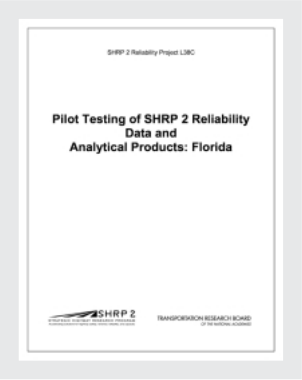

SHRP 2 Reliability Project L38C

Pilot Testing of SHRP 2 Reliability Data and Analytical Products: Florida

Pilot Testing of SHRP 2 Reliability Data and Analytical Products: Florida

DETAILS

0 pages | 8.5 x 11 | PAPERBACK
ISBN 978-0-309-43338-9 | DOI 10.17226/22331

AUTHORS

Hadi, Mohammed; Xiao, Yan; Wang, Tao; Hu, Pei; Jia, Jianmin; Edelstein, Robert; and Alexandra Lopez

SHRP 2 Reliability Project L38C

Pilot Testing of SHRP 2 Reliability Data and Analytical Products: Florida

Mohammed Hadi, Yan Xiao, Tao Wang, Pei Hu, and Jianmin Jia
Florida International University, Miami

Robert Edelstein
AECOM, Inc., Miami

Alexandra Lopez
Florida Department of Transportation, District 6, Miami

TRANSPORTATION RESEARCH BOARD
Washington, D.C.
2015
www.TRB.org

ACKNOWLEDGMENTS

This work was sponsored by the Federal Highway Administration in cooperation with the American Association of State Highway and Transportation Officials. It was conducted in the second Strategic Highway Research Program (SHRP 2), which is administered by the Transportation Research Board of the National Academies. This project was managed by Reena Mathews, Senior Program Officer for the SHRP 2 Reliability focus area.

The authors acknowledge the contributions to the research of various stakeholders who participated in project activities and provided valuable inputs to these activities. In particular, the authors thank participants from the Florida Department of Transportation (DOT) District 6 and District 4 transportation system management and operations programs and transportation management centers, Florida DOT District 6 multimodal system planning office, Miami-Dade Public Works Department, and Florida DOT multimodal performance measurement program and their consultants (AECOM, Jacobs Engineering Group, and Cambridge Systematics).

COPYRIGHT INFORMATION

Authors herein are responsible for the authenticity of their materials and for obtaining written permissions from publishers or persons who own the copyright to any previously published or copyrighted material used herein.

The second Strategic Highway Research Program grants permission to reproduce material in this publication for classroom and not-for-profit purposes. Permission is given with the understanding that none of the material will be used to imply TRB, AASHTO, or FHWA endorsement of a particular product, method, or practice. It is expected that those reproducing material in this document for educational and not-for-profit purposes will give appropriate acknowledgment of the source of any reprinted or reproduced material. For other uses of the material, request permission from SHRP 2.

NOTICE

The project that is the subject of this document was a part of the second Strategic Highway Research Program, conducted by the Transportation Research Board with the approval of the Governing Board of the National Research Council.

The Transportation Research Board of the National Academies, the National Research Council, and the sponsors of the second Strategic Highway Research Program do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of the report.

DISCLAIMER

The opinions and conclusions expressed or implied in this document are those of the researchers who performed the research. They are not necessarily those of the second Strategic Highway Research Program, the Transportation Research Board, the National Research Council, or the program sponsors. The information contained in this document was taken directly from the submission of the authors. This material has not been edited by the Transportation Research Board.

SPECIAL NOTE: This document IS NOT an official publication of the second Strategic Highway Research Program, the Transportation Research Board, the National Research Council, or the National Academies.

THE NATIONAL ACADEMIES

Advisers to the Nation on Science, Engineering, and Medicine

The **National Academy of Sciences** is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. On the authority of the charter granted to it by Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Ralph J. Cicerone is president of the National Academy of Sciences.

The **National Academy of Engineering** was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. C. D. (Dan) Mote, Jr., is president of the National Academy of Engineering.

The **Institute of Medicine** was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, upon its own initiative, to identify issues of medical care, research, and education. Dr. Victor J. Dzau is president of the Institute of Medicine.

The **National Research Council** was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both Academies and the Institute of Medicine. Dr. Ralph J. Cicerone and Dr. C.D. (Dan) Mote, Jr., are chair and vice chair, respectively, of the National Research Council.

The **Transportation Research Board** is one of six major divisions of the National Research Council. The mission of the Transportation Research Board is to provide leadership in transportation innovation and progress through research and information exchange, conducted within a setting that is objective, interdisciplinary, and multimodal. The Board's varied activities annually engage about 7,000 engineers, scientists, and other transportation researchers and practitioners from the public and private sectors and academia, all of whom contribute their expertise in the public interest. The program is supported by state transportation departments, federal agencies including the component administrations of the U.S. Department of Transportation, and other organizations and individuals interested in the development of transportation. **www.TRB.org**

www.national-academies.org

Contents

Executive Summary

Introduction

Transportation agencies have realized the importance of performance estimation, measurement, and management. The Moving Ahead for Progress in the 21st Century Act legislation identifies travel time reliability as one of the goals of the federal highway programs to be supported by established performance measurement processes in each state. The Reliability Program of the second Strategic Highway Research Program (SHRP 2) has developed a number of products to support estimating travel time reliability, identifying reliability deficiencies and contributing factors, identifying alternative solutions, and analyzing the impacts of these solutions. As part of the SHRP 2 program, tools have been developed to assess reliability based on a variety of approaches such as sketch planning, analytical analysis, simulation analysis, and travel time monitoring.

SHRP 2 initiated the L38 project to pilot test products from five of the program's completed projects. The products support reliability estimation and use based on data analyses, analytical techniques, and decision-making framework. The L38 project has two main objectives: (1) to assist agencies in using travel time reliability as a measure in their business practices and (2) to receive feedback from the project research teams on the applicability and usefulness of the products tested, along with their suggested possible refinements. SHRP 2 selected four teams from California, Minnesota, Florida, and Washington.

This document reports on the activities performed as part of the Florida project (Project L38C). Project L38C tested elements from Projects L02, L05, L07, and L08. Project L02 identified methods to collect, archive, and integrate required data for reliability estimation and methods for analyzing and visualizing the causes of unreliability based on the collected data. Projects L07 and L08 produced analytical techniques and tools for estimating reliability based on developed models and allowing the estimation of reliability and the impacts on reliability of alternative mitigating strategies. Project L05 provided guidance regarding how to use reliability assessments to support the business processes of transportation agencies.

Evaluation and Implementation Plan

At the start of the project, an evaluation and implementation plan was developed describing how the products from the four SHRP 2 projects were to be used in the L38C project to support business processes associated with transportation agency planning and operations activities, with a focus on the Florida Department of Transportation (DOT) transportation system management and operations (TSM&O) program activities and transportation management center (TMC) operations in Miami-Dade County. The plan also considered other regional processes, as none of these processes can be considered in isolation. The evaluation and implementation plan development was based on the L05 project guidelines and information from other tested SHRP 2 products. The plan also considered stakeholder inputs, which were gathered in a stakeholder workshop at the beginning of the project and during several face-to-face meetings with agencies in South Florida. The evaluation and implementation plan identified the project stakeholders and related business processes that would benefit from reliability estimation, reliability performance measures, analysis scope, setting of reliability performance thresholds (thresholds beyond which the system is considered unreliable), the methods used for assessing reliability, and the method for assessing improvement alternatives. These methods and measures are in line with L05 guidance regarding reliability measurement and use.

Table ES.1 shows the relation of the L38C project activities to the identified stakeholder business processes and how the project activities support these processes. Definitions of reliability performance measures and their use in SHRP 2 projects are presented in Table ES.2.

Table ES.1. Relation between Project Activities and Identified Business Processes

Stakeholder	Process or Stakeholders	L05	C11	L02	L07	L08	Involvement of This Project
MPO	LRTP, TIP, CMP, and UTPW	Yes	Yes	Yes	Yes	No	Share information and results with Miami-Dade MPO and their LRTP and CMP consultants
Florida DOT System Planning	Interchange modification	Yes	No	Yes	No	Yes	Share information with Florida DOT central office (planning office)
	Q/LOS guidelines	Yes	No	No	No	Yes	
	Corridor/ subarea planning	Yes	No	Yes	No	Yes	Work closely with Florida DOT District 6 SR-7 corridor study and I-95 master plan teams
Florida DOT PD&E office	PD&E traffic analysis	Yes	No	Yes	No	Yes	Share information with PD&E office and recommend that the Q/LOS guidelines be modified to include reliability
Florida DOT Traffic Operations	Traffic studies	Yes	No	Yes	No	Yes	Communicate results to Florida DOT District 6 traffic operation engineer and staff
	Planning for operations	Yes	Yes	Yes	Yes	Yes	Work extensively with TMC staff on deriving strategies
	TMC operations	Yes	No	Yes	No	No	Detect unreliability threshold in real time by using IRISDS or District 6 TMC tools. Share information with Florida DOT District 4, Miami-Dade Expressway Authority, and turnpike TMC
	TSM&O	Yes	Yes	Yes	Yes	Yes	Share information with Districts 4 and 6 TSM&O partners and Florida TSM&O coordinators

Stakeholder	Process or Stakeholders	L05	C11	L02	L07	L08	Involvement of This Project
Analysis Tools	Florida DOT	Yes	Yes	Yes	Yes	Yes	Recommend modifications to intelligent transportation systems data capture and performance management system, integrated regional information sharing and decision support system, and postprocessors to demand forecasting models
Other Agency Planning for Operations	Miami-Dade Public Works	Yes	Yes	Yes	Yes	Yes	Present SR-7 analysis to Miami-Dade Public Works for potential use in signal control
	Miami-Dade Transit	Yes	Yes	Yes	Yes	Yes	Present SR-7 analysis to Miami-Dade Transit for potential use in transit planning
	Florida DOT freight office	Yes	Yes	Yes	Yes	Yes	Share project activities and findings
	Florida multimodal mobility performance measures program	Yes	Yes	Yes	Yes	Yes	Coordinate with program activities

Table ES.2. Definitions and Use of Reliability Performance Measures in SHRP 2 Projects

Reliability Performance Metric	Definition	Projects Using Measure
Buffer Index	The difference between the 95th percentile travel time and the average travel time, normalized by the average travel time	L03, L08
Failure/On-Time Performance	Percentage of trips with travel times less than • 1.1 × median travel time • 1.25 × median travel time Or percentage of trips with speed less than 50, 45, 40, or 35 mph	L03, L08
95th Percentile Planning Time Index	95th percentile of the TTI distribution (95th percentile travel time divided by the free-flow travel time)	L03, L08
80th Percentile TTI	80th percentile of the TTI distribution (80th percentile travel time divided by the free-flow travel time)	L03, L08
Skew Statistics	The ratio of 90th percentile travel time minus the median travel time divided by the median travel time minus the 10th travel time percentile	L03
Misery Index	The average of the highest 5% of travel times divided by the free-flow travel time	L03
Probability Density Function of Travel Time Rate	Probability density function of travel time rate distribution	L02
Cumulative Density Function of Travel Time Rate	Cumulative density function of travel time rate distribution	L02
Semivariance	The variance of travel time rate (in second/mile) pegged to the free-flow travel time instead of the mean travel time	L02
Standard Deviation	Usual statistical definition	L08
Kurtosis	Usual statistical definition	L08
Reliability Rating	Percentage of vehicle miles traveled at a TTI less than a certain threshold (e.g., 1.33 for freeway and 2.5 for urban streets)	L08
Policy Index	Mean travel time divided by travel time at target speed	L08
Semistandard Deviation	One-sided standard deviation that is referenced to the free-flow travel time	L08

Note: TTI = travel time index.

The tested products in this project were implemented to analyze the I-95 corridor general-purpose lanes (GPLs) and express lanes in the northbound (NB) and southbound (SB) directions and the SR-7/US-441 corridor, which is a parallel arterial facility to the I-95 corridor. Figure ES.1 shows a map of the selected corridors. The analysis was conducted for 24-hour periods of weekdays. Data were collected from multiple sources and fused to support the project activities.

The collected data included traffic flow parameter and performance data, geometry data, event data, and traffic management data.

