013
Total	3139	31160	226460	260759

Table 16: Traffic Prediction Error (Relative) in the Morning Peak

Relative Predict Error	Observed Speed			Total
	Heavy Congested	Mild Congested	Free Flow	
Below 0.05	1071 (45.00%)	7187 (58.75%)	121475 (95.27%)	129733
0.05 - 0.10	202 (8.49%)	1000 (8.17%)	3943 (3.09%)	5145
Above 0.10	1107 (46.51%)	4047 (33.08%)	2082 (1.63%)	7236
Total	2380	12234	127500	142114

Table 17: Traffic Prediction Error (Relative) vs. Off Peak Period

Relative Predict Error	Observed Speed			Total
	Heavy Congested	Mild Congested	Free Flow	
Below 0.05	154 (26.10%)	4427 (60.12%)	207255 (96.39%)	211836
0.05 - 0.10	18 (3.05%)	599 (8.14%)	4706 (2.19%)	5323
Above 0.10	418 (70.85%)	2337 (31.74%)	3059 (1.42%)	5814
Total	590	7363	215020	222973

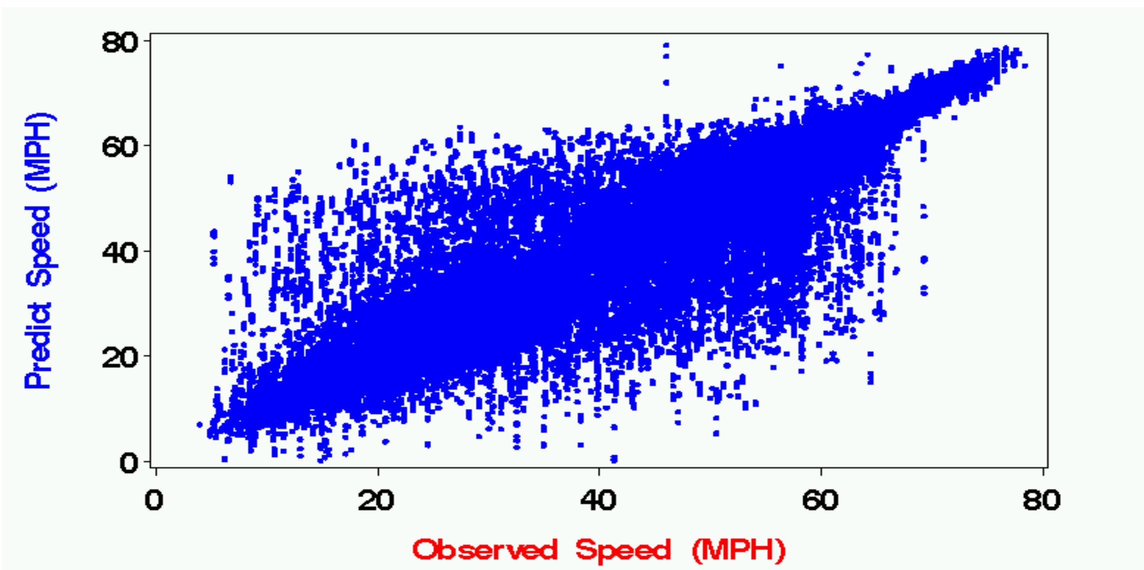


Figure 38: Speed Comparison (Observed vs. Predicted)

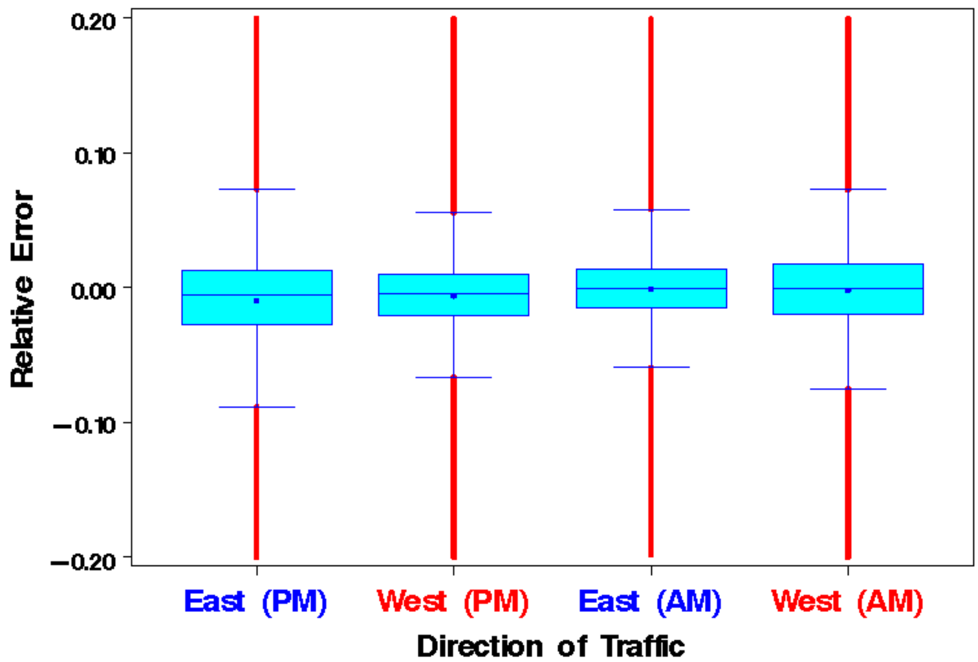


Figure 39: Relative Prediction Error

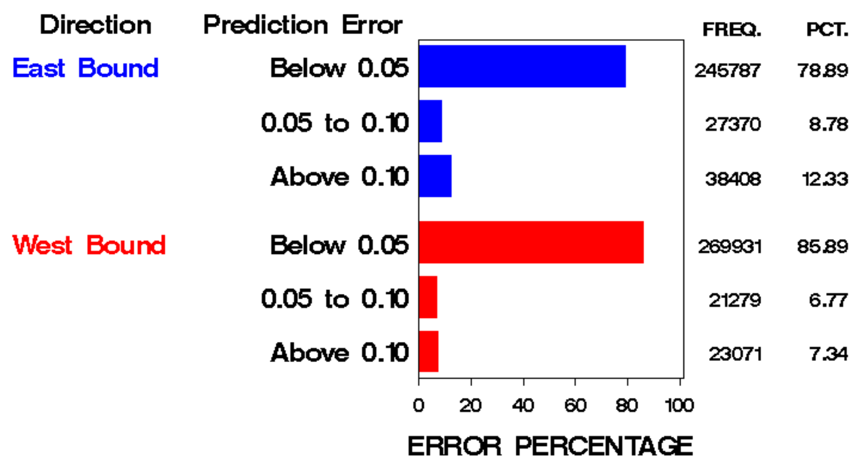


Figure 40: Traffic Direction Error (Eastbound vs. Westbound)

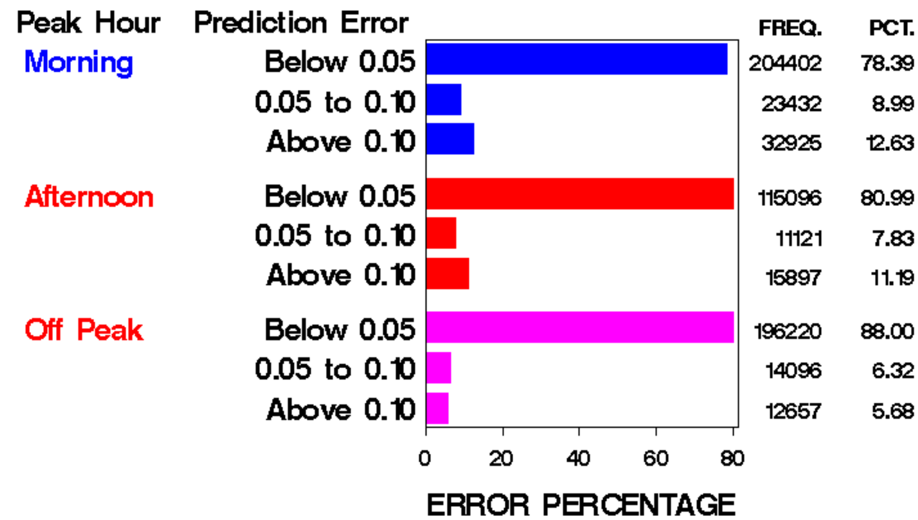


Figure 41: Traffic Prediction Error (Morning vs. Afternoon)

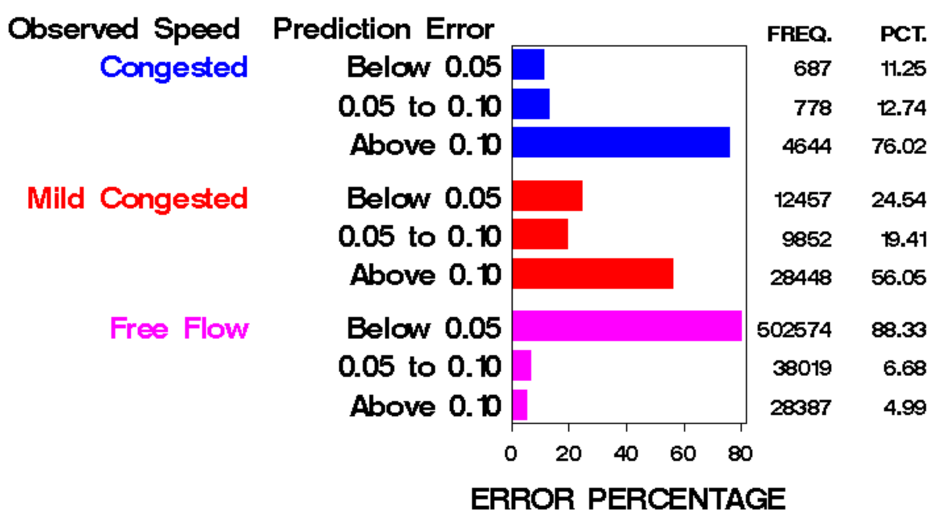


Figure 42: Traffic Prediction Error (Congested vs. Uncongested)

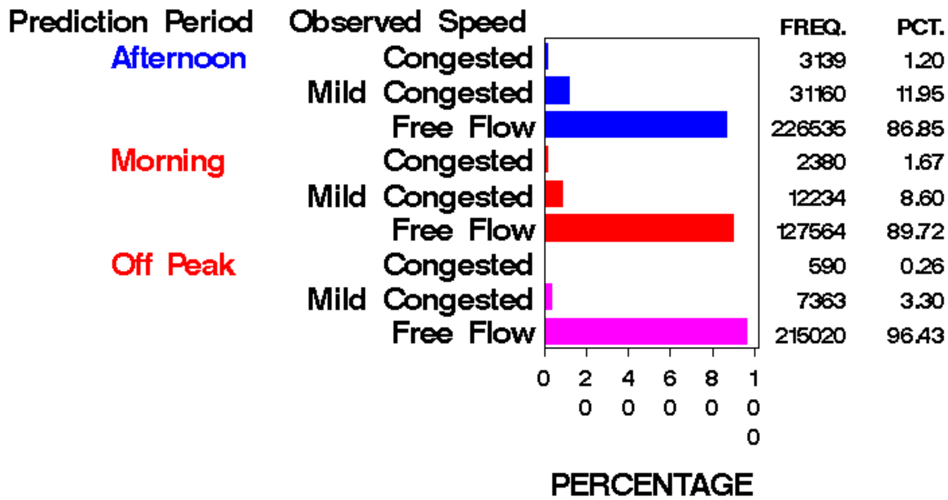


Figure 43: Traffic Prediction Error (Afternoon vs. Morning)

3 CONCLUSIONS

This volume of the report presented the research and development efforts to improve and validate the time-series short-term traffic prediction model on I-4. Several techniques were investigated such as the effect of decay factors and the use of multivariable traffic prediction methods. The traffic prediction system was also developed as a stand-alone module using MS Visual Basic 6.0. The developed module is capable of running in both off-line and on-line modes. Extensive testing using the developed module was also conducted to explore the impact of the model parameters and the traffic conditions on the performance of the model. It was found that the model performed very well except under heavy traffic congestion, due primarily to the rapid change and instability in traffic conditions. However, the model performance during congested conditions may be improved by incorporating the historical traffic information. This will result in one hybrid model that predicts traffic conditions using historical data and the most recent data to improve the accuracy of prediction. This is one focus for the continued research project supported by the Florida Department of Transportation.

