FINAL REPORT

to

THE FLORIDA DEPARTMENT OF TRANSPORTATION
SYSTEM PLANNING OFFICE

on Project

"Travel Time Reliability and Truck Level of Service on the Strategic Intermodal System"

FDOT Contract BD-545, RPWO #48 (UF Project 00054045)

PART A : TRAVEL TIME RELIABILITY

April 2007

The University of Florida

DISCLAIMER

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the State of Florida Department of Transportation.

METRIC CONVERSION CHART

U.S. UNITS TO METRIC (SI) UNITS

LENGTH

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km

METRIC (SI) UNITS
TO U.S. UNITS

LENGTH

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi

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16. Abstract

The goal of the Strategic Intermodal System (SIS) is to provide a transportation system that efficiently serves Florida's citizens, businesses and visitors; helps Florida become a worldwide economic leader; enhances economic prosperity and competitiveness; enriches quality of life; and reflects responsible environmental stewardship. The SIS is composed of transportation facilities and services of statewide and interregional significance. Much research on the SIS and its users is needed. This initial research effort focused on two areas: travel time reliability and truck level of service. This report (Part A) describes the research conducted on travel time reliability for the SIS. The objective of this research was to develop preliminary models for estimating the travel time reliability on freeway facilities. At the time this research was initiated, there were no data available in the State of Florida suitable for this project. Therefore, the models developed here were based on field data from Philadelphia, PA.

The project first reviewed travel time reliability approaches found in the literature, and provided recommendations regarding the use of a travel time reliability definition for this project. Next, it provides an overview of previously developed travel time estimation models, and develops a travel time estimation framework based on the literature review findings. A series of models for estimating travel time reliability along freeway segments is then developed based on data from Philadelphia, PA. The report provides two examples for applying those models and determining the reliability of a highway network. Conclusions and recommendations from the research are provided in the last chapter of the report.

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EXECUTIVE SUMMARY

The goal of the Strategic Intermodal System (SIS) is to provide a transportation system that efficiently serves Florida's citizens, businesses and visitors; helps Florida become a worldwide economic leader; enhances economic prosperity and competitiveness; enriches quality of life; and reflects responsible environmental stewardship. The SIS is composed of transportation facilities and services of statewide and interregional significance. Much research on the SIS and its users is needed. This initial research effort focuses on two areas: travel time reliability and truck level of service. This report (Part A) describes the research conducted on travel time reliability for the SIS. The objective of this research was to develop preliminary models for estimating the travel time reliability on freeway facilities. At the time this research was initiated, there were no data available in the State of Florida suitable for this project. Therefore, the models developed here were based on field data from Philadelphia, PA. It is expected that subsequent research will refine and calibrate these preliminary models using Florida data.

The project first reviewed travel time reliability approaches found in the literature, and provided recommendations regarding the use of a travel time reliability definition for this project.

The definitions of, or approaches to travel time reliability found in the literature fall in two categories: a) Approaches based on the concept of reliability used in manufacturing and other engineering disciplines, which define reliability as the probability of non-failure over time; and b) Approaches based on the concept of variability of travel time. Those later approaches focus on the perspective of the traveler, and they define reliability as the "unpredictability" of travel times. It was concluded that an agency may need to develop two (or more) different performance measuring techniques related to reliability: a) A performance measure which would be appropriate for use by an agency to monitor and project the performance of various facilities; and b) a performance measure appropriate to be ultimately provided to travelers for estimating travel times between a given origin and a given destination. For the purposes of this project it was recommened that the first type of approach (i.e., on-time performance) be used, because the primary objective of the analysis is facility performance monitoring and projection. Thus the definition recommended for use in this study is as follows: "Travel time reliability is defined as the percent of trips that reach a destination over a designated facility within a given travel time (or equivalently, at a given travel speed or higher)." The models developed in this project predict travel time reliability based on on-time performance, however travel time monitoring data can be used to obtain both types of reliability measures.

The project next provided an overview of previously developed travel time estimation models, and developed a travel time estimation framework based on the literature review findings. This framework is based on the following four steps:

Step 1: Establish appropriate levels and determine suitable parameters for each of the four factors (congestion, weather, work zones, and incidents) which may affect travel time.

Step 2: Develop a list of scenarios (where each scenario describes a set of prevailing conditions), and estimate travel time for each scenario. An example of a scenario is: Congested conditions, rain, no work zone, no incident. There are a total of 24 possible scenarios based on the categories developed for this project.

Step 3: Develop a travel time estimation model (i.e., regression equation) for each scenario. Data from Philadelphia, PA were used to develop these models.

Step 4: Obtain the expected travel time for the freeway facility based on the probability of occurrence for each of the scenarios identified in Step 3. These probabilities were estimated based on the field data, both in terms of percent of time each scenario occurred, and in terms of percent of trips under each scenario.

The next part of the report provides two examples for estimating the reliability of a freeway facility based on the framework developed in this project. There are two options for obtaining a travel time distribution and travel time reliability, based on whether travel time data are directly available or they need to be estimated. If data are available, the travel time distribution can be plotted using these data, and the variance of travel time can be calculated. If data are not available, the analyst should obtain the list of scenarios that occur at the facility as well as the frequency of occurrence of these scenarios, and then use travel time estimation models, such as those developed for the Philadelphia, PA corridor, to obtain the travel time distribution, and the reliability of the facility.

Based on the field data obtained for this project, it is recommended that on-time arrival be considered to be 10 mph below the speed limit. For the study facility, and for on-time arrival equal to "speed limit – 10 mph", the reliability is 96 %.

The following are recommendations for further research in support of the travel time reliability efforts of the Florida Department of Transportation.

1. *Refinement of freeway model based on data from Florida.* In the next phase of the travel time reliability research, the model developed under this project should be refined based on data from Florida. Such data may become available either from District 4 (Ft. Lauderdale) or from District 2 (Jacksonville). Given that the speed limit at the Philadelphia, PA freeway facility was 55 mph, it would be desirable to obtain data from freeways with various speed limits.
2. *Development of travel time reliability models for arterials.* An extension of the work described in this interim report would use data from arterials to develop travel time reliability models for these facilities. Those models would consider the presence of intersections and the impacts of interrupted flow on travel time.
3. *Application of the proposed methodology for both freeways and arterials to the SIS/FIHS.* This research would implement the methodologies formulated for both freeways and arterials to estimate travel time reliability on the entire SIS/FIHS network.
4. *Travel time reliability with consideration of various modes for the SIS.* This research would expand the previously developed methodologies regarding travel time reliability to consider other travel modes as well intermodal connections (for example, freight reliability through port, rail, aviation, truck modes).

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I. BACKGROUND

The goal of the Strategic Intermodal System (SIS) is to provide a transportation system that efficiently serves Florida's citizens, businesses and visitors; helps Florida become a worldwide economic leader; enhances economic prosperity and competitiveness; enriches quality of life; and reflects responsible environmental stewardship. The SIS is composed of transportation facilities and services of statewide and interregional significance. Much research on the SIS and its users is needed. This initial research effort focused on two areas: travel time reliability and truck level of service. This report (Part A) describes the research conducted on travel time reliability for the SIS. The objective of this research was to develop preliminary models for estimating the travel time reliability on freeway facilities. At the time this research was initiated, there were no data available in the State of Florida suitable for this project. Therefore, the models developed here were based on field data from Philadelphia, PA. It is expected that subsequent research will refine and calibrate these preliminary models using Florida data.

Chapter II contains an overview of travel time reliability approaches, as well as recommendations regarding the use of a travel time reliability definition for this project. The third chapter provides an overview of previously developed travel time estimation models, while the fourth chapter formulates a travel time estimation framework. Chapter V provides a series of models for estimating travel time reliability, and Chapter VI provides two examples for applying those models and determining the reliability of a highway network. The final chapter provides conclusions and recommendations.

II. TRAVEL TIME RELIABILITY APPROACHES

The concept of reliability is relatively new in the engineering disciplines, but it is becoming increasingly important as part of the engineering design process, the establishment of preventive maintenance programs, and others. There is one definition of reliability generally accepted in various areas of engineering and manufacturing: Reliability is "the probability that a component or system will perform a required function for a given period of time when used under stated operating conditions. It is the probability of non-failure over time." (Ebeling, 1997). Ebeling further states that the definition must be made specific by providing an unambiguous and observable description of a failure, including the unit of time over which failure will be evaluated. This definition of reliability is widely accepted in engineering. In the area of transportation, on the other hand, there are several different definitions of reliability which have been developed.

In a report by Turner et al. (1996), trip time reliability is defined as the range of travel times experienced during a large number of daily trips. This definition considers the range of travel times. However it does not specify when "failure" has occurred. In addition, it does not provide a good assessment of actual operting conditions, the presence and duration of congestion, or the percent of time the facility operates as expected.

Lomax et al. (1997) defined reliability as the impact of non-recurrent congestion on the transportation system. In NCHRP report 399 (1998), travel time reliability is defined as a measure of the variability of travel time; it is stated that reliability could be presented as the standard deviation of travel time.

In the 1998 California Transportation Plan (Booz-Allen & Hamilton, Inc.,1998; also discussed in NCHRP, 2003; FDOT, 2000; Jackson, 2000; Shaw, 2002), reliability is defined as the level of variability between the expected travel time (based on scheduled or average travel time) and the actual travel time experienced. In that definition, the expected travel time is based on scheduled or average travel time, while the actual travel time incorporates the effects of non-recurrent congestion. The expected travel time is well defined, and is represented by the mean travel time during the period of interest. The level of variability however is not well defined, i.e., it is not clear what variability level is considered reliable (failure is not defined). In addition, for facilities that are congested for a large portion of the time, the expected travel time would be high. In those cases the difference between the two values (expected –actual travel time) may be small, labeling the facility as "reliable", when it is consistently congested.

The Florida Department of Transportation (FDOT, 2000) developed and documented the Florida Reliability Method. They defined reliability on a highway segment as the percent of travel that takes no longer than the expected travel time plus a certain acceptable additional time. They defined these three variables (travel time, expected travel time, and acceptable additional time) as follows:

- Travel time is the time it takes a typical commuter to move from the beginning to the end of a corridor.

- Expected travel time is the median travel time across the corridor during the time period being analyzed.
- Acceptable additional time is the amount of additional time, beyond the expected travel time, that a commuter would find acceptable during a commute.

Mathematically, the acceptable travel time can be estimated as follows:

Acceptable TT = $\bar{x} + \Delta$

Where $\bar{x}$: The median travel time

Δ : Acceptable additional time, expressed as a percentage of median travel time

The percent of reliable travel time is calculated as the percent of travel on a corridor that takes no longer than this acceptable travel time. This definition defines failure clearly and quantitatively, however it relies on the value of the median travel time, which may change from year to year. Thus this definition does not allow the tracking of reliability over time.

TTI (2000) defined reliability and variability separately in their report. They stated that reliability is commonly used in reference to the level of consistency in transportation service, while variability is the amount of inconsistency of operating conditions. To quantify the reliability and variability, they defined two measures. A measure of reliability they recommended is the Buffer Time, which is the amount of extra time that must be allowed for the traveler to achieve their destination in a high percentage of the trips. A measure of variability is the average travel time plus one or two standard deviations. Lomax et al. (2004) defined the reliability Buffer Time Index as follows:

Buffer Index (BI) =

[95th percentile confidence travel rate-average travel rate] /[average travel rate] x 100%

Similarly to the Florida Reliability Method which is based on the median travel time, this definition is based on the average travel rate. For similar reasons, this definition also does not allow the tracking of reliability over time.

In AASHTO's freight report (2000), reliability is defined as the percent of on-time performance for a given time schedule. This definition is provided for freight transportation. For example, within 1.0 hours of schedule, reliability is defined as being 99 percent on time. This definition is more consistent with the one generally used in engineering applications.

Shaw (2002) suggested the following definition of reliability: "Reliability is generally defined as the operational consistency of a facility over an extended period of time. Reliability has historically been associated with the performance of mechanical equipment or devices. In this context, reliability is defined as the probability of a device performing its purpose adequately for the period of time intended under the stated operating conditions". This definition is consistent with definitions frequently used in reliability engineering.

TranSystems (2003) explored some of the definitions that are recommended for travel time reliability. A common definition for reliability was recommended based on the probability of travel times meeting users' expectations. The report stated that different definitions of reliability depend on different viewpoint of users. They stated that in other reports and articles reliability is often defined as a probability or a percentage of acceptable performance, while in transportation it is typically reported as on-time performance.

Chen et al (2003) use the terms variability, reliability, and predictability interchangeably. They used data from Los Angeles, CA, to estimate travel time reliability, which they define as the 90th percentile of travel times. In their conclusions they note that there is nothing special about the 90th percentile, and that for their study corridor the form of the changes over time to the mean, standard deviation, and 90th percentile were very similar. They also stress that travel time is particularly important to the driver, and is a performance measure that can be equivalently expressed in monetary cost.

WSDOT (2004) maintains a web page called "Calculate your commute" (http://www.wsdot.wa.gov/traffic/seattle/traveltimes/reliability/default.htm) that provides the 95th percentile travel time in 5-min intervals from 6 a.m. to 7 p.m., for each of 22 routes. This estimate is based on archived weekday travel time data from 2002.

NCHRP 8-36 (Cambridge Systematics, Inc.,2004) reviewed the definition of travel time reliability in the F-SHRP program. In the F-SHRP Reliability Research Program, it is indicated that travel time reliability can be defined in terms of how travel times vary over time (e.g., hour-to-hour, day-to-day). This concept of variability can be extended to any other travel time-based metrics such as average speeds and delay. In that study the terms travel time variability and reliability are used interchangeably. Freeway travel time reliability metrics mentioned are the Buffer Time Index, 95th percentile of travel times, coefficient of variation of travel times, percent "on-time performance", and travel time window. In Task 39 of NCHRP 8-36, the report concluded that there is no explicit definition of travel time reliability, but that travel time reliability has been used similarly to travel time variability.

van Lint and van Zuylen (2005) presented the Unreliability Index (UI) to measure travel time reliability. They indicate that travel time reliability relates to the properties of the travel time distribution as a function of time of day (TOD) and day of the week (DOW). They mentioned that variation coefficients such as variance and standard deviation are not useful as indicators of reliability since sometimes the travel times are highly skewed. They stated that the width and the skew of the travel time distribution can be considered as an indicator of unreliability.

The definitions reviewed above all refer to highway transportation. Other modes however have also defined and used reliability for their purposes. For example, in rail transportation, travel time reliability is defined as the percentage of on-time performance (AASHTO's freight report, 2000). No specific number is given in that report to define "on-time" performance. Also, the US DOT (May, 2005) evaluates the reliability of travel for airlines using the percentage of on-time performance. A flight is considered to be "on-time" if it is not delayed more than 15 minutes beyond the scheduled arrival (www.transtats.bts.gov/HomeDrillChart.asp). Reliability for port operations is similarly defined (TranSystems, 2005).

Camus et. al (2005) developed a new mesuare for travel time reliabilty for transit. They stated that for transit there could be several levels of reliability: on-time performance, regularity of headway between successive vehicles, missed trips, and distance traveled between mechanical breakdowns. In the Transit Capacity and Quality of Service Manual (TCQSM) "on-time" performance is defined to occur when a trip is less than 5 minutes late relative to the scheduled arrival time. The authors indicated that this measure only considers how many trips are on time, but it does not consider how late the remaining trips are. They indicated that the reliability measure should not only consider how many trips are on time, it should also consider the amount of delay. Thus, they proposed a new reliability service measure called weighted delay index, which considers a weighted sum of delays.

Summary

The definitions of, or approaches to travel time reliability found in the literature fall in two categories: a) Approaches based on the concept of reliability used in manufacturing and other engineering disciplines, which define reliability as the probability of non-failure over time; and b) Approaches based on the concept of variability of travel time. Those later approaches focus on the perspective of the traveler, and they define reliability as the "unpredictability" of travel times. The advantages of the first category of approaches are:

- They are more appropriate for tracking the performance of a facility over time;
- They are more appropriate in establishing project priorities;
- They correlate well with congestion occurrence;
- They are consistent with the approaches across various transportation modes, as well as with reliability definitions in other engineering disciplines;
- They are more easily understood by the public.

The disadvantages of this category are:

- Travelers would not find such a measure of particular relevance for their trip planning;
- There is no "schedule" for travel time on highway facilities, thus an assumption would have to be made on what constitutes an "acceptable", or "reliable" trip duration.

The advantages of the second category of approaches are:

- These types of approaches would be useful to travelers planning their trip;
- They are consistent with definitions of reliability developed by FHWA and some other States.

The disadvantages of this category are:

- This type of definition would generally not be appropriate for use by an agency to monitor or project facility performance with respect to congestion;
- The equations developed for these methods are not easy to understand, and they would have to be appropriately translated into useful traveler information.

In conclusion, an agency may need to develop two (or more) different performance measuring techniques related to reliability: a) A performance measure which would be appropriate for use by an agency to monitor and project the performance of various facilities; and b) a performance measure appropriate to be ultimately provided to travelers for estimating travel times between a given origin and a given destination. For the purposes of this project it is recommened that the first type of approach (i.e., on-time performance) be used, because the primary objective of the analysis is facility performance monitoring and projection. Thus the definition recommended for use in this study is as follows: "Travel time reliability is defined as the percent of trips that reach a destination over a designated facility within a given travel time (or equivalently, at a given travel speed or higher)." The models developed in this project predict travel time reliability based on on-time performance, however travel time monitoring data can be used to obtain both types of reliability measures.

It is important to stress that travel time reliability is not the only relevant performance measure for assessing the operational performance of a transportation facility. For example, travel time reliability does not provide any information on the magnitude of delay for the non-reliable trips. When such information is required, other measures such as delay should be used.

III. TRAVEL TIME ESTIMATION MODELS IN THE LITERATURE

Several freeway travel time estimation models have been developed in the literature. Each of these models focuses on impacts from different factors, such as incidents or work zones. This literature review summarizes travel time estimation models considering four factors: congestion, weather effects, work zones, and incidents. The first section introduces travel time estimation models in general including those considering recurring congestion effects, while the second section reviews models that consider weather, work zone, and incident effects.

Overview of Travel Time Estimation and Prediction Methods for Freeways

There are two types of freeway travel time models:

- Travel Time Estimation Models
- Travel Time Prediction Models

a) Travel Time Estimation Models

These models use field data to estimate travel time. Loop detector models are the simplest travel time estimation models. Loop detectors can provide traffic volume and occupancy data, which can be converted to speed and then to travel time. The speed can be estimated as (Chu, 2005):

$$v = \frac{\sum_{i=1}^{L}(q_i \cdot v_i)}{\sum_{j=1}^{L} q_j}$$

where L is the number of lanes, q_i is the traffic volume and v_i is the speed at lane i of a detector station. Next, the travel time is estimated as the average of the speeds at upstream and downstream detector stations:

$$tt_l = \frac{1}{2}\left(\frac{\Delta x}{v_u} + \frac{\Delta x}{v_d}\right)$$

where v_u and v_t are spot speeds at the upstream and downstream detector stations, and Δx is the distance between upstream and downstream detectors.

This travel time estimation method is straightforward, however, it includes two kinds of estimation errors: speed estimation errors from the loop data, and errors in the conversion from two spot speeds to travel time. Several papers have devised various methods for overcoming those errors. More recently, Palacharla and Nelson (1999) presented a method which applies fuzzy logic to convert detector data into travel time data.

b) Travel Time Prediction Models

Shaw (2002) reviewed a time series model developed by D' Angelo, Al-Deek, and Wang (1999). They presented a freeway travel time prediction model using time series techniques. They proposed a Self-Exciting Threshold AutoRegressive Model (SETAR), which is a type of time series models. The model is developed to predict travel speed for a time interval as a function of the speed in the previous interval. The model was applied for travel time prediction on an 11.2 mile section of I-4 in Orlando, Florida, and was compared to a previously developed model. The authors concluded that the time series model is better in predicting travel time. They also concluded that the model is relatively straightforward, but it is based on what happened in the previous time period, so it can only predict travel time for the immediate future, with the assumption that there are no drastic changes in traffic conditions.

Zhang and Rice (2003) proposed a method for predicting freeway travel time using a linear model in which the coefficients can vary according to the departure time. The model is built based on freeway sensor data. To predict travel time, they first estimate the current travel time using a model called the current travel time predictor. Then assuming that velocity does not change after the vehicle enters the link, travel time can be estimated by dividing the link length by the entering speed. Only the data up to $t - \Delta$ are available for predicting travel time (Δ is an external parameter determined by the delay caused by data transmission and processing.)

Rice and Zwet (2004) presented a similar model using regression analysis. This model focuses on predicting travel time between two points on a freeway for any future departure time, based on the combination of historical data and prevailing traffic conditions. Emperical studies showed that there is a linear relationship between future travel time and the current status travel time, which is the travel time expected if the driver departs immediately and there are no significant changes in traffic conditions. The authors concluded that this model is relatively straightforward and easy to build and apply. However, the model can only predict travel time for the near future, under the assumption that speed will not change. This assumption limits the applicability of the model.

Adaptive Kalman Filter Algorithms

The Adaptive Kalman Filter(AKF) algorithm has been used in several travel time estimation studies. Chien and Kuchipudi (2003) applied it to develop dynamic models that can predict travel time.They applied the AKF because of its ability to update the variables from new observations.

Chu (2005) explains the use of the AKF method to estimate travel time with a limited sample of travel time field data. The main focus of this paper is to develop an improved travel time estimation method by applying (AKF) that fuses both point detection data and probe vehicle data. The algorithm provides an updated travel time prediction when a new observation becomes available, and thus is adaptive to new data. This method however is more complicated than other models, and requires extensive calculations.

Artificial Neural Networks (ANN) models

Shaw (2002) reviewed an ANN model developed by Park and Rilett (1998). The model is used to forecast short-term multiple-period link travel times. There are three steps in developing an ANN model: performing clustering design, choosing clustering technique, and identifying the structure for each cluster. The model is a combination of relatively simple functions that are calibrated separately by modular ANNs, so the results are reasonably accurate. However, the overall method and calibration process are complicated.

Travel Time Estimation Methods for Freeways Considering Weather, Incidents, and Work Zones

Cambridge Systematics, Inc. (1998) conducted a study for estimating incident-related impacts; this study relies on the QSIM model which is a stochastic macroscopic simulation model used for recurring congestion. The model considers the following incident-related factors:

- Duration of incidents
- Shoulders: usable shoulders to store a vehicle without blocking the traffic
- Incident rate: local incident rates can vary widely
- Accident rates
- Number of lanes
- AADT/C (Annual Average Daily Traffic-to-Capacity) ratio

Models were developed to predict travel time for different scenarios. These scenarios are combinations of the factors listed above. The models were validated using freeway surveillance data, and then were applied to two sites, based on the factors listed above, as well as Average Annual Daily Traffic (AADT), percent of traffic in the peak period, speed limit, number of lanes per direction, one-way capacity, link length, shoulder locations, etc.

Fu and Hellinga (1999) presented a fuzzy queuing model to predict incident-related delays based on real-time vehicle queuing, lane closures, predicted traffic volumes, and vehicle arrival times. They stated that incident-related delay depends on the following factors:

- Traffic arrival rate (V): since drivers can change their route to avoid congestion in the incident area, traffic arrival rates cannot be predicted by the historical traffic counts under normal conditions.
- Incident Duration (L): incident duration can vary greatly based on incident severity and location, traffic conditions, and the availability of incident management.

- Current Queue (Q): during the time lag between the incident occurrence and detection, a queue can be formed.
- Incident Capacity: incident capacity can vary significantly.
- Vehicle Arrival Time (T): delay that a vehicle experiences also depends on when the vehicle arrived. It is a random variable and may not follow a distribution.

These factors are subject to uncertainty, thus the authors indicate that fuzzy queuing can be a more accurate approach.

Ozbay and Kachroo (1999) reviewed previous studies on incident duration estimation. They state that Golob et al (1987) conducted a study based on truck incident data from California, and they found that the incident duration is log-normally distributed. Wang (1991) conducted a study and found several statistically significant variables in predicting incident duration. Based on these he developed a linear regression model. In another study (Sethi et al, 1994), the research team developed a decision tree for incident duration prediction. Incident duration is strongly related to incident type. In each incident type, the duration is determined by the number of police vehicles dispatched and the number of fire trucks or ambulances dispatched. Garib et al (1997) developed a regression-based model to estimate incident duration. There are six factors involved in this model: number of lanes affected by the incident, number of vehicles involved in the incident, truck involvement, time of day, natural logarithm of police response time, and weather conditions. The model used a dummy variable to present rainy days vs. other days. The model also included the number of vehicles involved in the incident, the time of day, and police response time. Ozbay and Kachroo (1999) also reviewed an incident study in Virginia. They found that the decision tree approach is appropriate and simple for incident-related studies. They also state that the vehicle type is more important than the number of vehicles involved in the incident. The incident delay model was developed using deterministic queuing analysis.

Chien and Chowdhury (2000) presented a simulation model that can reflect traffic operations in a work zone area on a segment of I-80 in New Jersey. Delay was defined as the sum of the queuing delay occurring before the work zone and the moving delay occurring while drivers travel through the work zone.

Jacorien et al (2005) developed a statistical algorithm to predict freeway travel time based on historical data. The purpose of the algorithm is to calculate the average travel time of any journey between freeway entry A and freeway exit B on date X and departure time Y using historical travel times. The authors considered time of day, and day of week in their prediction model. They also considered weather, incidents, and work zones indirectly. They defined several types of days: every weekday (5 categories); weekend days (2categories); different types of school vacations (4 categories); and public holidays (1 category). They obtained data for various day types, and used the data to calculate average travel time.

Oh and Chung (2006) developed a GIS database to report travel time variability using data from Orange County, California. They analyzed variability at the section level and for selected routes, and they studied day-to-day variability, within-day variability, and spatial variability.

Dong and et.al (2006) developed a scheme for providing predictive travel time and associated reliability information in route guidance systems. The authors evalute the impacts of providing such information to drivers, using both theoretical analysis and simulation. They concluded that the scheme could reduce travel time in the network. In the strategy they developed however, only the mean travel time was considered in route choice, and not the associated reliability, or variability of travel times.

Emam and Al-Deek (2006) used data from I-4 in Orlando, Florida, and tested four distributions (Weibull, exponential, lognormal, and normal) to identify the one that fit best the field travel time distributions. They concluded that the lognormal distribution provided the best fit. In their research, link travel time reliability is defined as the probability of non-failure. They assumed that a trip is “on-time” if its travel time is equal to or less than the travel time at the posted speed limit.

Literature Review Summary

In summary, several travel time models have been previously developed. These include models based primarily on field data, as well as various travel time prediction models, such as regression type models, time-series based models, AKF models, and ANN models. These models have been applied to estimate or predict freeway travel time for non-congested and congested conditions. In addition several travel time models have been developed to account for weather effects, incidents, and work zones. There has been no research however on how all these factors can be considered in determining the expected travel time for a facility over a longer period of time. Also, there are no models that predict travel time variability or reliability as a function of the frequency of incidents, work zones, and weather conditions.

IV. TRAVEL TIME ESTIMATION

This section develops models for predicting travel time under various conditions (i.e., with congestion, rain, etc.), and discusses the basic framework for obtaining travel time distributions (and also variability and reliability of travel times) for a freeway facility. Field data from Philadelphia, PA, obtained over a period of four moths (May-August 2004) are used in the model development for this project. Figure 1 provides a sketch of the study facility.

Data Processing and Analysis

The data used for the project were obtained by the Philadelphia Transportation Management Center (TMC), and Mobility Technologies, a traveler information provider. The data set includes spot speeds, volume, and occupancy data from May 2004 to August 2004 for an 8.72 mile portion of US 202 located in Philadelphia, PA. There are eight data collection locations which record speeds and flows for 24 hours a day, seven days a week, in 1-minute intervals. These data are collected using Remote Traffic Microwave Sensors (RTMS). Distances between detectors are shown on the left side of the sketch in Figure 1. In addition, five CCTV cameras installed along the study area were used to obtain sample travel times for validation purposes. Distances between cameras are shown on the right side of the sketch in Figure 1. The speed limit at the facility is 55 mph, while free-flow speeds for each section are shown in Table 1. Free flow speed is defined as the average operating speed when the flow is below 1,300 vehicles per hour per lane.