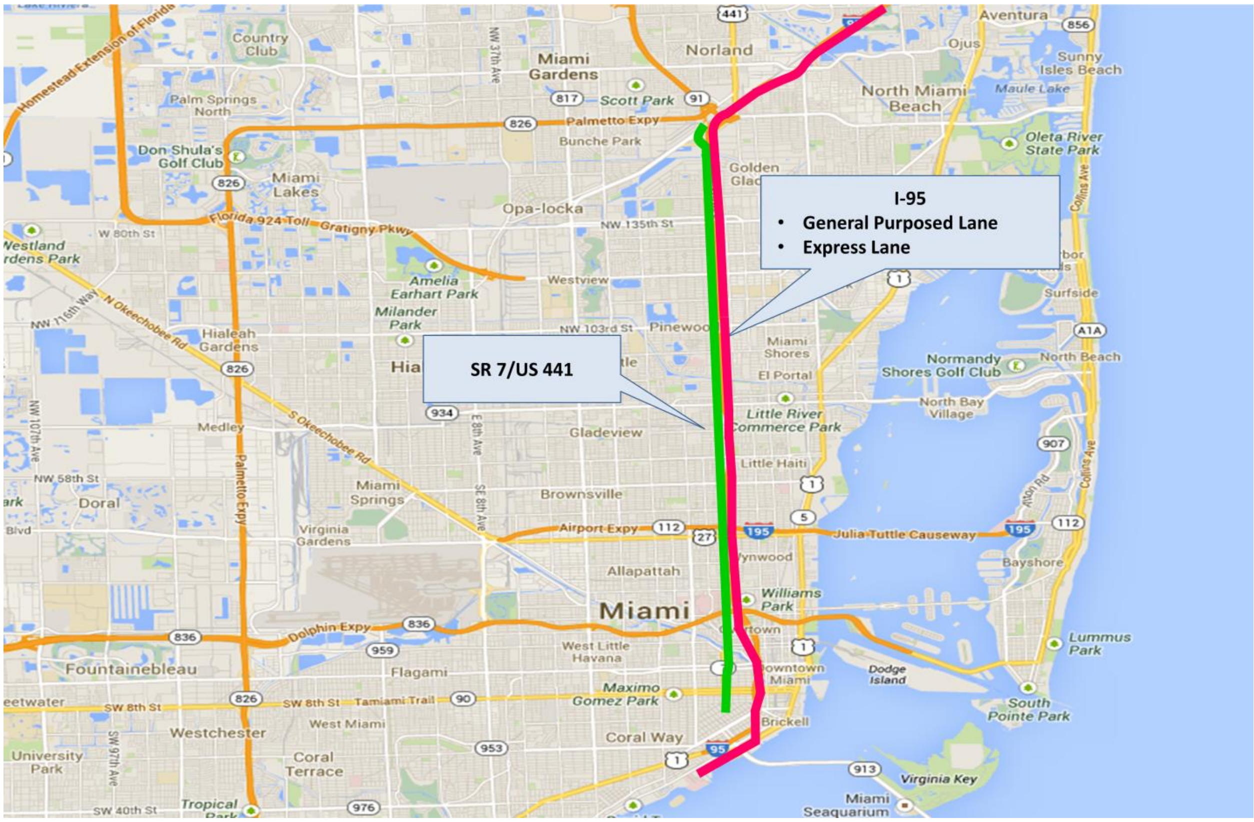


Figure ES.1. Study corridors.

Analysis of Existing Reliability Based on Data

The existing reliability of the tested corridors was assessed based on real-world data obtained from multiple sources using the L02 project guidelines combined with other performance measures and assessment techniques. For the I-95 GPLs and express lane, the estimates were based on data collected from infrastructure-based traffic detectors (true-presence microwave detectors) located at one-third- to one-half-mile spacing. Infrastructure devices were not available for SR-7 to provide data for use in travel time estimation. Therefore, travel time data from a private-sector data provider, INRIX, were used in estimating the travel time reliability of SR-7.

The travel time measurements were combined with nonrecurrent event data (e.g., weather, incidents, construction, and special events) to estimate the impacts of these factors on incidents. The incident data for I-95 were obtained from the detailed SunGuide incident database maintained by the Florida DOT. Because incident data were not available from the transportation management agencies for SR-7, they were obtained from the Florida Highway Patrol crash database, which lacks the details required for estimating incident impact, such as the number and duration of lane blockages and even the direction of incidents.

Reliability was assessed based on various reliability measures in accordance with L05 project guidance, which encourages agencies to estimate multiple reliability performance measures because different measures capture different aspects of the travel time distribution and may suggest different strategies to employ. In addition, additional data analysis and visualization techniques of various performance measures were produced to visualize the reliability by time of day, at the five-minute aggregation level, and for 24 hours of the day. The data analyses were performed for different combinations of the influencing factors to isolate the impacts of these factors. The analysis at five-minute intervals is needed when performing planning for operations analysis to determine the exact times when the roadway segments become unreliable so that the activation of active management strategies can be recommended at those times.

The L02 recommendations for establishing reliability regimes were used to categorize the impacts of various contributing factors on the reliability of the system. By examining the results under different regimes, it is possible to identify the factors contributing to the unreliability of the analyzed segments. Initially, this project used L02 recommendations for categorizing the data by congestion level. However, it was later decided than binning the data by time of day, considering different causes of congestion at different times of the day, is more appropriate as it allows analyzing the reliability of the specific condition under consideration.

Other approaches to binning data by regime were also used. For example, instead of having only one incident category, as in L02, incidents were subcategorized by duration and/or number of lanes blocked, and rain events were categorized by rain intensity. The impacts of overlapped incident plus weather conditions were also analyzed.

When determining the contribution of an event type or a combination of event types on reliability, L02 uses the semivariance measure. This contribution is a function of the multiplication of the average impact of a single event and the frequency of that event type. However, some events may be severe but rare, resulting in low overall contribution to unreliability. Although the contribution of some events is low, agencies may still be interested in knowing the average impact of a single event on reliability. Thus, in addition to estimating the percentage of overall unreliability contribution of an event type on reliability, the severity of a single event was also calculated based on a normalized semivariance, which is calculated as the percentage of semivariance of a single event type without considering its occurrence frequency. Although the frequency of outlier events is by definition low, the impacts are often high. The exclusion of outliers can have a marked effect on travel time reliability performance measures. It is important to capture severe infrequent occurrences.

Figures ES.2 to ES.8 and Tables ES.3 to ES.5, which show examples of the measures and visualization techniques used for the I-95 NB GPLs, clearly show the unreliability of travel during the PM peak periods. The abbreviations in the figures and tables are as follows: AM, 6:00 to 9:00 a.m.; MD (midday), 9:00 a.m. to 3:00 p.m.; PM1, 3:00 to 5:00 p.m.; PM2, 5:00 to 7:00 p.m.; APM (after-PM), 7:00 to 10:00 p.m.; and MN, midnight and early morning period.

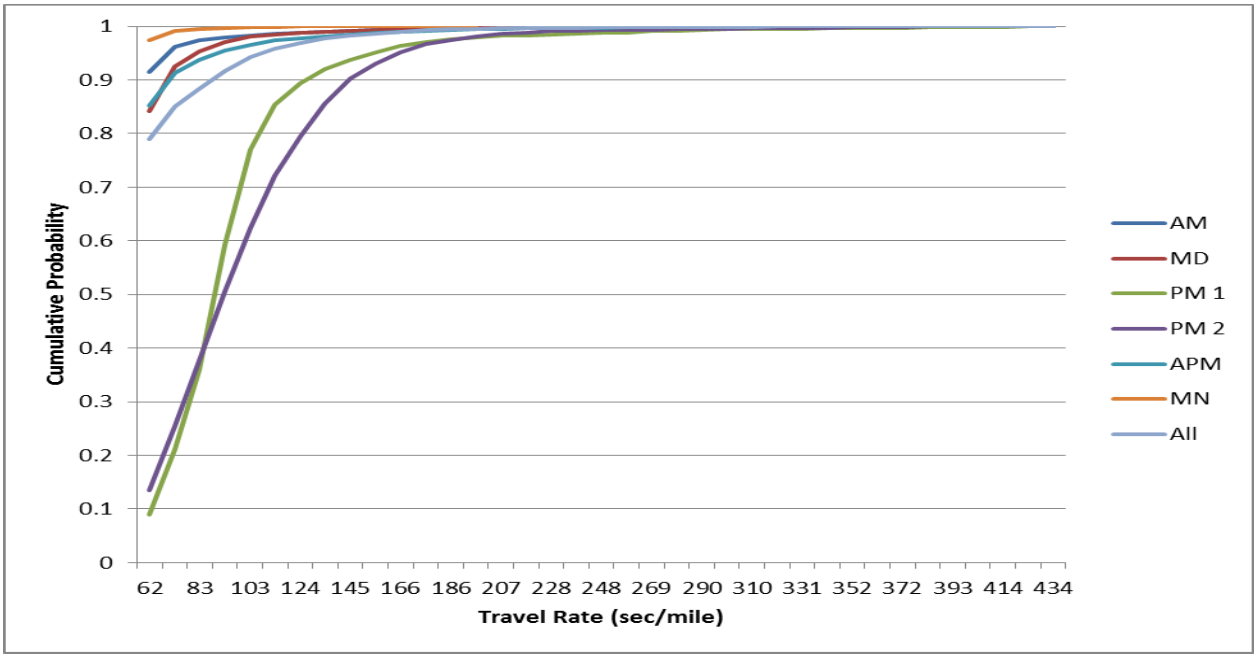


Figure ES.2. Cumulative density function of travel time rate.

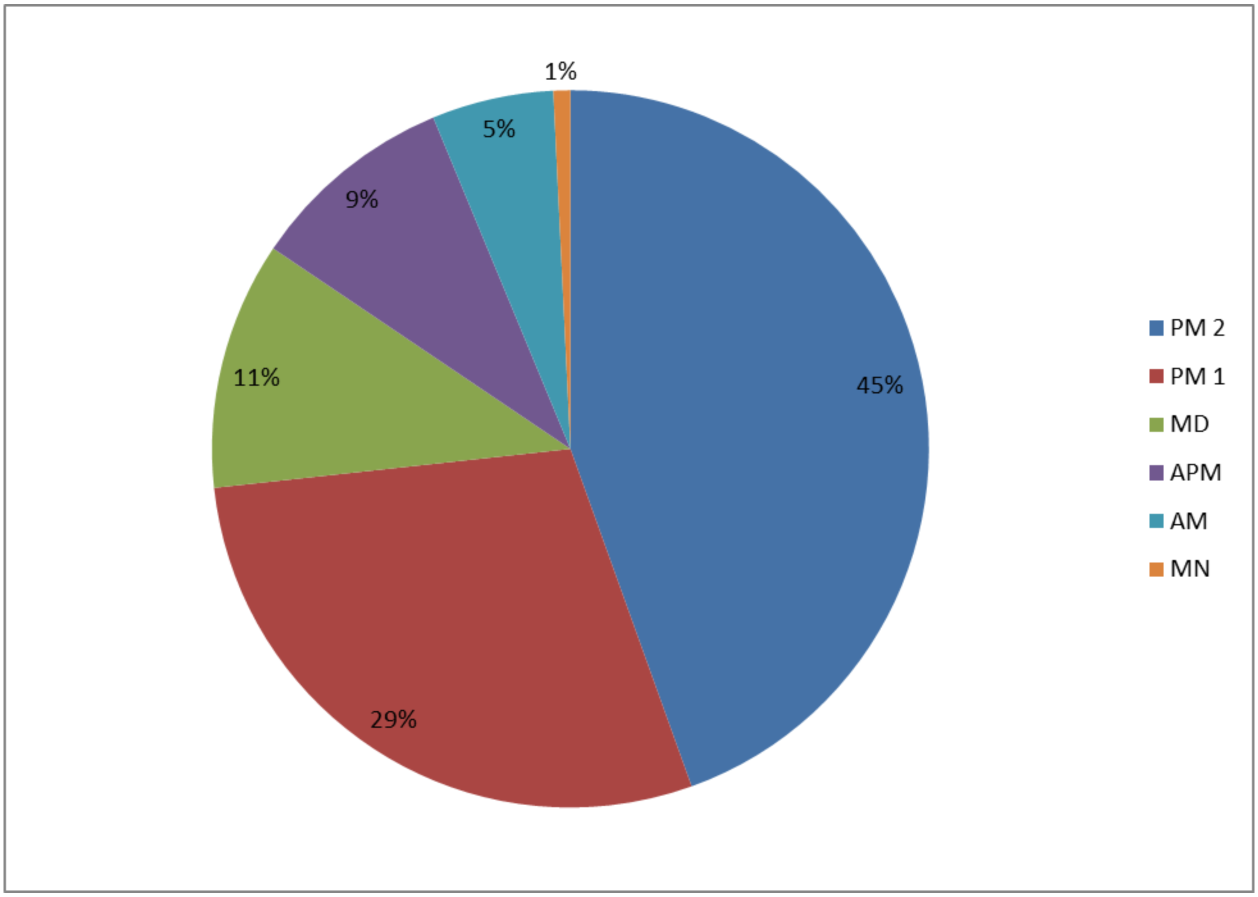


Figure ES.3. Percentage of unreliability contribution.