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APPENDIX:

TRAFFIC PREDICTION ERRORS

Traffic Prediction						
Observed Speed Below 15 Miles						
Rolling Horizon	Rolling Step	Prediction Horizon	Prediction Step	Frequency	Average Relative Error	Standard Deviation
15 Minute	1 Minute	5 Minute	5 Minute	431	0.227	0.0565
15 Minute	1 Minute	5 Minute	10 Minute	217	0.228	0.1001
15 Minute	1 Minute	5 Minute	15 Minute	124	0.249	0.0990
15 Minute	1 Minute	10 Minute	5 Minute	296	0.281	0.0449
15 Minute	1 Minute	10 Minute	10 Minute	207	0.284	0.0488
15 Minute	1 Minute	10 Minute	15 Minute	196	0.296	0.0700
15 Minute	3 Minute	5 Minute	5 Minute	730	0.235	0.0378
15 Minute	3 Minute	5 Minute	10 Minute	287	0.216	0.0773
15 Minute	3 Minute	5 Minute	15 Minute	150	0.248	0.0836
15 Minute	5 Minute	5 Minute	5 Minute	530	0.218	0.0586
15 Minute	5 Minute	5 Minute	10 Minute	267	0.226	0.0996
15 Minute	5 Minute	5 Minute	15 Minute	180	0.226	0.1005
20 Minute	1 Minute	5 Minute	5 Minute	280	0.237	0.0501
20 Minute	1 Minute	5 Minute	10 Minute	340	0.186	0.0778
20 Minute	1 Minute	5 Minute	15 Minute	231	0.203	0.0954
20 Minute	1 Minute	10 Minute	5 Minute	294	0.285	0.0463
20 Minute	1 Minute	10 Minute	10 Minute	342	0.245	0.0539
20 Minute	1 Minute	10 Minute	15 Minute	219	0.252	0.0730
20 Minute	1 Minute	15 Minute	5 Minute	286	0.327	0.1093
20 Minute	1 Minute	15 Minute	10 Minute	325	0.301	0.0739
20 Minute	1 Minute	15 Minute	15 Minute	216	0.320	0.0862
20 Minute	3 Minute	5 Minute	5 Minute	411	0.224	0.0426
20 Minute	3 Minute	5 Minute	10 Minute	217	0.222	0.0767

20 Minute	3 Minute	5 Minute	15 Minute	150	0.232	0.0783
20 Minute	3 Minute	10 Minute	5 Minute	486	0.292	0.1703
20 Minute	3 Minute	10 Minute	10 Minute	247	0.315	0.2297
20 Minute	3 Minute	10 Minute	15 Minute	169	0.311	0.2767
20 Minute	5 Minute	5 Minute	5 Minute	530	0.229	0.0644
20 Minute	5 Minute	5 Minute	10 Minute	241	0.236	0.1016
20 Minute	5 Minute	5 Minute	15 Minute	150	0.252	0.0836
20 Minute	5 Minute	10 Minute	5 Minute	1177	0.243	0.0518
20 Minute	5 Minute	10 Minute	10 Minute	294	0.307	0.2572
20 Minute	5 Minute	10 Minute	15 Minute	201	0.328	0.3125
25 Minute	1 Minute	5 Minute	5 Minute	682	0.181	0.0476
25 Minute	1 Minute	5 Minute	10 Minute	340	0.182	0.0727
25 Minute	1 Minute	5 Minute	15 Minute	230	0.198	0.0912
25 Minute	1 Minute	10 Minute	5 Minute	670	0.239	0.0474
25 Minute	1 Minute	10 Minute	10 Minute	341	0.247	0.0547
25 Minute	1 Minute	10 Minute	15 Minute	219	0.253	0.0729
25 Minute	1 Minute	15 Minute	5 Minute	647	0.297	0.0718
25 Minute	1 Minute	15 Minute	10 Minute	325	0.299	0.0743
25 Minute	1 Minute	15 Minute	15 Minute	216	0.322	0.0878
25 Minute	3 Minute	5 Minute	5 Minute	432	0.237	0.0468
25 Minute	3 Minute	5 Minute	10 Minute	218	0.243	0.0874
25 Minute	3 Minute	5 Minute	15 Minute	150	0.260	0.0862
25 Minute	3 Minute	10 Minute	5 Minute	442	0.288	0.1931
25 Minute	3 Minute	10 Minute	10 Minute	183	0.309	0.2690
25 Minute	3 Minute	10 Minute	15 Minute	149	0.362	0.3647
25 Minute	3 Minute	15 Minute	5 Minute	409	0.329	0.1096

25 Minute	3 Minute	15 Minute	10 Minute	205	0.338	0.1156
25 Minute	3 Minute	15 Minute	15 Minute	141	0.371	0.1283
25 Minute	5 Minute	5 Minute	5 Minute	534	0.227	0.0612
25 Minute	5 Minute	5 Minute	10 Minute	271	0.235	0.1037
25 Minute	5 Minute	5 Minute	15 Minute	184	0.246	0.0935
25 Minute	5 Minute	10 Minute	5 Minute	586	0.300	0.1969
25 Minute	5 Minute	10 Minute	10 Minute	153	0.355	0.3724
25 Minute	5 Minute	10 Minute	15 Minute	201	0.335	0.3203
25 Minute	5 Minute	15 Minute	5 Minute	682	0.329	0.1146
25 Minute	5 Minute	15 Minute	10 Minute	256	0.323	0.1158
25 Minute	5 Minute	15 Minute	15 Minute	173	0.360	0.1376
30 Minute	1 Minute	5 Minute	5 Minute	681	0.183	0.0487
30 Minute	1 Minute	5 Minute	10 Minute	529	0.176	0.0676
30 Minute	1 Minute	5 Minute	15 Minute	230	0.199	0.0926
30 Minute	1 Minute	10 Minute	5 Minute	669	0.238	0.0480
30 Minute	1 Minute	10 Minute	10 Minute	341	0.246	0.0541
30 Minute	1 Minute	10 Minute	15 Minute	218	0.253	0.0727
30 Minute	1 Minute	15 Minute	5 Minute	646	0.298	0.0715
30 Minute	1 Minute	15 Minute	10 Minute	324	0.300	0.0752
30 Minute	1 Minute	15 Minute	15 Minute	216	0.323	0.0863
30 Minute	3 Minute	5 Minute	5 Minute	432	0.243	0.0508
30 Minute	3 Minute	5 Minute	10 Minute	218	0.245	0.0954
30 Minute	3 Minute	5 Minute	15 Minute	150	0.264	0.0841
30 Minute	3 Minute	10 Minute	5 Minute	358	0.297	0.1798
30 Minute	3 Minute	10 Minute	10 Minute	213	0.277	0.0583
30 Minute	3 Minute	10 Minute	15 Minute	144	0.263	0.0843

30 Minute	3 Minute	15 Minute	5 Minute	351	0.321	0.1170
30 Minute	3 Minute	15 Minute	10 Minute	205	0.324	0.1229
30 Minute	3 Minute	15 Minute	15 Minute	141	0.362	0.1369
30 Minute	5 Minute	5 Minute	5 Minute	600	0.232	0.0614
30 Minute	5 Minute	5 Minute	10 Minute	217	0.250	0.1088
30 Minute	5 Minute	5 Minute	15 Minute	150	0.261	0.0846
30 Minute	5 Minute	10 Minute	5 Minute	486	0.298	0.1787
30 Minute	5 Minute	10 Minute	10 Minute	213	0.283	0.0527
30 Minute	5 Minute	10 Minute	15 Minute	169	0.321	0.2910
30 Minute	5 Minute	15 Minute	5 Minute	409	0.322	0.1178
30 Minute	5 Minute	15 Minute	10 Minute	205	0.323	0.1297
30 Minute	5 Minute	15 Minute	15 Minute	141	0.369	0.1355

Traffic Prediction Observed Speed Between 15 and 30 Miles						
Rolling Horizon	Rolling Step	Prediction Horizon	Prediction Step	Frequency	Average relative Error	Standard Deviation
15 Minute	1 Minute	5 Minute	5 Minute	589	0.178	0.0830
15 Minute	1 Minute	5 Minute	10 Minute	289	0.173	0.0961
15 Minute	1 Minute	5 Minute	15 Minute	156	0.175	0.0973
15 Minute	1 Minute	10 Minute	5 Minute	451	0.199	0.0917
15 Minute	1 Minute	10 Minute	10 Minute	280	0.180	0.0986
15 Minute	1 Minute	10 Minute	15 Minute	294	0.184	0.0979
15 Minute	3 Minute	5 Minute	5 Minute	1037	0.190	0.0855
15 Minute	3 Minute	5 Minute	10 Minute	408	0.181	0.1033
15 Minute	3 Minute	5 Minute	15 Minute	186	0.163	0.0951
15 Minute	5 Minute	5 Minute	5 Minute	794	0.161	0.0806
15 Minute	5 Minute	5 Minute	10 Minute	395	0.155	0.0913
15 Minute	5 Minute	5 Minute	15 Minute	252	0.147	0.0905
20 Minute	1 Minute	5 Minute	5 Minute	448	0.197	0.0804
20 Minute	1 Minute	5 Minute	10 Minute	481	0.165	0.0802
20 Minute	1 Minute	5 Minute	15 Minute	306	0.161	0.0895
20 Minute	1 Minute	10 Minute	5 Minute	450	0.201	0.0925
20 Minute	1 Minute	10 Minute	10 Minute	474	0.193	0.0774
20 Minute	1 Minute	10 Minute	15 Minute	323	0.184	0.0966
20 Minute	1 Minute	15 Minute	5 Minute	457	0.213	0.1246
20 Minute	1 Minute	15 Minute	10 Minute	483	0.225	0.0989
20 Minute	1 Minute	15 Minute	15 Minute	316	0.218	0.1066
20 Minute	3 Minute	5 Minute	5 Minute	555	0.190	0.0818
20 Minute	3 Minute	5 Minute	10 Minute	289	0.180	0.1008