Regarding the accuracy of RTMS, research (Martin et al, 2003) showed that they provide flows with an accuracy of ±5%, and speeds with an accuracy of ±10% for normal high flow conditions. For low-speed, high-congestion conditions (i.e., occupancy > 35 %), the RTMS tends to over-count the number of vehicles. For low-flow high-speed conditions, these sensors have higher speed errors. According to a MNDOT study (SRF Consulting Group, Inc., 1997) RTMS speeds were 7.9% higher than adjusted loop detector speeds.

Data processing was conducted to obtain a data set with travel times for each section (defined as the highway portion between consecutive detectors) and for the entire facility. First, the data were adjusted so that the starting time of each interval coincided for all eight detectors. In the original data base, the speeds and flows were collected in intervals that were not exactly one minute, and also they didn't start at the exact same time. Adjustments were made assuming uniform volumes within each interval. Second, data were grouped in 5- minute intervals, rather than 1-minute intervals which can result in highly variable data. Third, travel times were calculated for each section based on the average speed between the upstream and downstream detector.

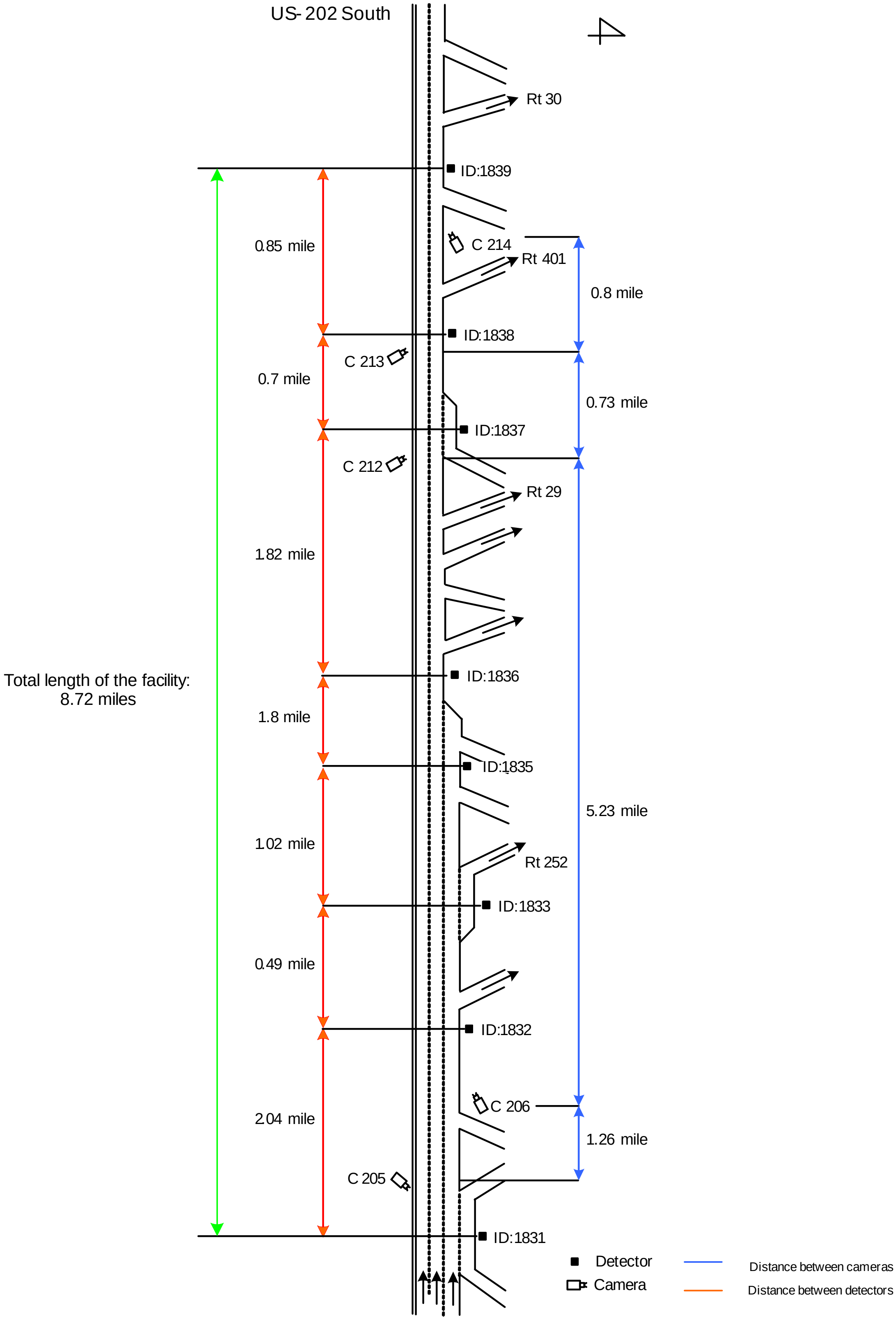


Figure 1. Sketch of study site (Philadelphia, PA)

Table 1. Free Flow Speeds for US 202 SB, Philadelphia, PA

Section	Free Flow Speed
1831-1832	65.16 mph
1832-1833	65.89 mph
1833-1835	65.12 mph
1835-1836	64.65 mph
1836-1837	59.36 mph
1837-1838	60.72 mph
1838-1839	62.93 mph

Travel Time Estimation Model Development

There are four steps in the model development, which are discussed below:

Step 1: Establish appropriate levels and determine suitable parameters for each of the four factors (congestion, weather, work zones, and incidents) which may affect travel time.

The four factors considered in the model are discussed below.

- Congestion. Three levels of congestion are considered, as follows:
    - Non-congested
    - Congested
        - Semi-congested
        - Fully congested

This recommendation is based on results from the field data analysis. It was determined that travel time under non-congested conditions remains relatively constant for the entire range of flows. An example is provided in Figure 2, which shows the relationship between travel time and flow for non-congested conditions, when there are no other events such as incidents or work zones. Figure 3 shows the relationship between travel time and flow for congested conditions, when there are no other events such as incidents or rain. Under congested conditions there are two general regions identified (Figure 3). The highest travel times (high congestion) are generally observed when speeds are low both at the upstream and the downstream detectors of a section. Semi-congested conditions generally were found to occur when conditions at one detector are congested while at the adjacent one they are non-congested. Fully-congested conditions are defined to occur when the section speed is below 50 mph. Semi-congested conditions are defined to occur when the speed is between 50 and 60 mph. Note that since the data obtained report flows rather than demands, the analysis cannot consider demand-to-capacity ratios.

- Weather Conditions. Two levels of weather conditions are used, as follows:
    - Good weather
    - Rain (expressed in inches per hour)

"Good" weather conditions indicates there is no rain during the analysis period. Weather data were obtained from AccuWeather, and entered into the database. The weather data indicate the precipitation for every hour of the day from May 1, 2004 to August 31, 2004, at the Philadelphia International Airport, which is the closest observation station to the study area. In the data provided by AccuWeather, if the amount of rain is lower than 0.01 inch, the actual precipitation is not reported. For coding purposes this was entered in the database as 0.005 inch. To account for the impacts of wet pavement, for a full hour after rainfall the weather was coded as having 0.005 inch precipitation.

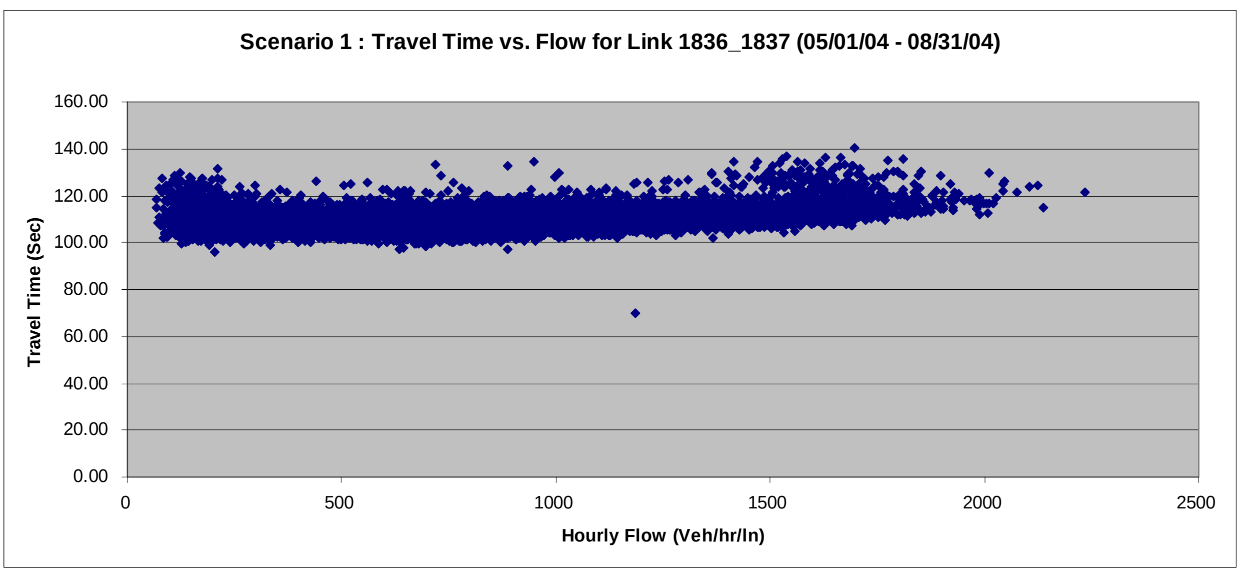


Figure 2. Travel time under non-congested conditions

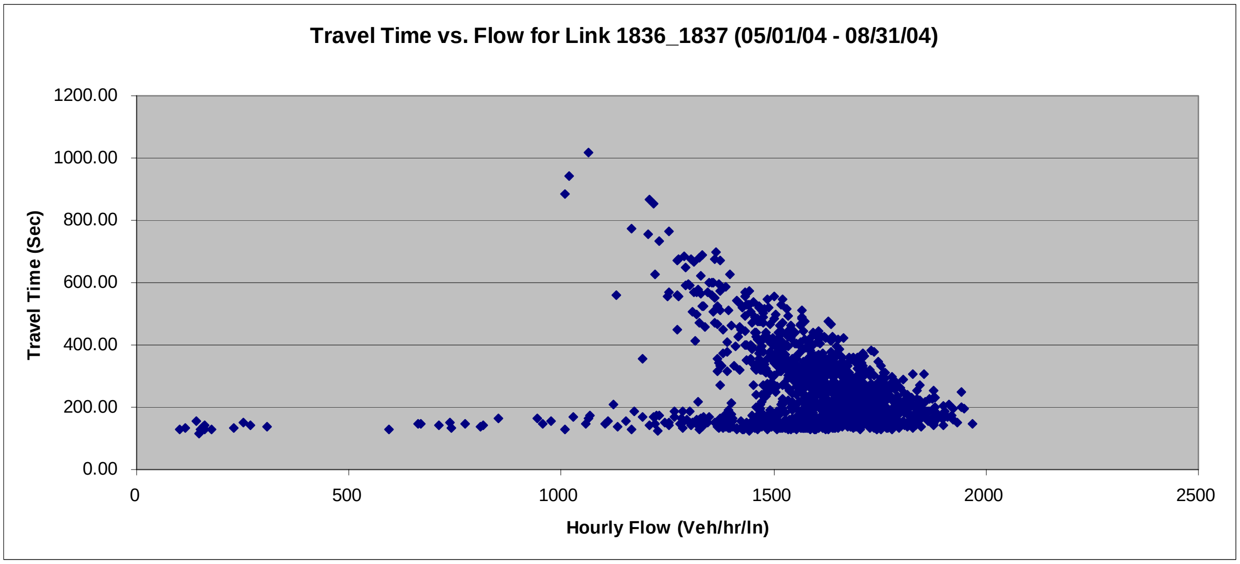


Figure 3. Travel time under semi- and fully-congested conditions

- Incidents. As suggested in the literature, various attributes of an incident can affect travel time. For the model development, those factors that previous research found to have a significant effect on travel time will be considered. In this proejct an incident is defined as an unplanned event which resulted in lane or shoulder blockage. The following factors associated with an incident have been identified:
  - Duration of incident
  - Incident capacity
  - Number of lanes/shoulder involved

Incident information was obtained by the TMC for the entire US 202, and the data were entered into the database. The Philadelphia TMC classified incidents into three categories: major, critical, and severe. For each incident or work zone there is a description along with its location information. The information was coded into the database, so that if an incident exists in one section, the upstream sections within 5 miles are considered to be under the influence of that event.

- Work zones. In this project a work zone is defined as a planned event which resulted in lane or shoulder closure. Similarly to incidents, there are several characteristics of work zones which would affect travel time. These include:
  - Duration of construction
  - Work zone capacity

- Number of lanes involved

Similarly to incident information, data were obtained by the TMC for the entire US 202, and entered into the database. The work zone information was coded into the database, so that if a work zone exists in one section, the upstream sections within 5 miles are considered to be under its influence.

Step 2: Develop a list of scenarios, and estimate travel time for each scenario.

After development of the data base the data were grouped into "scenarios", based on the prevailing conditions during each time interval. There are a total of 24 scenarios identified (Table 2.) These include three levels for congestion (fully or semi-congested, and non-congested), two levels for weather (rain, and no rain), two levels for incidents, and two levels for workzones. Definitions for each of those conditions are provided above in Step 1.

Table 2. List of scenarios

	Congestion Level	Weather Level	Incident Level	Work Zone Level
Scenario 1	Non-congested	No rain	No incident	No work zone
Scenario 2	Non-congested	Rain	No incident	No work zone
Scenario 3	Non-congested	No rain	Incident	No work zone
Scenario 4	Non-congested	No rain	No incident	Work zone
Scenario 5	Non-congested	Rain	Incident	No work zone
Scenario 6	Non-congested	Rain	No incident	Work zone
Scenario 7	Non-congested	No rain	Incident	Work zone
Scenario 8	Non-congested	Rain	Incident	Work zone
Scenario 9	Fully-congested	No rain	No incident	No work zone
Scenario 10	Fully-congested	Rain	No incident	No work zone
Scenario 11	Fully-congested	No rain	Incident	No work zone
Scenario 12	Fully-congested	No rain	No incident	Work zone
Scenario 13	Fully-congested	Rain	Incident	No work zone
Scenario 14	Fully-congested	Rain	No incident	Work zone
Scenario 15	Fully-congested	No rain	Incident	Work zone
Scenario 16	Fully-congested	Rain	Incident	Work zone
Scenario 17	Semi-Congested	No rain	No incident	No work zone
Scenario 18	Semi-Congested	Rain	No incident	No work zone
Scenario 19	Semi-Congested	No rain	Incident	No work zone
Scenario 20	Semi-Congested	No rain	No incident	Work zone
Scenario 21	Semi-Congested	Rain	Incident	No work zone
Scenario 22	Semi-Congested	Rain	No incident	Work zone
Scenario 23	Semi-Congested	No rain	Incident	Work zone
Scenario 24	Semi-Congested	Rain	Incident	Work zone

Note: Scenarios in **bold** are the ones that occurred in the 4-month period analyzed in this project

The format of the final data set is shown in Table 3. Appendix A provides a series of figures plotting travel time as a function of flow for each scenario and for each section in the study corridor. The number of incidents and work zone events along the route are summarized in Table 4. The information provided about each of these events was very limited. When a lane was closed, the event was categorized as such. Therefore, it was assumed that for incidents on the median, disabled vehicles, and when the incident type was not specified, there were no closed lanes, and capacity was not reduced.

Table 5 provides a summary of the average travel times and the respective speed for each section and each scenario, while Tables 6 to 12 summarize the same information by section.

Table 3. Database format

TT	**Factors for congestion**		**Factors for weather**	**Factors for incidents**		**Factors for work zones**	
	Level	Flow	Rainfall	# of opened lanes	# of lanes	# of opened lanes	# of lanes

Table 4. Number of incidents and work zone events by type and by month

	MAY	JUNE	JULY	AUGUST
INCIDENT ON THE SHOULDER	3	4	1	2
INCIDENT ON THE RAMP	1			
LANE CLOSURE	1		2	2
DISABLED VEHICLE		1	4	2
INCIDENT ON THE MEDIAN			2	1
INCIDENT TYPE NOT SPECIFIED		1	7	3
WORK ZONE EVENT	1	6	0	7

Table 5. Average travel time and average speed for each section and scenario

SCENARIO	SECTION	AVERAGE TRAVEL TIME (SEC)	AVERAGE SPEED (MPH)
Scenario 1	1831-1832	112.42	65.43
Scenario 1	1832-1833	26.65	66.29
Scenario 1	1833-1835	55.82	65.93
Scenario 1	1835-1836	100.81	64.47
Scenario 1	1836-1837	109.78	59.77
Scenario 1	1837-1838	41.53	60.78
Scenario 1	1838-1839	48.99	62.63
Scenario 2	1831-1832	115.89	63.59
Scenario 2	1832-1833	27.59	64.16
Scenario 2	1833-1835	57.21	64.39
Scenario 2	1835-1836	104.01	62.55
Scenario 2	1836-1837	113.81	57.72
Scenario 2	1837-1838	42.59	59.33
Scenario 2	1838-1839	49.92	61.49
Scenario 3	1831-1832	112.81	65.18
Scenario 3	1832-1833	27.12	65.33
Scenario 3	1833-1835	55.96	65.69
Scenario 3	1835-1836	101.26	64.54
Scenario 3	1836-1837	110.91	59.16
Scenario 3	1838-1839	50.28	61.07
Scenario 4	1831-1832	119.87	61.45
Scenario 4	1832-1833	26.97	65.43
Scenario 4	1836-1837	111.17	59.00
Scenario 4	1838-1839	50.77	60.38
Scenario 5	1831-1832	113.04	64.98
Scenario 5	1832-1833	26.77	65.98
Scenario 5	1833-1835	72.72	50.49
Scenario 5	1836-1837	112.51	58.46
Scenario 5	1838-1839	49.36	62.04
Scenario 6	1836-1837	108.31	60.51
Scenario 9	1835-1836	334.99	19.34
Scenario 9	1836-1837	405.31	16.17
Scenario 9	1837-1838	185.17	13.61
Scenario 9	1838-1839	187.39	16.33
Scenario 10	1832-1833	125.69	14.03
Scenario 10	1833-1835	194.97	18.83
Scenario 10	1835-1836	351.06	18.46
Scenario 10	1836-1837	499.03	13.13
Scenario 10	1837-1838	159.88	15.76
Scenario 10	1838-1839	141.92	21.56
Scenario 11	1836-1837	179.88	36.42
Scenario 11	1838-1839	114.64	26.69
Scenario 12	1836-1837	158.97	41.21
Scenario 12	1838-1839	129.84	23.57
Scenario 13	1836-1837	993.47	6.60
Scenario 13	1838-1839	75.04	40.78
Scenario 17	1831-1832	154.81	47.44
Scenario 17	1832-1833	37.05	47.61
Scenario 17	1833-1835	93.18	39.41

SCENARIO	SECTION	AVERAGE TRAVEL TIME (SEC)	AVERAGE SPEED (MPH)
Scenario 17	1835-1836	158.49	40.89
Scenario 17	1836-1837	181.02	36.20
Scenario 17	1837-1838	65.54	38.45
Scenario 17	1838-1839	69.16	44.25
Scenario 18	1831-1832	162.03	45.32
Scenario 18	1832-1833	40.27	34.81
Scenario 18	1833-1835	96.31	38.13
Scenario 18	1835-1836	167.89	38.60
Scenario 18	1836-1837	170.59	38.41
Scenario 18	1837-1838	67.87	37.13
Scenario 18	1838-1839	72.95	41.95
Scenario 19	1831-1832	144.22	50.92
Scenario 19	1835-1836	146.21	44.32
Scenario 19	1836-1837	173.89	37.68
Scenario 19	1838-1839	80.46	38.03
Scenario 20	1836-1837	170.69	38.39
Scenario 20	1838-1839	91.89	33.30
Scenario 21	1833-1835	171.11	21.46
Scenario 21	1835-1836	313.55	20.67
Scenario 21	1836-1837	217.00	30.19
Scenario 21	1838-1839	72.63	42.13

Table 6. Average travel times and speed for section 1831-1832

SCENARIO	AVERAGE TRAVEL TIME (SEC)	AVERAGE SPEED (MPH)
Scenario 1	112.42	65.43
Scenario 2	115.89	63.59
Scenario 3	112.81	65.18
Scenario 4	119.87	61.45
Scenario 5	113.04	64.98
Scenario 17	154.81	47.44
Scenario 18	162.03	45.32
Scenario 19	144.22	50.92

Table 7. Average travel times and speed for section 1832-1833

SCENARIO	AVERAGE TRAVEL TIME (SEC)	AVERAGE SPEED (MPH)
Scenario 1	26.65	66.29
Scenario 2	27.59	64.16
Scenario 3	27.12	65.33
Scenario 4	26.97	65.43
Scenario 5	26.77	65.98
Scenario 10	125.69	14.03
Scenario 17	37.05	47.61
Scenario 18	40.27	43.81

Table 8. Average travel times and speed for section 1833-1835

SCENARIO	AVERAGE TRAVEL TIME (SEC)	AVERAGE SPEED (MPH)
Scenario 1	55.82	65.93
Scenario 2	57.21	64.39
Scenario 3	55.96	65.69
Scenario 5	72.72	50.49
Scenario 10	194.97	18.83
Scenario 17	93.18	39.41
Scenario 18	96.31	38.13
Scenario 21	171.11	21.46

Table 9. Average travel times and speed for section 1835-1836

SCENARIO	AVERAGE TRAVEL TIME (SEC)	AVERAGE SPEED (MPH)
Scenario 1	100.81	64.47
Scenario 2	104.01	62.55
Scenario 3	101.26	64.54
Scenario 9	334.99	19.34
Scenario 10	351.06	18.46
Scenario 17	158.49	40.89
Scenario 18	167.89	38.60
Scenario 19	146.21	44.32
Scenario 21	313.55	20.67

Table 10. Average travel times and speed for section 1836-1837

SCENARIO	AVERAGE TRAVEL TIME (SEC)	AVERAGE SPEED (MPH)
Scenario 1	109.78	59.77
Scenario 2	113.81	57.72
Scenario 3	110.91	59.16
Scenario 4	111.17	59.00
Scenario 5	112.51	58.46
Scenario 6	108.31	60.51
Scenario 9	405.31	16.17
Scenario 10	499.03	13.13
Scenario 11	179.88	36.42
Scenario 12	158.97	41.21
Scenario 13	993.47	6.6
Scenario 17	181.02	36.20
Scenario 18	170.59	37.13
Scenario 19	173.89	37.68
Scenario 20	170.69	38.39
Scenario 21	217.00	30.19

Table 11. Average travel times and speed for section 1837-1838

SCENARIO	AVERAGE TRAVEL TIME (SEC)	AVERAGE SPEED (MPH)
Scenario 1	41.53	60.78
Scenario 2	42.59	59.33
Scenario 9	185.17	13.61
Scenario 10	159.88	15.76
Scenario 17	65.54	38.45
Scenario 18	67.87	41.95

Table 12. Average travel times and speed for section 1838-1839

SCENARIO	AVERAGE TRAVEL TIME (SEC)	AVERAGE SPEED (MPH)
Scenario 1	48.99	62.63
Scenario 2	49.92	61.49
Scenario 3	50.28	61.07
Scenario 4	50.77	60.38
Scenario 5	49.36	62.04
Scenario 9	187.39	16.33
Scenario 10	141.92	21.56
Scenario 11	114.64	26.69
Scenario 12	129.84	23.57
Scenario 13	75.04	40.78
Scenario 17	69.16	44.25
Scenario 18	72.95	41.95
Scenario 19	80.46	29.36
Scenario 20	91.89	33.30
Scenario 21	72.63	42.13

The speeds reported in Tables 5 through 12 may seem somewhat higher than expected, particularly for fully congested conditions combined with other events. There is some concern that due to RTMS limitations, the speed data may not be accurate under congested conditions. Also, because the detectors have relatively long spacing (in some cases approximately 2 miles), they may not fully capture congested conditions for the entire length of the facility. As an additional check, Table 13 provides percentages of intervals with speeds under 20 mph observed at each RTMS. Detector 1837 has the highest percent of speeds below 20 mph (1.78%), which corresponds to approximately 3 hours per week. That amount of time does not seem unreasonable, given that speeds are not likely to be below 20 mph for recurring congestion only. In future work however, it would be desirable to conduct additional checks and comparisons to evaluate the accuracy of speed and flow measurements.

Table 13. Percent of intervals with speeds less than 20 mph by sensor location

RTMS	Percent of Intervals with Speeds < 20 mph (May 1-August 31, 2004)
1831	0.21%
1832	0.24%
1833	0.31%
1835	0.65%
1836	0.85%
1837	1.78%
1838	0.05%
1839	0.08%

Step 3: Develop a travel time estimation model for each scenario.

For each scenario, and based on the data set, a model is developed to predict travel time based on all relevant factors (i.e., congestion level, weather conditions, impact of work zone level, and impact of incident level.) These models are of the form:

$$E(TT_{scenario}) = f(congestion, weather, work\_zone, incident)$$

Table 14 provides the set of models for estimating travel time per mile for each scenario, while Table 15 provides the same set of models translated to provide the average speed through a section for each scenario. Appendix B provides statisical information regarding the development of the travel time models, while Appendix C provides the same information for the average speed models.