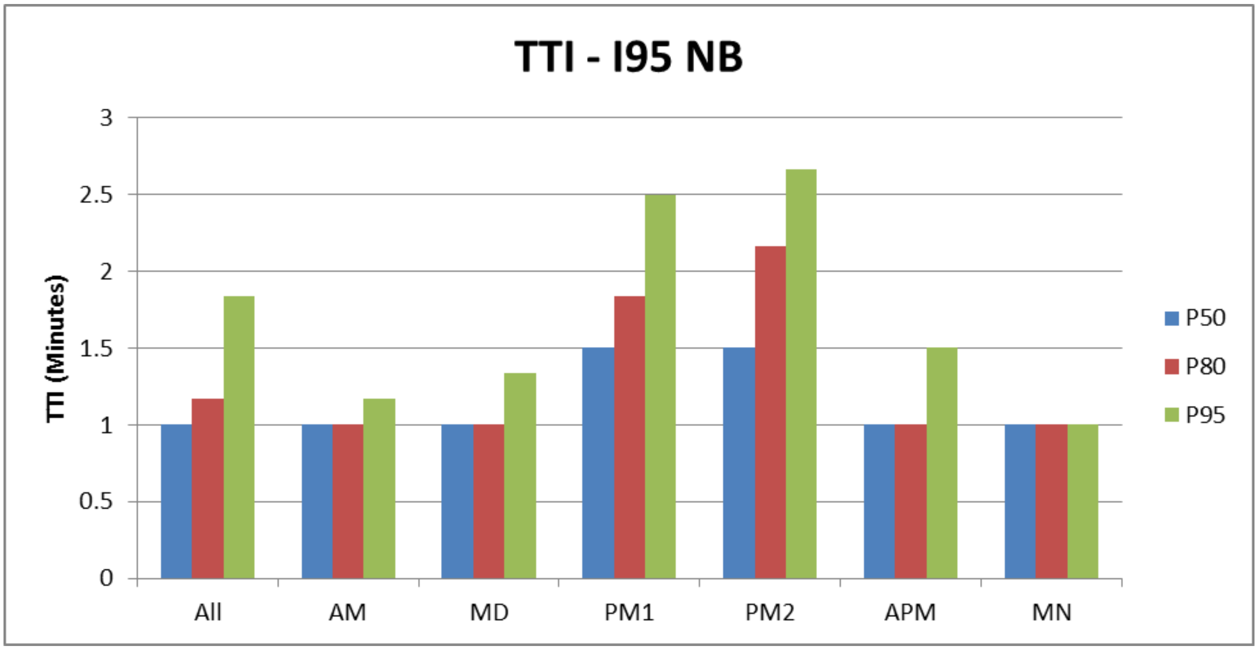


Figure ES.4. I-95 NB GPL TTI.

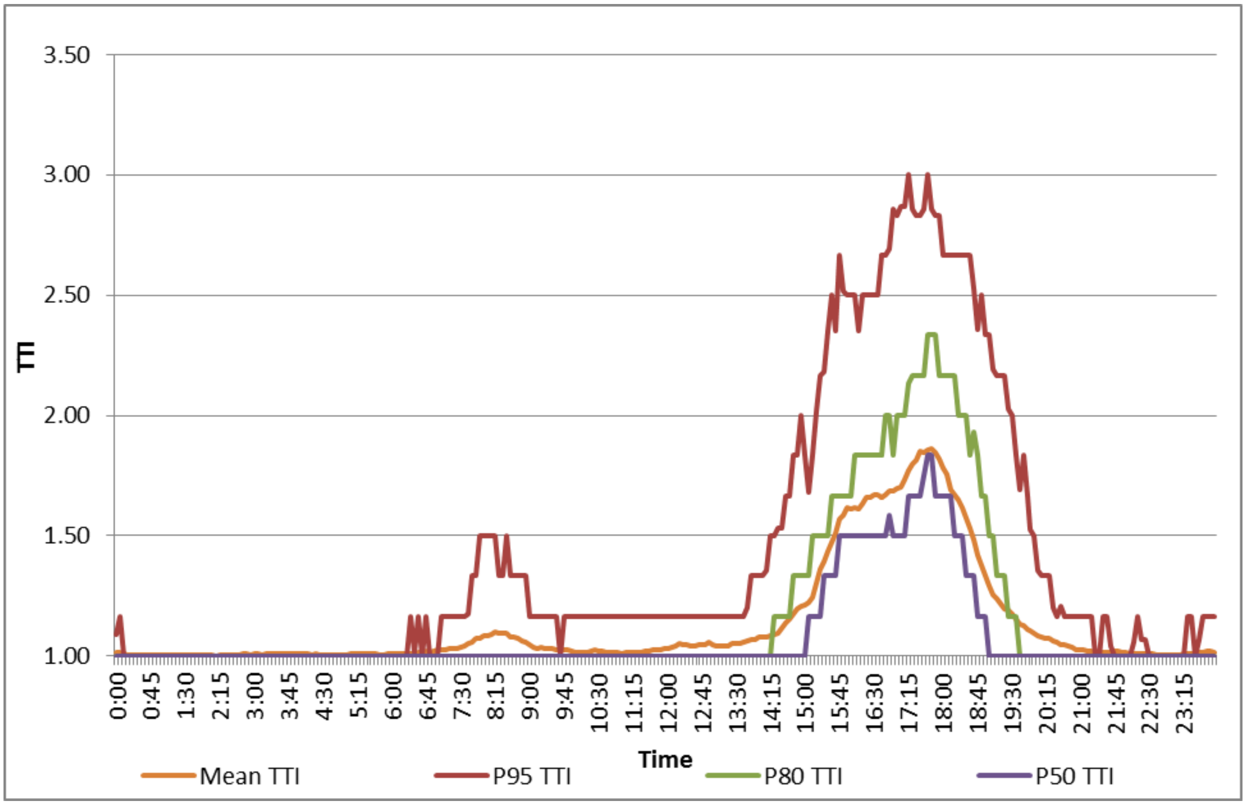


Figure ES.5. TTI values for each 5 minutes of the day.

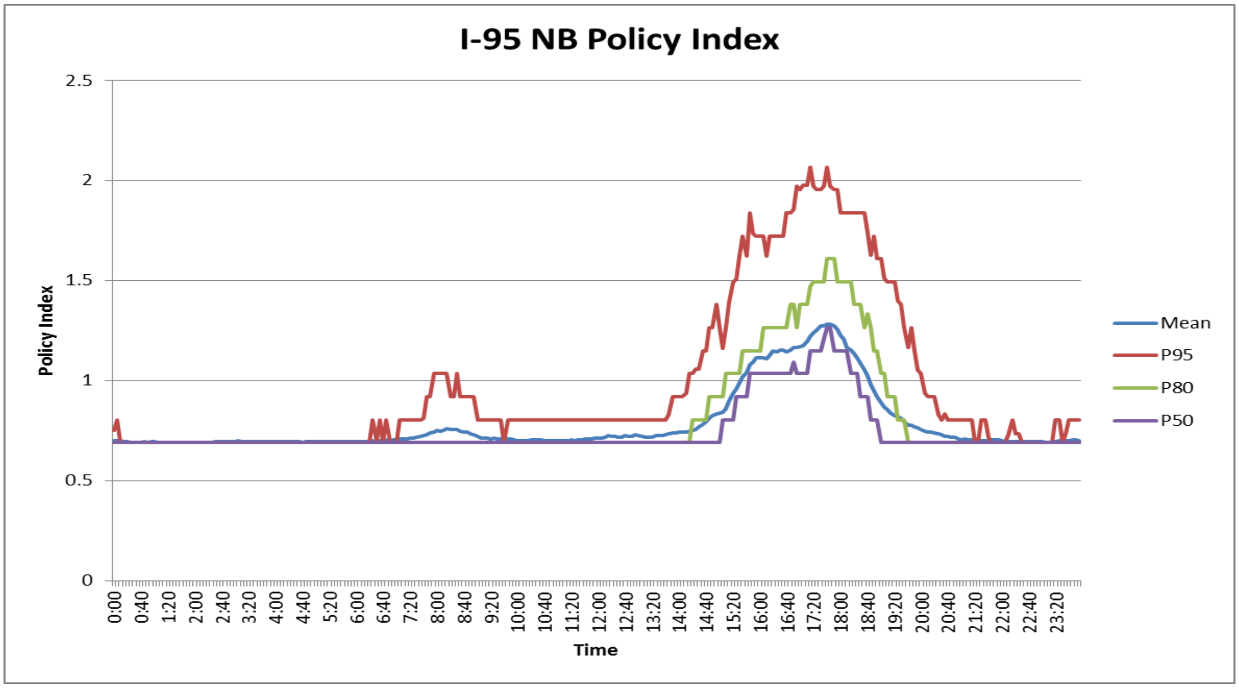


Figure ES.6. Policy index variation by time of day.

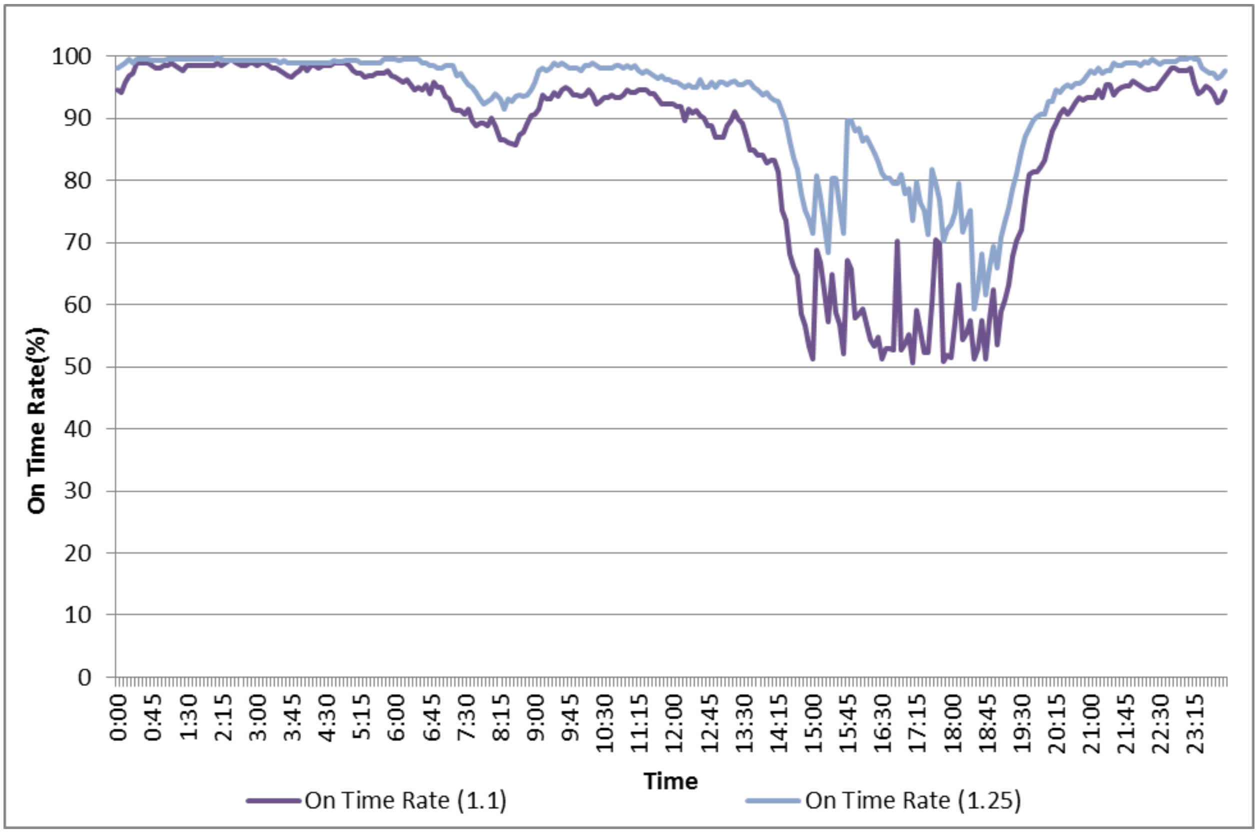
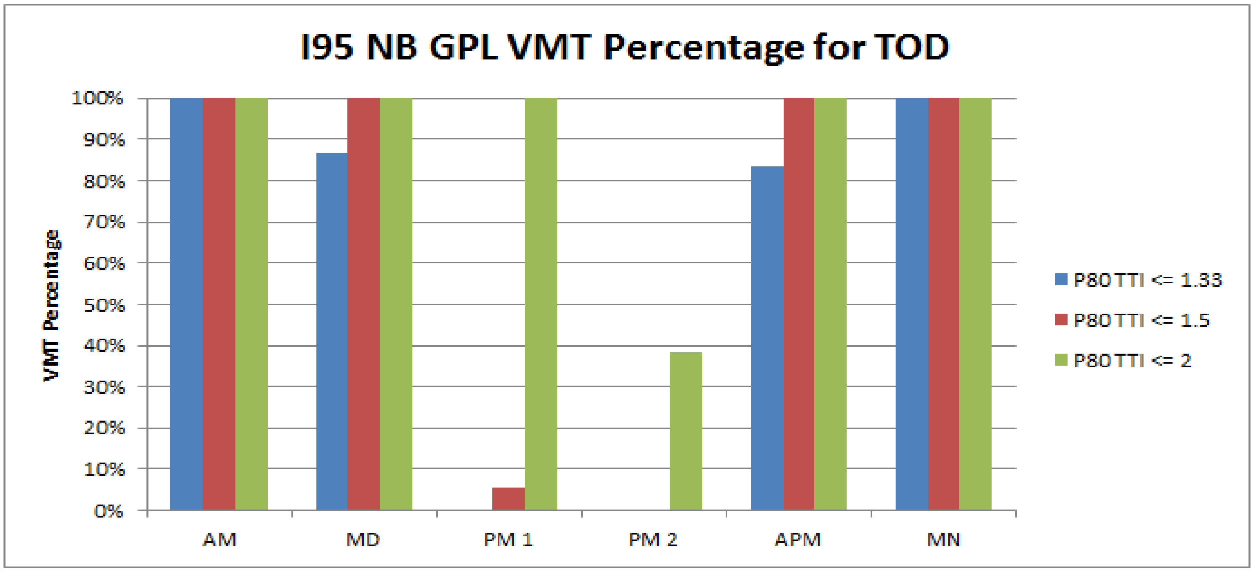
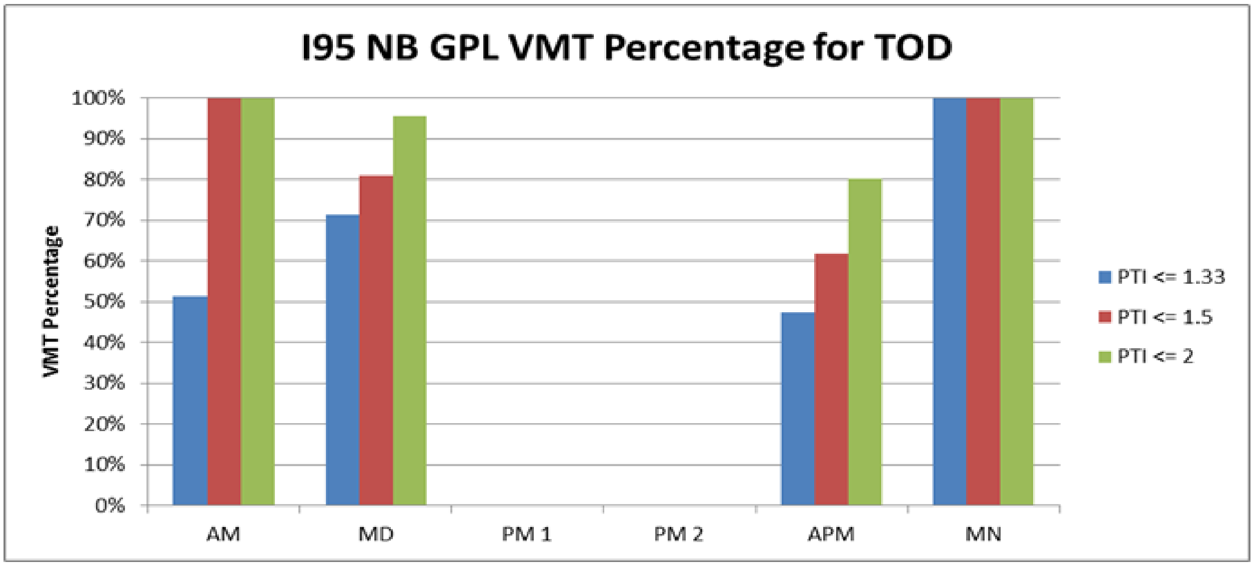