20 Minute	3 Minute	5 Minute	15 Minute	186	0.170	0.1006
20 Minute	3 Minute	10 Minute	5 Minute	710	0.200	0.1162
20 Minute	3 Minute	10 Minute	10 Minute	349	0.186	0.1051
20 Minute	3 Minute	10 Minute	15 Minute	237	0.179	0.1174
20 Minute	5 Minute	5 Minute	5 Minute	794	0.166	0.0813
20 Minute	5 Minute	5 Minute	10 Minute	390	0.157	0.0903
20 Minute	5 Minute	5 Minute	15 Minute	186	0.168	0.0914
20 Minute	5 Minute	10 Minute	5 Minute	1748	0.181	0.0845
20 Minute	5 Minute	10 Minute	10 Minute	455	0.175	0.1070
20 Minute	5 Minute	10 Minute	15 Minute	306	0.168	0.1180
25 Minute	1 Minute	5 Minute	5 Minute	959	0.166	0.0695
25 Minute	1 Minute	5 Minute	10 Minute	481	0.164	0.0805
25 Minute	1 Minute	5 Minute	15 Minute	306	0.159	0.0889
25 Minute	1 Minute	10 Minute	5 Minute	962	0.191	0.0736
25 Minute	1 Minute	10 Minute	10 Minute	474	0.193	0.0783
25 Minute	1 Minute	10 Minute	15 Minute	323	0.183	0.0970
25 Minute	1 Minute	15 Minute	5 Minute	973	0.225	0.0982
25 Minute	1 Minute	15 Minute	10 Minute	483	0.225	0.0994
25 Minute	1 Minute	15 Minute	15 Minute	316	0.217	0.1068
25 Minute	3 Minute	5 Minute	5 Minute	589	0.183	0.0833
25 Minute	3 Minute	5 Minute	10 Minute	289	0.174	0.0964
25 Minute	3 Minute	5 Minute	15 Minute	186	0.164	0.0882
25 Minute	3 Minute	10 Minute	5 Minute	667	0.210	0.1212
25 Minute	3 Minute	10 Minute	10 Minute	282	0.204	0.1107
25 Minute	3 Minute	10 Minute	15 Minute	192	0.167	0.1276
25 Minute	3 Minute	15 Minute	5 Minute	588	0.201	0.1324

25 Minute	3 Minute	15 Minute	10 Minute	290	0.194	0.1237
25 Minute	3 Minute	15 Minute	15 Minute	188	0.179	0.1265
25 Minute	5 Minute	5 Minute	5 Minute	794	0.169	0.0817
25 Minute	5 Minute	5 Minute	10 Minute	395	0.161	0.0919
25 Minute	5 Minute	5 Minute	15 Minute	252	0.154	0.0898
25 Minute	5 Minute	10 Minute	5 Minute	915	0.192	0.1194
25 Minute	5 Minute	10 Minute	10 Minute	234	0.163	0.1164
25 Minute	5 Minute	10 Minute	15 Minute	306	0.171	0.1158
25 Minute	5 Minute	15 Minute	5 Minute	1114	0.200	0.1288
25 Minute	5 Minute	15 Minute	10 Minute	384	0.185	0.1174
25 Minute	5 Minute	15 Minute	15 Minute	254	0.175	0.1196
30 Minute	1 Minute	5 Minute	5 Minute	959	0.167	0.0696
30 Minute	1 Minute	5 Minute	10 Minute	744	0.156	0.0751
30 Minute	1 Minute	5 Minute	15 Minute	306	0.160	0.0910
30 Minute	1 Minute	10 Minute	5 Minute	962	0.191	0.0736
30 Minute	1 Minute	10 Minute	10 Minute	474	0.193	0.0776
30 Minute	1 Minute	10 Minute	15 Minute	323	0.184	0.0966
30 Minute	1 Minute	15 Minute	5 Minute	973	0.225	0.0985
30 Minute	1 Minute	15 Minute	10 Minute	483	0.225	0.0995
30 Minute	1 Minute	15 Minute	15 Minute	316	0.218	0.1072
30 Minute	3 Minute	5 Minute	5 Minute	589	0.187	0.0902
30 Minute	3 Minute	5 Minute	10 Minute	289	0.175	0.1028
30 Minute	3 Minute	5 Minute	15 Minute	186	0.167	0.0965
30 Minute	3 Minute	10 Minute	5 Minute	579	0.215	0.1126
30 Minute	3 Minute	10 Minute	10 Minute	288	0.171	0.0968
30 Minute	3 Minute	10 Minute	15 Minute	190	0.163	0.1014

30 Minute	3 Minute	15 Minute	5 Minute	538	0.213	0.1289
30 Minute	3 Minute	15 Minute	10 Minute	290	0.194	0.1244
30 Minute	3 Minute	15 Minute	15 Minute	188	0.180	0.1287
30 Minute	5 Minute	5 Minute	5 Minute	882	0.174	0.0884
30 Minute	5 Minute	5 Minute	10 Minute	289	0.189	0.1125
30 Minute	5 Minute	5 Minute	15 Minute	186	0.185	0.1040
30 Minute	5 Minute	10 Minute	5 Minute	710	0.205	0.1208
30 Minute	5 Minute	10 Minute	10 Minute	288	0.177	0.0975
30 Minute	5 Minute	10 Minute	15 Minute	237	0.182	0.1211
30 Minute	5 Minute	15 Minute	5 Minute	588	0.202	0.1325
30 Minute	5 Minute	15 Minute	10 Minute	290	0.194	0.1213
30 Minute	5 Minute	15 Minute	15 Minute	188	0.180	0.1272

Traffic Prediction Observed Speed Between 30 and 45 Miles						
Rolling Horizon	Rolling Step	Prediction Horizon	Prediction Step	Frequency	Average relative Error	Standard Deviation
15 Minute	1 Minute	5 Minute	5 Minute	544	0.122	0.0726
15 Minute	1 Minute	5 Minute	10 Minute	272	0.125	0.0821
15 Minute	1 Minute	5 Minute	15 Minute	108	0.136	0.0901
15 Minute	1 Minute	10 Minute	5 Minute	276	0.147	0.0987
15 Minute	1 Minute	10 Minute	10 Minute	230	0.131	0.0940
15 Minute	1 Minute	10 Minute	15 Minute	166	0.146	0.0971
15 Minute	3 Minute	5 Minute	5 Minute	814	0.134	0.0824
15 Minute	3 Minute	5 Minute	10 Minute	361	0.137	0.0906
15 Minute	3 Minute	5 Minute	15 Minute	188	0.134	0.0894
15 Minute	5 Minute	5 Minute	5 Minute	802	0.115	0.0635
15 Minute	5 Minute	5 Minute	10 Minute	391	0.114	0.0743
15 Minute	5 Minute	5 Minute	15 Minute	272	0.119	0.0805
20 Minute	1 Minute	5 Minute	5 Minute	262	0.143	0.0845
20 Minute	1 Minute	5 Minute	10 Minute	254	0.127	0.0815
20 Minute	1 Minute	5 Minute	15 Minute	177	0.126	0.0826
20 Minute	1 Minute	10 Minute	5 Minute	274	0.148	0.0989
20 Minute	1 Minute	10 Minute	10 Minute	256	0.139	0.0850
20 Minute	1 Minute	10 Minute	15 Minute	164	0.138	0.0872
20 Minute	1 Minute	15 Minute	5 Minute	268	0.152	0.1103
20 Minute	1 Minute	15 Minute	10 Minute	271	0.161	0.0989
20 Minute	1 Minute	15 Minute	15 Minute	167	0.155	0.0996
20 Minute	3 Minute	5 Minute	5 Minute	469	0.132	0.0786
20 Minute	3 Minute	5 Minute	10 Minute	272	0.131	0.0853

20 Minute	3 Minute	5 Minute	15 Minute	188	0.138	0.0908
20 Minute	3 Minute	10 Minute	5 Minute	661	0.134	0.0984
20 Minute	3 Minute	10 Minute	10 Minute	322	0.137	0.1036
20 Minute	3 Minute	10 Minute	15 Minute	213	0.135	0.0915
20 Minute	5 Minute	5 Minute	5 Minute	802	0.121	0.0681
20 Minute	5 Minute	5 Minute	10 Minute	336	0.120	0.0791
20 Minute	5 Minute	5 Minute	15 Minute	188	0.137	0.0876
20 Minute	5 Minute	10 Minute	5 Minute	1373	0.129	0.0815
20 Minute	5 Minute	10 Minute	10 Minute	458	0.127	0.0942
20 Minute	5 Minute	10 Minute	15 Minute	300	0.128	0.0874
25 Minute	1 Minute	5 Minute	5 Minute	521	0.126	0.0737
25 Minute	1 Minute	5 Minute	10 Minute	254	0.127	0.0822
25 Minute	1 Minute	5 Minute	15 Minute	177	0.127	0.0832
25 Minute	1 Minute	10 Minute	5 Minute	527	0.139	0.0862
25 Minute	1 Minute	10 Minute	10 Minute	256	0.139	0.0850
25 Minute	1 Minute	10 Minute	15 Minute	164	0.138	0.0871
25 Minute	1 Minute	15 Minute	5 Minute	540	0.157	0.0994
25 Minute	1 Minute	15 Minute	10 Minute	271	0.161	0.0987
25 Minute	1 Minute	15 Minute	15 Minute	167	0.155	0.0995
25 Minute	3 Minute	5 Minute	5 Minute	545	0.129	0.0757
25 Minute	3 Minute	5 Minute	10 Minute	273	0.132	0.0837
25 Minute	3 Minute	5 Minute	15 Minute	188	0.138	0.0868
25 Minute	3 Minute	10 Minute	5 Minute	538	0.143	0.1084
25 Minute	3 Minute	10 Minute	10 Minute	172	0.155	0.1216
25 Minute	3 Minute	10 Minute	15 Minute	189	0.137	0.0945
25 Minute	3 Minute	15 Minute	5 Minute	593	0.133	0.0957

25 Minute	3 Minute	15 Minute	10 Minute	300	0.137	0.0958
25 Minute	3 Minute	15 Minute	15 Minute	195	0.139	0.0999
25 Minute	5 Minute	5 Minute	5 Minute	803	0.123	0.0694
25 Minute	5 Minute	5 Minute	10 Minute	392	0.123	0.0804
25 Minute	5 Minute	5 Minute	15 Minute	273	0.129	0.0823
25 Minute	5 Minute	10 Minute	5 Minute	926	0.132	0.0952
25 Minute	5 Minute	10 Minute	10 Minute	327	0.126	0.0960
25 Minute	5 Minute	10 Minute	15 Minute	300	0.136	0.0933
25 Minute	5 Minute	15 Minute	5 Minute	1087	0.133	0.0945
25 Minute	5 Minute	15 Minute	10 Minute	451	0.135	0.0906
25 Minute	5 Minute	15 Minute	15 Minute	291	0.135	0.0936
30 Minute	1 Minute	5 Minute	5 Minute	521	0.126	0.0731
30 Minute	1 Minute	5 Minute	10 Minute	378	0.121	0.0764
30 Minute	1 Minute	5 Minute	15 Minute	177	0.126	0.0834
30 Minute	1 Minute	10 Minute	5 Minute	527	0.139	0.0861
30 Minute	1 Minute	10 Minute	10 Minute	256	0.139	0.0844
30 Minute	1 Minute	10 Minute	15 Minute	164	0.138	0.0870
30 Minute	1 Minute	15 Minute	5 Minute	540	0.157	0.0999
30 Minute	1 Minute	15 Minute	10 Minute	271	0.161	0.0992
30 Minute	1 Minute	15 Minute	15 Minute	167	0.154	0.1004
30 Minute	3 Minute	5 Minute	5 Minute	545	0.131	0.0801
30 Minute	3 Minute	5 Minute	10 Minute	273	0.133	0.0868
30 Minute	3 Minute	5 Minute	15 Minute	188	0.138	0.0901
30 Minute	3 Minute	10 Minute	5 Minute	353	0.154	0.1141
30 Minute	3 Minute	10 Minute	10 Minute	281	0.127	0.0860
30 Minute	3 Minute	10 Minute	15 Minute	188	0.138	0.0978