Table 14. Travel time-based estimation models

	Congestion Level	Weather Level	Incident Level	Work Zone Level	Number of data points	Model
Scenario 1	Non-congested	No rain	No incident	No work zone	51947	TT/mile = 65.4 - 3.56 number of lanes
Scenario 2	Non-congested	rain	No incident	No work zone	17179	TT/mile = 66.6 + 5.22 amount of rain - 3.51 number of lanes
Scenario 3	Non-congested	No rain	Incident	No work zone	334	TT/Mile = 61.1 - 4.27 O/T
Scenario 4	Non-congested	No rain	No incident	work zone	838	TT/Mile = 61.6 - 0.854 number of lanes opened
Scenario 5	Non-congested	rain	Incident	No work zone	79	TT/Mile = 70.4 - 3.70 O/T - 4.34 number of lanes + 10.5 amount of rain
Scenario 6	Non-congested	rain	No incident	work zone	23	Not enough data, Number of lanes, number of lanes closed, number of on ramps, and number of off-ramps are constant values. (They are all from one construction between 1836-1837)
Scenario 7	Non-congested	No rain	Incident	work zone	None	None
Scenario 8	Non-congested	rain	Incident	work zone	None	None
Scenario 9	Congested	No rain	No incident	No work zone	563	TT/mile = - 62.4 + 987.6022 e^(-0.0008 hourly flow per lane)
Scenario 10	Congested	rain	No incident	No work zone	258	
Scenario 11	Congested	No rain	Incident	No work zone	15	The constant in the model is not significant
Scenario 12	Congested	No rain	No incident	work zone	3	not enough data, only 3 data points, and the constant in the model is not significant
Scenario 13	Congested	rain	Incident	No work zone	6	TT/Mile = 1003 - 915 O/T
Scenario 14	Congested	rain	No incident	work zone	None	None
Scenario 15	Congested	No rain	Incident	work zone	None	None
Scenario 16	Congested	rain	Incident	work zone	None	None
Scenario 17	Semi-Congested	No rain	No incident	No work zone	3978	TT/mile = 98.8 - 3.19 number of lanes
Scenario 18	Semi-Congested	rain	No incident	No work zone	1201	
Scenario 19	Semi-Congested	No rain	Incident	No work zone	40	None of the variables can be included in the model, they are all insignificant.
Scenario 20	Semi-Congested	No rain	No incident	work zone	97	O/T, number of lanes, number of lanes open, and number of lanes closed are all constants. If flow is included in the model, it is insignificant.
Scenario 21	Semi-Congested	rain	Incident	No work zone	34	TT/Mile = 171 - 84.6 O/T
Scenario 22	Semi-Congested	rain	No incident	work zone	None	None
Scenario 23	Semi-Congested	No rain	Incident	work zone	None	None
Scenario 24	Semi-Congested	rain	Incident	work zone	None	None

Table 15. –Average speed-based estimation models

	Congestion Level	Weather Level	Incident Level	Work Zone Level	Number of data points	Model
Scenario 1	Non-congested	No rain	No incident	No work zone	51947	Speed = 54.0 + 3.95 number of lanes
Scenario 2	Non-congested	rain	No incident	No work zone	17179	Speed = 53.2 - 5.27 amount of rain + 3.72 number of lanes
Scenario 3	Non-congested	No rain	Incident	No work zone	334	Speed = 58.9 + 4.70 OT
Scenario 4	Non-congested	No rain	No incident	work zone	838	Speed = 58.4 + 0.912 number of lanes opened
Scenario 5	Non-congested	rain	Incident	No work zone	79	Speed = 48.9 + 3.46 O/T + 4.78 number of lanes - 9.21 rain
Scenario 6	Non-congested	rain	No incident	work zone	23	Not enough data, Number of lanes, number of lanes closed, number of on ramps, and number of off-ramps are constant values. (They are all from one construction between 1836-1837)
Scenario 7	Non-congested	No rain	Incident	work zone	None	None
Scenario 8	Non-congested	rain	Incident	work zone	None	None
Scenario 9	Congested	No rain	No incident	No work zone	563	Speed = 33.9 – 56.828 e^ (-0.0008 hourly flow per lane)
Scenario 10	Congested	rain	No incident	No work zone	258	
Scenario 11	Congested	No rain	Incident	No work zone	15	The constant in the model is not significant
Scenario 12	Congested	No rain	No incident	work zone	3	not enough data, only 3 data points, and the constant in the model is not significant
Scenario 13	Congested	rain	Incident	No work zone	6	Speed = - 28.0 + 69.2 O/T
Scenario 14	Congested	rain	No incident	work zone	None	None
Scenario 15	Congested	No rain	Incident	work zone	None	None
Scenario 16	Congested	rain	Incident	work zone	None	None
Scenario 17	Semi-Congested	No rain	No incident	No work zone	3978	Speed = 38.0 + 1.18 number of lanes
Scenario 18	Semi-Congested	rain	No incident	No work zone	1201	
Scenario 19	Semi-Congested	No rain	Incident	No work zone	40	None of the variables can be included in the model, they are all insignificant.
Scenario 20	Semi-Congested	No rain	No incident	work zone	97	O/T, number of lanes, number of lanes open, and number of lanes closed are all constants. If flow is included in the model, it is insignificant.
Scenario 21	Semi-Congested	rain	Incident	No work zone	34	Speed = 21.3 + 20.6 O/T
Scenario 22	Semi-Congested	rain	No incident	work zone	None	None
Scenario 23	Semi-Congested	No rain	Incident	work zone	None	None
Scenario 24	Semi-Congested	rain	Incident	work zone	None	None

Step 4: Develop the expected travel time model.

The expected travel time for the entire facility is based on the probability of occurrence for each of the scenarios listed previously. These probabilities are estimated based on the field data and are provided in Table 16. The probabilities are given both in terms of percent of time each scenario occurred, and in terms of percent of trips under each scenario.

Table 16. Probability for each scenario to occur at each section

		1831-1832	P (%)	1832-1833	P (%)	1833-1835	P (%)	1835-1836	P (%)	1836-1837	P (%)	1837-1838	P (%)	1838-1839	P (%)
Scenario 1	No. of time points	17341	86.02%	17407	86.35%	17079	84.71%	16538	82.01%	15766	77.78%	16331	81.01%	16863	83.43%
	No. of trips	678291	86.58%	550093	86.82%	551117	83.90%	529052	79.41%	443978	72.67%	463976	75.09%	514423	80.34%
Scenario 2	No. of time points	2627	13.03%	2614	12.97%	2507	12.43%	2386	11.83%	2143	10.57%	2332	11.57%	2479	12.26%
	No. of trips	97987	12.51%	79788	12.59%	76525	11.65%	71218	10.69%	57413	9.40%	65378	10.58%	74749	11.67%
Scenario 3	No. of time points	83	0.41%	26	0.13%	11	0.05%	9	0.04%	134	0.66%	0	0.00%	91	0.45%
	No. of trips	3706	0.47%	1119	0.18%	469	0.07%	272	0.04%	4202	0.69%	0	0.00%	3335	0.52%
Scenario 4	No. of time points	36	0.18%	13	0.06%	0	0.00%	0	0.00%	153	0.75%	0	0.00%	17	0.08%
	No. of trips	1515	0.19%	487	0.08%	0	0.00%	0	0.00%	5467	0.89%	0	0.00%	563	0.09%
Scenario 5	No. of time points	9	0.04%	10	0.05%	1	0.00%	0	0.00%	45	0.22%	0	0.00%	14	0.07%
	No. of trips	435	0.06%	479	0.08%	42	0.01%	0	0.00%	1270	0.21%	0	0.00%	273	0.04%
Scenario 6	No. of time points	0	0.00%	0	0.00%	0	0.00%	0	0.00%	22	0.11%	0	0.00%	0	0.00%
	No. of trips	0	0.00%	0	0.00%	0	0.00%	0	0.00%	871	0.14%	0	0.00%	0	0.00%
Scenario 9	No. of time points	0	0.00%	0	0.00%	0	0.00%	122	0.61%	426	2.10%	12	0.06%	3	0.01%
	No. of trips	0	0.00%	0	0.00%	0	0.00%	7518	1.13%	21734	3.56%	588	0.10%	137	0.02%
Scenario 10	No. of time points	0	0.00%	3	0.01%	6	0.03%	74	0.37%	152	0.75%	19	0.09%	4	0.02%
	No. of trips	0	0.00%	135	0.02%	344	0.05%	4160	0.62%	7149	1.17%	897	0.15%	201	0.03%
Scenario 11	No. of time points	0	0.00%	0	0.00%	0	0.00%	0	0.00%	2	0.01%	0	0.00%	13	0.06%
	No. of trips	0	0.00%	0	0.00%	0	0.00%	0	0.00%	185	0.03%	0	0.00%	1113	0.17%
Scenario 12	No. of time points	0	0.00%	0	0.00%	0	0.00%	0	0.00%	2	0.01%	0	0.00%	1	0.00%
	No. of trips	0	0.00%	0	0.00%	0	0.00%	0	0.00%	110	0.02%	0	0.00%	38	0.01%
Scenario 13	No. of time points	0	0.00%	0	0.00%	0	0.00%	0	0.00%	4	0.02%	0	0.00%	2	0.01%
	No. of trips	0	0.00%	0	0.00%	0	0.00%	0	0.00%	140	0.02%	0	0.00%	136	0.02%
Scenario 17	No. of time points	34	0.17%	48	0.24%	405	2.01%	826	4.10%	997	4.92%	1151	5.71%	517	2.56%
	No. of trips	574	0.07%	399	0.06%	20101	3.06%	43119	6.47%	50846	8.32%	70162	11.36%	33239	5.19%
Scenario 18	No. of time points	28	0.14%	37	0.18%	150	0.74%	204	1.01%	302	1.49%	313	1.55%	167	0.83%
	No. of trips	903	0.12%	1077	0.17%	8118	1.24%	10614	1.59%	12857	2.10%	16854	2.73%	10021	1.57%

		1831-1832	P (%)	1832-1833	P (%)	1833-1835	P (%)	1835-1836	P (%)	1836-1837	P (%)	1837-1838	P (%)	1838-1839	P (%)
Scenario 19	No. of time points	1	0.00%	0	0.00%	0	0.00%	2	0.01%	28	0.14%	0	0.00%	11	0.05%
	No. of trips	4	0.00%	0	0.00%	0	0.00%	149	0.02%	1999	0.33%	0	0.00%	734	0.11%
Scenario 20	No. of time points	0	0.00%	0	0.00%	0	0.00%	0	0.00%	76	0.37%	0	0.00%	21	0.10%
	No. of trips	0	0.00%	0	0.00%	0	0.00%	0	0.00%	2220	0.36%	0	0.00%	708	0.11%
Scenario 21	No. of time points	0	0.00%	0	0.00%	3	0.01%	4	0.02%	17	0.08%	0	0.00%	10	0.05%
	No. of trips	0	0.00%	0	0.00%	163	0.02%	154	0.02%	493	0.08%		0.00%	605	0.09%
Total	No. of time points	20159	1	20158	1	20162	1	20165	1	20269	1	20158	1	20213	1
	No. of trips	783415	1	633577	1	656879	1	666256	1	610934	1	617855	1	640275	1

Based on the travel time for each scenario and the probability of each scenario occurrence, the expected travel time is estimated as:

$$E[TT] = \sum_{1}^{n} TT_{scenario} \times scenario\%$$

Where:

$E[TT]$: expected travel time

$TT_{scenario}$: travel time for each scenario

n : Number of scenarios

$scenario\%$: Probability associated with each scenario

Tables 17 to 23 present the expected travel time for each section, as well as the respective speed, calculated using the above equation. The expected travel time is estimated in two ways: using the percentages based on time, and the percentages based on the number of trips.

A comparison between the analysis using 10 days of data (which was completed for the interim report of this project) and using 4 months of data showed that there is a difference of about 3-7 seconds (2-3 mph) in speed estimation for the most congested links only (1835-1836 and 1836-1837). Table 24 provides a summary of this comparison. The first two columns provide the results as a function of the percent of time a particular scenario occurred, while the last two columns provide the results as a function of the percent of trips under each scenario.

Table 17. Expected travel time for section 1831-1832

SCENARIO	AVERAGE TRAVEL TIME (SEC)	EXPECTED TRAVEL TIME (BASED ON NUMBER OF DATA POINTS)	EXPECTED TRAVEL TIME (BASED ON NUMBER OF TRIPS)
Scenario 1	112.42	113.03 (=64.97 mph)	112.96 (=65.01 mph)
Scenario 2	115.89		
Scenario 3	112.81		
Scenario 4	119.87		
Scenario 5	113.04		
Scenario 11	144.22		
Scenario 17	154.81		
Scenario 18	162.03		
Scenario 19	144.22		

Table 18. Expected travel time for section 1832-1833

SCENARIO	AVERAGE TRAVEL TIME (SEC)	EXPECTED TRAVEL TIME (BASED ON NUMBER OF DATA POINTS)	EXPECTED TRAVEL TIME (BASED ON NUMBER OF TRIPS)
Scenario 1	26.65	26.84 (=65.73 mph)	26.82 (=65.77 mph)
Scenario 2	27.59		
Scenario 3	27.12		
Scenario 4	26.97		
Scenario 5	26.77		
Scenario 10	125.69		
Scenario 17	37.05		
Scenario 18	40.27		

Table 19. Expected travel time for section 1833-1835

SCENARIO	AVERAGE TRAVEL TIME (SEC)	EXPECTED TRAVEL TIME (BASED ON NUMBER OF DATA POINTS)	EXPECTED TRAVEL TIME (BASED ON NUMBER OF TRIPS)
Scenario 1	55.82	57.10 (=64.30 mph)	57.73 (=63.61 mph)
Scenario 2	57.21		
Scenario 3	55.96		
Scenario 5	72.72		
Scenario 10	194.97		
Scenario 17	93.18		
Scenario 18	96.31		
Scenario 21	171.11		

Table 20. Expected travel time for section 1835-1836

SCENARIO	AVERAGE TRAVEL TIME (SEC)	EXPECTED TRAVEL TIME (BASED ON NUMBER OF DATA POINTS)	EXPECTED TRAVEL TIME (BASED ON NUMBER OF TRIPS)
Scenario 1	100.81	106.61 (=60.78 mph)	110.22 (=58.79 mph)
Scenario 2	104.01		
Scenario 3	101.26		
Scenario 9	334.99		
Scenario 10	351.06		
Scenario 11	146.21		
Scenario 17	158.49		
Scenario 18	167.89		
Scenario 19	146.21		
Scenario 21	313.55		

Table 21. Expected travel time for section 1836-1837

SCENARIO	AVERAGE TRAVEL TIME (SEC)	EXPECTED TRAVEL TIME (BASED ON NUMBER OF DATA POINTS)	EXPECTED TRAVEL TIME (BASED ON NUMBER OF TRIPS)
Scenario 1	109.78	124.36 (=52.68 mph)	133.21 (=49.19 mph)
Scenario 2	113.81		
Scenario 3	110.91		
Scenario 4	111.17		
Scenario 5	112.51		
Scenario 6	108.31		
Scenario 9	405.31		
Scenario 10	499.03		
Scenario 11	179.88		
Scenario 12	158.97		
Scenario 13	993.47		
Scenario 17	181.02		
Scenario 18	170.59		
Scenario 19	173.89		
Scenario 20	170.69		
Scenario 21	217.00		

Table 22. Expected travel time for section 1837-1838

SCENARIO	AVERAGE TRAVEL TIME (SEC)	EXPECTED TRAVEL TIME (BASED ON NUMBER OF DATA POINTS)	EXPECTED TRAVEL TIME (BASED ON NUMBER OF TRIPS)
Scenario 1	41.53	43.63 (=57.76 mph)	45.40 (=55.51 mph)
Scenario 2	42.59		
Scenario 9	185.17		
Scenario 10	159.88		
Scenario 17	65.54		
Scenario 18	67.87		

Table 23. Expected travel time for section 1838-1839

SCENARIO	AVERAGE TRAVEL TIME (SEC)	EXPECTED TRAVEL TIME (BASED ON NUMBER OF DATA POINTS)	EXPECTED TRAVEL TIME (BASED ON NUMBER OF TRIPS)
Scenario 1	48.99	49.99 (=61.22 mph)	50.82 (=60.21 mph)
Scenario 2	49.92		
Scenario 3	50.28		
Scenario 4	50.77		
Scenario 5	49.36		
Scenario 9	187.39		
Scenario 10	141.92		
Scenario 11	114.64		
Scenario 12	129.84		
Scenario 13	75.04		
Scenario 17	69.16		
Scenario 18	72.95		
Scenario 19	80.46		
Scenario 20	91.89		
Scenario 21	72.63		

Table 24. Comparison between the results from 10 days of data and 4 months of data

Link	Expected Travel Time (sec) Based on Percent of Time for 10 Days of Data	Expected Travel Time (sec) Based on Percent of Time for 4-month Data	Expected Travel Time (sec) Based on Number of Trips for 10 Days of Data	Expected Travel Time(sec) Based on Number of Trips for 4 Months of Data
1831-1832	113.29 (=64.82 mph)	113.03 (=64.97 mph)	113.43 (=64.74mph)	112.96 (=65.01 mph)
1832-1833	26.95 (=65.45 mph)	26.84 (=65.73 mph)	26.99 (=65.35 mph)	26.82 (=65.77 mph)
1833-1835	57.60 (=63.75 mph)	57.10 (=64.30 mph)	58.82 (=65.30 mph)	57.73 (=63.61 mph)
1835-1836	109.42 (=59.22 mph)	106.61 (=60.78 mph)	114.23 (=56.73 mph)	110.22 (=58.79 mph)
1836-1837	131.56 (=49.80 mph)	124.36 (=52.68 mph)	141.15 (=46.42 mph)	133.21 (=49.19 mph)
1837-1838	43.65 (=57.73 mph)	43.63 (=57.76 mph)	45.78 (=55.04 mph)	45.40 (=55.51 mph)
1838-1839	49.48 (=61.84 mph)	49.99 (=61.22 mph)	50.23 (=60.92 mph)	50.82 (=60.21 mph)

Travel time distributions and reliability

There are two options for obtaining a travel time distribution and travel time reliability, based on whether travel time data are directly available or they need to be estimated. If data are available, the travel time distribution can be plotted using these data, and the variance of travel time can be calculated as:

$$s^2 = \frac{\sum_{i=1}^{n}(x_i - \overline{x})^2}{n-1}$$

where :

s^2 : travel time variance

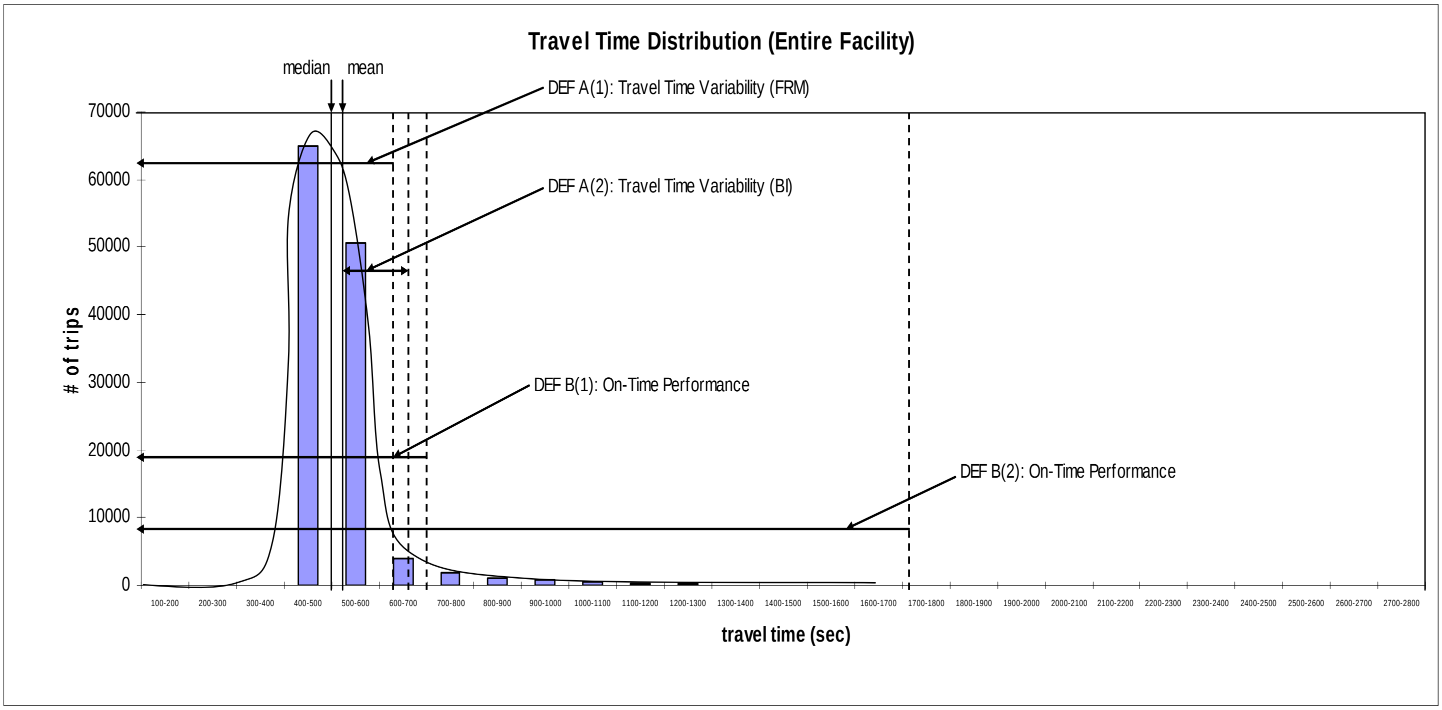
x_i : individual travel time

$\overline{x}$: mean travel time

n : number of samples

Figure 4 presents the entire travel time distribution for the facility described above, indicating travel time reliability measures according to various approaches. Table 25 indicates the percent of on-time trips for various approaches of reporting travel time reliability. Note that in the first and last lines of the table, the reliability is estimated as a function of the given speed boundary, while in the remaining lines of the table the speed boundary was determined as a function of a given reliability.

As shown in Figure 4 and Table 25, if the measure of on-time performance is "Speed Limit – 10 mph", over 95% of the trips will be reliable. If the measure used is "1/3 * Speed Limit", the resulting speed would be very low (18.3 mph) and all trips would be considered reliable. A reasonable boundary may be 10 – 15 mph below the speed limit, since this would result in approximately 95-96% travel time reliability. As shown in the plot of Figure 4, the curve is fairly flat when travel times are higher than 700 to 800 sec (corresponding to speeds between 40-45 mph).



Notes: DEF A(1) is travel time reliabilitiy according to the Florida Reliability Method
DEFA(2) is travel time reliability according to the Buffer Index
DEF B(1) is travel time reliability when on-time performance is "Speed Limit -10 mph"
DEF B(2) is travel time reliability when on-time performance is "1/3 x Speed Limit"

Figure 4. Travel time distribution for the entire US 202 study facility

Table 25. Percent of "reliable trips" as a function of various on-time performance approaches

Percent of "reliable" trips	**Travel time boundary(sec) (Trips with higher travel time are unreliable)**	**Speed (mph) (Speeds below this threshold correspond to "unreliable" conditions)**
95.88	697.6	45 mph (= Speed Limit-10 mph)
95.00	659.4	43.2 (=0.79*Speed Limit)
96.00	703.3	40.5 (=0.74*Speed Limit)
97.00	765.7	37.0 (=0.67*Speed Limit)
98.00	862.0	33.2 (=0.60*Speed Limit)
99.00	1,030.6	27.0 (=0.49*Speed Limit)
100.00	2759.1	18.3 (=1/3*Speed Limit)

Note: Speed Limit = 55 mph

If travel time data are not available, the analyst may estimate travel times based on the scenarios listed above, and using the models previously developed and summarized in Table 14. A travel time distribution may be obtained using the frequency of occurrence of each scenario, along with the predicted travel time. The travel time reliability can finally be obtained using the technique outlined above. The next section provides two examples for determining the travel time reliability for each of those two options, i.e., when data are available, and when data are not available.

V. EXAMPLE APPLICATIONS

There are two methods for estimating travel time reliability. The first one can be used when field travel time data are available (summarized below in Figure 5) while the other should be used when field travel time data are not available (summarized below in Figure 6). For the first method, required inputs include the averabe travel time for each scenario, and the percentage of occurance for each sccenario during the study period. Based on these, the travel time distribution can be generated and the expected travel time can be estimated as shown in Figure 5.

If data are not available, travel times for each scenario have to be estimated using previously developed models, such as the ones developed in this research, and shown in Table 14. (Note that these models may not apply to facilities with speed limit other than 55 mph. It is expected that subsequent research will expand on these models and will provide a more generalized set of models for estimating travel time reliability for the SIS.) To apply this method, input data should be available on the frequency of congestion, incidents, percipitation, and work zone occurance for the analysis period. Based on these, a travel time distribution can be generated and the expected travel time can be estimated. If the frequency of each scenario is not available, the methodology can provide expected travel times for each scenario, but not an overall expected travel time, nor an overall measure of reliability.

1) Inputs:

a. Travel times

b. Percentage of occurrence for each scenario

Group them by scenarios based on congestion level, rain occurrence, incident occurrence, and work zone occurrence

2) Obtain travel time for each scenario

3) Estimate the percentage of occurrence for each scenario during the study period

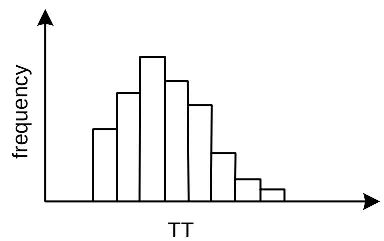
4) Estimate expected travel time for the study period (typically a year) based on the percentage of occurrence for each scenario during this period (Eqn.1)

5) Report travel time reliability for the system: (Graph A)

Worksheet A

Scenario	TT	% occurrence

$$\text{Expected TT} = \sum_{1}^{n} TT_n \times (\%occurance\_for\_n) \quad \text{Eqn. 1}$$



Graph A: TT Distribution

Figure 5. Method for Estimating Travel Time Reliability with Field Travel Time Data

1) Inputs: for each link and each hour in the network:
   a. Frequency of congestion levels (congested, semi-congested, non-congested)
   b.Flow rates (hourly flow per lane)
   c. Precipitation (hourly rainfall)
   d. Incident occurrence/ number of lanes/number of lanes closed due to incident
   e. Work zone occurrence/number of lanes/number of lanes closed due to incident

Group them by scenarios based on congestion level, rain occurrence, incident occurrence, and work zone occurrence

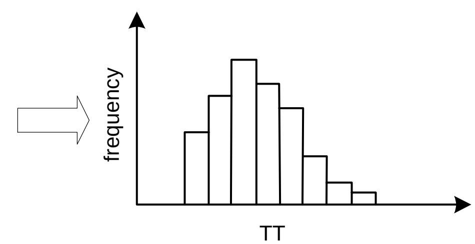
2) Estimate travel time for each scenario (see Table xx for examples of such models). These are entered in Worksheet A, and the respective travel time estimated
3) Estimate the percentage of occurrence for each scenario during the study period (the information is entered in Worksheet B)
4) Estimate the expected travel time for the year based on the percentage occurrence for each scenario during a year (Eqn. 1)
5) Report travel time reliability for the system (Graph A)

Worksheet A

Scenario	Model	TT

Worksheet B

Scenario	TT	% occurrence



Graph A: TT Distribution

$$\text{Expected TT}=\sum_{1}^{n} TT_n \times (\%\_occurance\_for\_n) \quad \text{Eqn. 1}$$

Figure 6: Method for Estimating Travel Time Reliability without Field Travel Time Data

VI. CONCLUSIONS AND RECOMMENDATIONS

This research has developed preliminary models for estimating the travel time reliability on freeway facilities. The models developed here were based on field data from Philadelphia, PA. The first step of the research evaluated various travel time reliability approaches, and recommended the following definition: "Travel time reliability is defined as the percent of trips that reach a destination over a designated facility within a given travel time (or equivalently, at a given travel speed or higher)." Based on the field data used in this project, it is recommended that on-time arrival be considered to be 10 mph below the speed limit. For the study facility, and for on-time arrival equal to "speed limit – 10 mph", the reliability is 96 %.

A series of empirical models were developed which estimate the travel time per mile (or average speed) for a series of scenarios, considering congestion occurrence, incidents, rain, and workzones. The report provided two examples for estimating travel time reliability on freeways. The first example assumes that travel time data are available, while the second focuses on cases when these are not available.

The following are recommendations for further research in support of the travel time reliability efforts of the Florida Department of Transportation.

1. *Refinement of freeway model based on data from Florida.* In the next phase of the travel time reliability research, the model developed under this project should be refined based on data from Florida. Such data may become available either from District 4 (Ft. Lauderdale) or from District 2 (Jacksonville). Given that the speed limit at the Philadelphia, PA freeway facility was 55 mph, it would be desirable to obtain data from freeways with various speed limits.
2. *Development of travel time reliability models for arterials.* An extension of the work described in this interim report would use data from arterials to develop travel time reliability models for these facilities. Those models would consider the presence of intersections and the impacts of interrupted flow on travel time.
3. *Application of the proposed methodology for both freeways and arterials to the SIS/FIHS.* This research would implement the methodologies formulated for both freeways and arterials to estimate travel time reliability on the entire SIS/FIHS network.
4. *Travel time reliability with consideration of various modes for the SIS.* This research would expand the previously developed methodologies regarding travel time reliability to consider other travel modes as well intermodal connections (for example, freight reliability through port, rail, aviation, truck modes).