Figure ES.7. I-95 NB on-time performance.



(a)



(b)

Figure ES.8. I-95 NB GPL reliability ratings showing comparison base on (a) 80th and (b) 95th percentile TTI.

Table ES.3. Percentage of Occurrence

Time Period	Nonevent	Incident	Weather	Incident + Weather	Total
AM	10%	2%	1%	0%	13%
MD	20%	6%	1%	0%	27%
PM1	4%	2%	0%	0%	6%
PM2	5%	3%	0%	0%	8%
APM	9%	3%	0%	0%	12%
MN	27%	4%	1%	0%	33%

Table ES.4. Percentage of Severity

Time Period	Nonevent	Incident	Weather	Incident + Weather	Total
AM	0%	0%	1%	17%	19%
MD	0%	1%	1%	5%	7%
PM1	3%	9%	7%	17%	35%
PM2	5%	8%	8%	14%	35%
APM	0%	3%	0%	1%	4%
MN	0%	0%	0%	0%	0%

Table ES.5. Percentage of Unreliability Contribution

Time Period	Nonevent	Incident	Weather	Incident + Weather	Total
AM	2%	1%	0%	3%	5%
MD	3%	6%	1%	2%	11%
PM1	10%	15%	1%	2%	29%
PM2	21%	21%	2%	1%	45%
APM	2%	7%	0%	0%	9%
MN	1%	0%	0%	0%	1%

To select capacity improvements and/or active traffic management strategies, it is not sufficient to identify congestion and unreliability values based on a general analysis of the contributing factors. Additional analysis and visualization techniques are needed to identify the exact locations of the problems. Analyzing the data and visualizing the bottleneck impacts by using contour (heat) maps, as shown in Figure ES.9, indicated that the main issues in the early part of the PM peak are two capacity problems on NW 79th Street and NW 103rd Street. The capacities on these links were found to be lower than that of the capacity reported by the *Highway Capacity Manual* (HCM). For the second part of the PM period, the main issue was a backup from the off-ramp to the Florida Turnpike.

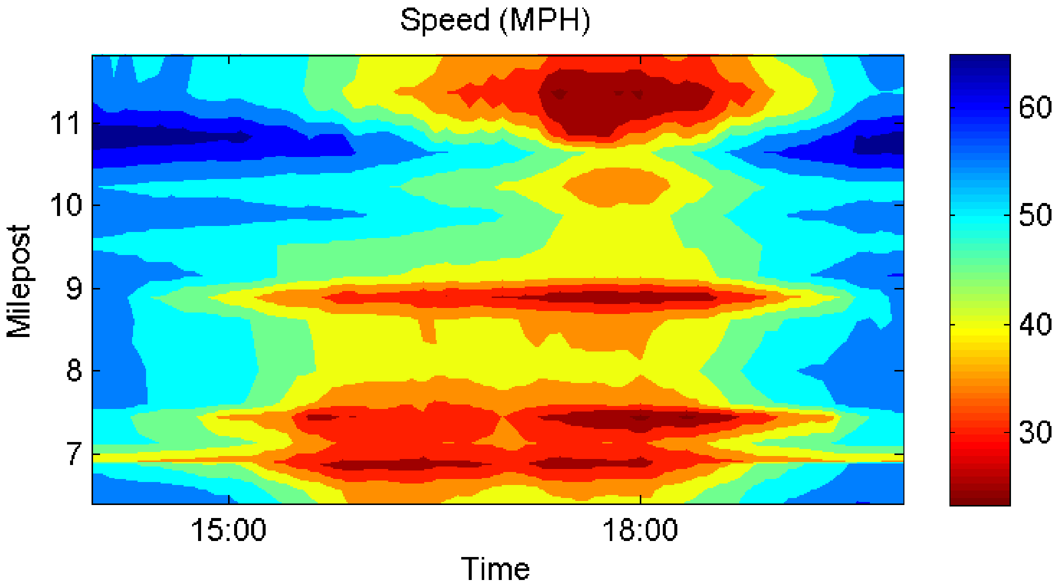


Figure ES.9. I-95 NB GPL speed contour map during the PM peak period.

Testing L07 Products to Assess Existing Reliability

Project L07 focused on the estimation of the effect of physical design treatments on freeway travel time reliability and the cost-effectiveness of these treatments. The L07 analysis was based on the reliability estimation methods developed in the SHRP 2 L03 project and can be considered as a sketch planning–level analysis that is not as detailed as the L08 procedures. Therefore, it may not be appropriate to support detailed operational analysis, but rather to give an overall estimation of the benefits of specific types of improvements at the planning stage. In addition, the L07 project analysis is only applicable to freeway segments and currently cannot be used for arterial streets.

The L07 project products provide an opportunity to estimate the travel time reliability of data-poor data environments based on limited traffic and network data and to evaluate improvement alternatives. However, it was important to further validate the results from the L07 tool and procedures. In this project, the results from the L07 sketch-planning spreadsheet were examined for the I-95 NB GPL segment and compared with the analysis results obtained based on the real-world monitoring system. The analysis was done for both the full I-95 NB GPL segment and for the three corresponding subsegments.

The results are presented in Figures ES.10 to ES.13. In these figures MIN refers to the minimum TTI, and MAX refers to the maximum TTI during the 24 hours of the day. It can be observed from these figures that there are significant differences in the comparisons of the estimated TTIs for different segments. The L07 TTI estimate for Segment 1 was lower than the real-world TTI, and the TTI estimates for Segment 3 and the whole facility were higher than the real-world TTI values. The differences in the comparison results for different segments may be due in part to the difference in segment lengths. Because of the differences, this study derived new regression models for the TTI estimation model based on local data. Different regression expressions were investigated, and a new variable, segment length, was added into the regression model. The incorporation of the new models in L07 tools resulted in significant improvements in the accuracy of the reliability estimation. Further research on this subject is necessary.

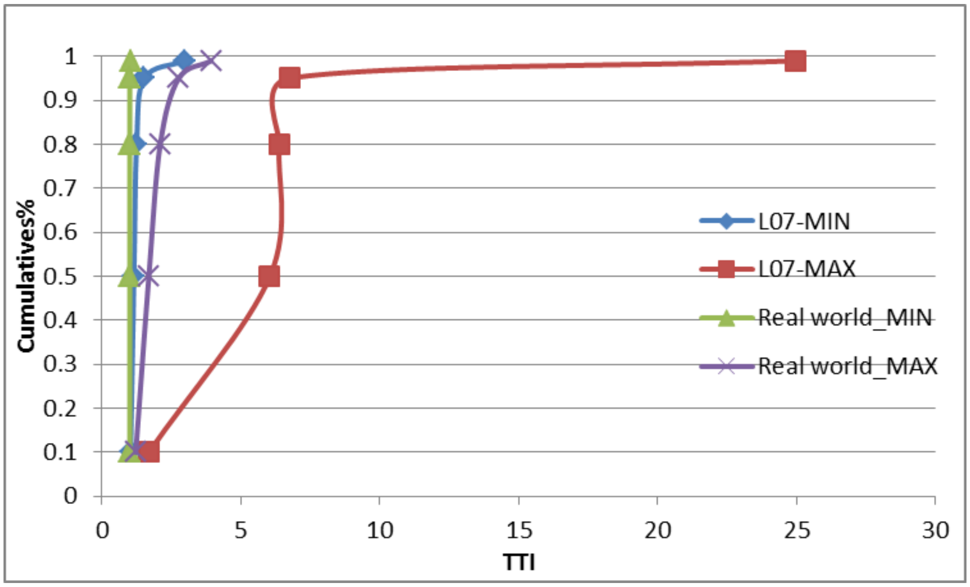


Figure ES.10. Cumulative TTIs for the whole corridor for the default model.

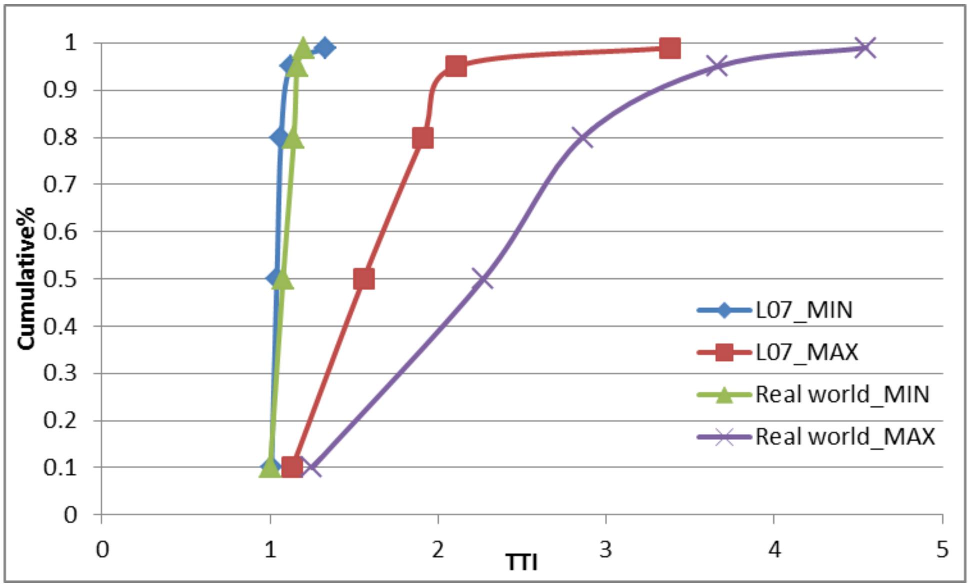


Figure ES.11. Cumulative TTIs for Segment 1 for the default model.