30 Minute	3 Minute	15 Minute	5 Minute	433	0.143	0.1025
30 Minute	3 Minute	15 Minute	10 Minute	300	0.136	0.0966
30 Minute	3 Minute	15 Minute	15 Minute	195	0.138	0.1011
30 Minute	5 Minute	5 Minute	5 Minute	934	0.128	0.0702
30 Minute	5 Minute	5 Minute	10 Minute	272	0.137	0.0919
30 Minute	5 Minute	5 Minute	15 Minute	188	0.145	0.0928
30 Minute	5 Minute	10 Minute	5 Minute	661	0.137	0.1045
30 Minute	5 Minute	10 Minute	10 Minute	281	0.132	0.0889
30 Minute	5 Minute	10 Minute	15 Minute	213	0.140	0.1010
30 Minute	5 Minute	15 Minute	5 Minute	593	0.135	0.0979
30 Minute	5 Minute	15 Minute	10 Minute	300	0.138	0.0979
30 Minute	5 Minute	15 Minute	15 Minute	195	0.140	0.1017

Traffic Prediction Observed Speed Between 45 and 60 Miles						
Rolling Horizon	Rolling Step	Prediction Horizon	Prediction Step	Frequency	Average relative Error	Standard Deviation
15 Minute	1 Minute	5 Minute	5 Minute	6721	0.046	0.0442
15 Minute	1 Minute	5 Minute	10 Minute	3379	0.045	0.0441
15 Minute	1 Minute	5 Minute	15 Minute	1422	0.043	0.0438
15 Minute	1 Minute	10 Minute	5 Minute	2739	0.054	0.0706
15 Minute	1 Minute	10 Minute	10 Minute	3329	0.039	0.0551
15 Minute	1 Minute	10 Minute	15 Minute	1793	0.054	0.0715
15 Minute	3 Minute	5 Minute	5 Minute	9322	0.050	0.0524
15 Minute	3 Minute	5 Minute	10 Minute	3966	0.045	0.0485
15 Minute	3 Minute	5 Minute	15 Minute	2252	0.045	0.0481
15 Minute	5 Minute	5 Minute	5 Minute	9186	0.044	0.0418
15 Minute	5 Minute	5 Minute	10 Minute	4623	0.043	0.0421
15 Minute	5 Minute	5 Minute	15 Minute	3010	0.042	0.0422
20 Minute	1 Minute	5 Minute	5 Minute	2394	0.051	0.0528
20 Minute	1 Minute	5 Minute	10 Minute	2731	0.049	0.0489
20 Minute	1 Minute	5 Minute	15 Minute	1766	0.049	0.0497
20 Minute	1 Minute	10 Minute	5 Minute	2658	0.055	0.0710
20 Minute	1 Minute	10 Minute	10 Minute	2760	0.053	0.0673
20 Minute	1 Minute	10 Minute	15 Minute	1791	0.052	0.0687
20 Minute	1 Minute	15 Minute	5 Minute	2670	0.061	0.0879
20 Minute	1 Minute	15 Minute	10 Minute	2760	0.059	0.0824
20 Minute	1 Minute	15 Minute	15 Minute	1802	0.059	0.0839
20 Minute	3 Minute	5 Minute	5 Minute	6115	0.047	0.0459
20 Minute	3 Minute	5 Minute	10 Minute	3379	0.046	0.0449

20 Minute	3 Minute	5 Minute	15 Minute	2252	0.046	0.0459
20 Minute	3 Minute	10 Minute	5 Minute	8343	0.045	0.0587
20 Minute	3 Minute	10 Minute	10 Minute	4195	0.044	0.0593
20 Minute	3 Minute	10 Minute	15 Minute	2851	0.043	0.0588
20 Minute	5 Minute	5 Minute	5 Minute	9184	0.047	0.0474
20 Minute	5 Minute	5 Minute	10 Minute	3470	0.048	0.0504
20 Minute	5 Minute	5 Minute	15 Minute	2252	0.046	0.0492
20 Minute	5 Minute	10 Minute	5 Minute	14500	0.047	0.0589
20 Minute	5 Minute	10 Minute	10 Minute	5445	0.043	0.0565
20 Minute	5 Minute	10 Minute	15 Minute	3683	0.042	0.0579
25 Minute	1 Minute	5 Minute	5 Minute	5433	0.050	0.0482
25 Minute	1 Minute	5 Minute	10 Minute	2731	0.049	0.0492
25 Minute	1 Minute	5 Minute	15 Minute	1766	0.049	0.0496
25 Minute	1 Minute	10 Minute	5 Minute	5448	0.052	0.0652
25 Minute	1 Minute	10 Minute	10 Minute	2760	0.053	0.0675
25 Minute	1 Minute	10 Minute	15 Minute	1791	0.052	0.0686
25 Minute	1 Minute	15 Minute	5 Minute	5455	0.058	0.0813
25 Minute	1 Minute	15 Minute	10 Minute	2760	0.059	0.0820
25 Minute	1 Minute	15 Minute	15 Minute	1802	0.059	0.0838
25 Minute	3 Minute	5 Minute	5 Minute	6719	0.047	0.0483
25 Minute	3 Minute	5 Minute	10 Minute	3379	0.046	0.0477
25 Minute	3 Minute	5 Minute	15 Minute	2252	0.046	0.0484
25 Minute	3 Minute	10 Minute	5 Minute	6974	0.044	0.0601
25 Minute	3 Minute	10 Minute	10 Minute	2169	0.049	0.0673
25 Minute	3 Minute	10 Minute	15 Minute	2327	0.044	0.0586
25 Minute	3 Minute	15 Minute	5 Minute	6697	0.048	0.0717

25 Minute	3 Minute	15 Minute	10 Minute	3383	0.048	0.0716
25 Minute	3 Minute	15 Minute	15 Minute	2280	0.048	0.0722
25 Minute	5 Minute	5 Minute	5 Minute	9244	0.047	0.0467
25 Minute	5 Minute	5 Minute	10 Minute	4683	0.046	0.0464
25 Minute	5 Minute	5 Minute	15 Minute	3072	0.046	0.0470
25 Minute	5 Minute	10 Minute	5 Minute	10894	0.047	0.0609
25 Minute	5 Minute	10 Minute	10 Minute	4204	0.042	0.0541
25 Minute	5 Minute	10 Minute	15 Minute	3683	0.045	0.0618
25 Minute	5 Minute	15 Minute	5 Minute	10861	0.048	0.0696
25 Minute	5 Minute	15 Minute	10 Minute	4705	0.047	0.0667
25 Minute	5 Minute	15 Minute	15 Minute	3115	0.047	0.0677
30 Minute	1 Minute	5 Minute	5 Minute	5433	0.049	0.0481
30 Minute	1 Minute	5 Minute	10 Minute	4178	0.047	0.0473
30 Minute	1 Minute	5 Minute	15 Minute	1766	0.049	0.0498
30 Minute	1 Minute	10 Minute	5 Minute	5448	0.052	0.0651
30 Minute	1 Minute	10 Minute	10 Minute	2760	0.052	0.0671
30 Minute	1 Minute	10 Minute	15 Minute	1791	0.052	0.0684
30 Minute	1 Minute	15 Minute	5 Minute	5455	0.058	0.0812
30 Minute	1 Minute	15 Minute	10 Minute	2760	0.059	0.0818
30 Minute	1 Minute	15 Minute	15 Minute	1802	0.059	0.0836
30 Minute	3 Minute	5 Minute	5 Minute	6717	0.048	0.0488
30 Minute	3 Minute	5 Minute	10 Minute	3377	0.046	0.0476
30 Minute	3 Minute	5 Minute	15 Minute	2250	0.046	0.0487
30 Minute	3 Minute	10 Minute	5 Minute	4285	0.049	0.0662
30 Minute	3 Minute	10 Minute	10 Minute	3389	0.046	0.0591
30 Minute	3 Minute	10 Minute	15 Minute	2267	0.044	0.0589

30 Minute	3 Minute	15 Minute	5 Minute	4875	0.047	0.0731
30 Minute	3 Minute	15 Minute	10 Minute	3383	0.048	0.0703
30 Minute	3 Minute	15 Minute	15 Minute	2280	0.048	0.0710
30 Minute	5 Minute	5 Minute	5 Minute	10737	0.047	0.0468
30 Minute	5 Minute	5 Minute	10 Minute	3377	0.049	0.0517
30 Minute	5 Minute	5 Minute	15 Minute	2250	0.049	0.0515
30 Minute	5 Minute	10 Minute	5 Minute	8341	0.046	0.0623
30 Minute	5 Minute	10 Minute	10 Minute	3391	0.048	0.0626
30 Minute	5 Minute	10 Minute	15 Minute	2851	0.045	0.0623
30 Minute	5 Minute	15 Minute	5 Minute	6697	0.050	0.0746
30 Minute	5 Minute	15 Minute	10 Minute	3383	0.050	0.0736
30 Minute	5 Minute	15 Minute	15 Minute	2280	0.050	0.0753

Traffic Prediction Observed Speed Greater Than 60 Miles						
Rolling Horizon	Rolling Step	Prediction Horizon	Prediction Step	Frequency	Average relative Error	Standard Deviation
15 Minute	1 Minute	5 Minute	5 Minute	3075	0.030	0.0312
15 Minute	1 Minute	5 Minute	10 Minute	1571	0.029	0.0297
15 Minute	1 Minute	5 Minute	15 Minute	664	0.027	0.0295
15 Minute	1 Minute	10 Minute	5 Minute	1340	0.026	0.0411
15 Minute	1 Minute	10 Minute	10 Minute	1378	0.022	0.0306
15 Minute	1 Minute	10 Minute	15 Minute	911	0.028	0.0479
15 Minute	3 Minute	5 Minute	5 Minute	4351	0.030	0.0359
15 Minute	3 Minute	5 Minute	10 Minute	1832	0.028	0.0309
15 Minute	3 Minute	5 Minute	15 Minute	1076	0.028	0.0333
15 Minute	5 Minute	5 Minute	5 Minute	5340	0.028	0.0291
15 Minute	5 Minute	5 Minute	10 Minute	2704	0.027	0.0282
15 Minute	5 Minute	5 Minute	15 Minute	1798	0.027	0.0283
20 Minute	1 Minute	5 Minute	5 Minute	1102	0.029	0.0354
20 Minute	1 Minute	5 Minute	10 Minute	1168	0.038	0.0431
20 Minute	1 Minute	5 Minute	15 Minute	768	0.036	0.0430
20 Minute	1 Minute	10 Minute	5 Minute	1316	0.026	0.0413
20 Minute	1 Minute	10 Minute	10 Minute	1146	0.035	0.0563
20 Minute	1 Minute	10 Minute	15 Minute	753	0.035	0.0593
20 Minute	1 Minute	15 Minute	5 Minute	1311	0.026	0.0466
20 Minute	1 Minute	15 Minute	10 Minute	1139	0.037	0.0671
20 Minute	1 Minute	15 Minute	15 Minute	749	0.036	0.0670
20 Minute	3 Minute	5 Minute	5 Minute	2750	0.030	0.0297
20 Minute	3 Minute	5 Minute	10 Minute	1571	0.029	0.0301