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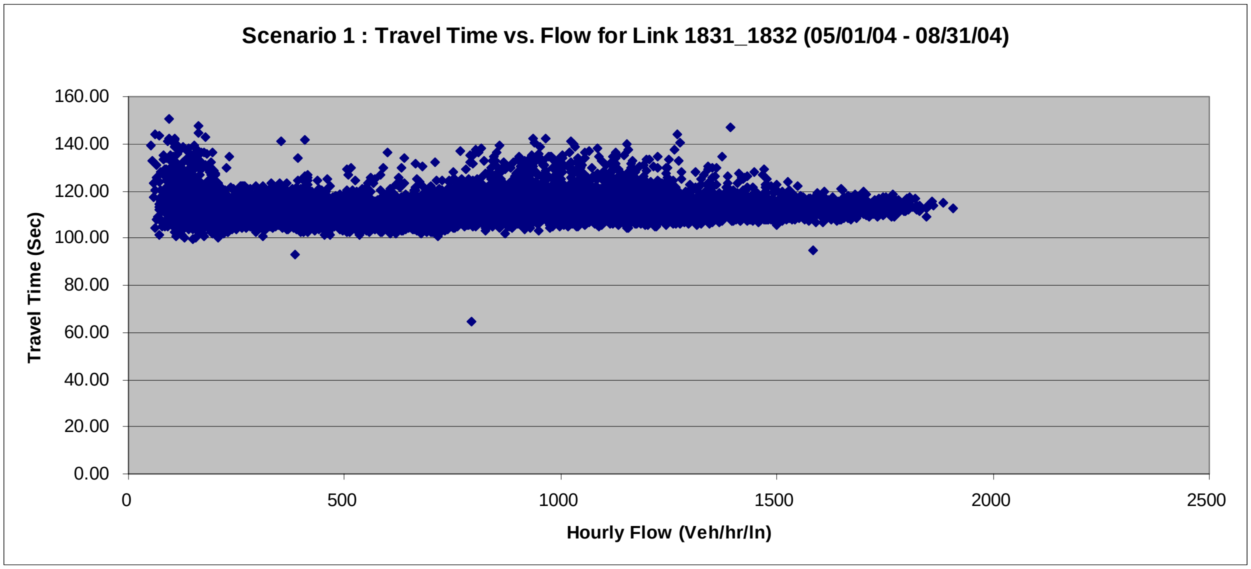
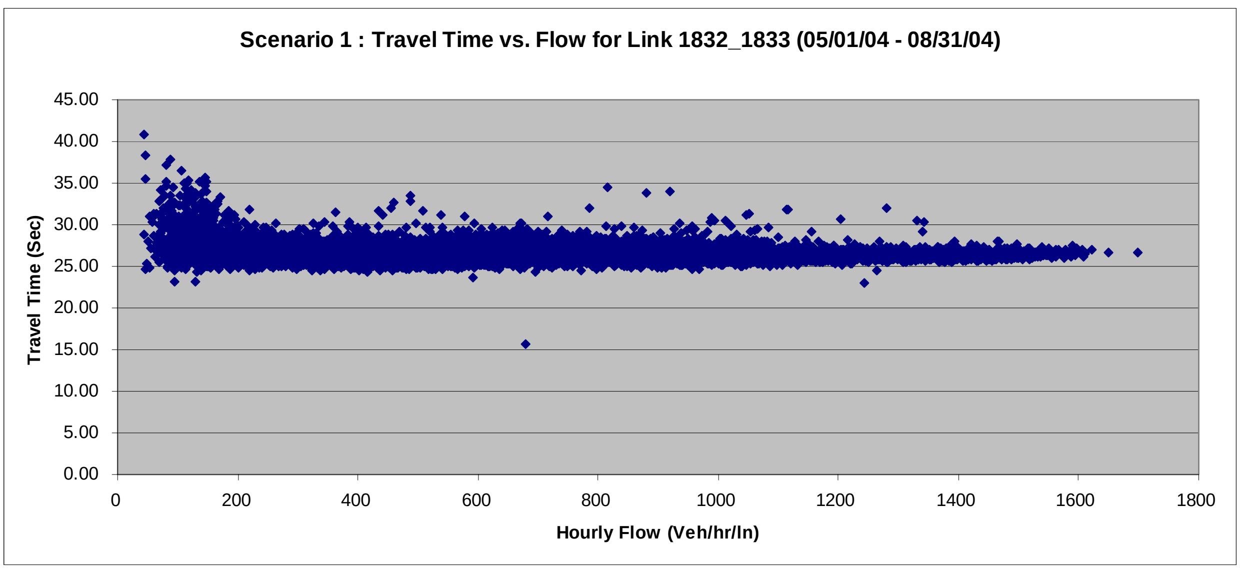
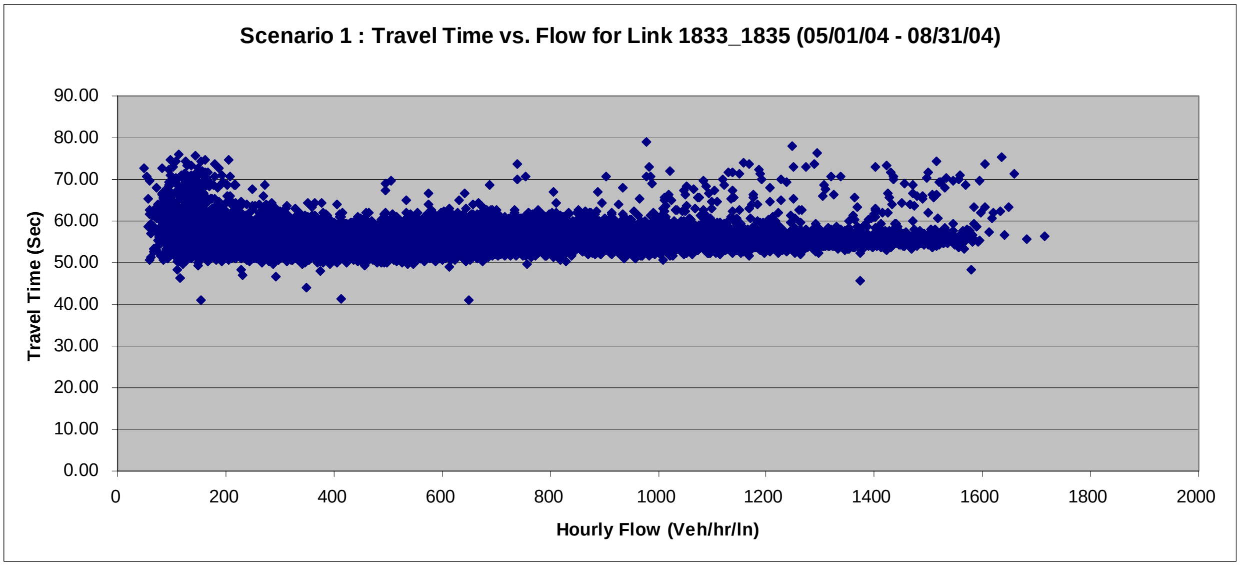
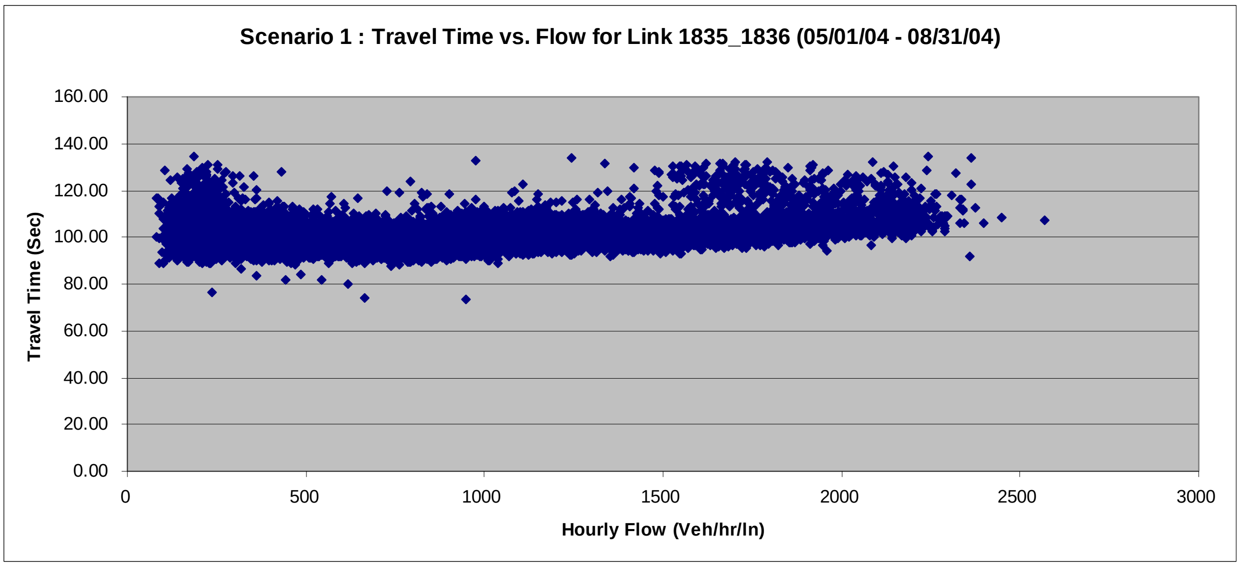
Appendix A. Travel Times Vs. Flow for Each Scenario (May 1-, August 31, 2004)



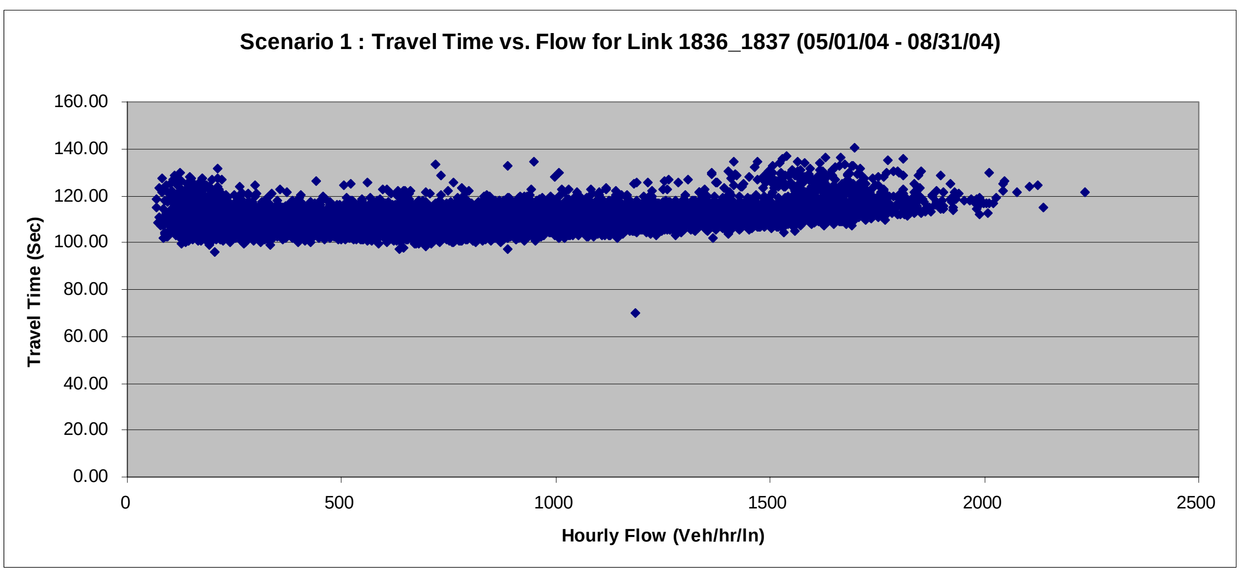




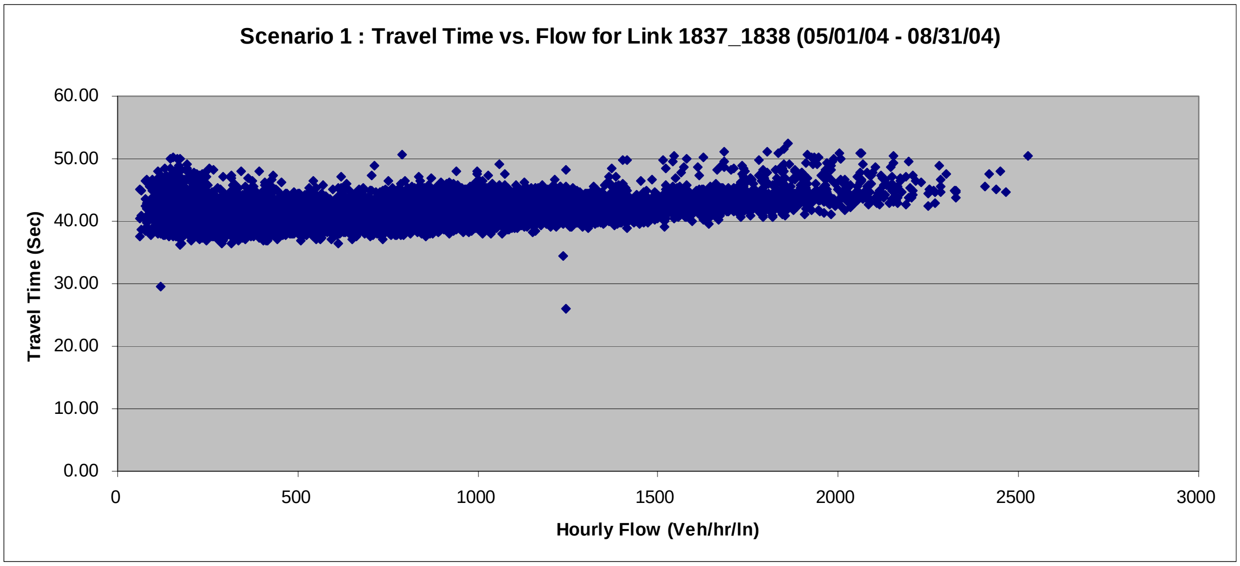
Scenario 1 : Travel Time vs. Flow for Link 1833_1835 (05/01/04 - 08/31/04)
Travel Time (Sec)
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Hourly Flow (Veh/hr/ln)



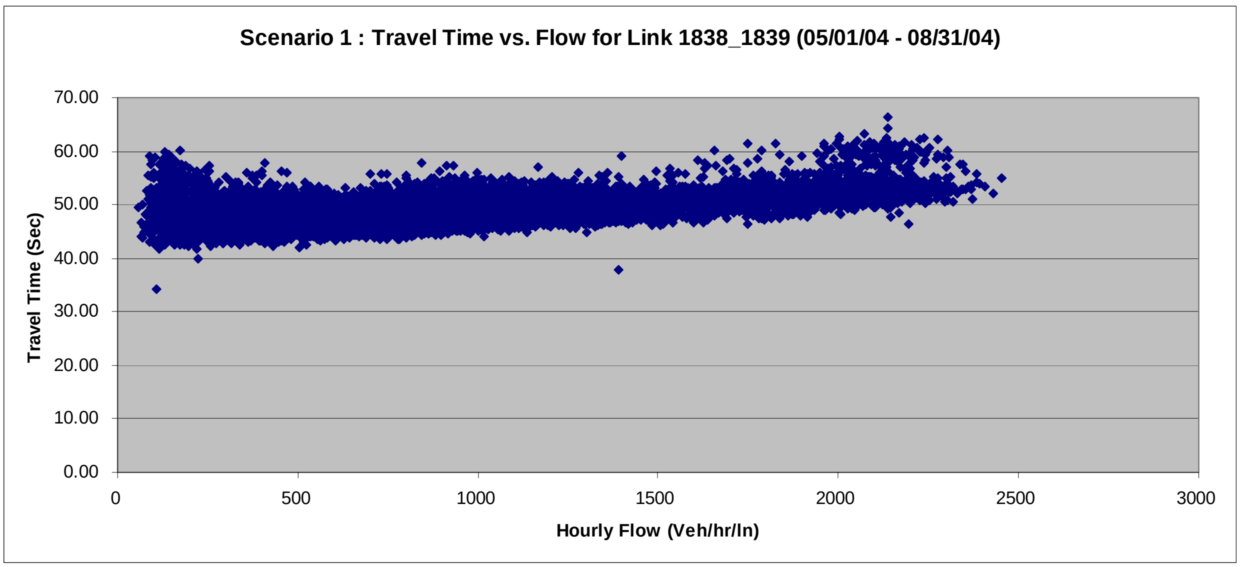
Scenario 1 : Travel Time vs. Flow for Link 1835_1836 (05/01/04 - 08/31/04)
Travel Time (Sec)
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
0
500
1000
1500
2000
2500
3000
Hourly Flow (Veh/hr/ln)



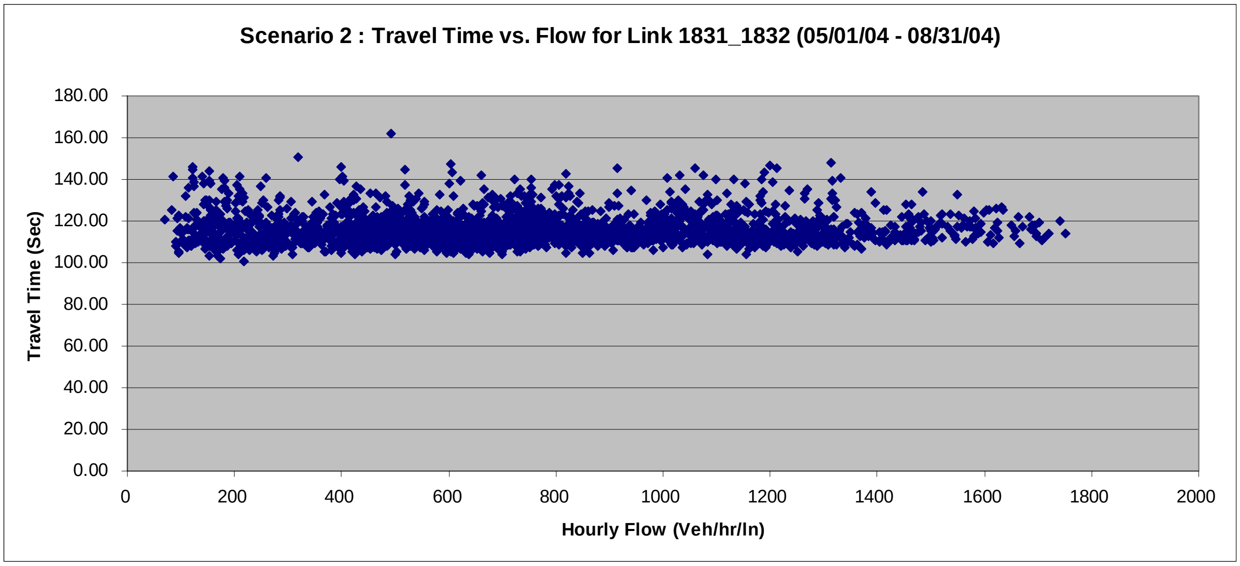
Scenario 1 : Travel Time vs. Flow for Link 1836_1837 (05/01/04 - 08/31/04)
Travel Time (Sec)
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
0
500
1000
1500
2000
2500
Hourly Flow (Veh/hr/ln)

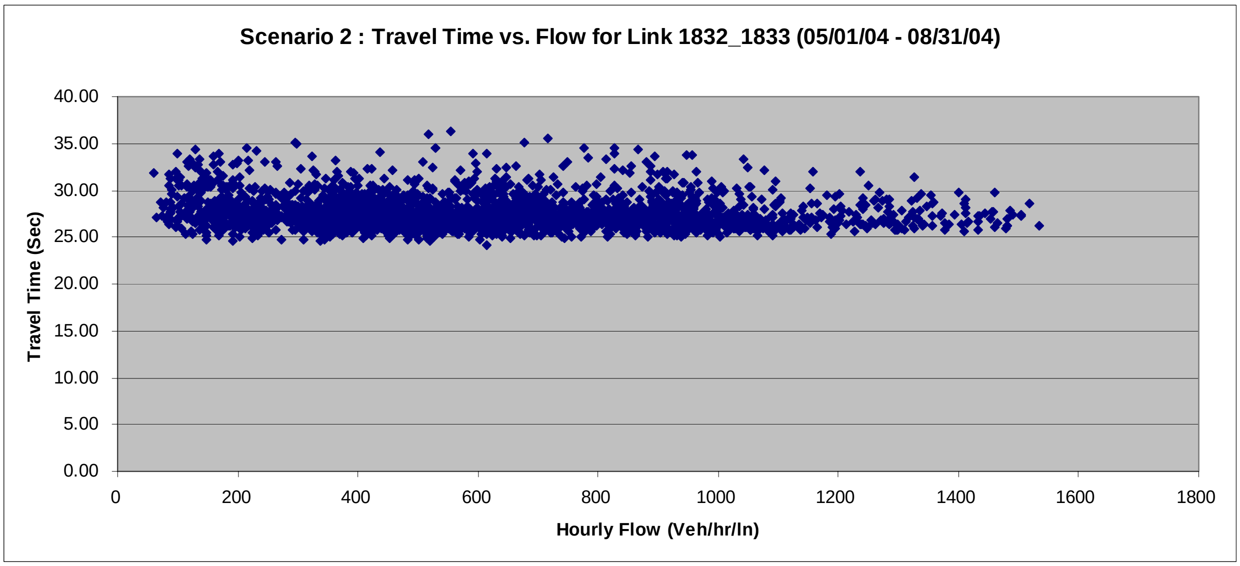


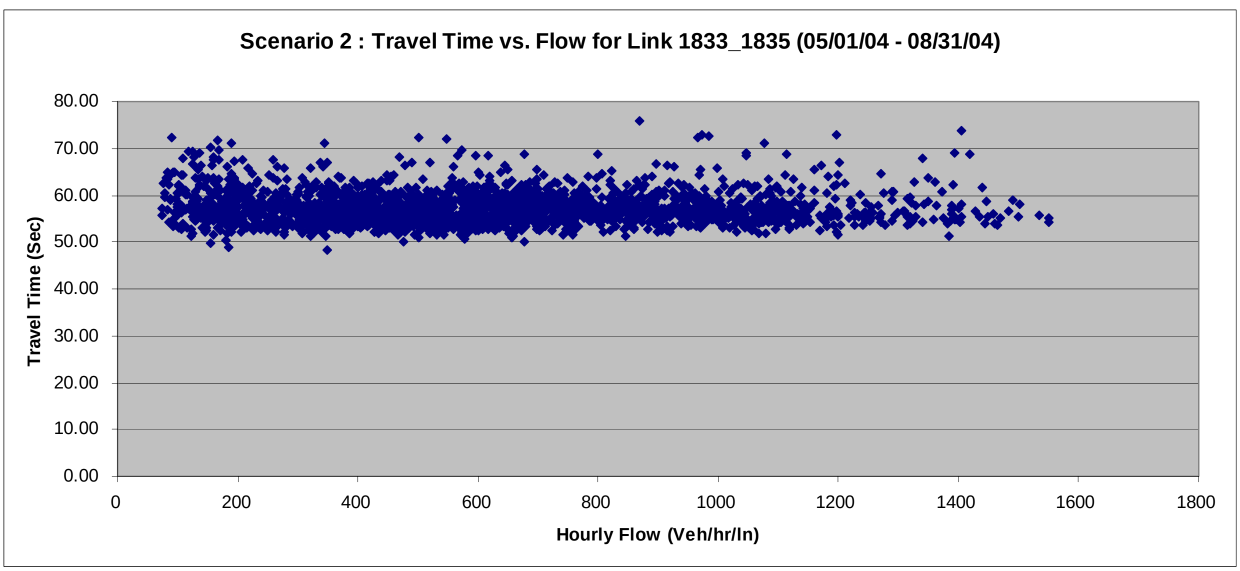
Scenario 1 : Travel Time vs. Flow for Link 1837_1838 (05/01/04 - 08/31/04)
Travel Time (Sec)
Hourly Flow (Veh/hr/ln)
60.00
50.00
40.00
30.00
20.00
10.00
0.00
0
500
1000
1500
2000
2500
3000

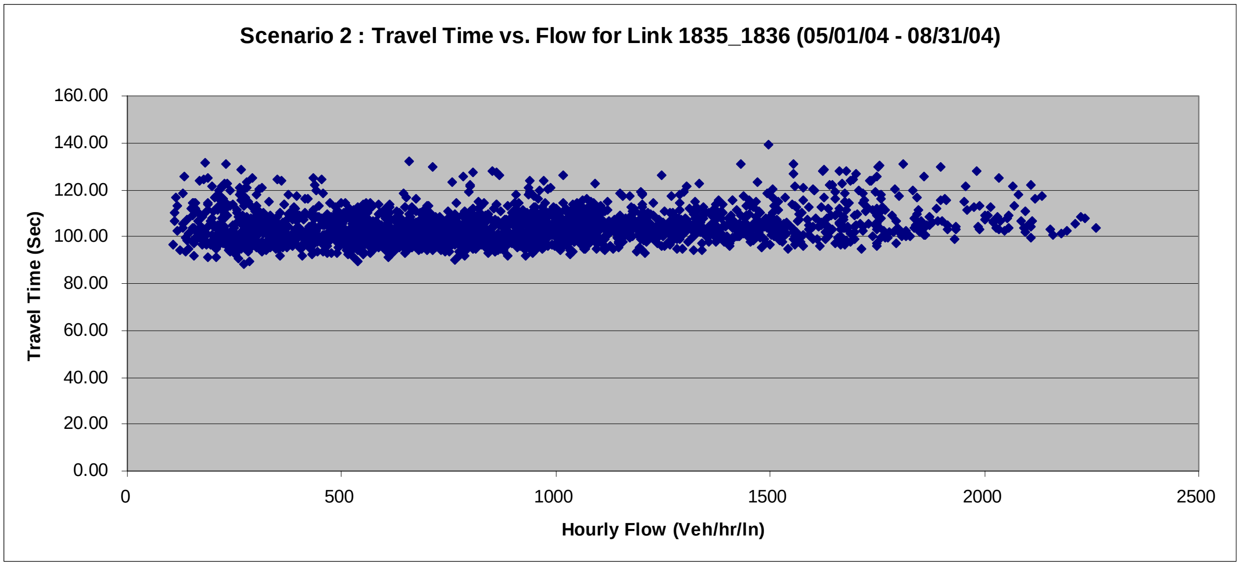


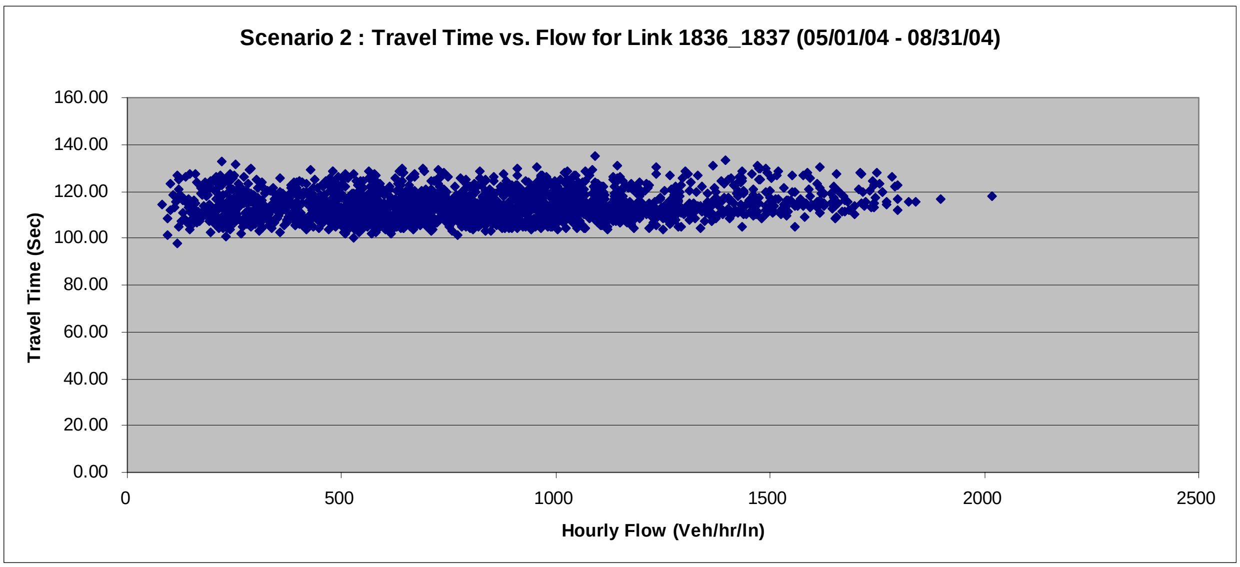
Scenario 1 : Travel Time vs. Flow for Link 1838_1839 (05/01/04 - 08/31/04)
Travel Time (Sec)
Hourly Flow (Veh/hr/ln)
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
0
500
1000
1500
2000
2500
3000