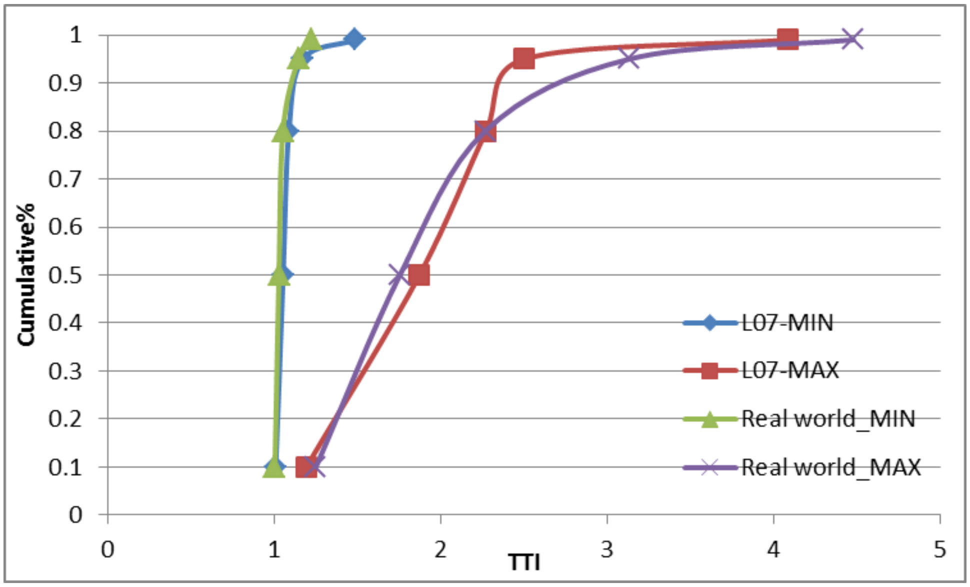


Figure ES.12. Cumulative TTIs for Segment 2 for the default model.

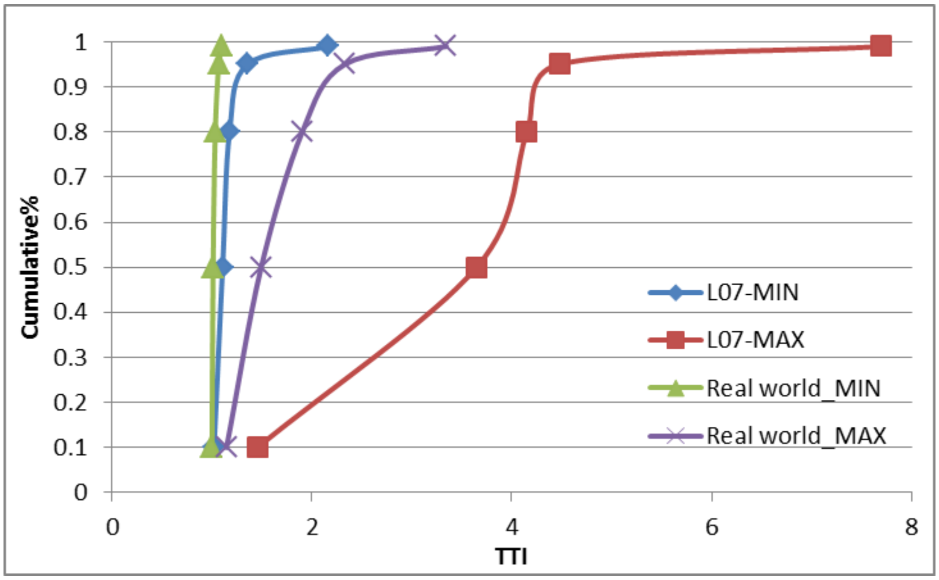


Figure ES.13. Cumulative TTIs for Segment 3 for the default model.

Testing L08 Products to Assess Existing Reliability

Project L08 developed reliability assessment methods and tools based on the HCM freeway and urban street facility procedures and computational engines. It also developed draft chapters for inclusion in a future edition of the HCM (draft HCM Chapter 36 and Chapter 37). Project L38C investigated the application of the L08 procedures to estimate the reliability of I-95 NB and SB GPLs and SR-7/US-441 segments. This investigation included testing the impacts of input parameters to the traffic flow model and the scenario generation module incorporated as part of the computational engines of the HCM-based reliability estimation procedure of freeway and urban street facilities.

Figures ES.14 to ES.19 show the speed contour maps of I-95 NB and SB based on field measurement and analysis results from the uncalibrated and calibrated FREEVAL (FREEway EVALuation) traffic flow model, respectively. These figures clearly show that the calibration of the model is necessary for the investigated corridor.

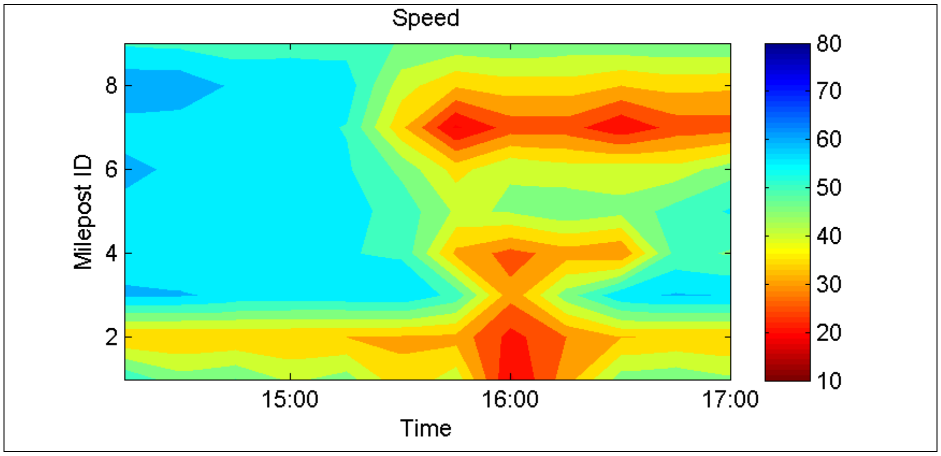


Figure ES.14. Speed contour map based on real-world data for I-95 NB.

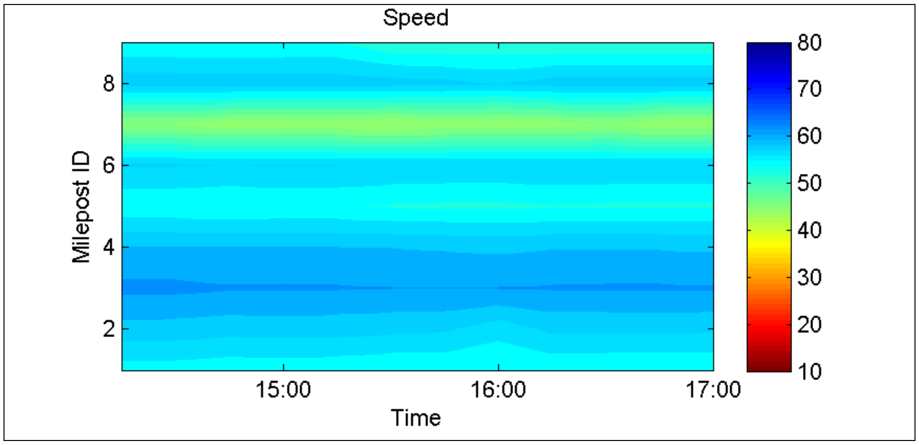


Figure ES.15. Speed contour map based on uncalibrated FREEVAL model for I-95 NB.

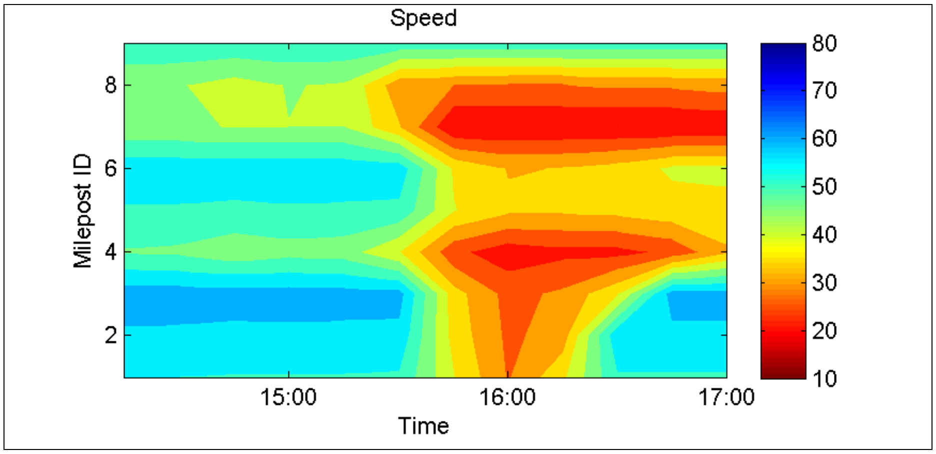


Figure ES.16. Speed contour map based on calibrated FREEVAL model with a capacity adjustment factor of 0.81 for I-95 NB.

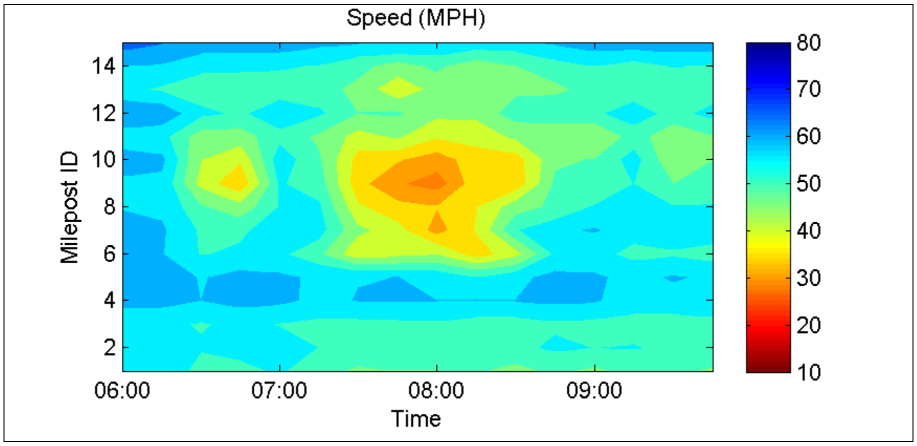


Figure ES.17. Speed contour map based on real-world data for I-95 SB.

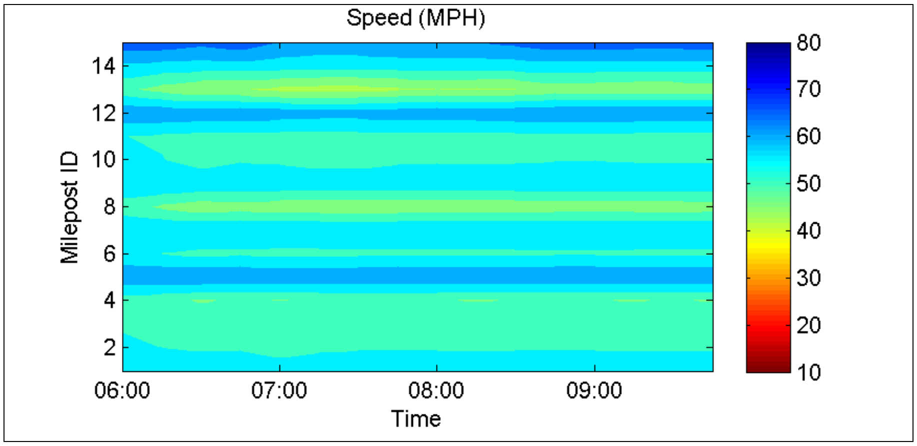


Figure ES.18. Speed contour map based on uncalibrated FREEVAL model for I-95 SB.

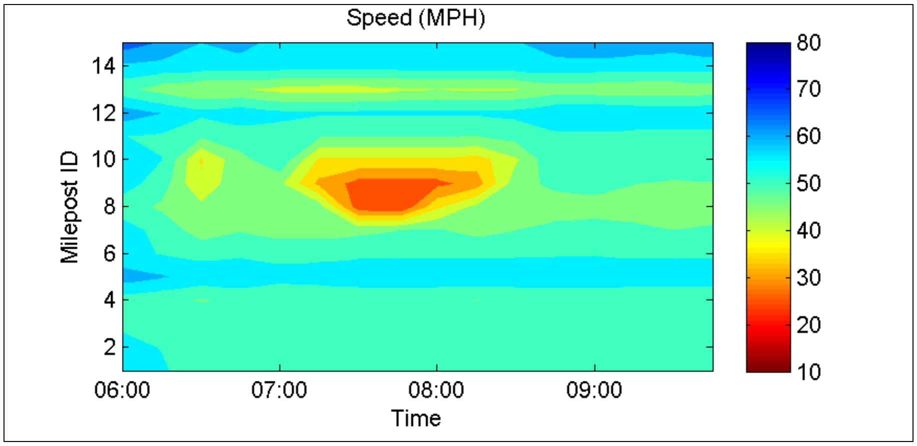


Figure ES.19. Speed contour map based on calibrated FREEVAL model with a capacity adjustment factor of 0.85 for bottleneck locations and a factor of 0.95 for the remaining segments along I-95 SB.