20 Minute	3 Minute	5 Minute	15 Minute	1076	0.029	0.0315
20 Minute	3 Minute	10 Minute	5 Minute	3852	0.025	0.0358
20 Minute	3 Minute	10 Minute	10 Minute	1961	0.024	0.0332
20 Minute	3 Minute	10 Minute	15 Minute	1344	0.025	0.0383
20 Minute	5 Minute	5 Minute	5 Minute	5340	0.030	0.0318
20 Minute	5 Minute	5 Minute	10 Minute	2617	0.030	0.0326
20 Minute	5 Minute	5 Minute	15 Minute	1076	0.028	0.0330
20 Minute	5 Minute	10 Minute	5 Minute	7410	0.027	0.0401
20 Minute	5 Minute	10 Minute	10 Minute	3074	0.024	0.0345
20 Minute	5 Minute	10 Minute	15 Minute	2084	0.025	0.0381
25 Minute	1 Minute	5 Minute	5 Minute	2249	0.036	0.0433
25 Minute	1 Minute	5 Minute	10 Minute	1168	0.037	0.0434
25 Minute	1 Minute	5 Minute	15 Minute	767	0.036	0.0437
25 Minute	1 Minute	10 Minute	5 Minute	2243	0.034	0.0544
25 Minute	1 Minute	10 Minute	10 Minute	1145	0.034	0.0568
25 Minute	1 Minute	10 Minute	15 Minute	753	0.035	0.0595
25 Minute	1 Minute	15 Minute	5 Minute	2237	0.035	0.0647
25 Minute	1 Minute	15 Minute	10 Minute	1139	0.037	0.0670
25 Minute	1 Minute	15 Minute	15 Minute	749	0.036	0.0669
25 Minute	3 Minute	5 Minute	5 Minute	3075	0.029	0.0310
25 Minute	3 Minute	5 Minute	10 Minute	1571	0.029	0.0326
25 Minute	3 Minute	5 Minute	15 Minute	1076	0.028	0.0333
25 Minute	3 Minute	10 Minute	5 Minute	3097	0.026	0.0379
25 Minute	3 Minute	10 Minute	10 Minute	1084	0.025	0.0402
25 Minute	3 Minute	10 Minute	15 Minute	1093	0.025	0.0365
25 Minute	3 Minute	15 Minute	5 Minute	3077	0.024	0.0363

25 Minute	3 Minute	15 Minute	10 Minute	1552	0.023	0.0364
25 Minute	3 Minute	15 Minute	15 Minute	1050	0.024	0.0381
25 Minute	5 Minute	5 Minute	5 Minute	5373	0.030	0.0315
25 Minute	5 Minute	5 Minute	10 Minute	2737	0.029	0.0307
25 Minute	5 Minute	5 Minute	15 Minute	1831	0.029	0.0312
25 Minute	5 Minute	10 Minute	5 Minute	6121	0.027	0.0390
25 Minute	5 Minute	10 Minute	10 Minute	2460	0.026	0.0366
25 Minute	5 Minute	10 Minute	15 Minute	2084	0.027	0.0420
25 Minute	5 Minute	15 Minute	5 Minute	5970	0.024	0.0378
25 Minute	5 Minute	15 Minute	10 Minute	2686	0.024	0.0399
25 Minute	5 Minute	15 Minute	15 Minute	1781	0.024	0.0402
30 Minute	1 Minute	5 Minute	5 Minute	2248	0.036	0.0433
30 Minute	1 Minute	5 Minute	10 Minute	1671	0.040	0.0454
30 Minute	1 Minute	5 Minute	15 Minute	767	0.035	0.0433
30 Minute	1 Minute	10 Minute	5 Minute	2242	0.034	0.0545
30 Minute	1 Minute	10 Minute	10 Minute	1145	0.034	0.0568
30 Minute	1 Minute	10 Minute	15 Minute	752	0.034	0.0598
30 Minute	1 Minute	15 Minute	5 Minute	2236	0.035	0.0647
30 Minute	1 Minute	15 Minute	10 Minute	1138	0.037	0.0668
30 Minute	1 Minute	15 Minute	15 Minute	749	0.036	0.0669
30 Minute	3 Minute	5 Minute	5 Minute	3075	0.029	0.0303
30 Minute	3 Minute	5 Minute	10 Minute	1571	0.029	0.0313
30 Minute	3 Minute	5 Minute	15 Minute	1076	0.028	0.0337
30 Minute	3 Minute	10 Minute	5 Minute	2105	0.027	0.0417
30 Minute	3 Minute	10 Minute	10 Minute	1557	0.024	0.0305
30 Minute	3 Minute	10 Minute	15 Minute	1063	0.025	0.0358

30 Minute	3 Minute	15 Minute	5 Minute	2091	0.023	0.0382
30 Minute	3 Minute	15 Minute	10 Minute	1552	0.023	0.0358
30 Minute	3 Minute	15 Minute	15 Minute	1050	0.024	0.0376
30 Minute	5 Minute	5 Minute	5 Minute	7223	0.029	0.0286
30 Minute	5 Minute	5 Minute	10 Minute	1571	0.030	0.0329
30 Minute	5 Minute	5 Minute	15 Minute	1076	0.031	0.0353
30 Minute	5 Minute	10 Minute	5 Minute	3852	0.026	0.0378
30 Minute	5 Minute	10 Minute	10 Minute	1557	0.025	0.0333
30 Minute	5 Minute	10 Minute	15 Minute	1344	0.026	0.0423
30 Minute	5 Minute	15 Minute	5 Minute	3077	0.025	0.0381
30 Minute	5 Minute	15 Minute	10 Minute	1552	0.024	0.0381
30 Minute	5 Minute	15 Minute	15 Minute	1050	0.025	0.0405

Traffic Prediction Predicted Speed Below 15 Miles						
Rolling Horizon	Rolling Step	Prediction Horizon	Prediction Step	Frequency	Average Relative Error	Standard Deviation
15 Minute	1 Minute	5 Minute	5 Minute	438	0.228	0.0546
15 Minute	1 Minute	5 Minute	10 Minute	220	0.222	0.0771
15 Minute	1 Minute	5 Minute	15 Minute	120	0.263	0.0950
15 Minute	1 Minute	10 Minute	5 Minute	298	0.285	0.0532
15 Minute	1 Minute	10 Minute	10 Minute	209	0.300	0.0607
15 Minute	1 Minute	10 Minute	15 Minute	198	0.308	0.0907
15 Minute	3 Minute	5 Minute	5 Minute	750	0.247	0.0502
15 Minute	3 Minute	5 Minute	10 Minute	297	0.248	0.0897
15 Minute	3 Minute	5 Minute	15 Minute	150	0.267	0.0963
15 Minute	5 Minute	5 Minute	5 Minute	530	0.221	0.0594
15 Minute	5 Minute	5 Minute	10 Minute	266	0.223	0.0777
15 Minute	5 Minute	5 Minute	15 Minute	172	0.232	0.1080
20 Minute	1 Minute	5 Minute	5 Minute	286	0.242	0.0539
20 Minute	1 Minute	5 Minute	10 Minute	350	0.184	0.0717
20 Minute	1 Minute	5 Minute	15 Minute	229	0.210	0.0934
20 Minute	1 Minute	10 Minute	5 Minute	296	0.288	0.0544
20 Minute	1 Minute	10 Minute	10 Minute	343	0.250	0.0604
20 Minute	1 Minute	10 Minute	15 Minute	225	0.262	0.0857
20 Minute	1 Minute	15 Minute	5 Minute	289	0.337	0.1133
20 Minute	1 Minute	15 Minute	10 Minute	331	0.306	0.0848
20 Minute	1 Minute	15 Minute	15 Minute	216	0.327	0.0952
20 Minute	3 Minute	5 Minute	5 Minute	429	0.236	0.0609
20 Minute	3 Minute	5 Minute	10 Minute	227	0.246	0.0872

20 Minute	3 Minute	5 Minute	15 Minute	151	0.263	0.1118
20 Minute	3 Minute	10 Minute	5 Minute	501	0.298	0.1063
20 Minute	3 Minute	10 Minute	10 Minute	249	0.296	0.0864
20 Minute	3 Minute	10 Minute	15 Minute	171	0.281	0.0980
20 Minute	5 Minute	5 Minute	5 Minute	553	0.243	0.0735
20 Minute	5 Minute	5 Minute	10 Minute	250	0.252	0.0928
20 Minute	5 Minute	5 Minute	15 Minute	152	0.263	0.0795
20 Minute	5 Minute	10 Minute	5 Minute	1177	0.246	0.0557
20 Minute	5 Minute	10 Minute	10 Minute	294	0.286	0.0861
20 Minute	5 Minute	10 Minute	15 Minute	199	0.293	0.1105
25 Minute	1 Minute	5 Minute	5 Minute	683	0.182	0.0503
25 Minute	1 Minute	5 Minute	10 Minute	349	0.179	0.0698
25 Minute	1 Minute	5 Minute	15 Minute	225	0.203	0.0916
25 Minute	1 Minute	10 Minute	5 Minute	672	0.241	0.0501
25 Minute	1 Minute	10 Minute	10 Minute	343	0.252	0.0602
25 Minute	1 Minute	10 Minute	15 Minute	223	0.261	0.0800
25 Minute	1 Minute	15 Minute	5 Minute	654	0.300	0.0765
25 Minute	1 Minute	15 Minute	10 Minute	333	0.307	0.0862
25 Minute	1 Minute	15 Minute	15 Minute	216	0.328	0.1008
25 Minute	3 Minute	5 Minute	5 Minute	440	0.246	0.0537
25 Minute	3 Minute	5 Minute	10 Minute	224	0.261	0.0826
25 Minute	3 Minute	5 Minute	15 Minute	147	0.270	0.0928
25 Minute	3 Minute	10 Minute	5 Minute	455	0.301	0.1279
25 Minute	3 Minute	10 Minute	10 Minute	184	0.286	0.1008
25 Minute	3 Minute	10 Minute	15 Minute	151	0.314	0.1150
25 Minute	3 Minute	15 Minute	5 Minute	420	0.331	0.1138