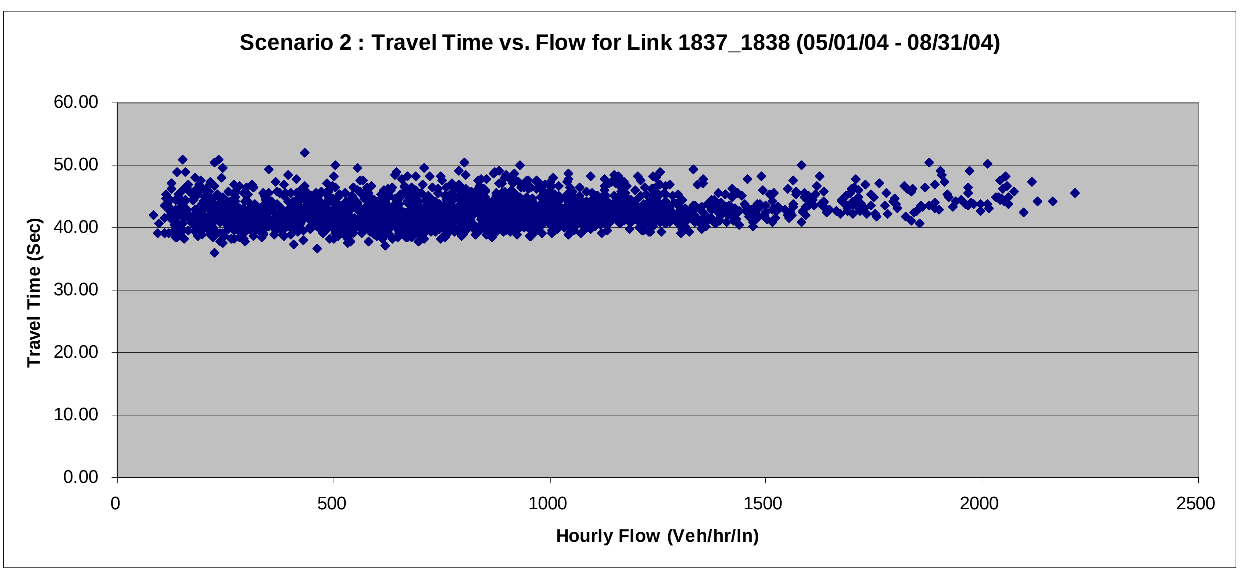

Scenario 2 : Travel Time vs. Flow for Link 1831_1832 (05/01/04 - 08/31/04)
Travel Time (Sec)
180.00
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Hourly Flow (Veh/hr/ln)

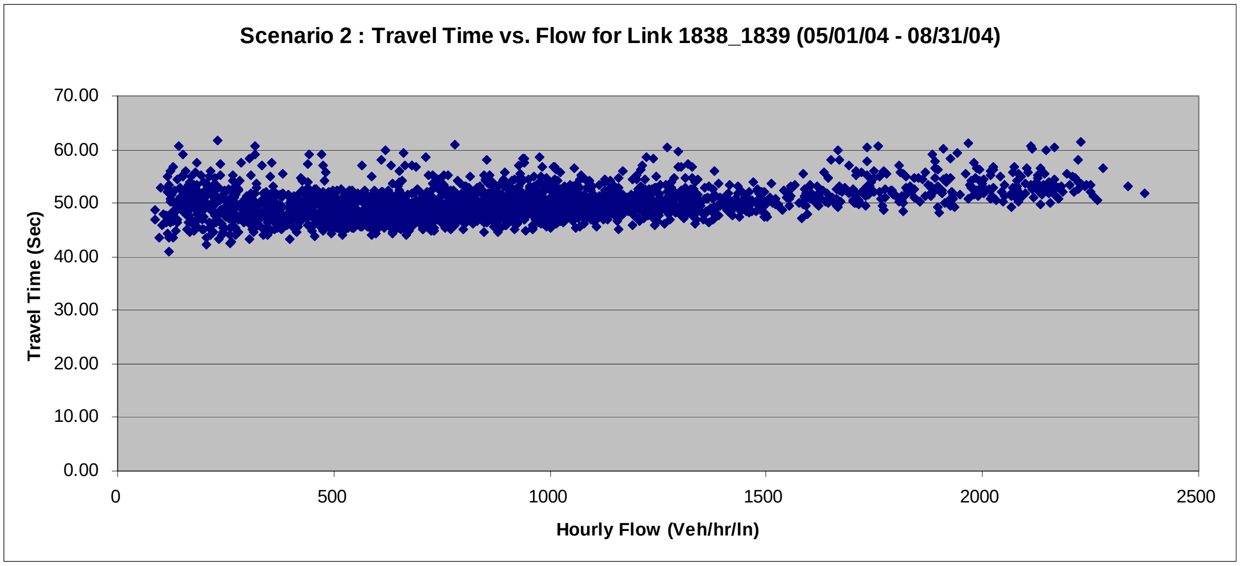

Scenario 2 : Travel Time vs. Flow for Link 1832_1833 (05/01/04 - 08/31/04)
Travel Time (Sec)
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
0
200
400
600
800
1000
1200
1400
1600
1800
Hourly Flow (Veh/hr/ln)

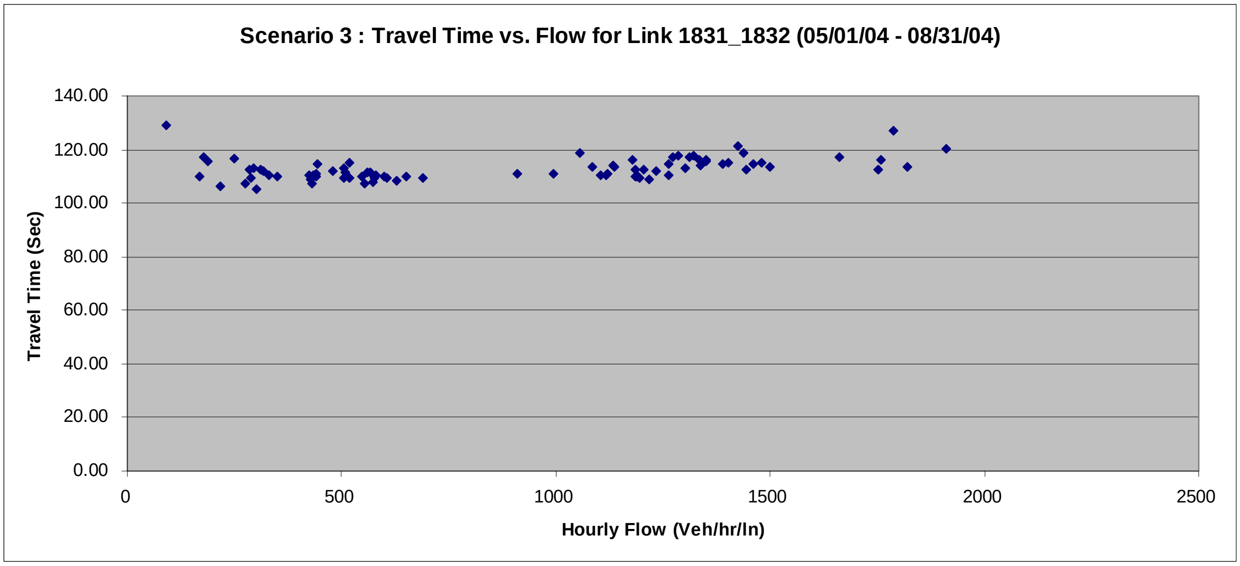

Scenario 2 : Travel Time vs. Flow for Link 1833_1835 (05/01/04 - 08/31/04)
Travel Time (Sec)
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
0
200
400
600
800
1000
1200
1400
1600
1800
Hourly Flow (Veh/hr/ln)

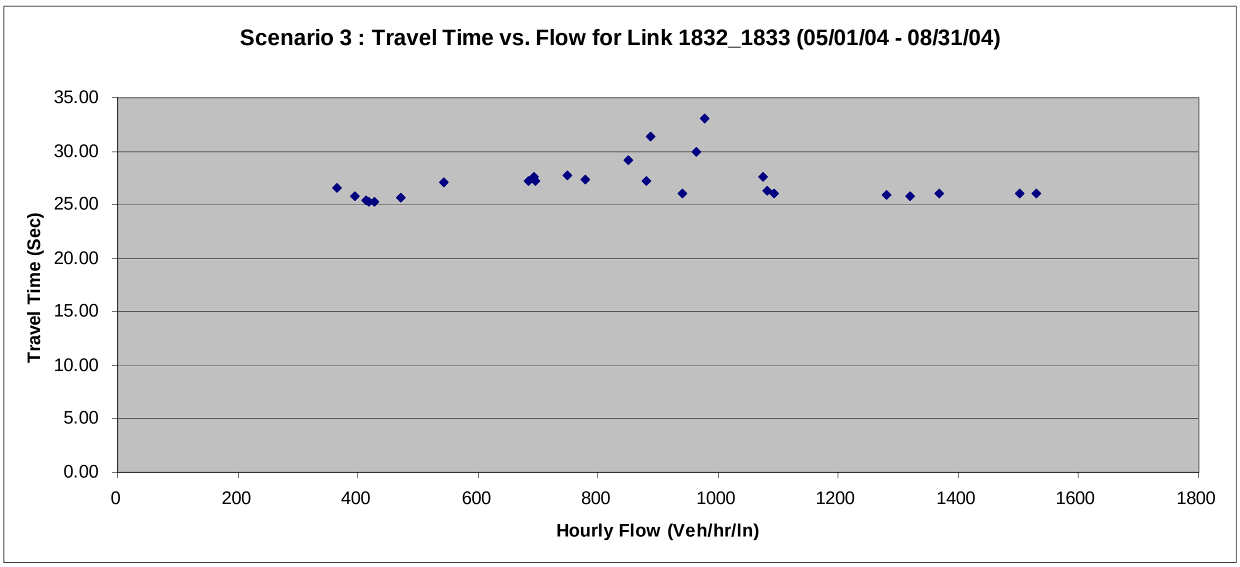

Scenario 2 : Travel Time vs. Flow for Link 1835_1836 (05/01/04 - 08/31/04)
Travel Time (Sec)
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
0
500
1000
1500
2000
2500
Hourly Flow (Veh/hr/ln)

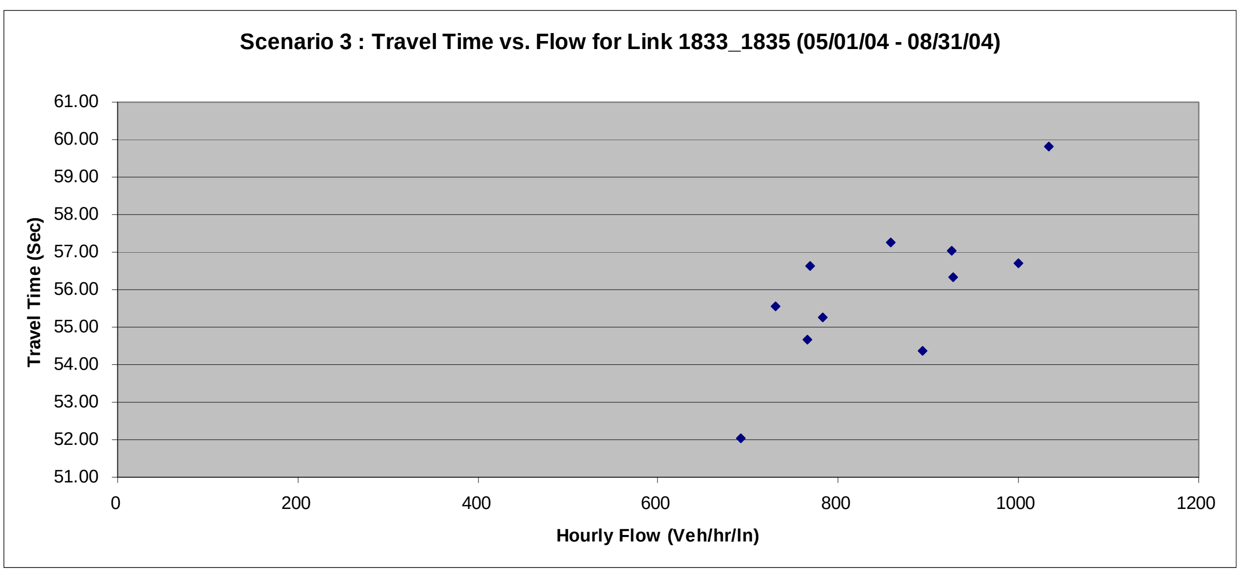

Scenario 2 : Travel Time vs. Flow for Link 1836_1837 (05/01/04 - 08/31/04)
Travel Time (Sec)
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
0
500
1000
1500
2000
2500
Hourly Flow (Veh/hr/ln)

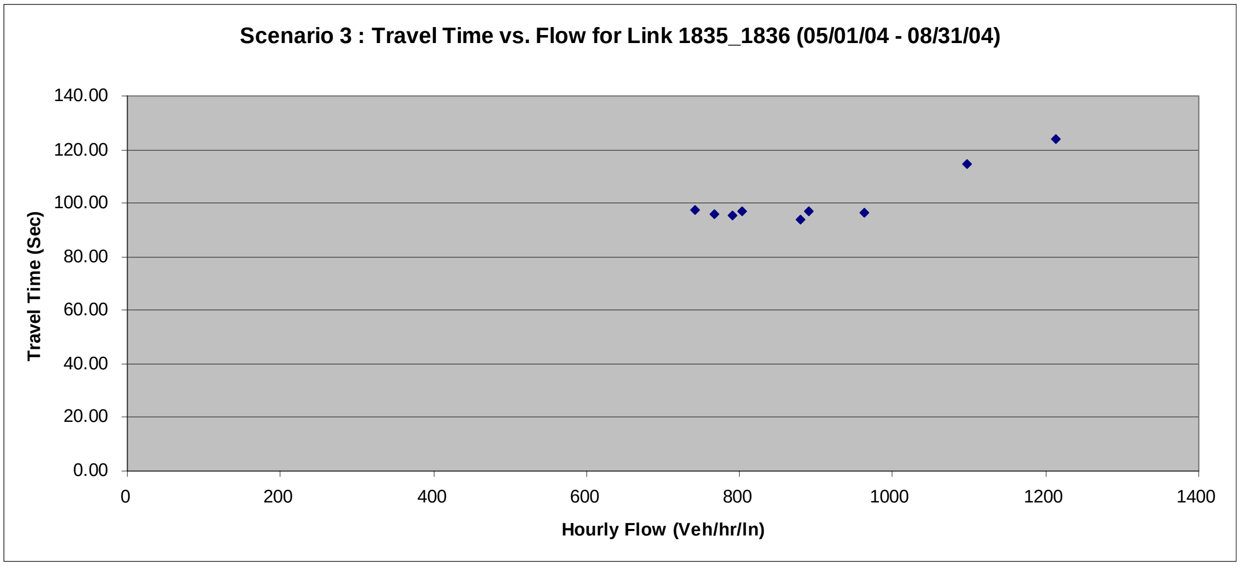

Scenario 2 : Travel Time vs. Flow for Link 1837_1838 (05/01/04 - 08/31/04)
Travel Time (Sec)
60.00
50.00
40.00
30.00
20.00
10.00
0.00
0
500
1000
1500
2000
2500
Hourly Flow (Veh/hr/ln)

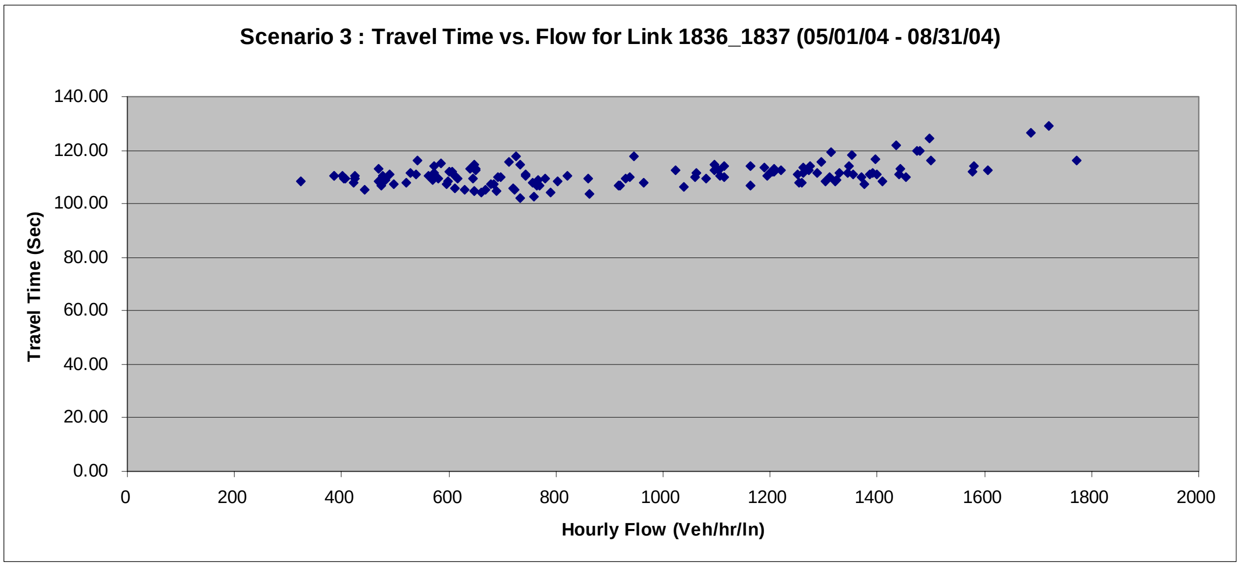

Scenario 2 : Travel Time vs. Flow for Link 1838_1839 (05/01/04 - 08/31/04)
Travel Time (Sec)
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
0
500
1000
1500
2000
2500
Hourly Flow (Veh/hr/ln)

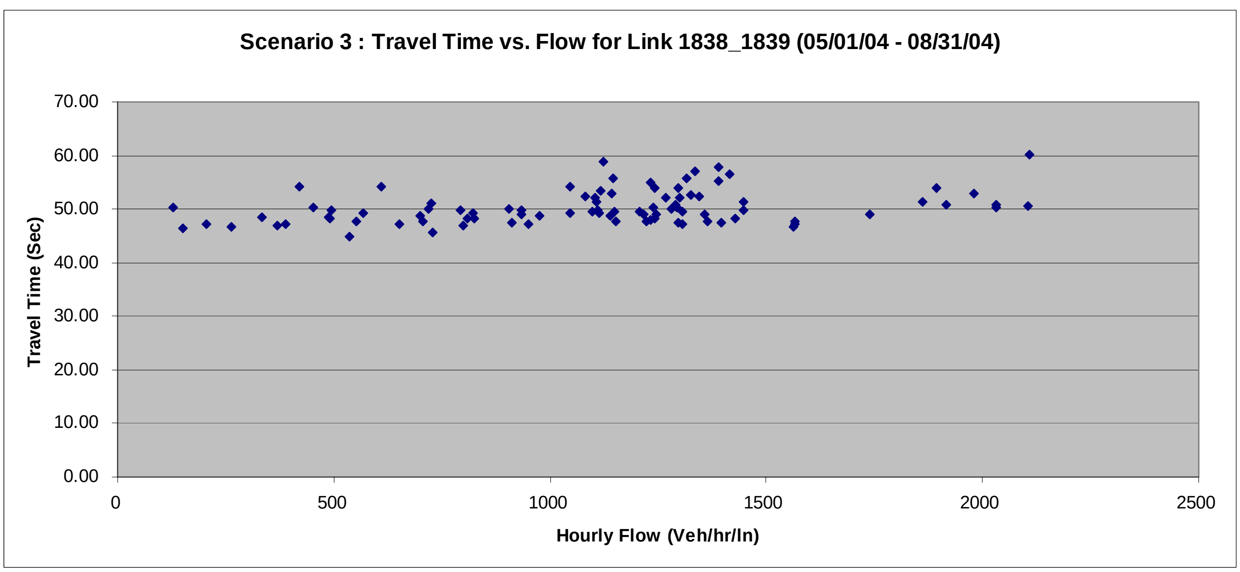

Scenario 3 : Travel Time vs. Flow for Link 1831_1832 (05/01/04 - 08/31/04)
Travel Time (Sec)
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
0
500
1000
1500
2000
2500
Hourly Flow (Veh/hr/ln)

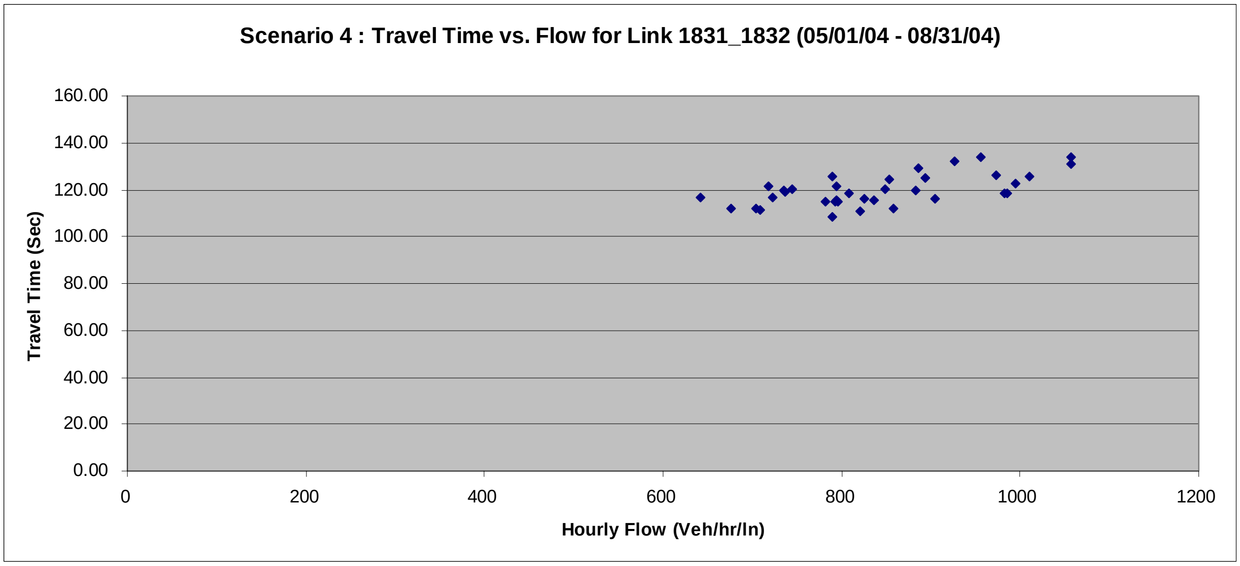

Scenario 3 : Travel Time vs. Flow for Link 1832_1833 (05/01/04 - 08/31/04)
Travel Time (Sec)
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
0
200
400
600
800
1000
1200
1400
1600
1800
Hourly Flow (Veh/hr/ln)

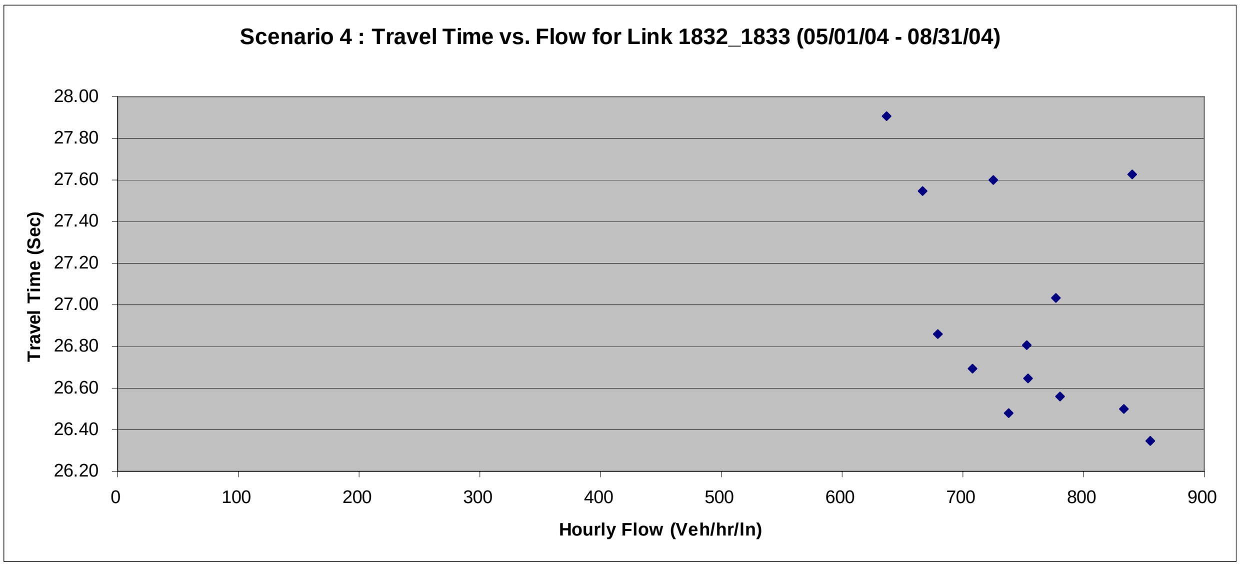

Scenario 3 : Travel Time vs. Flow for Link 1833_1835 (05/01/04 - 08/31/04)
Travel Time (Sec)
61.00
60.00
59.00
58.00
57.00
56.00
55.00
54.00
53.00
52.00
51.00
0
200
400
600
800
1000
1200
Hourly Flow (Veh/hr/ln)

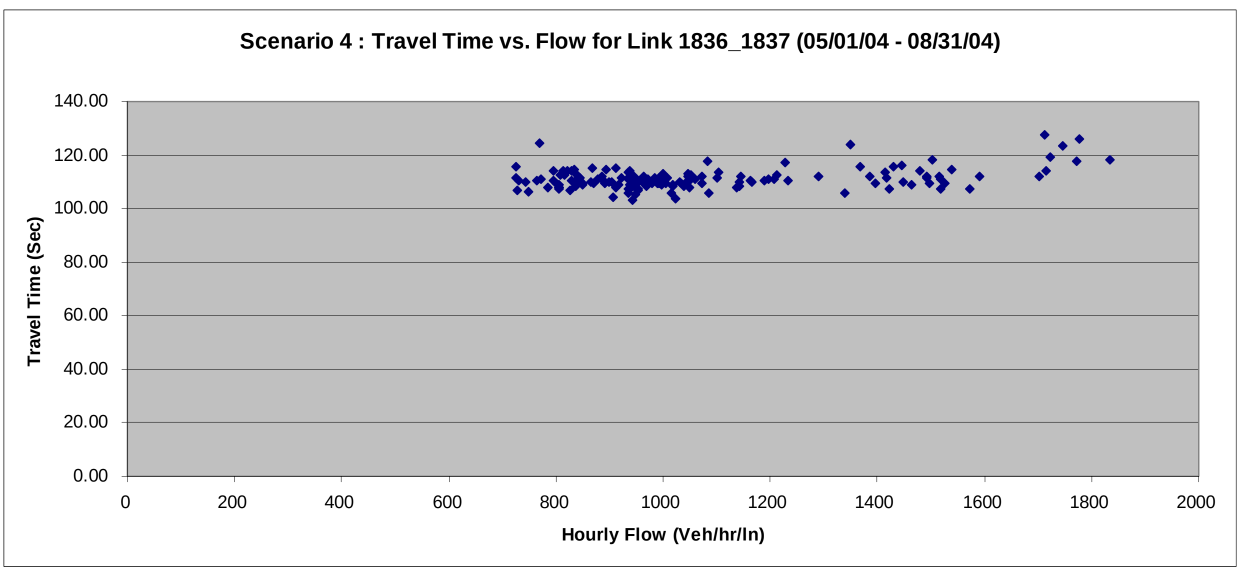

Scenario 3 : Travel Time vs. Flow for Link 1835_1836 (05/01/04 - 08/31/04)
Travel Time (Sec)
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
0
200
400
600
800
1000
1200
1400
Hourly Flow (Veh/hr/ln)