Tables ES.6 and ES.7 show that when using local incident rates and duration data as inputs to the scenario generator of FREEVAL-RL, significantly higher TTIs, misery index, and average travel time values were estimated compared to those estimated by FREEVAL-RL when using the default values for these parameters. For data-rich environments, it is recommended that the user conduct more detailed processing of incident data to estimate the proportion of time with incidents by lane blockage severity (Option C in the tables).

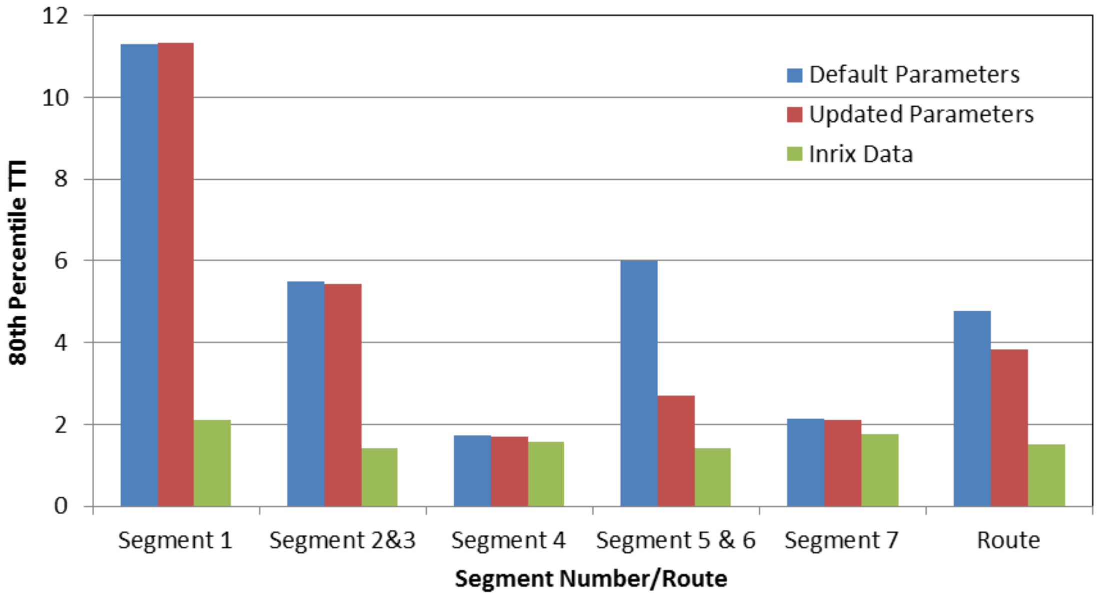
The estimated travel time reliability indexes by STREETVAL-RL for SR-7 during the uncongested periods were close to those values obtained based on INRIX data. However, for the more congested periods, there were significant differences between the modeling results and estimation from INRIX data, as shown in Figure ES.20, with STREETVAL-RL producing higher TTIs. Updating STREETVAL-RL reliability input parameters improved the estimation performance.

Table ES.6. Impacts of Updating Incident Information on I-95 NB Travel Time Reliability Analysis Results

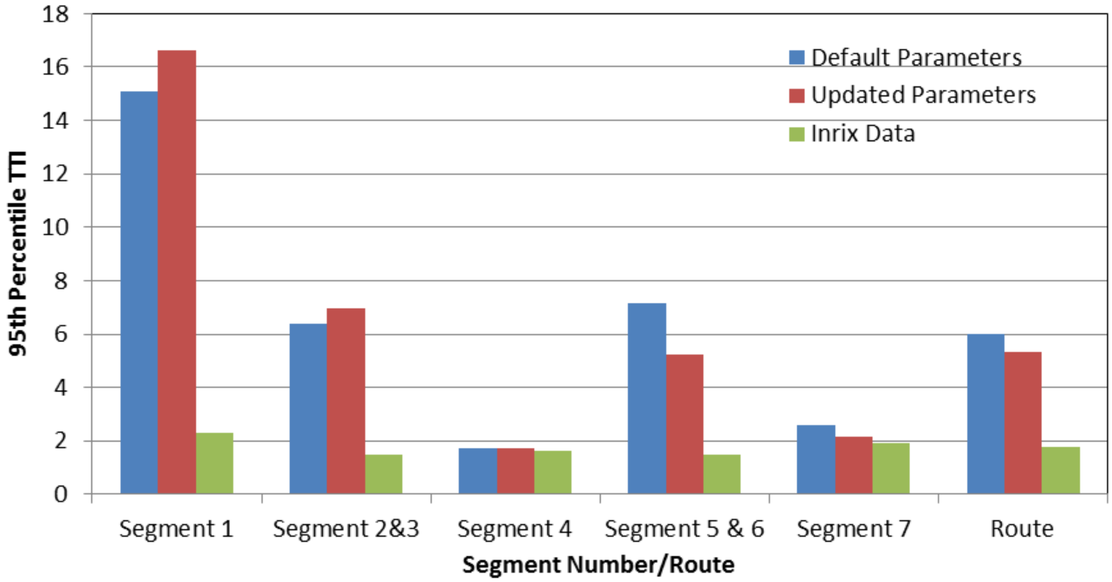
Measure	I-95 Crash Rate and National Default Duration Data	I-95 Crash Rate and I-95 Duration Data	I-95 Incident Rate and National Default Duration Data	Option C Coding
Mean TTI	1.16	1.20	1.15	1.33
50th Percentile TTI	1.13	1.13	1.13	1.14
80th Percentile TTI	1.15	1.15	1.15	1.28
95th Percentile TTI	1.19	1.37	1.18	2.12
Misery Index	1.74	2.32	1.44	3.84
Average Travel Time per Vehicle (min)	6.72	7.04	6.59	7.76
Space Mean Speed (mph)	52.33	51.65	52.67	50.46

Table ES.7. Impacts of Updating Incident Information on I-95 SB Travel Time Reliability Analysis Results

Measure	I-95 Crash Rate and National Default Duration Data	I-95 Crash Rate and I-95 Duration Data	I-95 Incident Rate and National Default Duration Data	Option C Coding
Mean TTI	1.29	1.40	1.28	1.68
50th Percentile TTI	1.12	1.12	1.12	1.13
80th Percentile TTI	1.14	1.16	1.14	1.87
95th Percentile TTI	2.00	2.80	1.91	3.86
Misery Index	4.02	5.09	3.89	6.75
Average Travel Time per Vehicle (min)	7.96	8.78	7.85	10.95
Space Mean Speed (mph)	51.44	49.81	51.61	45.73



(a)



(b)

Figure ES.20. Reliability analysis results for SR-7 SB during AM peak period for (a) 80th and (b) 95th percentile TTIs.

Potential Strategies to Address Congestion

Potential strategies for addressing the reliability issues were identified for the study corridors based on discussion with the project stakeholders. Detailed potential planning for operations and operations applications for including travel time reliability in TMC operations were identified in the following areas:

- Trend analyses,
- Predictive analyses,
- Transportation management strategies,
- Decision support systems, and
- Integrated corridor management.

It was suggested that these functional areas begin to include travel time reliability in their day-to-day processes, standard operating guidelines, and performance reporting systems. TMC operations should be audited to determine where gaps exist in the services provided versus what is needed, and the reliability tools should be applied to address these gaps. It is anticipated that this process is to be conducted offline initially, then transitioned to real-time, online processes as the TMC operations staff begins to be more comfortable with the accuracy, timeliness, and usefulness of such information. Each of these functional areas is discussed in detail.

Example assessments of these strategies were also conducted in this study by using the L07 and L08 tools, considering the limited ability of these tools to evaluate such strategies. Tables ES.8 to ES.10 show examples of these assessments.

Table ES.8. Benefit–Cost Ratio for Different Treatments Using the L07 Tools

Benefit–Cost Ratio for Segments	Scenario	Incident Screen	Incident Investigate Site	Emergency Pull-Off	Emergency Crossover	Drivable Shoulder
Segment 1	Default Duration and Default Proportion	0.57	1.15	5.35	5.27	0.15
	Local Duration and Default Proportion	0.74	17.90	61.52	5.45	0.16
	Default Duration and Local Proportion	0.57	1.10	5.14	5.27	0.15
	Local Duration and Local Proportion	0.48	18.58	61.25	5.44	0.16
Segment 2	Default Duration and Default Proportion	1.06	1.60	7.45	12.58	0.41
	Local Duration and Default Proportion	1.34	25.76	90.76	13.10	0.45
	Default Duration and Local Proportion	1.05	1.63	7.60	12.55	0.41
	Local Duration and Local Proportion	1.15	71.18	274.45	20.23	0.44

Benefit–Cost Ratio for Segments	Scenario	Incident Screen	Incident Investigate Site	Emergency Pull-Off	Emergency Crossover	Drivable Shoulder
Segment 3	Default Duration and Default Proportion	5.9	30.66	142.7	163.25	3.45
	Local Duration and Default Proportion	15.73	707.57	2667.86	241.07	5.02
	Default Duration and Local Proportion	6.66	41.68	193.96	185.37	3.66
	Local Duration and Local Proportion	24.58	1467.36	6023.80	378.14	7.42

Table ES.9. Impacts of Incident Management on I-95 NB Corridor Reliability Using FREEVAL-RL

Performance Measure	Local Incident Rate and Existing Duration (Option B)	Local Incident Rate and Increased Duration (Option B)	Existing Incident Time (Option C)	Increased Incident Duration (Option C)
Mean TTI	1.17	1.19	1.33	1.36
50th Percentile TTI	1.13	1.13	1.14	1.14
80th Percentile TTI	1.15	1.15	1.28	1.28
95th Percentile TTI	1.21	1.31	2.12	2.85
Misery Index	1.83	2.22	3.84	4.22
Average Travel Time per Vehicle (min)	6.77	6.83	7.76	8.65
Space Mean Speed (mph)	52.21	50.86	50.46	48.16

Table ES.10. Impacts of Incident Management on I-95 SB Corridor Reliability Using FREEVAL-RL

Performance Measure	Local Incident Rate and Existing Duration (Option B)	Local Incident Rate and Increased Duration (Option B)	Existing Incident Time (Option C)	Increased Incident Duration (Option C)
Mean TTI	1.37	1.44	1.68	1.77
50th Percentile TTI	1.12	1.12	1.13	1.13
80th Percentile TTI	1.15	1.17	1.87	2.03
95th Percentile TTI	2.67	2.96	3.86	4.24
Misery Index	4.87	5.56	6.75	7.73
Average Travel time per Vehicle (min)	8.52	9.32	10.95	11.98
Space Mean Speed (mph)	50.14	49.26	45.73	44.88

Usability and Acceptability by Stakeholders

This study presents observations concerning the usefulness of the products tested in the SHRP 2 L38C project, a look at the issues identified by the research team related to those products, and a review of the level of understanding and acceptance by the stakeholders involved in the project.

Outreach activities were performed at the end of the project to communicate the project results to the project stakeholders. A stakeholder workshop was conducted on May 21, 2014. The workshops were successful in presenting the objectives and results of the research, providing high-level training, and introducing how the reliability data and analytical products may begin to be integrated within transportation planning and operations business processes. Positive feedback was provided by the stakeholders.

Next Steps

The SHRP 2 Reliability Program has made significant investments in developing products to support estimating travel time reliability, identifying reliability deficiencies and contributing factors, identifying alternative solutions, and analyzing the impacts of these solutions. The return on these investments will be realized by integrating reliability in planning and operations processes by using the phased approach described above. These actions will support integrating performance estimation, measurement, and management in each state, which is one of the goals of the Moving Ahead for Progress in the 21st Century Act.

CHAPTER 1

Introduction

1.1 Background

Transportation agencies have realized the importance of performance estimation, measurement, reporting, and management. This realization has become even greater with the signing of the Moving Ahead for Progress in the 21st Century Act (MAP-21) legislation in July 2012 (FHWA 2012, 2013). MAP-21 specifies that states will invest resources in projects to achieve performance targets. Increasingly, travel time reliability is considered as an important component of the performance of transportation systems and of travelers' perceptions of this performance. For example, the National Transportation Operations Coalition initiative selected a travel time reliability measure as one of a few good transportation operation measures to use for internal management, external communications, and comparative assessments (National Transportation Operations Coalition 2005). MAP-21 identifies travel time reliability as one of the goals of the federal highway programs to be supported by established performance measurement processes in each state.

The guide document produced by the L05 project of the second Strategic Highway Research Program (SHRP 2) defined reliability as "a measure of how consistent or predictable travel times are over time" (Cambridge Systematics 2013b). The L05 project *Technical Reference* document provided two definitions of reliability: "(1) the variability of travel times that occur on a facility or a trip over the course of time, and (2) the number of times (trips) that either 'fail' or 'succeed' in accordance with a predetermined performance standard or schedule" (Cambridge Systematics 2013c). Unreliability of the transportation system operation is caused by a number of contributing factors, including fluctuations in demand, traffic control device operations, traffic incidents, inclement weather, work zones, and capacity limitations.