25 Minute	3 Minute	15 Minute	10 Minute	211	0.342	0.1282
25 Minute	3 Minute	15 Minute	15 Minute	145	0.372	0.1355
25 Minute	5 Minute	5 Minute	5 Minute	558	0.244	0.0719
25 Minute	5 Minute	5 Minute	10 Minute	284	0.257	0.0931
25 Minute	5 Minute	5 Minute	15 Minute	185	0.263	0.0945
25 Minute	5 Minute	10 Minute	5 Minute	609	0.315	0.1284
25 Minute	5 Minute	10 Minute	10 Minute	156	0.297	0.0955
25 Minute	5 Minute	10 Minute	15 Minute	207	0.302	0.1095
25 Minute	5 Minute	15 Minute	5 Minute	676	0.342	0.1198
25 Minute	5 Minute	15 Minute	10 Minute	259	0.341	0.1250
25 Minute	5 Minute	15 Minute	15 Minute	172	0.373	0.1512
30 Minute	1 Minute	5 Minute	5 Minute	685	0.184	0.0522
30 Minute	1 Minute	5 Minute	10 Minute	548	0.174	0.0671
30 Minute	1 Minute	5 Minute	15 Minute	225	0.206	0.0932
30 Minute	1 Minute	10 Minute	5 Minute	677	0.242	0.0529
30 Minute	1 Minute	10 Minute	10 Minute	348	0.252	0.0622
30 Minute	1 Minute	10 Minute	15 Minute	224	0.264	0.0808
30 Minute	1 Minute	15 Minute	5 Minute	660	0.299	0.0757
30 Minute	1 Minute	15 Minute	10 Minute	332	0.303	0.0862
30 Minute	1 Minute	15 Minute	15 Minute	220	0.325	0.0983
30 Minute	3 Minute	5 Minute	5 Minute	449	0.259	0.0709
30 Minute	3 Minute	5 Minute	10 Minute	227	0.267	0.0897
30 Minute	3 Minute	5 Minute	15 Minute	151	0.283	0.0904
30 Minute	3 Minute	10 Minute	5 Minute	374	0.312	0.1255
30 Minute	3 Minute	10 Minute	10 Minute	216	0.308	0.0825
30 Minute	3 Minute	10 Minute	15 Minute	146	0.316	0.1053

30 Minute	3 Minute	15 Minute	5 Minute	360	0.327	0.1171
30 Minute	3 Minute	15 Minute	10 Minute	213	0.334	0.1273
30 Minute	3 Minute	15 Minute	15 Minute	144	0.365	0.1422
30 Minute	5 Minute	5 Minute	5 Minute	628	0.259	0.0924
30 Minute	5 Minute	5 Minute	10 Minute	234	0.279	0.1289
30 Minute	5 Minute	5 Minute	15 Minute	157	0.292	0.1155
30 Minute	5 Minute	10 Minute	5 Minute	511	0.315	0.1230
30 Minute	5 Minute	10 Minute	10 Minute	220	0.310	0.0664
30 Minute	5 Minute	10 Minute	15 Minute	170	0.309	0.1007
30 Minute	5 Minute	15 Minute	5 Minute	426	0.330	0.1163
30 Minute	5 Minute	15 Minute	10 Minute	214	0.341	0.1287
30 Minute	5 Minute	15 Minute	15 Minute	148	0.387	0.1324

Traffic Prediction Predicted Speed Between 15 and 30 Miles						
Rolling Horizon	Rolling Step	Prediction Horizon	Prediction Step	Frequency	Average relative Error	Standard Deviation
15 Minute	1 Minute	5 Minute	5 Minute	603	0.180	0.0801
15 Minute	1 Minute	5 Minute	10 Minute	305	0.173	0.0947
15 Minute	1 Minute	5 Minute	15 Minute	166	0.175	0.0852
15 Minute	1 Minute	10 Minute	5 Minute	472	0.200	0.0915
15 Minute	1 Minute	10 Minute	10 Minute	291	0.182	0.0989
15 Minute	1 Minute	10 Minute	15 Minute	302	0.181	0.0957
15 Minute	3 Minute	5 Minute	5 Minute	1108	0.191	0.0816
15 Minute	3 Minute	5 Minute	10 Minute	448	0.182	0.0988
15 Minute	3 Minute	5 Minute	15 Minute	203	0.168	0.0919
15 Minute	5 Minute	5 Minute	5 Minute	795	0.162	0.0777
15 Minute	5 Minute	5 Minute	10 Minute	394	0.156	0.0901
15 Minute	5 Minute	5 Minute	15 Minute	261	0.148	0.0851
20 Minute	1 Minute	5 Minute	5 Minute	464	0.196	0.0772
20 Minute	1 Minute	5 Minute	10 Minute	482	0.167	0.0798
20 Minute	1 Minute	5 Minute	15 Minute	311	0.160	0.0832
20 Minute	1 Minute	10 Minute	5 Minute	473	0.200	0.0906
20 Minute	1 Minute	10 Minute	10 Minute	491	0.196	0.0781
20 Minute	1 Minute	10 Minute	15 Minute	322	0.182	0.0914
20 Minute	1 Minute	15 Minute	5 Minute	483	0.207	0.1133
20 Minute	1 Minute	15 Minute	10 Minute	490	0.223	0.0928
20 Minute	1 Minute	15 Minute	15 Minute	329	0.219	0.1029
20 Minute	3 Minute	5 Minute	5 Minute	571	0.188	0.0763
20 Minute	3 Minute	5 Minute	10 Minute	300	0.176	0.0940

20 Minute	3 Minute	5 Minute	15 Minute	195	0.170	0.0879
20 Minute	3 Minute	10 Minute	5 Minute	732	0.200	0.1087
20 Minute	3 Minute	10 Minute	10 Minute	367	0.189	0.1023
20 Minute	3 Minute	10 Minute	15 Minute	242	0.176	0.1002
20 Minute	5 Minute	5 Minute	5 Minute	843	0.168	0.0791
20 Minute	5 Minute	5 Minute	10 Minute	420	0.159	0.0919
20 Minute	5 Minute	5 Minute	15 Minute	205	0.172	0.0932
20 Minute	5 Minute	10 Minute	5 Minute	1776	0.183	0.0837
20 Minute	5 Minute	10 Minute	10 Minute	461	0.178	0.1000
20 Minute	5 Minute	10 Minute	15 Minute	299	0.165	0.0955
25 Minute	1 Minute	5 Minute	5 Minute	981	0.168	0.0672
25 Minute	1 Minute	5 Minute	10 Minute	481	0.167	0.0798
25 Minute	1 Minute	5 Minute	15 Minute	313	0.158	0.0831
25 Minute	1 Minute	10 Minute	5 Minute	994	0.193	0.0727
25 Minute	1 Minute	10 Minute	10 Minute	492	0.196	0.0792
25 Minute	1 Minute	10 Minute	15 Minute	322	0.182	0.0935
25 Minute	1 Minute	15 Minute	5 Minute	1005	0.225	0.0932
25 Minute	1 Minute	15 Minute	10 Minute	495	0.224	0.0943
25 Minute	1 Minute	15 Minute	15 Minute	334	0.218	0.1029
25 Minute	3 Minute	5 Minute	5 Minute	595	0.185	0.0811
25 Minute	3 Minute	5 Minute	10 Minute	295	0.178	0.0964
25 Minute	3 Minute	5 Minute	15 Minute	194	0.171	0.0887
25 Minute	3 Minute	10 Minute	5 Minute	693	0.205	0.1078
25 Minute	3 Minute	10 Minute	10 Minute	297	0.204	0.0974
25 Minute	3 Minute	10 Minute	15 Minute	197	0.162	0.0926
25 Minute	3 Minute	15 Minute	5 Minute	609	0.199	0.1220

25 Minute	3 Minute	15 Minute	10 Minute	302	0.194	0.1161
25 Minute	3 Minute	15 Minute	15 Minute	196	0.180	0.1203
25 Minute	5 Minute	5 Minute	5 Minute	832	0.170	0.0793
25 Minute	5 Minute	5 Minute	10 Minute	418	0.161	0.0921
25 Minute	5 Minute	5 Minute	15 Minute	277	0.157	0.0881
25 Minute	5 Minute	10 Minute	5 Minute	956	0.192	0.1082
25 Minute	5 Minute	10 Minute	10 Minute	234	0.167	0.1059
25 Minute	5 Minute	10 Minute	15 Minute	320	0.172	0.0961
25 Minute	5 Minute	15 Minute	5 Minute	1127	0.199	0.1208
25 Minute	5 Minute	15 Minute	10 Minute	398	0.188	0.1134
25 Minute	5 Minute	15 Minute	15 Minute	262	0.179	0.1160
30 Minute	1 Minute	5 Minute	5 Minute	976	0.169	0.0665
30 Minute	1 Minute	5 Minute	10 Minute	730	0.159	0.0733
30 Minute	1 Minute	5 Minute	15 Minute	312	0.159	0.0831
30 Minute	1 Minute	10 Minute	5 Minute	988	0.192	0.0722
30 Minute	1 Minute	10 Minute	10 Minute	487	0.195	0.0776
30 Minute	1 Minute	10 Minute	15 Minute	320	0.181	0.0920
30 Minute	1 Minute	15 Minute	5 Minute	998	0.225	0.0935
30 Minute	1 Minute	15 Minute	10 Minute	494	0.225	0.0948
30 Minute	1 Minute	15 Minute	15 Minute	329	0.219	0.1036
30 Minute	3 Minute	5 Minute	5 Minute	595	0.188	0.0860
30 Minute	3 Minute	5 Minute	10 Minute	302	0.174	0.1004
30 Minute	3 Minute	5 Minute	15 Minute	193	0.169	0.0940
30 Minute	3 Minute	10 Minute	5 Minute	589	0.210	0.0989
30 Minute	3 Minute	10 Minute	10 Minute	303	0.173	0.0923
30 Minute	3 Minute	10 Minute	15 Minute	197	0.163	0.0932

30 Minute	3 Minute	15 Minute	5 Minute	570	0.209	0.1189
30 Minute	3 Minute	15 Minute	10 Minute	302	0.193	0.1171
30 Minute	3 Minute	15 Minute	15 Minute	198	0.183	0.1223
30 Minute	5 Minute	5 Minute	5 Minute	895	0.171	0.0828
30 Minute	5 Minute	5 Minute	10 Minute	295	0.183	0.1040
30 Minute	5 Minute	5 Minute	15 Minute	191	0.182	0.0946
30 Minute	5 Minute	10 Minute	5 Minute	735	0.204	0.1085
30 Minute	5 Minute	10 Minute	10 Minute	313	0.181	0.0946
30 Minute	5 Minute	10 Minute	15 Minute	251	0.181	0.0969
30 Minute	5 Minute	15 Minute	5 Minute	614	0.201	0.1221
30 Minute	5 Minute	15 Minute	10 Minute	310	0.194	0.1114
30 Minute	5 Minute	15 Minute	15 Minute	197	0.180	0.1167