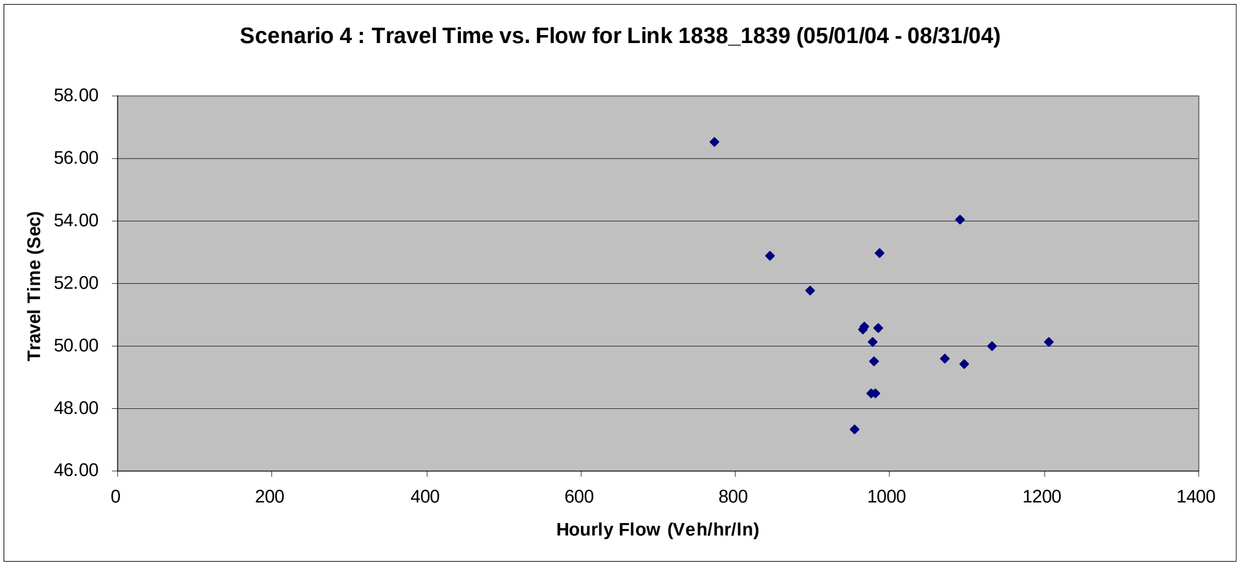

Scenario 3 : Travel Time vs. Flow for Link 1836_1837 (05/01/04 - 08/31/04)
Travel Time (Sec)
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Hourly Flow (Veh/hr/ln)

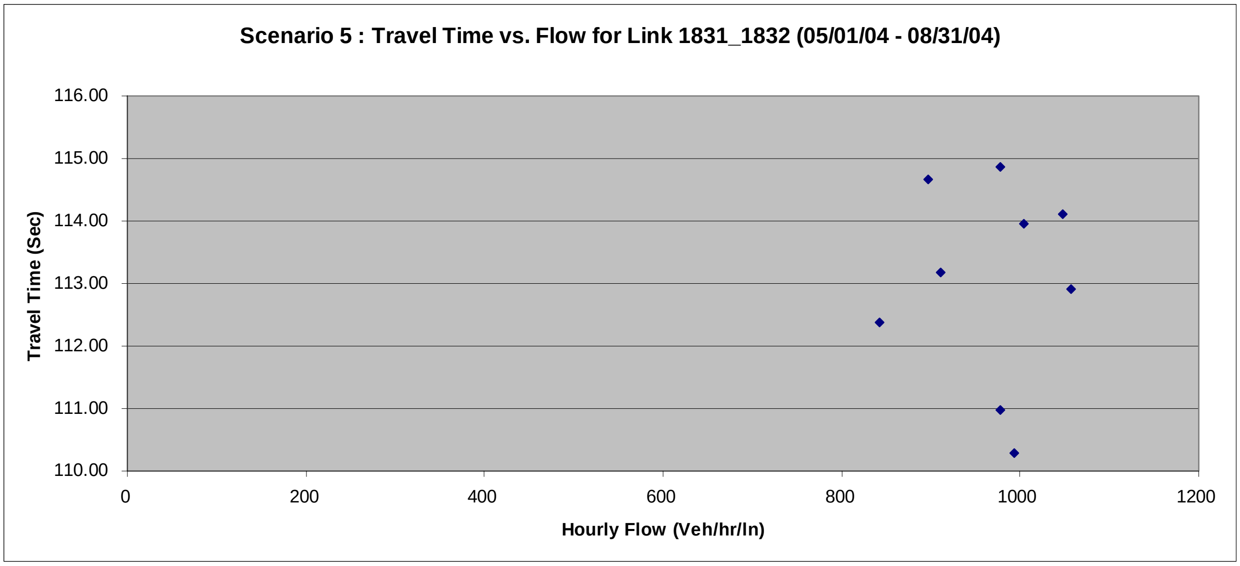

Scenario 3 : Travel Time vs. Flow for Link 1838_1839 (05/01/04 - 08/31/04)
Travel Time (Sec)
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
0
500
1000
1500
2000
2500
Hourly Flow (Veh/hr/ln)

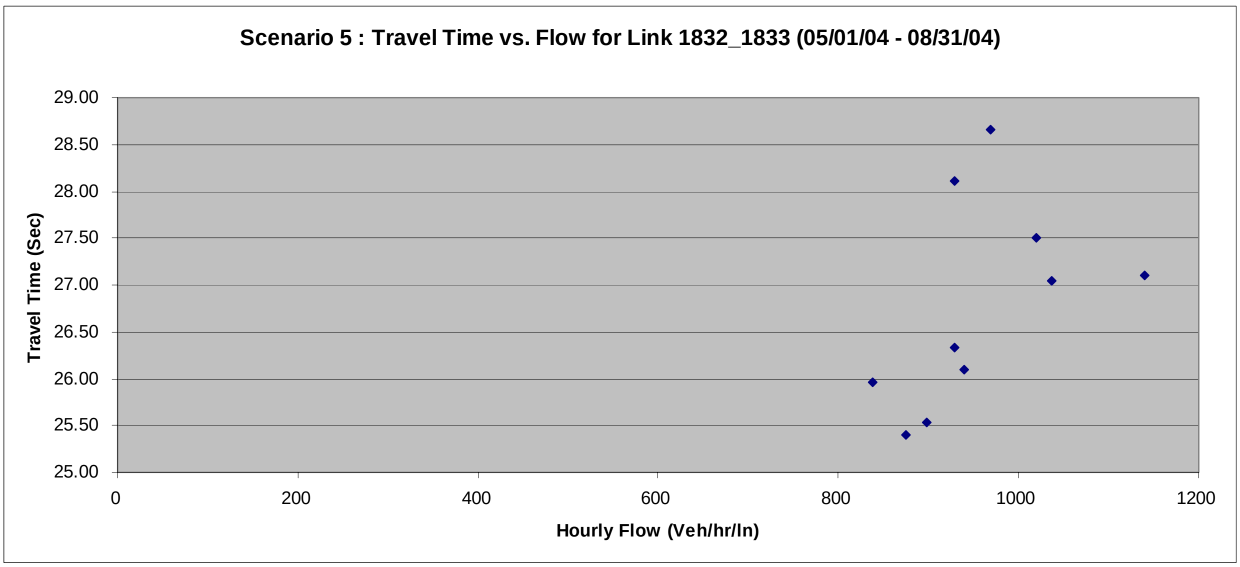

Scenario 4 : Travel Time vs. Flow for Link 1831_1832 (05/01/04 - 08/31/04)
Travel Time (Sec)
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
0
200
400
600
800
1000
1200
Hourly Flow (Veh/hr/ln)

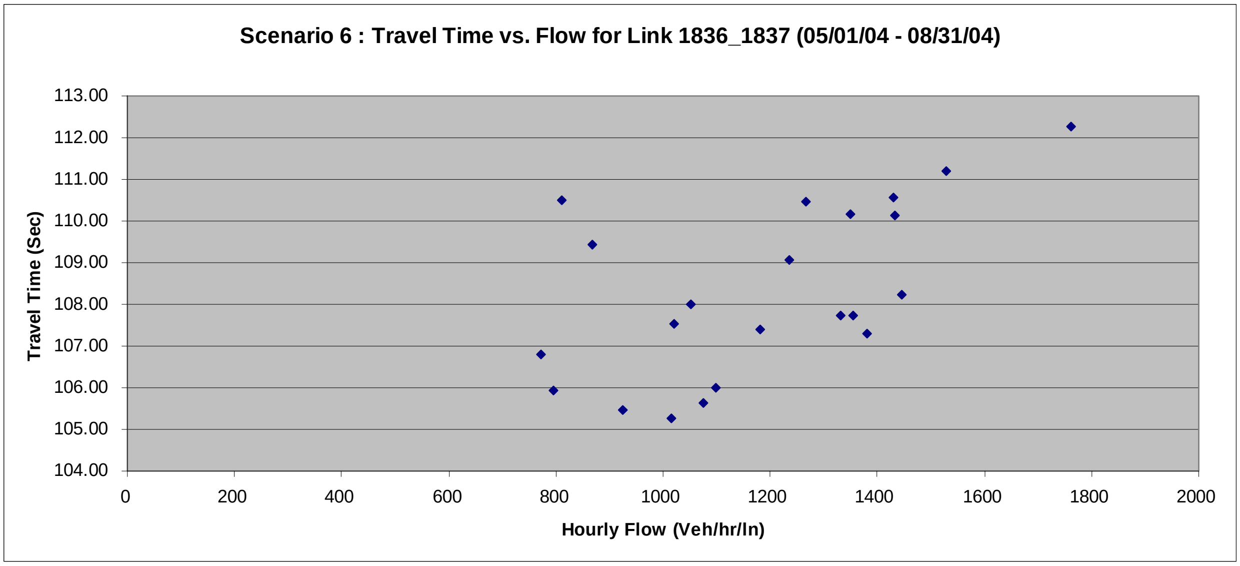

Scenario 4 : Travel Time vs. Flow for Link 1832_1833 (05/01/04 - 08/31/04)
Travel Time (Sec)
28.00
27.80
27.60
27.40
27.20
27.00
26.80
26.60
26.40
26.20
0
100
200
300
400
500
600
700
800
900
Hourly Flow (Veh/hr/ln)


Scenario 4 : Travel Time vs. Flow for Link 1836_1837 (05/01/04 - 08/31/04)
Travel Time (Sec)
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Hourly Flow (Veh/hr/ln)

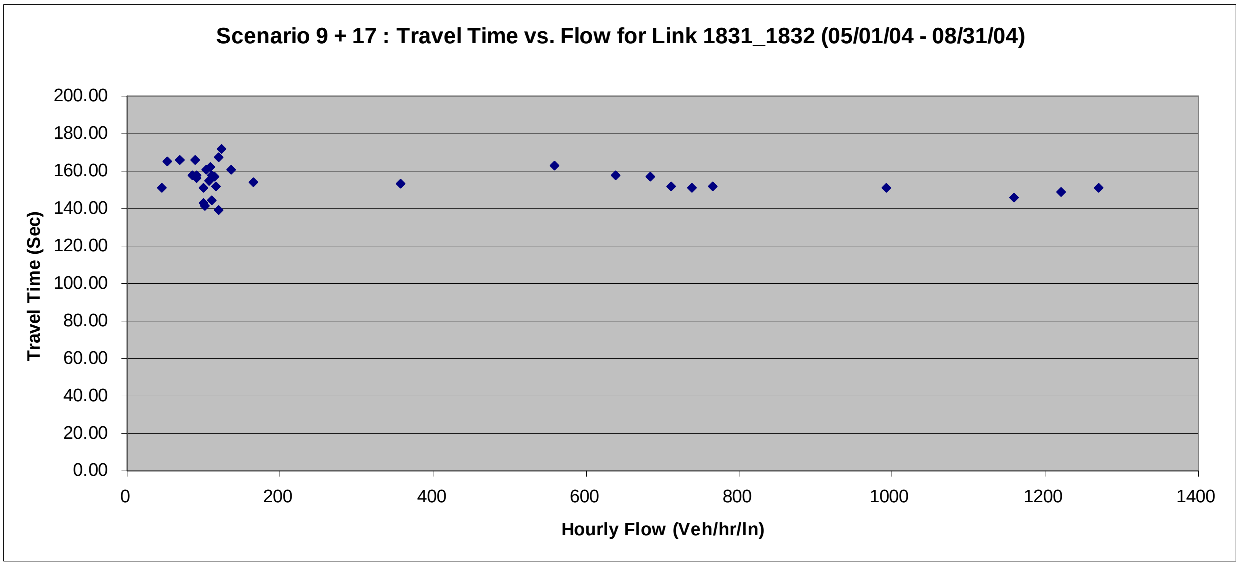

Scenario 4 : Travel Time vs. Flow for Link 1838_1839 (05/01/04 - 08/31/04)
Travel Time (Sec)
58.00
56.00
54.00
52.00
50.00
48.00
46.00
0
200
400
600
800
1000
1200
1400
Hourly Flow (Veh/hr/ln)

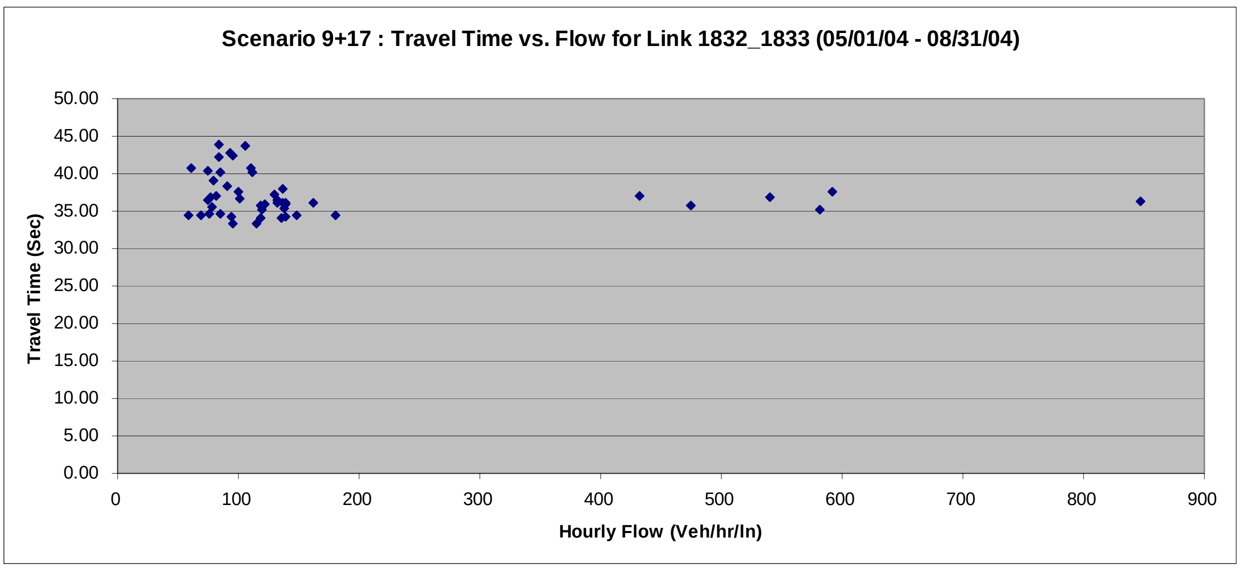

Scenario 5 : Travel Time vs. Flow for Link 1831_1832 (05/01/04 - 08/31/04)
Travel Time (Sec)
116.00
115.00
114.00
113.00
112.00
111.00
110.00
0
200
400
600
800
1000
1200
Hourly Flow (Veh/hr/ln)

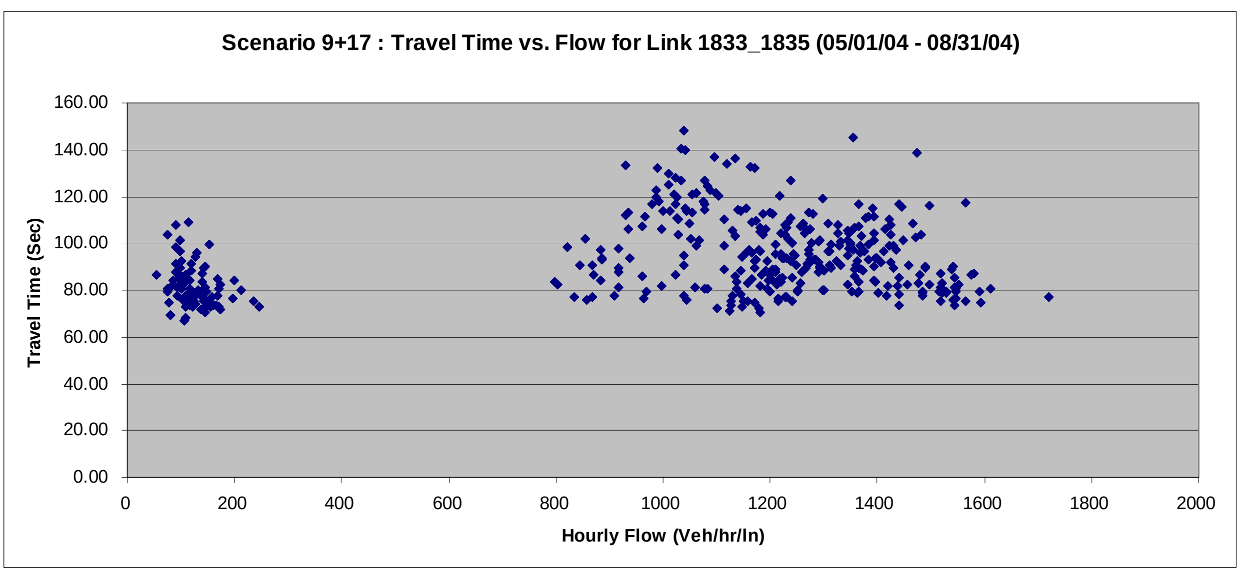

Scenario 5 : Travel Time vs. Flow for Link 1832_1833 (05/01/04 - 08/31/04)
Travel Time (Sec)
29.00
28.50
28.00
27.50
27.00
26.50
26.00
25.50
25.00
0
200
400
600
800
1000
1200
Hourly Flow (Veh/hr/ln)

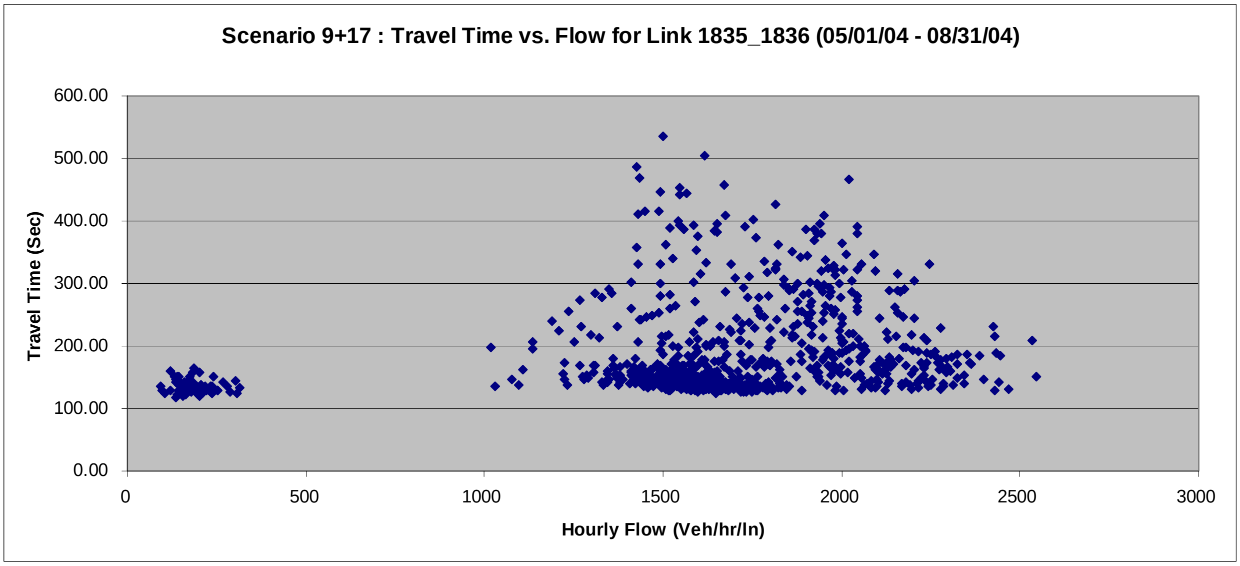


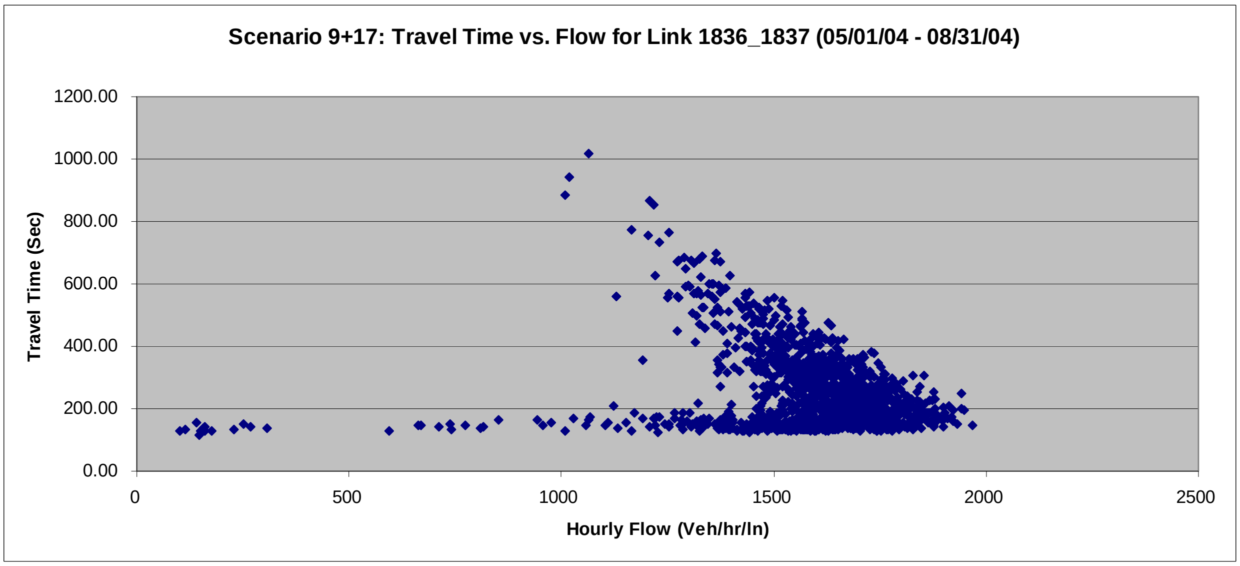
Scenario 6 : Travel Time vs. Flow for Link 1836_1837 (05/01/04 - 08/31/04)
113.00
112.00
111.00
110.00
109.00
108.00
107.00
106.00
105.00
104.00
Travel Time (Sec)
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Hourly Flow (Veh/hr/ln)

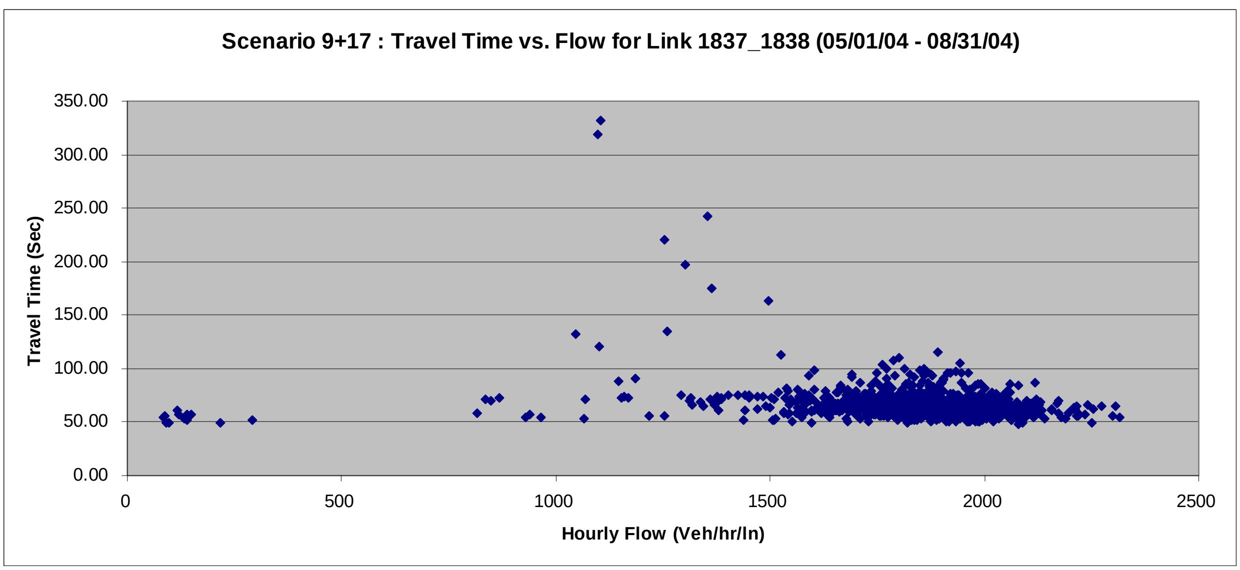

Scenario 9 + 17 : Travel Time vs. Flow for Link 1831_1832 (05/01/04 - 08/31/04)
Travel Time (Sec)
200.00
180.00
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
0
200
400
600
800
1000
1200
1400
Hourly Flow (Veh/hr/ln)

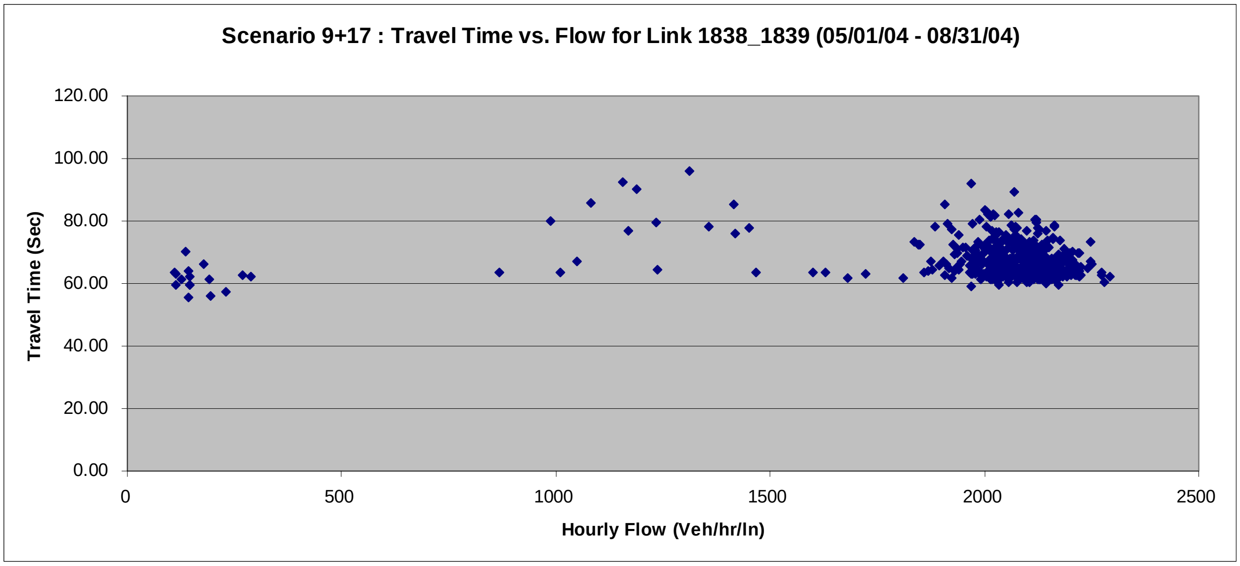

Scenario 9+17 : Travel Time vs. Flow for Link 1832_1833 (05/01/04 - 08/31/04)
Travel Time (Sec)
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
0
100
200
300
400
500
600
700
800
900
Hourly Flow (Veh/hr/ln)