Travel time reliability is important because uncertainty in travel time requires travelers to build in extra trip time or risk arriving late. Therefore, reliability influences decisions about where, when, and how travel is made. The extra costs of unreliable travel require traffic management agencies to consider reliability in their decision-making processes.

Reliability can be measured based on data collected from travel time monitoring systems, including those based on infrastructure point detectors, automatic vehicle identification readers, automatic vehicle location technologies, and private-sector travel time data. Although travel time monitoring provides a powerful platform for estimating reliability, additional methods based on traffic modeling are needed for two reasons: (1) there are locations where travel time data are not available at the resolution and period of time required to estimate reliability, and (2) reliability estimation based on monitored travel time is suitable for assessing existing system performance, but this method does not allow the estimation of reliability for future conditions and under alternative capacity and operational improvement strategies.

The SHRP 2 Reliability Program has developed products to support estimating travel time reliability, identifying reliability deficiencies and contributing factors, identifying alternative solutions, and analyzing the impacts of these solutions. As part of the SHRP 2 program, tools have been developed to assess reliability based on a variety of approaches, such as sketch planning, analytical analysis, simulation analysis, and travel time monitoring.

SHRP 2 initiated the L38 project to pilot test products from five of the program's completed projects. The products support reliability estimation and use based on data analyses, analytical techniques, and decision-making framework. The L38 project has two main objectives. The first objective is to assist agencies in using travel time reliability as a measure in their business practices. The second objective is for the project research teams to provide feedback on the applicability and usefulness of the products tested and to suggest possible refinements. SHRP 2 selected four teams from California, Minnesota, Florida, and Washington. This document reports on the activities performed as part of the Florida project (Project L38C).

1.2 Tested SHRP 2 Products

SHRP 2 specified that products from all or a subset of five program projects be implemented and tested. These projects are L02, L05, L07, L08, and C11. Project L02 identified methods to collect, archive, and integrate required data for reliability estimation and methods for analyzing and visualizing the causes of unreliability based on the collected data. Projects C11, L07, and L08 produced analytical techniques and tools for estimating reliability based on developed models, allowing the estimation of reliability and the impacts on reliability of alternative mitigating strategies. Project L05 provided guidance regarding how to use reliability assessments to support the business processes of transportation agencies. Elements from Projects L02, L05, L07, and L08 were tested in this project. The C11 products were not tested in this project because L38C focuses on corridor studies, planning for operations, and operations. The main C11 product is a sketch-planning tool for benefit–cost estimation that is more appropriate for earlier planning stages. The four projects selected for the L38C pilot are described in the following subsections.

1.2.1 Project L02: Establishing Monitoring Programs for Travel Time Reliability

Project L02 developed methods for monitoring and evaluating travel time reliability based on data generated by traffic monitoring systems such as those based on point traffic detectors, automatic vehicle identification, automatic vehicle location, and private-sector data. It provided guidelines for measuring, categorizing, identifying, and understanding the causes of unreliability necessary to identify possible mitigating actions.

Project L02 provided recommendations to agencies regarding the establishment and use of a travel time reliability monitoring system. The three major components of the system—a data manager, a computational engine, and a report generator—are briefly outlined below.

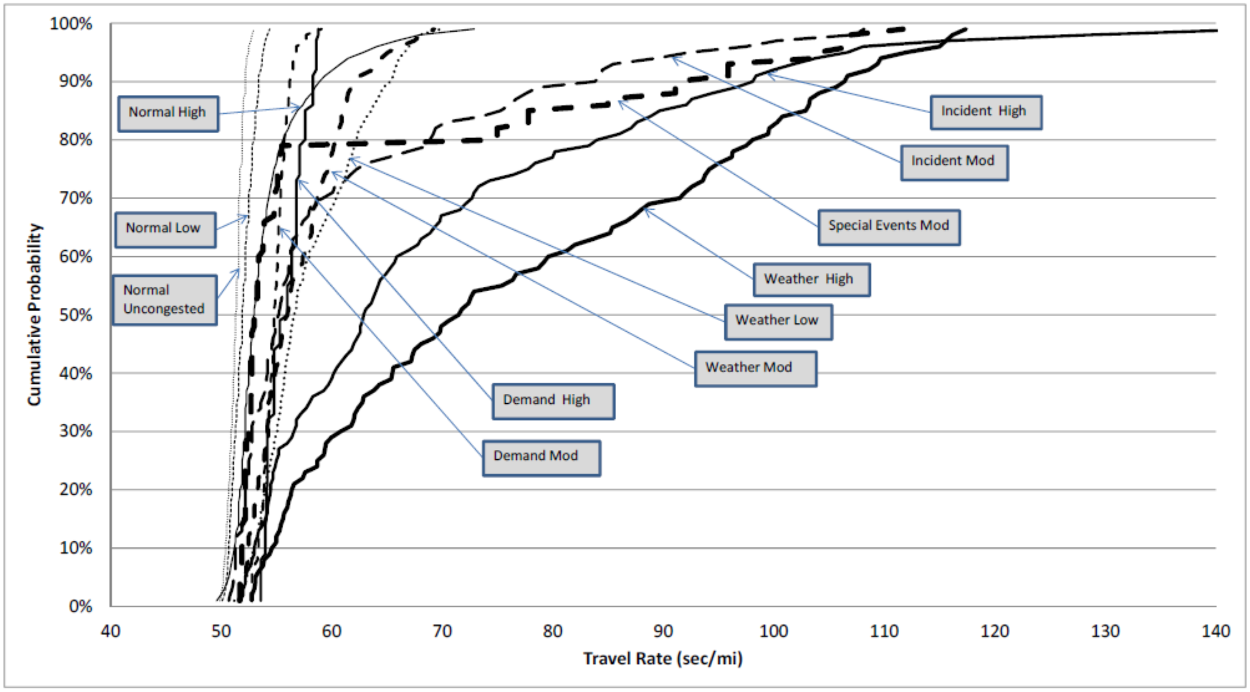
The data manager assembles incoming information from traffic sensors and other systems, such as weather data feeds and incident reporting systems, and places it in a database that is ready for analysis. The L02 project documents describe the types and applications of various types of sensors, the management of data from those sensors, and the integration of data from other systems such as weather and incident data. Because the Florida Department of Transportation (DOT) has both a well-established data archive and a data collection, fusion, and analysis tool (described in Section 1.3) that already have many of the L02-recommended data manager functions, this part of the L02 project was not used in this study.

The second component of the monitoring system, the computational engine, uses the collected, fused, and cleaned data to provide an assessment of the system reliability and the contributing factors. New visualization and analysis methods were introduced in the L02 project, such as how to use data from multiple sources to derive travel time rate probability density functions (PDFs) and their associated cumulative density functions (CDFs). Other recommended visualization and analysis techniques include the production of reliability contribution tables by regime and pie charts to visualize these contributions. One of the important techniques recommended by the L02 project is to assess reliability based on PDFs and CDFs of travel time rates (in second/mile) under different conditions and regimes. The PDFs allow the identification of the existence of multiple operating conditions within the data. This ability is referred to as multimodality in L02 project documentation. CDFs allow the visualization of the relative reliability performance under different operating conditions by displaying the percentage of the time that the travel time rate is at or less than a particular value.

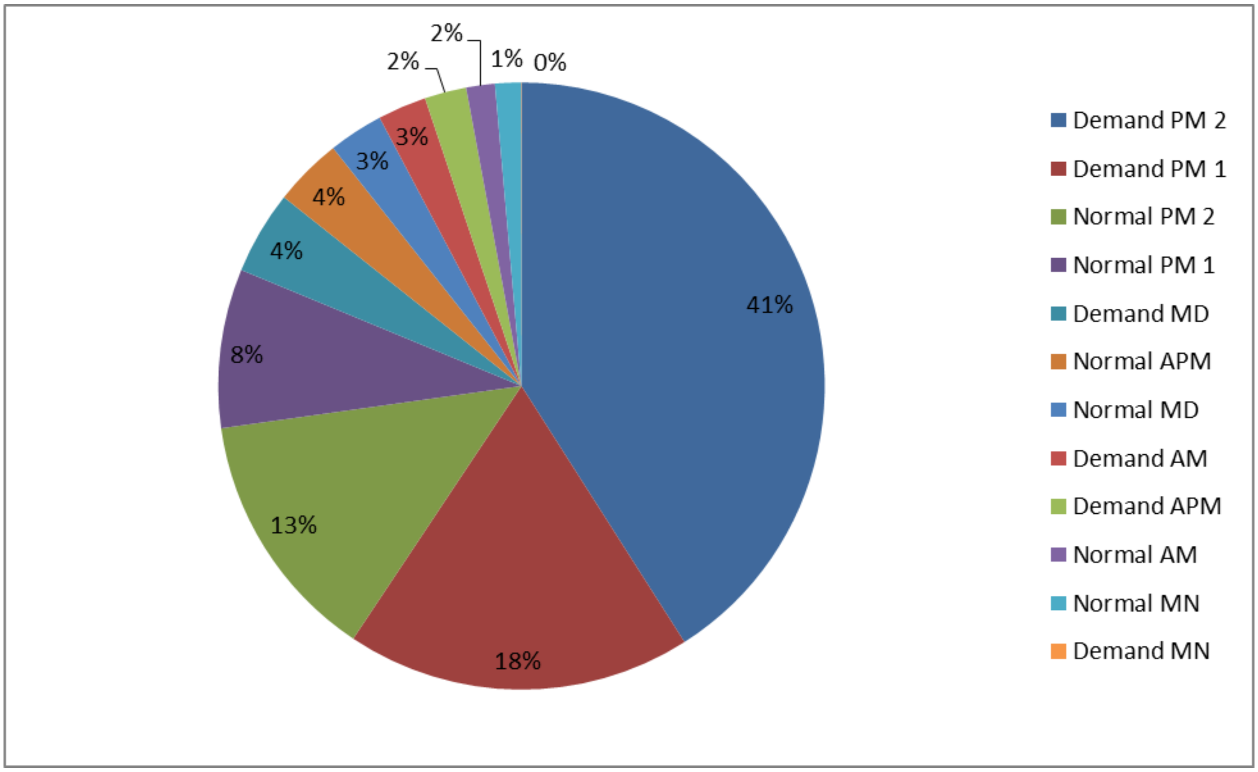
Examples of the recommended visualization techniques are shown in Figure 1.1. The recommended L02 methods were implemented and evaluated in the L38C project in combination with other statistics and performance measures to assess the reliability of the study corridors and contributing factors.

The L02 project also provided recommendations regarding the third component of the monitoring system, the report generator, which presents results based on user requests. These recommendations were considered in the ongoing effort to update to the Florida DOT data analysis tools.

The L02 project discusses five real-world case studies conducted as part of the project and a set of use cases to demonstrate the applications of the methods. These case studies and use cases were useful for this project and should be useful for other efforts that implement the L02 project recommendations.



(a)



(b)

Figure 1.1. Examples of L02 visualization techniques: (a) CDF and (b) reliability contribution pie chart.

1.2.2 L07 Project: Identification and Evaluation of the Cost-Effectiveness of Highway Design Features to Reduce Nonrecurrent Congestion

The L07 project addressed the estimation of the effects on freeway travel time reliability of physical design treatments and the cost-effectiveness of these treatments. The L07 project produced a guide and a sketch planning–level spreadsheet that can be used in this estimation. The L07 project used reliability estimation methods developed in the L03 project. However, the L03 reliability estimation equations were modified to account for snow and ice effects. The products of the project also allow the user to conduct benefit–cost analyses of various design treatments.