Traffic Prediction

Predicted Speed Between 30 and 45 Miles

Rolling Horizon	Rolling Step	Prediction Horizon	Prediction Step	Frequency	Average relative Error	Standard Deviation
15 Minute	1 Minute	5 Minute	5 Minute	540	0.123	0.0768
15 Minute	1 Minute	5 Minute	10 Minute	267	0.124	0.0872
15 Minute	1 Minute	5 Minute	15 Minute	113	0.133	0.1042
15 Minute	1 Minute	10 Minute	5 Minute	295	0.153	0.1025
15 Minute	1 Minute	10 Minute	10 Minute	249	0.130	0.0909
15 Minute	1 Minute	10 Minute	15 Minute	198	0.151	0.1029
15 Minute	3 Minute	5 Minute	5 Minute	847	0.133	0.0856
15 Minute	3 Minute	5 Minute	10 Minute	376	0.125	0.0884
15 Minute	3 Minute	5 Minute	15 Minute	193	0.128	0.0873
15 Minute	5 Minute	5 Minute	5 Minute	805	0.118	0.0684
15 Minute	5 Minute	5 Minute	10 Minute	416	0.116	0.0790
15 Minute	5 Minute	5 Minute	15 Minute	275	0.123	0.0866
20 Minute	1 Minute	5 Minute	5 Minute	261	0.143	0.0904
20 Minute	1 Minute	5 Minute	10 Minute	266	0.126	0.0849
20 Minute	1 Minute	5 Minute	15 Minute	185	0.132	0.0916
20 Minute	1 Minute	10 Minute	5 Minute	290	0.156	0.1054
20 Minute	1 Minute	10 Minute	10 Minute	271	0.144	0.0830
20 Minute	1 Minute	10 Minute	15 Minute	178	0.147	0.0976
20 Minute	1 Minute	15 Minute	5 Minute	294	0.180	0.1365
20 Minute	1 Minute	15 Minute	10 Minute	283	0.184	0.1137
20 Minute	1 Minute	15 Minute	15 Minute	180	0.169	0.1027
20 Minute	3 Minute	5 Minute	5 Minute	502	0.129	0.0819
20 Minute	3 Minute	5 Minute	10 Minute	287	0.128	0.0886

20 Minute	3 Minute	5 Minute	15 Minute	199	0.135	0.0919
20 Minute	3 Minute	10 Minute	5 Minute	674	0.142	0.1180
20 Minute	3 Minute	10 Minute	10 Minute	332	0.142	0.1315
20 Minute	3 Minute	10 Minute	15 Minute	231	0.148	0.1499
20 Minute	5 Minute	5 Minute	5 Minute	862	0.121	0.0679
20 Minute	5 Minute	5 Minute	10 Minute	377	0.118	0.0739
20 Minute	5 Minute	5 Minute	15 Minute	200	0.133	0.0832
20 Minute	5 Minute	10 Minute	5 Minute	1376	0.140	0.0870
20 Minute	5 Minute	10 Minute	10 Minute	456	0.134	0.1249
20 Minute	5 Minute	10 Minute	15 Minute	325	0.141	0.1448
25 Minute	1 Minute	5 Minute	5 Minute	535	0.130	0.0773
25 Minute	1 Minute	5 Minute	10 Minute	267	0.128	0.0852
25 Minute	1 Minute	5 Minute	15 Minute	189	0.134	0.0912
25 Minute	1 Minute	10 Minute	5 Minute	538	0.153	0.0920
25 Minute	1 Minute	10 Minute	10 Minute	266	0.144	0.0831
25 Minute	1 Minute	10 Minute	15 Minute	179	0.146	0.0976
25 Minute	1 Minute	15 Minute	5 Minute	565	0.183	0.1166
25 Minute	1 Minute	15 Minute	10 Minute	278	0.181	0.1096
25 Minute	1 Minute	15 Minute	15 Minute	179	0.168	0.0999
25 Minute	3 Minute	5 Minute	5 Minute	579	0.131	0.0777
25 Minute	3 Minute	5 Minute	10 Minute	293	0.125	0.0806
25 Minute	3 Minute	5 Minute	15 Minute	204	0.133	0.0853
25 Minute	3 Minute	10 Minute	5 Minute	558	0.154	0.1354
25 Minute	3 Minute	10 Minute	10 Minute	188	0.161	0.1738
25 Minute	3 Minute	10 Minute	15 Minute	197	0.141	0.1669
25 Minute	3 Minute	15 Minute	5 Minute	590	0.154	0.1193

25 Minute	3 Minute	15 Minute	10 Minute	304	0.152	0.1083
25 Minute	3 Minute	15 Minute	15 Minute	197	0.147	0.1002
25 Minute	5 Minute	5 Minute	5 Minute	858	0.122	0.0679
25 Minute	5 Minute	5 Minute	10 Minute	421	0.120	0.0741
25 Minute	5 Minute	5 Minute	15 Minute	294	0.124	0.0775
25 Minute	5 Minute	10 Minute	5 Minute	956	0.142	0.1159
25 Minute	5 Minute	10 Minute	10 Minute	342	0.138	0.1389
25 Minute	5 Minute	10 Minute	15 Minute	326	0.142	0.1463
25 Minute	5 Minute	15 Minute	5 Minute	1074	0.151	0.1139
25 Minute	5 Minute	15 Minute	10 Minute	427	0.146	0.0962
25 Minute	5 Minute	15 Minute	15 Minute	284	0.145	0.0947
30 Minute	1 Minute	5 Minute	5 Minute	540	0.130	0.0776
30 Minute	1 Minute	5 Minute	10 Minute	399	0.122	0.0803
30 Minute	1 Minute	5 Minute	15 Minute	189	0.133	0.0932
30 Minute	1 Minute	10 Minute	5 Minute	538	0.154	0.0915
30 Minute	1 Minute	10 Minute	10 Minute	263	0.145	0.0820
30 Minute	1 Minute	10 Minute	15 Minute	178	0.151	0.0963
30 Minute	1 Minute	15 Minute	5 Minute	563	0.185	0.1168
30 Minute	1 Minute	15 Minute	10 Minute	278	0.183	0.1102
30 Minute	1 Minute	15 Minute	15 Minute	179	0.170	0.1007
30 Minute	3 Minute	5 Minute	5 Minute	565	0.132	0.0814
30 Minute	3 Minute	5 Minute	10 Minute	282	0.130	0.0865
30 Minute	3 Minute	5 Minute	15 Minute	198	0.135	0.0890
30 Minute	3 Minute	10 Minute	5 Minute	371	0.164	0.1403
30 Minute	3 Minute	10 Minute	10 Minute	286	0.130	0.0861
30 Minute	3 Minute	10 Minute	15 Minute	191	0.137	0.1010

30 Minute	3 Minute	15 Minute	5 Minute	438	0.163	0.1270
30 Minute	3 Minute	15 Minute	10 Minute	296	0.150	0.1090
30 Minute	3 Minute	15 Minute	15 Minute	195	0.149	0.1059
30 Minute	5 Minute	5 Minute	5 Minute	969	0.129	0.0723
30 Minute	5 Minute	5 Minute	10 Minute	285	0.132	0.0921
30 Minute	5 Minute	5 Minute	15 Minute	198	0.139	0.0911
30 Minute	5 Minute	10 Minute	5 Minute	687	0.145	0.1240
30 Minute	5 Minute	10 Minute	10 Minute	298	0.131	0.0887
30 Minute	5 Minute	10 Minute	15 Minute	237	0.150	0.1580
30 Minute	5 Minute	15 Minute	5 Minute	611	0.156	0.1204
30 Minute	5 Minute	15 Minute	10 Minute	305	0.155	0.1128
30 Minute	5 Minute	15 Minute	15 Minute	201	0.149	0.1040

Traffic Prediction

Predicted Speed Between 45 and 60 Miles

Rolling Horizon	Rolling Step	Prediction Horizon	Prediction Step	Frequency	Average relative Error	Standard Deviation
15 Minute	1 Minute	5 Minute	5 Minute	6817	0.045	0.0430
15 Minute	1 Minute	5 Minute	10 Minute	3434	0.044	0.0429
15 Minute	1 Minute	5 Minute	15 Minute	1461	0.042	0.0437
15 Minute	1 Minute	10 Minute	5 Minute	2764	0.052	0.0671
15 Minute	1 Minute	10 Minute	10 Minute	3372	0.038	0.0530
15 Minute	1 Minute	10 Minute	15 Minute	1809	0.052	0.0683
15 Minute	3 Minute	5 Minute	5 Minute	9575	0.048	0.0497
15 Minute	3 Minute	5 Minute	10 Minute	4080	0.044	0.0451
15 Minute	3 Minute	5 Minute	15 Minute	2342	0.044	0.0453
15 Minute	5 Minute	5 Minute	5 Minute	9189	0.043	0.0410
15 Minute	5 Minute	5 Minute	10 Minute	4613	0.043	0.0413
15 Minute	5 Minute	5 Minute	15 Minute	3038	0.041	0.0412
20 Minute	1 Minute	5 Minute	5 Minute	2407	0.050	0.0502
20 Minute	1 Minute	5 Minute	10 Minute	2774	0.048	0.0467
20 Minute	1 Minute	5 Minute	15 Minute	1799	0.048	0.0485
20 Minute	1 Minute	10 Minute	5 Minute	2691	0.053	0.0674
20 Minute	1 Minute	10 Minute	10 Minute	2773	0.051	0.0648
20 Minute	1 Minute	10 Minute	15 Minute	1810	0.051	0.0665
20 Minute	1 Minute	15 Minute	5 Minute	2698	0.056	0.0819
20 Minute	1 Minute	15 Minute	10 Minute	2793	0.057	0.0786
20 Minute	1 Minute	15 Minute	15 Minute	1817	0.057	0.0808
20 Minute	3 Minute	5 Minute	5 Minute	6212	0.046	0.0439
20 Minute	3 Minute	5 Minute	10 Minute	3450	0.044	0.0427

20 Minute	3 Minute	5 Minute	15 Minute	2320	0.044	0.0441
20 Minute	3 Minute	10 Minute	5 Minute	8571	0.043	0.0563
20 Minute	3 Minute	10 Minute	10 Minute	4325	0.043	0.0586
20 Minute	3 Minute	10 Minute	15 Minute	2920	0.042	0.0585
20 Minute	5 Minute	5 Minute	5 Minute	9550	0.045	0.0448
20 Minute	5 Minute	5 Minute	10 Minute	3644	0.046	0.0470
20 Minute	5 Minute	5 Minute	15 Minute	2358	0.045	0.0465
20 Minute	5 Minute	10 Minute	5 Minute	14502	0.046	0.0565
20 Minute	5 Minute	10 Minute	10 Minute	5443	0.043	0.0575
20 Minute	5 Minute	10 Minute	15 Minute	3670	0.042	0.0593
25 Minute	1 Minute	5 Minute	5 Minute	5445	0.049	0.0462
25 Minute	1 Minute	5 Minute	10 Minute	2770	0.048	0.0471
25 Minute	1 Minute	5 Minute	15 Minute	1791	0.048	0.0481
25 Minute	1 Minute	10 Minute	5 Minute	5483	0.051	0.0619
25 Minute	1 Minute	10 Minute	10 Minute	2777	0.051	0.0652
25 Minute	1 Minute	10 Minute	15 Minute	1806	0.051	0.0664
25 Minute	1 Minute	15 Minute	5 Minute	5505	0.056	0.0766
25 Minute	1 Minute	15 Minute	10 Minute	2793	0.057	0.0785
25 Minute	1 Minute	15 Minute	15 Minute	1817	0.057	0.0812
25 Minute	3 Minute	5 Minute	5 Minute	6800	0.046	0.0461
25 Minute	3 Minute	5 Minute	10 Minute	3422	0.045	0.0456
25 Minute	3 Minute	5 Minute	15 Minute	2289	0.044	0.0463
25 Minute	3 Minute	10 Minute	5 Minute	7085	0.042	0.0575
25 Minute	3 Minute	10 Minute	10 Minute	2219	0.047	0.0686
25 Minute	3 Minute	10 Minute	15 Minute	2368	0.044	0.0619
25 Minute	3 Minute	15 Minute	5 Minute	6891	0.046	0.0670