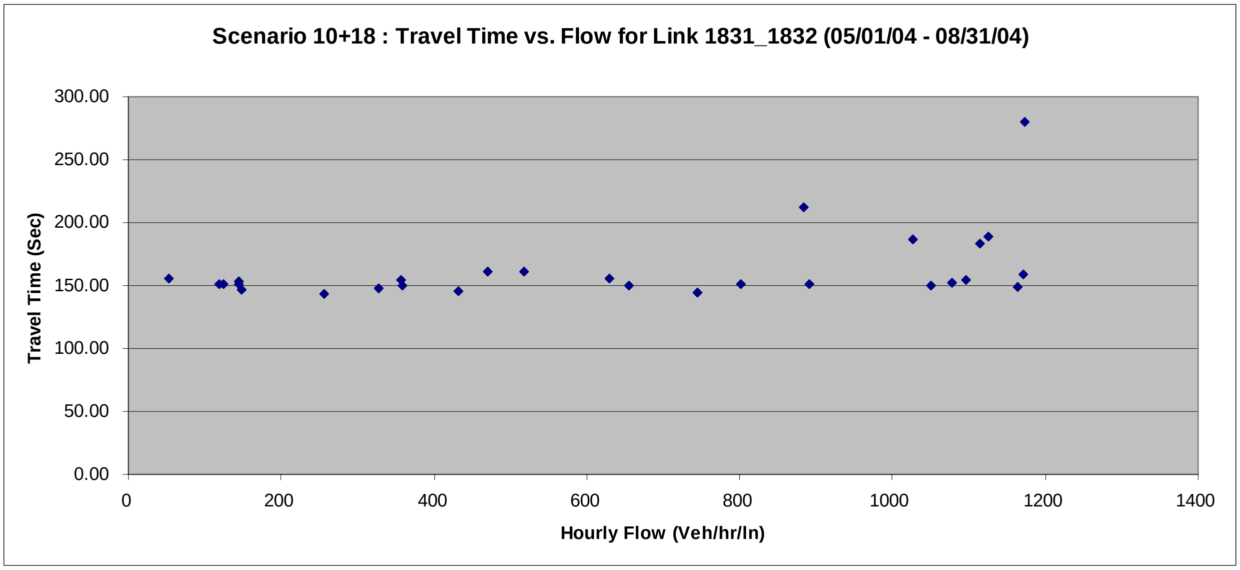

Scenario 9+17 : Travel Time vs. Flow for Link 1833_1835 (05/01/04 - 08/31/04)
Travel Time (Sec)
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Hourly Flow (Veh/hr/ln)

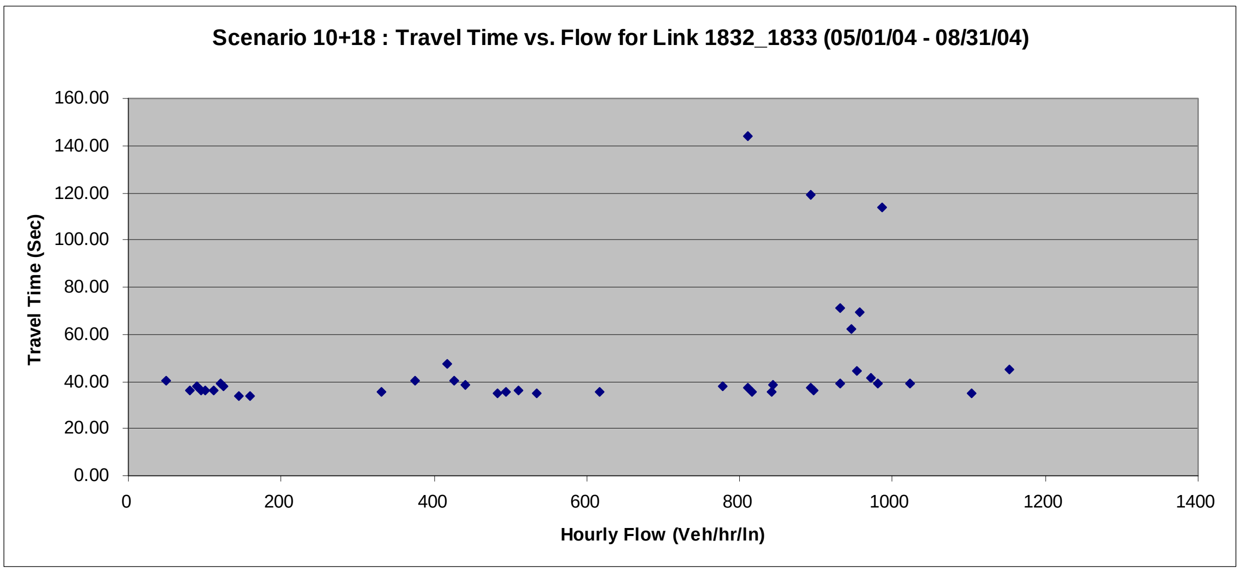

Scenario 9+17 : Travel Time vs. Flow for Link 1835_1836 (05/01/04 - 08/31/04)
Travel Time (Sec)
600.00
500.00
400.00
300.00
200.00
100.00
0.00
0
500
1000
1500
2000
2500
3000
Hourly Flow (Veh/hr/ln)

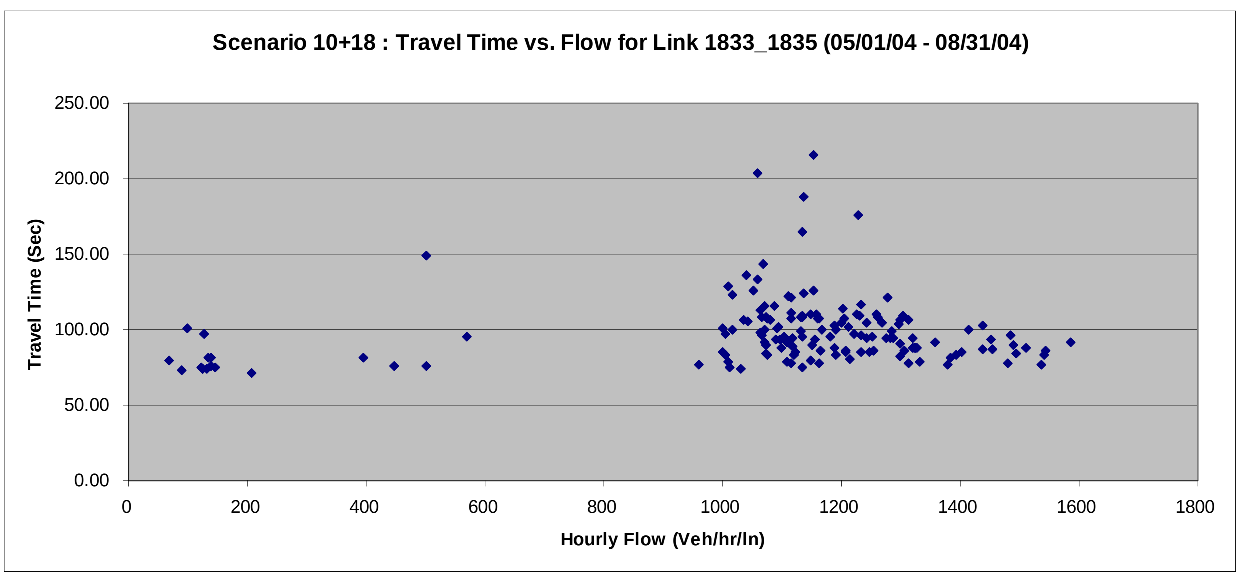

Scenario 9+17: Travel Time vs. Flow for Link 1836_1837 (05/01/04 - 08/31/04)
Travel Time (Sec)
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00
0
500
1000
1500
2000
2500
Hourly Flow (Veh/hr/ln)

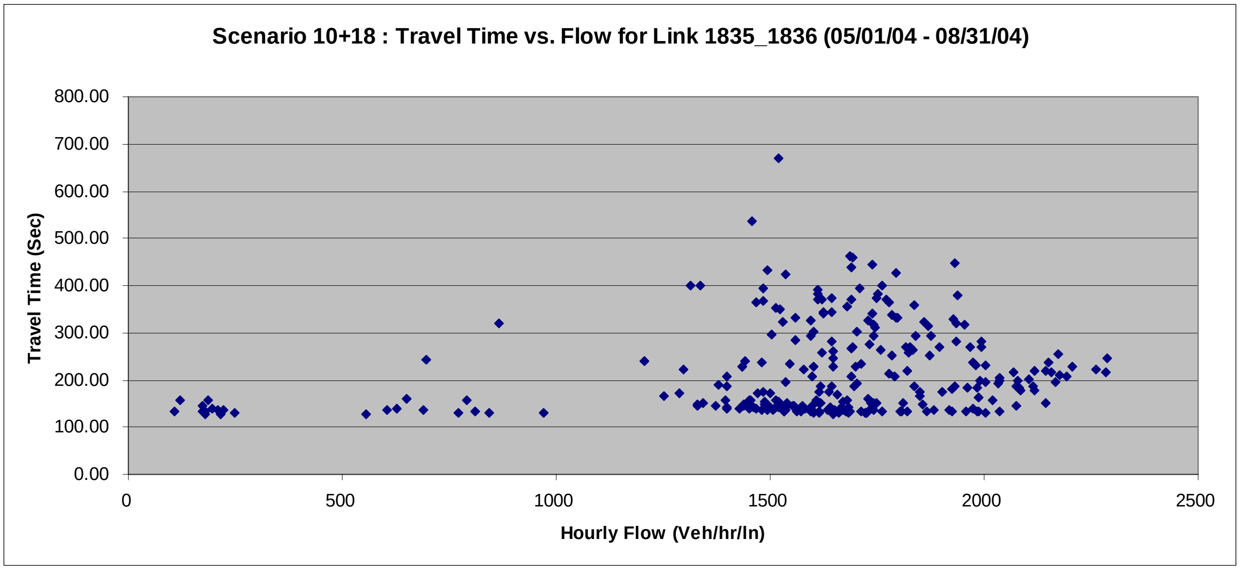

Scenario 9+17 : Travel Time vs. Flow for Link 1837_1838 (05/01/04 - 08/31/04)
Travel Time (Sec)
350.00
300.00
250.00
200.00
150.00
100.00
50.00
0.00
0
500
1000
1500
2000
2500
Hourly Flow (Veh/hr/ln)

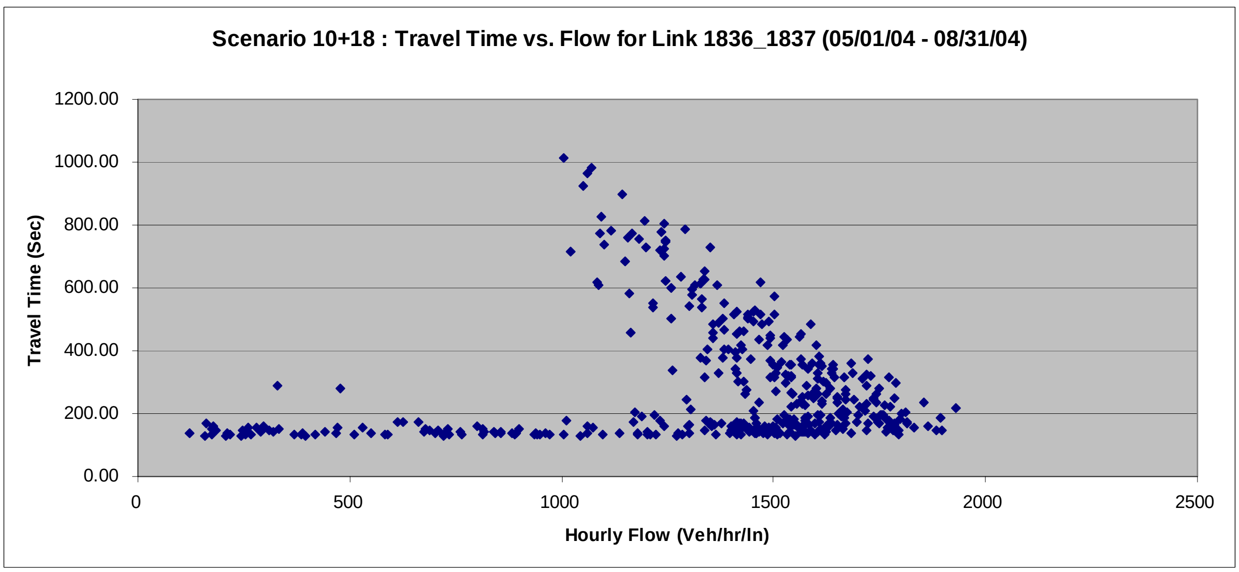

Scenario 9+17 : Travel Time vs. Flow for Link 1838_1839 (05/01/04 - 08/31/04)
120.00
100.00
80.00
60.00
40.00
20.00
0.00
Travel Time (Sec)
0
500
1000
1500
2000
2500
Hourly Flow (Veh/hr/ln)

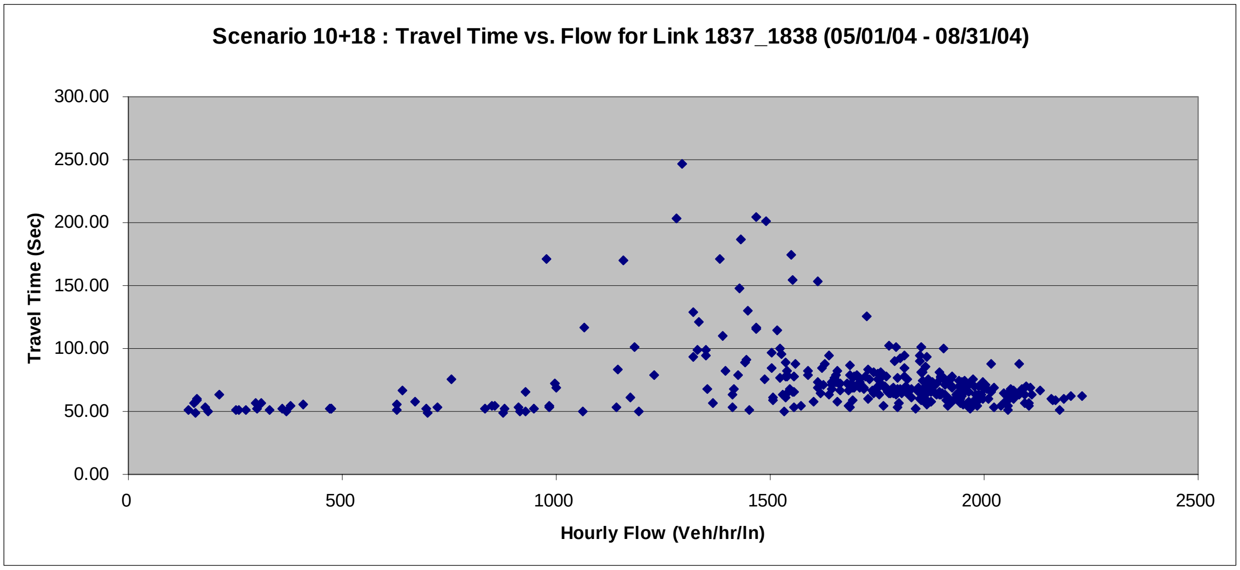

Scenario 10+18 : Travel Time vs. Flow for Link 1831_1832 (05/01/04 - 08/31/04)
Travel Time (Sec)
300.00
250.00
200.00
150.00
100.00
50.00
0.00
0
200
400
600
800
1000
1200
1400
Hourly Flow (Veh/hr/ln)

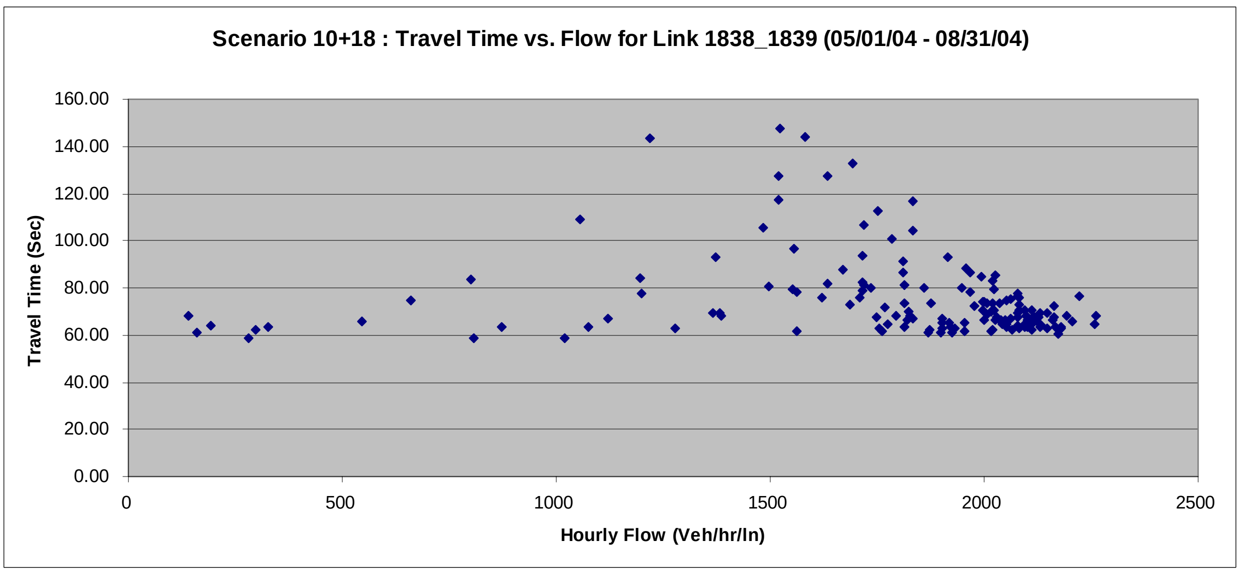

Scenario 10+18 : Travel Time vs. Flow for Link 1832_1833 (05/01/04 - 08/31/04)
Travel Time (Sec)
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
0
200
400
600
800
1000
1200
1400
Hourly Flow (Veh/hr/ln)

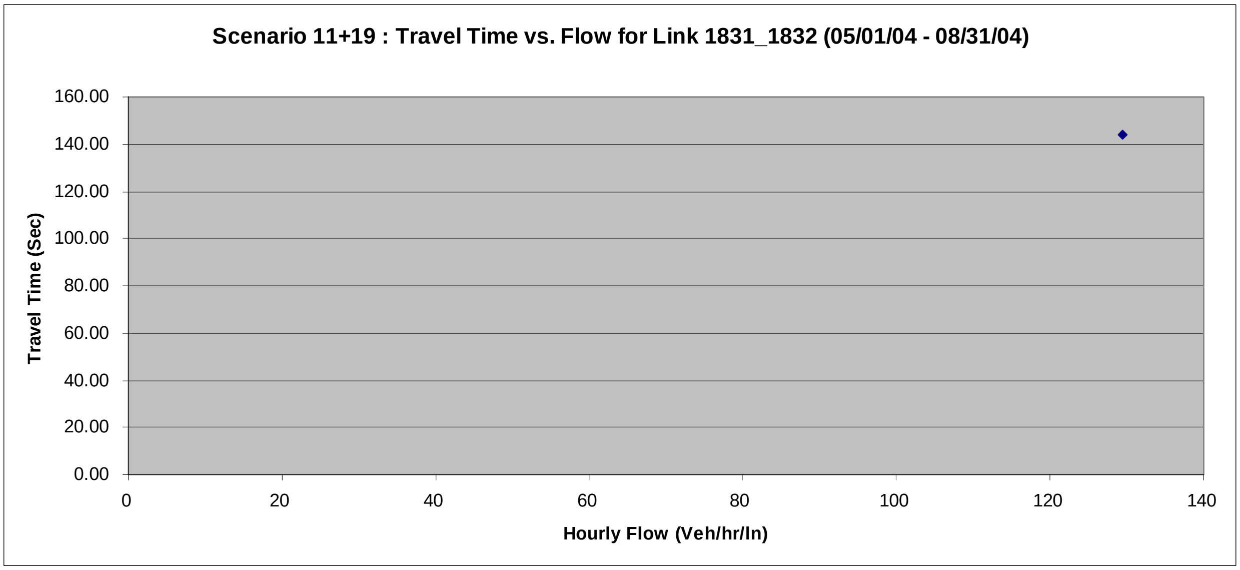

Scenario 10+18 : Travel Time vs. Flow for Link 1833_1835 (05/01/04 - 08/31/04)
Travel Time (Sec)
250.00
200.00
150.00
100.00
50.00
0.00
0
200
400
600
800
1000
1200
1400
1600
1800
Hourly Flow (Veh/hr/ln)

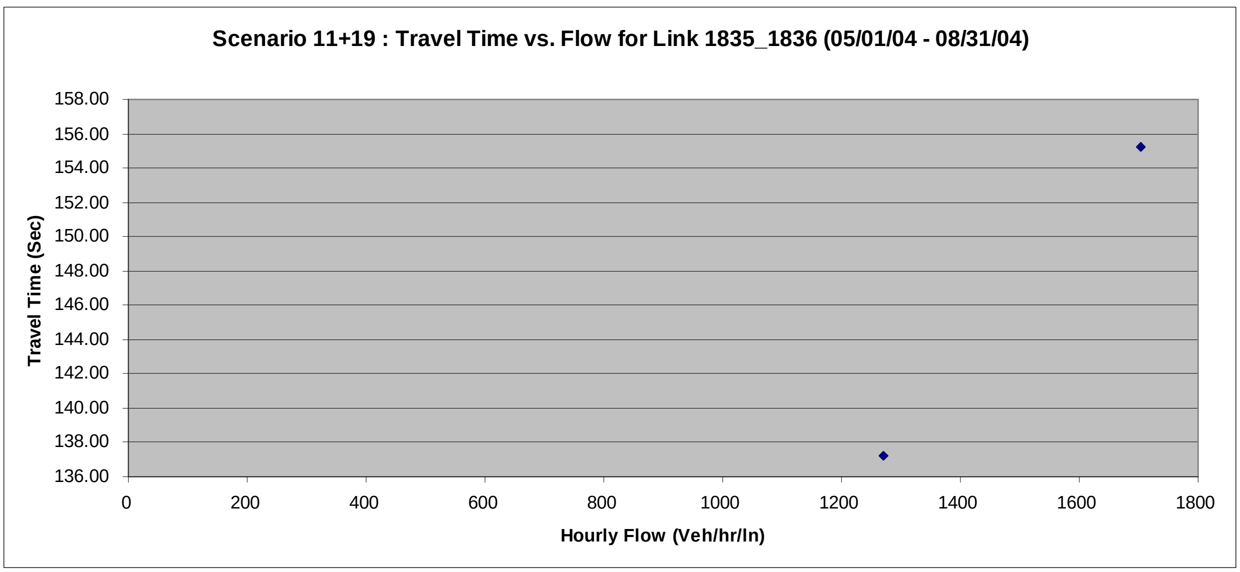

Scenario 10+18 : Travel Time vs. Flow for Link 1835_1836 (05/01/04 - 08/31/04)
Travel Time (Sec)
800.00
700.00
600.00
500.00
400.00
300.00
200.00
100.00
0.00
0
500
1000
1500
2000
2500
Hourly Flow (Veh/hr/ln)

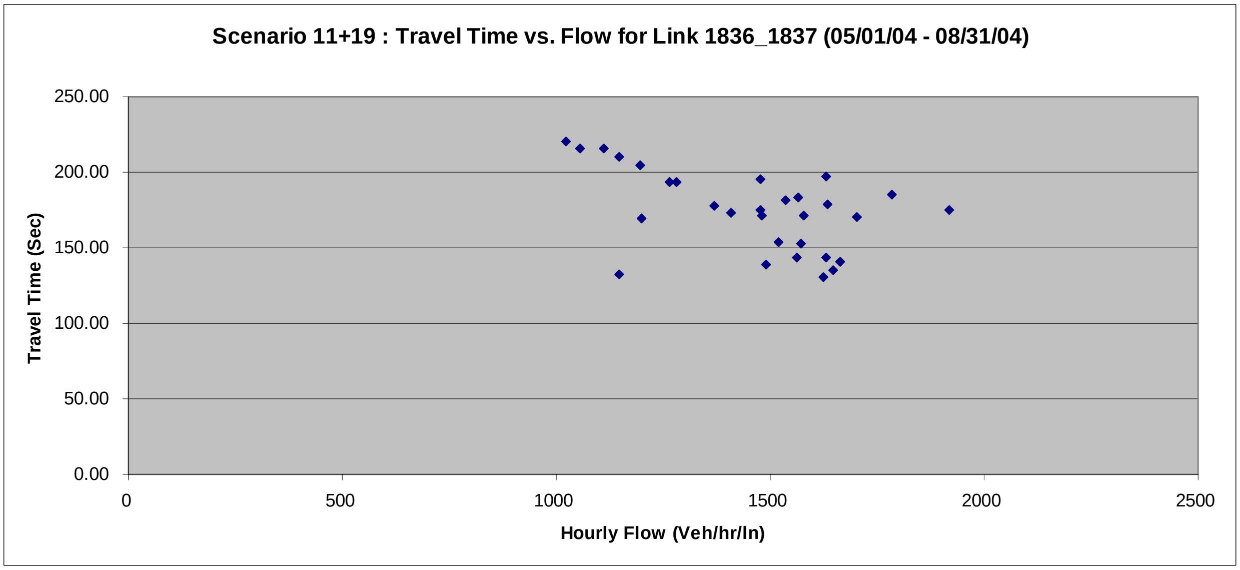

Scenario 10+18 : Travel Time vs. Flow for Link 1836_1837 (05/01/04 - 08/31/04)
Travel Time (Sec)
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00
0
500
1000
1500
2000
2500
Hourly Flow (Veh/hr/ln)


Scenario 10+18 : Travel Time vs. Flow for Link 1837_1838 (05/01/04 - 08/31/04)
Travel Time (Sec)
300.00
250.00
200.00
150.00
100.00
50.00
0.00
0
500
1000
1500
2000
2500
Hourly Flow (Veh/hr/ln)