25 Minute	3 Minute	15 Minute	10 Minute	3459	0.046	0.0671
25 Minute	3 Minute	15 Minute	15 Minute	2333	0.046	0.0699
25 Minute	5 Minute	5 Minute	5 Minute	9548	0.046	0.0446
25 Minute	5 Minute	5 Minute	10 Minute	4857	0.045	0.0441
25 Minute	5 Minute	5 Minute	15 Minute	3197	0.044	0.0455
25 Minute	5 Minute	10 Minute	5 Minute	11188	0.045	0.0580
25 Minute	5 Minute	10 Minute	10 Minute	4327	0.041	0.0541
25 Minute	5 Minute	10 Minute	15 Minute	3774	0.044	0.0613
25 Minute	5 Minute	15 Minute	5 Minute	10879	0.047	0.0667
25 Minute	5 Minute	15 Minute	10 Minute	4697	0.046	0.0647
25 Minute	5 Minute	15 Minute	15 Minute	3109	0.046	0.0665
30 Minute	1 Minute	5 Minute	5 Minute	5438	0.048	0.0462
30 Minute	1 Minute	5 Minute	10 Minute	4209	0.047	0.0458
30 Minute	1 Minute	5 Minute	15 Minute	1790	0.047	0.0485
30 Minute	1 Minute	10 Minute	5 Minute	5478	0.050	0.0617
30 Minute	1 Minute	10 Minute	10 Minute	2774	0.051	0.0647
30 Minute	1 Minute	10 Minute	15 Minute	1802	0.051	0.0657
30 Minute	1 Minute	15 Minute	5 Minute	5490	0.056	0.0764
30 Minute	1 Minute	15 Minute	10 Minute	2786	0.057	0.0781
30 Minute	1 Minute	15 Minute	15 Minute	1814	0.057	0.0811
30 Minute	3 Minute	5 Minute	5 Minute	6849	0.047	0.0467
30 Minute	3 Minute	5 Minute	10 Minute	3446	0.045	0.0451
30 Minute	3 Minute	5 Minute	15 Minute	2306	0.045	0.0467
30 Minute	3 Minute	10 Minute	5 Minute	4350	0.047	0.0643
30 Minute	3 Minute	10 Minute	10 Minute	3434	0.044	0.0566
30 Minute	3 Minute	10 Minute	15 Minute	2306	0.043	0.0560

30 Minute	3 Minute	15 Minute	5 Minute	4940	0.045	0.0679
30 Minute	3 Minute	15 Minute	10 Minute	3430	0.046	0.0660
30 Minute	3 Minute	15 Minute	15 Minute	2315	0.046	0.0681
30 Minute	5 Minute	5 Minute	5 Minute	10977	0.046	0.0446
30 Minute	5 Minute	5 Minute	10 Minute	3451	0.047	0.0488
30 Minute	5 Minute	5 Minute	15 Minute	2317	0.048	0.0492
30 Minute	5 Minute	10 Minute	5 Minute	8586	0.044	0.0587
30 Minute	5 Minute	10 Minute	10 Minute	3476	0.045	0.0585
30 Minute	5 Minute	10 Minute	15 Minute	2922	0.043	0.0608
30 Minute	5 Minute	15 Minute	5 Minute	6876	0.047	0.0690
30 Minute	5 Minute	15 Minute	10 Minute	3447	0.047	0.0680
30 Minute	5 Minute	15 Minute	15 Minute	2324	0.048	0.0723

Traffic Prediction

Predicted Speed Greater Than 60 Miles

Rolling Horizon	Rolling Step	Prediction Horizon	Prediction Step	Frequency	Average relative Error	Standard Deviation
15 Minute	1 Minute	5 Minute	5 Minute	2962	0.029	0.0294
15 Minute	1 Minute	5 Minute	10 Minute	1502	0.028	0.0293
15 Minute	1 Minute	5 Minute	15 Minute	614	0.026	0.0245
15 Minute	1 Minute	10 Minute	5 Minute	1273	0.023	0.0331
15 Minute	1 Minute	10 Minute	10 Minute	1303	0.020	0.0239
15 Minute	1 Minute	10 Minute	15 Minute	853	0.024	0.0371
15 Minute	3 Minute	5 Minute	5 Minute	3974	0.027	0.0295
15 Minute	3 Minute	5 Minute	10 Minute	1653	0.026	0.0273
15 Minute	3 Minute	5 Minute	15 Minute	964	0.027	0.0309
15 Minute	5 Minute	5 Minute	5 Minute	5333	0.028	0.0277
15 Minute	5 Minute	5 Minute	10 Minute	2691	0.027	0.0274
15 Minute	5 Minute	5 Minute	15 Minute	1766	0.027	0.0277
20 Minute	1 Minute	5 Minute	5 Minute	1068	0.029	0.0349
20 Minute	1 Minute	5 Minute	10 Minute	1102	0.036	0.0424
20 Minute	1 Minute	5 Minute	15 Minute	724	0.035	0.0413
20 Minute	1 Minute	10 Minute	5 Minute	1242	0.024	0.0340
20 Minute	1 Minute	10 Minute	10 Minute	1100	0.031	0.0509
20 Minute	1 Minute	10 Minute	15 Minute	715	0.032	0.0534
20 Minute	1 Minute	15 Minute	5 Minute	1228	0.022	0.0352
20 Minute	1 Minute	15 Minute	10 Minute	1081	0.031	0.0557
20 Minute	1 Minute	15 Minute	15 Minute	708	0.031	0.0580
20 Minute	3 Minute	5 Minute	5 Minute	2586	0.029	0.0277
20 Minute	3 Minute	5 Minute	10 Minute	1464	0.028	0.0292

20 Minute	3 Minute	5 Minute	15 Minute	987	0.028	0.0293
20 Minute	3 Minute	10 Minute	5 Minute	3574	0.023	0.0292
20 Minute	3 Minute	10 Minute	10 Minute	1801	0.022	0.0274
20 Minute	3 Minute	10 Minute	15 Minute	1250	0.023	0.0326
20 Minute	5 Minute	5 Minute	5 Minute	4842	0.028	0.0271
20 Minute	5 Minute	5 Minute	10 Minute	2363	0.027	0.0281
20 Minute	5 Minute	5 Minute	15 Minute	937	0.025	0.0252
20 Minute	5 Minute	10 Minute	5 Minute	7377	0.025	0.0353
20 Minute	5 Minute	10 Minute	10 Minute	3072	0.023	0.0316
20 Minute	5 Minute	10 Minute	15 Minute	2081	0.024	0.0348
25 Minute	1 Minute	5 Minute	5 Minute	2200	0.035	0.0416
25 Minute	1 Minute	5 Minute	10 Minute	1107	0.036	0.0424
25 Minute	1 Minute	5 Minute	15 Minute	728	0.035	0.0425
25 Minute	1 Minute	10 Minute	5 Minute	2163	0.030	0.0477
25 Minute	1 Minute	10 Minute	10 Minute	1098	0.031	0.0511
25 Minute	1 Minute	10 Minute	15 Minute	720	0.032	0.0536
25 Minute	1 Minute	15 Minute	5 Minute	2123	0.029	0.0520
25 Minute	1 Minute	15 Minute	10 Minute	1079	0.031	0.0558
25 Minute	1 Minute	15 Minute	15 Minute	704	0.031	0.0576
25 Minute	3 Minute	5 Minute	5 Minute	2946	0.028	0.0285
25 Minute	3 Minute	5 Minute	10 Minute	1496	0.028	0.0310
25 Minute	3 Minute	5 Minute	15 Minute	1018	0.028	0.0319
25 Minute	3 Minute	10 Minute	5 Minute	2927	0.024	0.0329
25 Minute	3 Minute	10 Minute	10 Minute	1002	0.024	0.0344
25 Minute	3 Minute	10 Minute	15 Minute	1037	0.024	0.0365
25 Minute	3 Minute	15 Minute	5 Minute	2854	0.021	0.0271

25 Minute	3 Minute	15 Minute	10 Minute	1454	0.021	0.0293
25 Minute	3 Minute	15 Minute	15 Minute	983	0.021	0.0309
25 Minute	5 Minute	5 Minute	5 Minute	4952	0.028	0.0276
25 Minute	5 Minute	5 Minute	10 Minute	2498	0.027	0.0272
25 Minute	5 Minute	5 Minute	15 Minute	1659	0.027	0.0264
25 Minute	5 Minute	10 Minute	5 Minute	5733	0.024	0.0322
25 Minute	5 Minute	10 Minute	10 Minute	2319	0.025	0.0328
25 Minute	5 Minute	10 Minute	15 Minute	1947	0.025	0.0366
25 Minute	5 Minute	15 Minute	5 Minute	5958	0.022	0.0325
25 Minute	5 Minute	15 Minute	10 Minute	2701	0.023	0.0350
25 Minute	5 Minute	15 Minute	15 Minute	1787	0.023	0.0367
30 Minute	1 Minute	5 Minute	5 Minute	2203	0.035	0.0421
30 Minute	1 Minute	5 Minute	10 Minute	1614	0.038	0.0442
30 Minute	1 Minute	5 Minute	15 Minute	730	0.036	0.0429
30 Minute	1 Minute	10 Minute	5 Minute	2167	0.031	0.0484
30 Minute	1 Minute	10 Minute	10 Minute	1104	0.032	0.0520
30 Minute	1 Minute	10 Minute	15 Minute	724	0.032	0.0550
30 Minute	1 Minute	15 Minute	5 Minute	2139	0.029	0.0519
30 Minute	1 Minute	15 Minute	10 Minute	1086	0.031	0.0565
30 Minute	1 Minute	15 Minute	15 Minute	708	0.031	0.0577
30 Minute	3 Minute	5 Minute	5 Minute	2900	0.028	0.0265
30 Minute	3 Minute	5 Minute	10 Minute	1471	0.028	0.0285
30 Minute	3 Minute	5 Minute	15 Minute	1002	0.028	0.0313
30 Minute	3 Minute	10 Minute	5 Minute	1996	0.025	0.0356
30 Minute	3 Minute	10 Minute	10 Minute	1489	0.023	0.0271
30 Minute	3 Minute	10 Minute	15 Minute	1012	0.024	0.0343

30 Minute	3 Minute	15 Minute	5 Minute	1980	0.021	0.0277
30 Minute	3 Minute	15 Minute	10 Minute	1489	0.022	0.0302
30 Minute	3 Minute	15 Minute	15 Minute	1002	0.022	0.0309
30 Minute	5 Minute	5 Minute	5 Minute	6907	0.028	0.0272
30 Minute	5 Minute	5 Minute	10 Minute	1461	0.029	0.0319
30 Minute	5 Minute	5 Minute	15 Minute	987	0.030	0.0332
30 Minute	5 Minute	10 Minute	5 Minute	3531	0.024	0.0319
30 Minute	5 Minute	10 Minute	10 Minute	1423	0.023	0.0286
30 Minute	5 Minute	10 Minute	15 Minute	1234	0.025	0.0396
30 Minute	5 Minute	15 Minute	5 Minute	2837	0.022	0.0274
30 Minute	5 Minute	15 Minute	10 Minute	1454	0.022	0.0298
30 Minute	5 Minute	15 Minute	15 Minute	984	0.022	0.0315