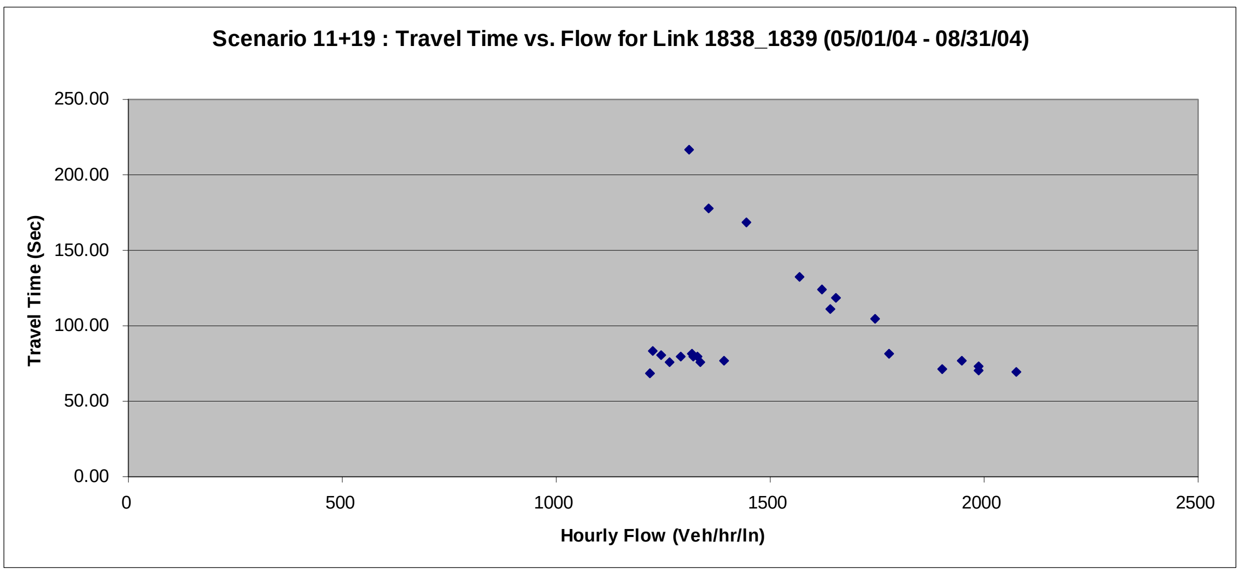

Scenario 10+18 : Travel Time vs. Flow for Link 1838_1839 (05/01/04 - 08/31/04)
Travel Time (Sec)
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
0
500
1000
1500
2000
2500
Hourly Flow (Veh/hr/ln)


Scenario 11+19 : Travel Time vs. Flow for Link 1831_1832 (05/01/04 - 08/31/04)
Travel Time (Sec)
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
0
20
40
60
80
100
120
140
Hourly Flow (Veh/hr/ln)

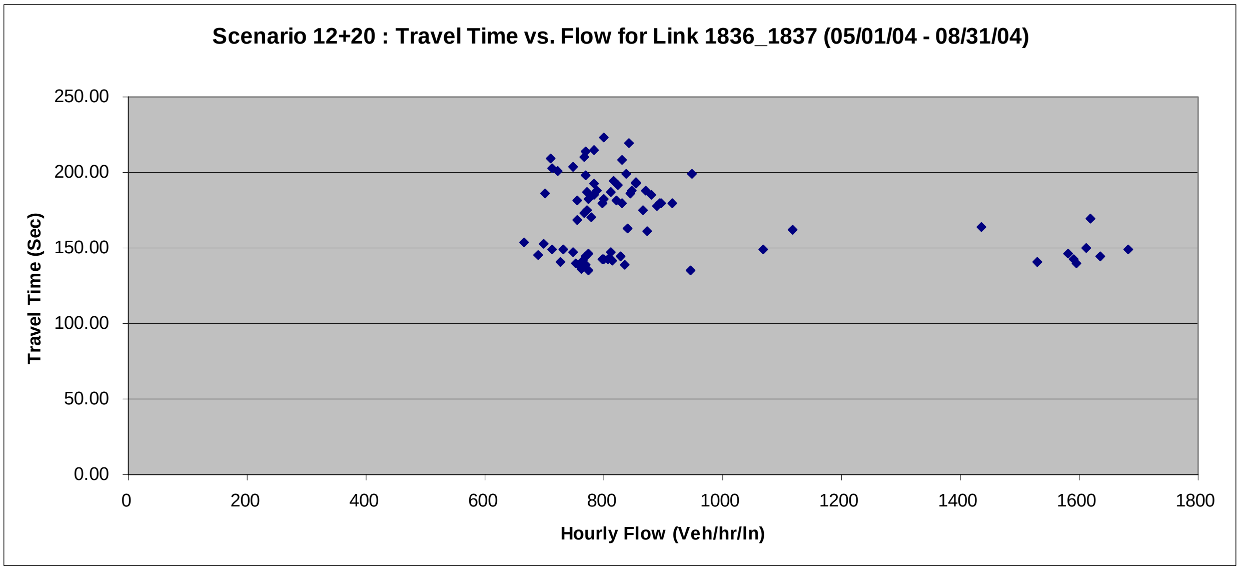

Scenario 11+19 : Travel Time vs. Flow for Link 1835_1836 (05/01/04 - 08/31/04)
Travel Time (Sec)
158.00
156.00
154.00
152.00
150.00
148.00
146.00
144.00
142.00
140.00
138.00
136.00
0
200
400
600
800
1000
1200
1400
1600
1800
Hourly Flow (Veh/hr/ln)



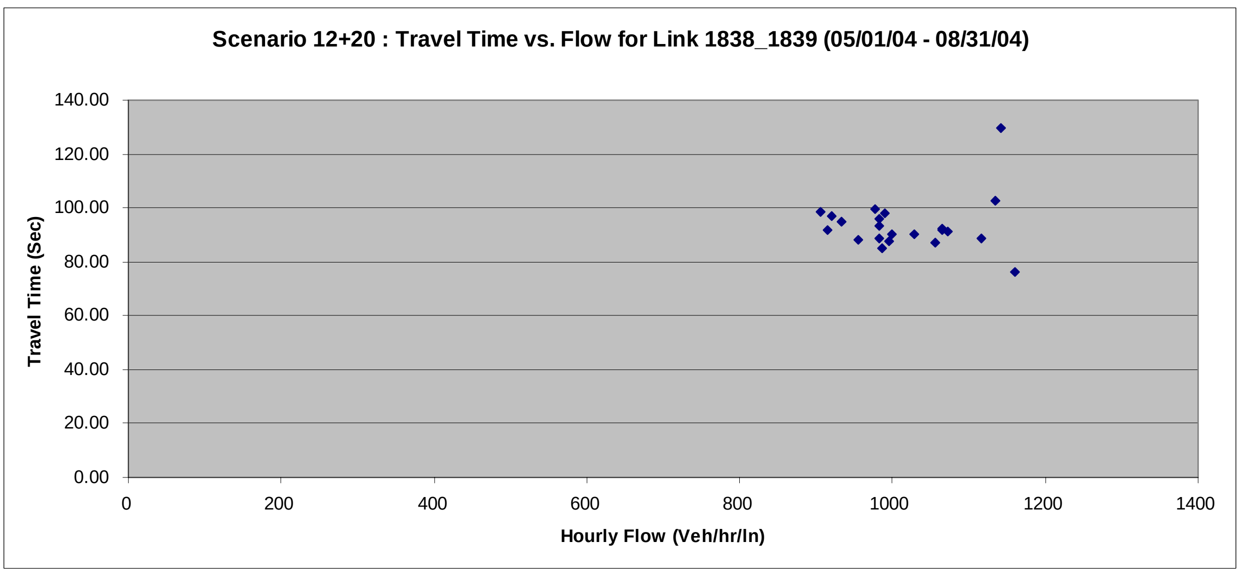
Scenario 11+19 : Travel Time vs. Flow for Link 1836_1837 (05/01/04 - 08/31/04)
Travel Time (Sec)
250.00
200.00
150.00
100.00
50.00
0.00
0
500
1000
1500
2000
2500
Hourly Flow (Veh/hr/ln)



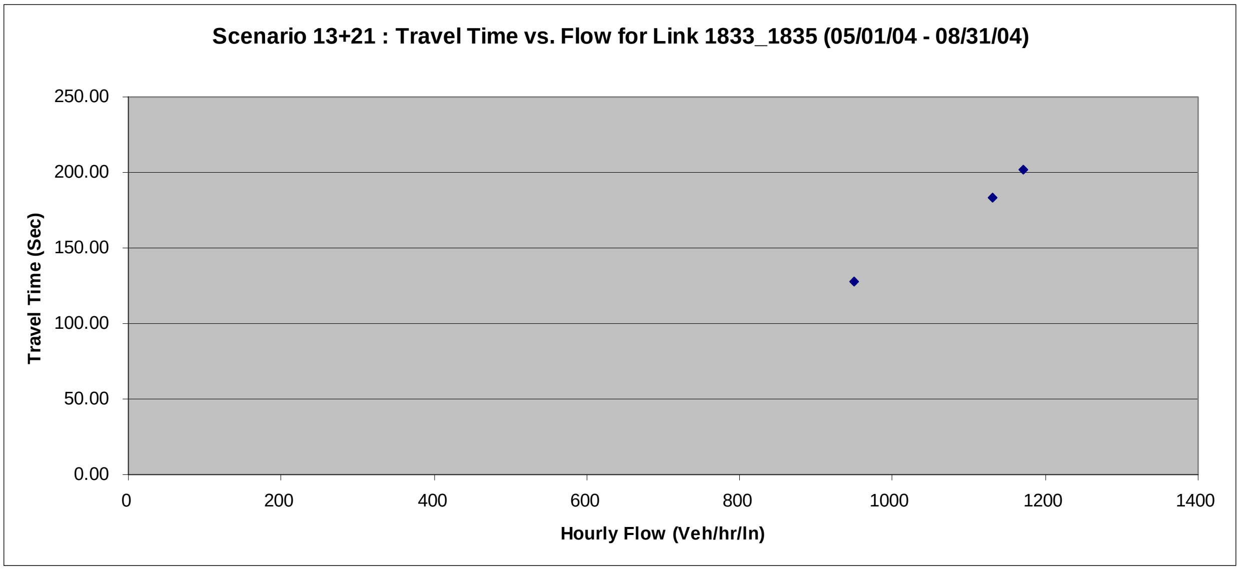
Scenario 11+19 : Travel Time vs. Flow for Link 1838_1839 (05/01/04 - 08/31/04)
Travel Time (Sec)
250.00
200.00
150.00
100.00
50.00
0.00
0
500
1000
1500
2000
2500
Hourly Flow (Veh/hr/ln)

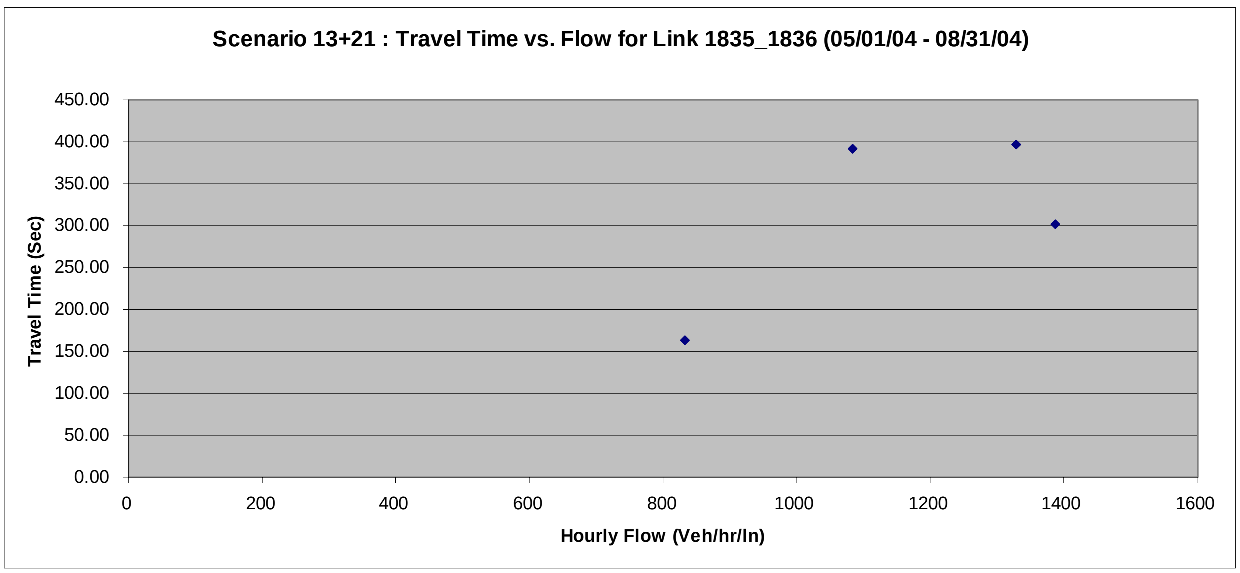


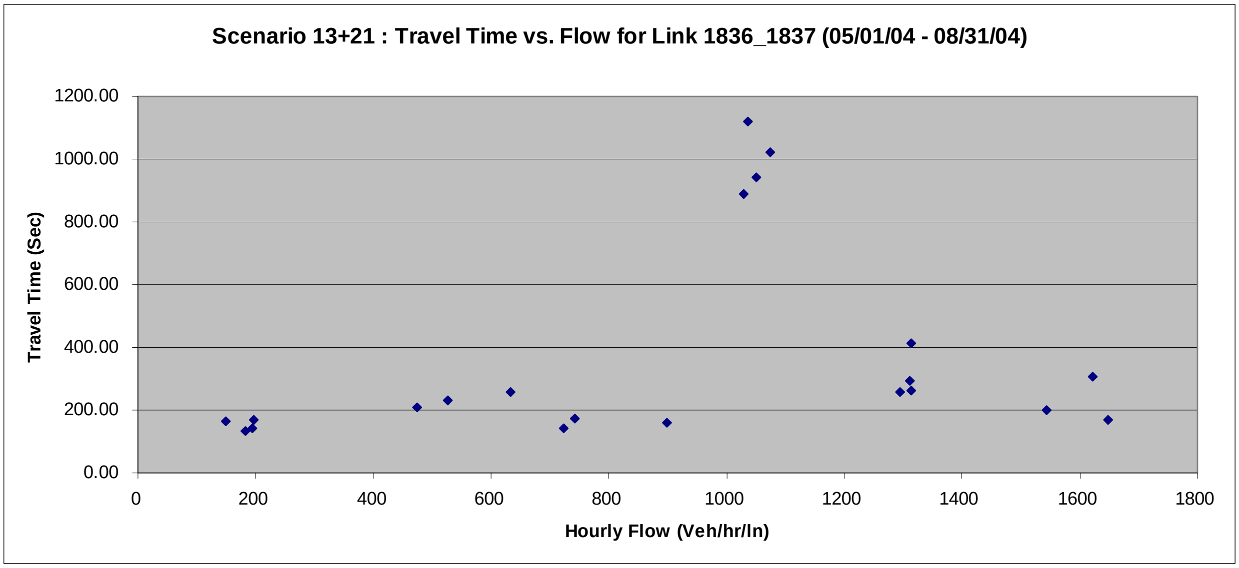
Scenario 12+20 : Travel Time vs. Flow for Link 1836_1837 (05/01/04 - 08/31/04)
Travel Time (Sec)
250.00
200.00
150.00
100.00
50.00
0.00
0
200
400
600
800
1000
1200
1400
1600
1800
Hourly Flow (Veh/hr/ln)

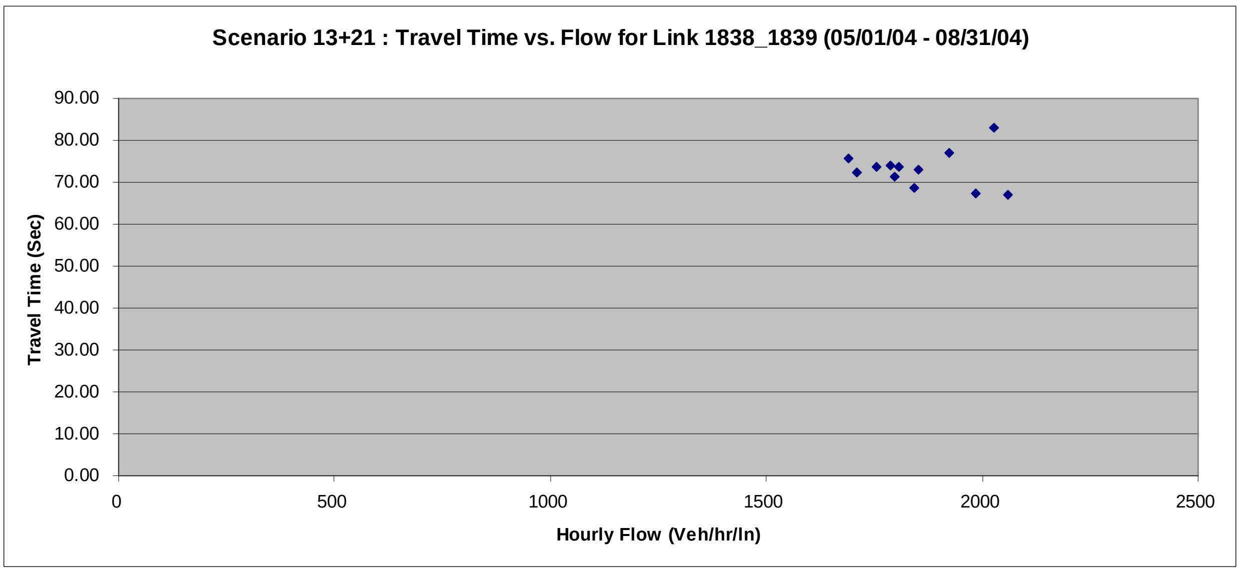


Scenario 12+20 : Travel Time vs. Flow for Link 1838_1839 (05/01/04 - 08/31/04)
Travel Time (Sec)
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
0
200
400
600
800
1000
1200
1400
Hourly Flow (Veh/hr/ln)


Scenario 13+21 : Travel Time vs. Flow for Link 1833_1835 (05/01/04 - 08/31/04)
Travel Time (Sec)
250.00
200.00
150.00
100.00
50.00
0.00
0
200
400
600
800
1000
1200
1400
Hourly Flow (Veh/hr/ln)


Scenario 13+21 : Travel Time vs. Flow for Link 1835_1836 (05/01/04 - 08/31/04)
Travel Time (Sec)
450.00
400.00
350.00
300.00
250.00
200.00
150.00
100.00
50.00
0.00
0
200
400
600
800
1000
1200
1400
1600
Hourly Flow (Veh/hr/ln)


Scenario 13+21 : Travel Time vs. Flow for Link 1836_1837 (05/01/04 - 08/31/04)
Travel Time (Sec)
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00
0
200
400
600
800
1000
1200
1400
1600
1800
Hourly Flow (Veh/hr/ln)


Scenario 13+21 : Travel Time vs. Flow for Link 1838_1839 (05/01/04 - 08/31/04)
Travel Time (Sec)
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
0
500
1000
1500
2000
2500
Hourly Flow (Veh/hr/ln)

Appendix B. Travel time-based models

- **Scenario 1: no congestion + no rain + no incident + no construction**

```
The regression equation is
tt/mile = 65.4 - 3.56 number of lanes


Predictor            Coef  SE Coef        T      P
Constant          65.4256   0.0421  1553.62  0.000
number of lanes  -3.56186  0.01690  -210.71  0.000


S = 2.88019   R-Sq = 27.4%   R-Sq(adj) = 27.4%


Analysis of Variance

Source              DF       SS      MS         F      P
Regression           1   368295  368295  44396.94  0.000
Residual Error  117746   976761       8
Total           117747  1345056
```

- **Scenario 2: no congestion + rain + no incident + no construction**

```
The regression equation is
tt/mile = 66.6 + 5.22 amount of rain - 3.51 number of lanes


Predictor            Coef  SE Coef       T      P
Constant          66.6188   0.1381  482.39  0.000
amount of rain     5.2242   0.2120   24.64  0.000
number of lanes  -3.51277  0.05505  -63.81  0.000


S = 3.59056   R-Sq = 21.2%   R-Sq(adj) = 21.2%


Analysis of Variance

Source             DF      SS     MS        F      P
Regression          2   59684  29842  2314.76  0.000
Residual Error  17176  221435     13
Total           17178  281119
```

- **Scenario 3: no congestion +no rain + incident + no construction**

```
The regression equation is
TT/Mile = 61.1 - 4.27 O/T


Predictor     Coef  SE Coef       T      P
Constant   61.1179   0.3916  156.05  0.000
O/T        -4.2659   0.5852   -7.29  0.000


S = 3.44544   R-Sq = 13.8%   R-Sq(adj) = 13.5%


Analysis of Variance

Source           DF       SS      MS      F      P
Regression        1   630.75  630.75  53.13  0.000
Residual Error  332  3941.20   11.87
```

```
Total           333  4571.95
```

- **Scenario 4: no congestion +no rain + no incident + construction**

```
The regression equation is
TT/Mile = 61.6 - 0.854 number of lanes opened


Predictor                  Coef  SE Coef      T      P
Constant                61.6097   0.6475  95.15  0.000
number of lanes opened  -0.8541   0.3855  -2.22  0.028


S = 2.78570   R-Sq = 2.2%   R-Sq(adj) = 1.8%


Analysis of Variance

Source           DF        SS      MS     F      P
Regression        1    38.097  38.097  4.91  0.028
Residual Error  217  1683.941   7.760
Total           218  1722.038
```

- **Scenario 5: no congestion + rain + incident + no construction**

```
The regression equation is
TT/Mile = 70.4 - 3.70 O/T - 4.34 number of lanes + 10.5 rain


Predictor           Coef  SE Coef      T      P
Constant          70.417    2.101  33.52  0.000
O/T               -3.702    1.073  -3.45  0.001
number of lanes  -4.3394   0.9272  -4.68  0.000
rain              10.517    2.816   3.73  0.000


S = 3.21968   R-Sq = 47.6%   R-Sq(adj) = 45.5%


Analysis of Variance

Source          DF       SS      MS      F      P
Regression       3   696.26  232.09  22.39  0.000
Residual Error  74   767.11   10.37
Total           77  1463.37
```

- **Scenario 9+10: congested + rain or not + no incident + no construction**

```
The regression equation is
tt/mile = - 62.4 + 987.6022 e^(-0.0008 hourly flow per lane)


Predictor     Coef  SE Coef      T      P
Constant    -62.39    10.30  -6.06  0.000
exp_flow   1.21565  0.04291  28.33  0.000


S = 52.3167   R-Sq = 49.5%   R-Sq(adj) = 49.4%


Analysis of Variance

Source           DF       SS       MS       F      P
Regression        1  2196836  2196836  802.63  0.000
Residual Error  819  2241629     2737
Total           820  4438466
```

- **Scenario 13: congested + rain + incident + no construction**

The regression equation is
TT/Mile = 1003 - 915 O/T

Predictor	Coef	SE Coef	T	P
Constant	1003.45	59.99	16.73	0.000
O/T	-915.18	84.84	-10.79	0.000

S = 48.9813   R-Sq = 96.7%   R-Sq(adj) = 95.8%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	279183	279183	116.37	0.000
Residual Error	4	9597	2399		
Total	5	288780			

- **Scenario 17+18: semi-congested + rain or not + no incident + no construction**

The regression equation is
tt/mile = 98.8 - 3.19 number of lanes

Predictor	Coef	SE Coef	T	P
Constant	98.799	1.630	60.63	0.000
number of lanes	-3.1921	0.7535	-4.24	0.000

S = 18.5607   R-Sq = 0.3%   R-Sq(adj) = 0.3%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	6183.3	6183.3	17.95	0.000
Residual Error	5177	1783481.3	344.5		
Total	5178	1789664.6			

- **Scenario 21: semi-congestion + rain + incident + no construction**

The regression equation is
TT/Mile = 171 - 84.6 O/T

Predictor	Coef	SE Coef	T	P
Constant	171.06	15.64	10.94	0.000
O/T	-84.62	23.36	-3.62	0.001

S = 39.7023   R-Sq = 29.1%   R-Sq(adj) = 26.9%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	20690	20690	13.13	0.001
Residual Error	32	50441	1576		
Total	33	71131			

Appendix C. Speed-based models

- **Scenario 1: no congestion + no rain + no incident + no construction**

The regression equation is
Speed = 54.0 + 3.95 number of lines

Predictor	Coef	SE Coef	T	P
Constant	54.0388	0.0453	1194.05	0.000
number of lanes	3.94747	0.01817	217.29	0.000

S = 3.09529   R-Sq = 28.6%   R-Sq(adj) = 28.6%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	452355	452355	47214.70	0.000
Residual Error	117746	1128102	10		
Total	117747	1580457			

- **Scenario 2: no congestion + rain + no incident + no construction**

The regression equation is
Speed = 53.2 - 5.27 amount of rain + 3.72 number of lanes

Predictor	Coef	SE Coef	T	P
Constant	53.2209	0.1407	378.14	0.000
amount of rain	-5.2717	0.2161	-24.40	0.000
number of lanes	3.71610	0.05611	66.23	0.000

S = 3.65925   R-Sq = 22.3%   R-Sq(adj) = 22.3%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	66037	33019	2465.89	0.000
Residual Error	17176	229989	13		
Total	17178	296026			

Scenario 3: no congestion +no rain + incident + no construction

The regression equation is
Speed = 58.9 + 4.70 OT

Predictor	Coef	SE Coef	T	P
Constant	58.9033	0.4004	147.13	0.000
OT	4.6956	0.5982	7.85	0.000

S = 3.52201   R-Sq = 15.7%   R-Sq(adj) = 15.4%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	764.19	764.19	61.61	0.000
Residual Error	332	4118.32	12.40		
Total	333	4882.51			

- **Scenario 4: no congestion +no rain + no incident + construction**

The regression equation is
Speed = 58.4 + 0.912 number of lanes working

Predictor	Coef	SE Coef	T	P
Constant	58.4279	0.6431	90.86	0.000
numbr of lanes working	0.9118	0.3828	2.38	0.018

S = 2.76658   R-Sq = 2.5%   R-Sq(adj) = 2.1%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	43.421	43.421	5.67	0.018
Residual Error	217	1660.912	7.654		
Total	218	1704.334			

- **Scenario 5: no congestion + rain + incident + no construction**

The regression equation is
Speed = 48.9 + 3.46 O/T + 4.78 number of lanes - 9.21 rain

Predictor	Coef	SE Coef	T	P
Constant	48.933	1.950	25.09	0.000
O/T	3.4636	0.9964	3.48	0.001
number of lanes	4.7772	0.8608	5.55	0.000
rain	-9.208	2.614	-3.52	0.001

S = 2.98903   R-Sq = 51.7%   R-Sq(adj) = 49.8%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	708.14	236.05	26.42	0.000
Residual Error	74	661.14	8.93		
Total	77	1369.28			

- **Scenario 9+10: congested + rain or not + no incident + no construction**

The regression equation is
Speed = 33.9 – 56.828 e^ (-0.0008 hourly flow per lane)

Predictor	Coef	SE Coef	T	P
Constant	33.9020	0.5868	57.78	0.000
exp_flow	-0.070248	0.002446	-28.72	0.000

S = 2.98177   R-Sq = 50.2%   R-Sq(adj) = 50.1%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	7336.0	7336.0	825.10	0.000
Residual Error	819	7281.7	8.9		
Total	820	14617.6			

- **Scenario 13: congested + rain + incident + no construction**

The regression equation is

Speed = - 28.0 + 69.2 O/T

Predictor	Coef	SE Coef	T	P
Constant	-27.964	3.900	-7.17	0.002
O/T	69.221	5.516	12.55	0.000

S = 3.18468   R-Sq = 97.5%   R-Sq(adj) = 96.9%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	1597.2	1597.2	157.48	0.000
Residual Error	4	40.6	10.1		
Total	5	1637.8			

- **Scenario 17+18: semi-congested + rain or not + no incident + no construction**

The regression equation is
Speed = 38.0 + 1.18 number of lanes

Predictor	Coef	SE Coef	T	P
Constant	37.9863	0.6076	62.51	0.000
number of lanes	1.1795	0.2810	4.20	0.000

S = 6.92100   R-Sq = 0.3%   R-Sq(adj) = 0.3%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	844.20	844.20	17.62	0.000
Residual Error	5177	247979.52	47.90		
Total	5178	248823.72			

- **Scenario 21: semi-congestion + rain + incident + no construction**

The regression equation is
Speed = 21.3 + 20.6 O/T

Predictor	Coef	SE Coef	T	P
Constant	21.329	3.337	6.39	0.000
O/T	20.570	4.982	4.13	0.000

S = 8.46907   R-Sq = 34.8%   R-Sq(adj) = 32.7%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	1222.7	1222.7	17.05	0.000
Residual Error	32	2295.2	71.7		
Total	33	3517.9			