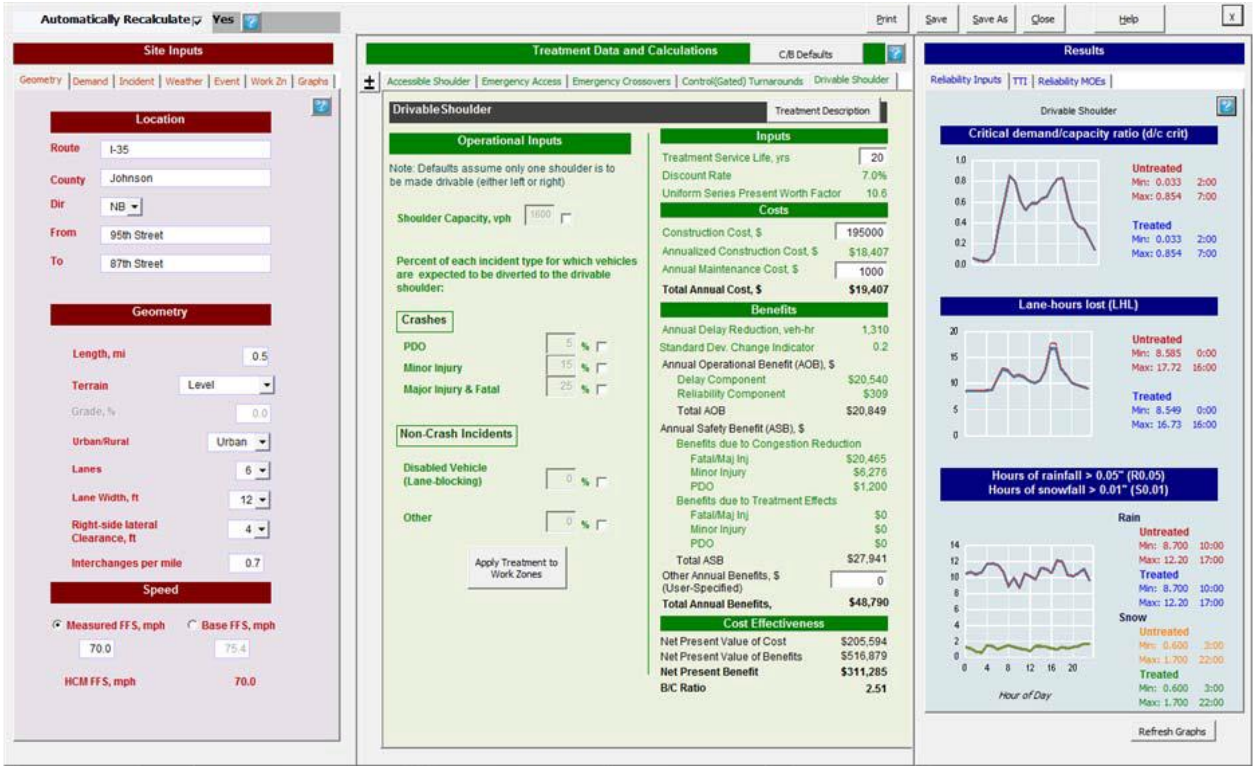
The guide produced as part of the L07 project presents descriptions of highway design treatments to reduce nonrecurrent congestion, expected traffic operational and safety impacts of the treatments, procedures for evaluating and selecting design treatments, and examples of actual treatment installations. Table 1.1 shows the design treatments considered by the L07 project.

Table 1.1. Candidate Design Treatments Considered in the Research

Directly Design-Related Treatments	Indirectly Design-Related Treatments
Medians	**Lane Types and Uses**
Median crossovers	Contraflow lanes—evacuation
Movable traffic barriers	Contraflow lanes—work zones
Controlled/gated turnarounds	HOV lanes/HOT lanes
Movable cable median barriers	Dual facilities
Extraheight median barriers	Reversible lanes
Mountable/traversable medians	Work zone express lanes
Shoulders	**Traffic Signals and Traffic Control**
Accessible shoulder	Traffic signal preemption
Drivable shoulder	Queue-jump lanes
Alternating shoulder	Traffic signalization improvements
Portable incident screen	Signal timing systems
Vehicle turnouts	Reversible (two-side) TCDs
Bus turnouts	Ramp metering/flow signals
Crash Investigation Sites	Temporary traffic signals
Crash investigation sites	Variable speed limits/speed limit reduction
Right-of-Way Edge	**Technology**
Emergency access between interchanges	Electronic toll collection
Arterials and Ramps	Overheight-vehicle detection systems
Ramp widening	**Emergency Response Notification**
Ramp closure	Reference location signs
Ramp terminal traffic control	Roadside call boxes
Ramp turn restrictions	**Weather**
Detours	Fog detection
Improvements to detour routes	RWIS
Truck Incident Design Considerations	Avalanche warning system
Runaway truck duration	Flood warning system
Construction	Wind warning system
Reduce construction duration	
Improved work site access/circulation	

The sketch-planning analysis tool is designed to analyze the effects on reliability of some of the highway geometric design treatments presented in Table 1.1. The tool was developed using a Visual-Basic-for-Application interface within an Excel spreadsheet. The user interface is shown in Figure 1.2. The tool is designed to analyze a generally homogeneous segment of a freeway. The user manual stated that the analyzed segment is typically between successive interchanges. The tool allows the user to input data regarding site geometry, traffic demand, incident history, weather, special events, and work zones. The default values provided for some of these parameters can be changed by the user if local data are available. Based on these data, the tool calculates base reliability conditions. The user can then analyze the effectiveness of selected design improvement alternatives.

The tool produces the CDF of the travel time index (TTI) curves for each hour of the day. Note that the TTI is calculated as the ratio of the actual travel time to the free-flow travel time, which is different but related to the travel time rate CDFs recommended by the L02 procedure. The tool also performs life-cycle benefit–cost analyses by converting delay, reliability, and safety impacts of the improvement alternatives to dollar values based on the life of each treatment. The L07 spreadsheet tool was tested in this project and used to assess improvement alternatives.



Location

Route: I-35
County: Johnson
Dir: NB
From: 95th Street
To: 87th Street

Geometry

Length, mi: 0.5
Terrain: Level
Grade, %: 0.0
Urban/Rural: Urban
Lanes: 6
Lane Width, ft: 12
Right-side lateral Clearance, ft: 4
Interchanges per mile: 0.7

Speed

● Measured FFS, mph: 70.0
○ Base FFS, mph: 75.4
HCM FFS, mph: 70.0

DrivableShoulder

Operational Inputs

Note: Defaults assume only one shoulder is to be made drivable (either left or right)

Shoulder Capacity, vph: 1600 ☐

Percent of each incident type for which vehicles are expected to be diverted to the drivable shoulder:

Crashes

PDO: 5 % ☐
Minor Injury: 15 % ☐
Major Injury & Fatal: 25 % ☐

Non-Crash Incidents

Disabled Vehicle (Lane-blocking): 0 % ☐
Other: 0 % ☐

Inputs	
Treatment Service Life, yrs	20
Discount Rate	7.0%
Uniform Series Present Worth Factor	10.6
Costs	
Construction Cost, $	195000
Annualized Construction Cost, $	$18,407
Annual Maintenance Cost, $	1000
Total Annual Cost, $	**$19,407**
Benefits	
Annual Delay Reduction, veh-hr	1,310
Standard Dev. Change Indicator	0.2
Annual Operational Benefit (AOB), $	
Delay Component	$20,540
Reliability Component	$309
Total AOB	$20,849
Annual Safety Benefit (ASB), $	
Benefits due to Congestion Reduction	
Fatal/Maj Inj	$20,465
Minor Injury	$6,276
PDO	$1,200
Benefits due to Treatment Effects	
Fatal/Maj Inj	$0
Minor Injury	$0
PDO	$0
Total ASB	$27,941
Other Annual Benefits, $ (User-Specified)	0
Total Annual Benefits,	**$48,790**
Cost Effectiveness	
Net Present Value of Cost	$205,594
Net Present Value of Benefits	$516,879
Net Present Benefit	**$311,285**
B/C Ratio	2.51

Drivable Shoulder

Critical demand/capacity ratio (d/c crit)

Untreated
Min: 0.033 2:00
Max: 0.854 7:00

Treated
Min: 0.033 2:00
Max: 0.854 7:00

Lane-hours lost (LHL)

Untreated
Min: 8.585 0:00
Max: 17.72 16:00

Treated
Min: 8.549 0:00
Max: 16.73 16:00

Rain

Untreated
Min: 8.700 10:00
Max: 12.20 17:00

Treated
Min: 8.700 10:00
Max: 12.20 17:00

Snow

Untreated
Min: 0.600 3:00
Max: 1.700 22:00

Treated
Min: 0.600 3:00
Max: 1.700 22:00

Figure 1.2. User interface of L07 project sketch-planning tool.

1.2.3 L08 Project: Incorporation of Travel Time Reliability into the Highway Capacity Manual

The L08 project developed procedures to include travel time reliability in the *Highway Capacity Manual* (HCM).

A modified version of the freeway facility computational engine was developed as part of the L08 project to allow the estimation of the reliability of freeway segments. The original FREEVAL (FREeway EVALuation) computational engine that implements the HCM freeway facility procedure was extended to estimate reliability by adding a scenario generator. The scenario generator assigns initial probabilities to a number of base scenarios. A scenario can contain combinations of weather or incident events. By assessing the travel time under different scenarios, it is possible to estimate the travel time distributions through a year or multiyear period, allowing the estimation of reliability.

Similarly, STREETVAL, which implements the HCM 2010 urban street procedure, was extended to estimate reliability by adding a scenario generator that generates different scenarios for use in the reliability estimation of signalized arterial streets. The resulting tool is referred to as STREETVAL-RL. Both FREEVAL-RL and STREETVAL-RL can be run either with the default traffic flow parameters and scenario generator parameters or with localized inputs. As described later in this report, both tools were tested and used in assessing the benefits of proposed improvement alternatives in this project.

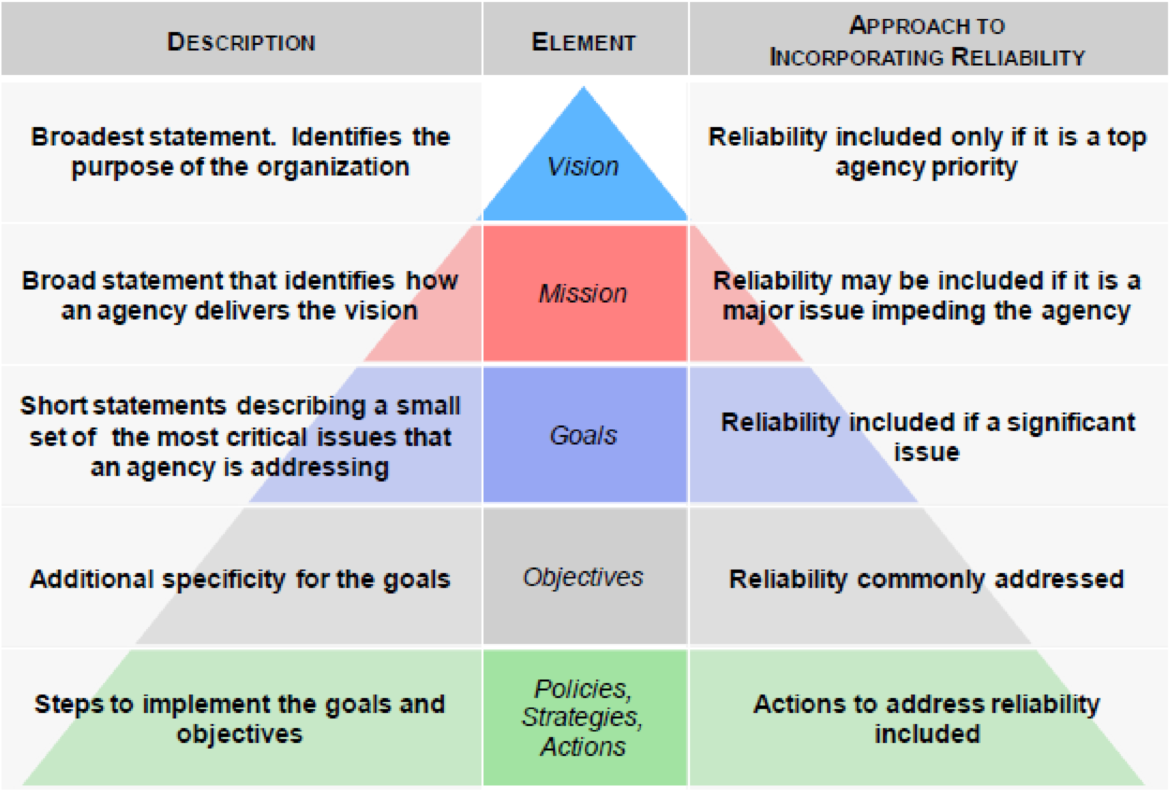
1.2.4 L05 Project: Incorporating Reliability Performance Measures into the Transportation Planning and Programming Processes

The objective of the L05 project was to provide guidance to transportation agencies to help incorporate reliability into the transportation planning, programming, and budgeting processes. The L05 documents summarize current research and practical use of travel time reliability, results from a survey of transportation agencies related to the current state of the practice of using travel time reliability, and case studies on using reliability in the transportation planning processes. The documents review reliability performance measures, potential strategies to address travel time reliability deficiency, and tools that estimate the impacts of strategies on reliability. The documents also describe a framework for incorporating reliability performance into the transportation planning process.

A guide was developed as part of the project to help agencies in using reliability performance measurement, including how to understand and communicate reliability, identify the tools and methods that can be used, incorporate reliability into their existing analysis tools, and identify emerging analysis tools to support reliability evaluation and use in investment choices. The guide produced by the L05 project discussed various aspects of incorporating reliability into planning and programming, including measuring and tracking reliability, incorporating reliability in policy statements, evaluating reliability needs and deficiencies, and incorporating reliability measures into program and project investment decisions. Another L05 product is a technical reference that provides detailed background and instruction on how to collect travel time data and select and evaluate reliability performance measures by using the full range of available analytical tools and methods. Case studies were also developed as part of the

L05 project to illustrate the implementation and validation of the guidance and techniques identified in the project.

The L05 products described above are useful to any reliability assessment effort, and components of them were used as needed in the project, particularly in developing the evaluation and implementation plan discussed in the next section. Figure 1.3, taken from the L05 user guide, illustrates incorporating reliability into various levels of policy statements.



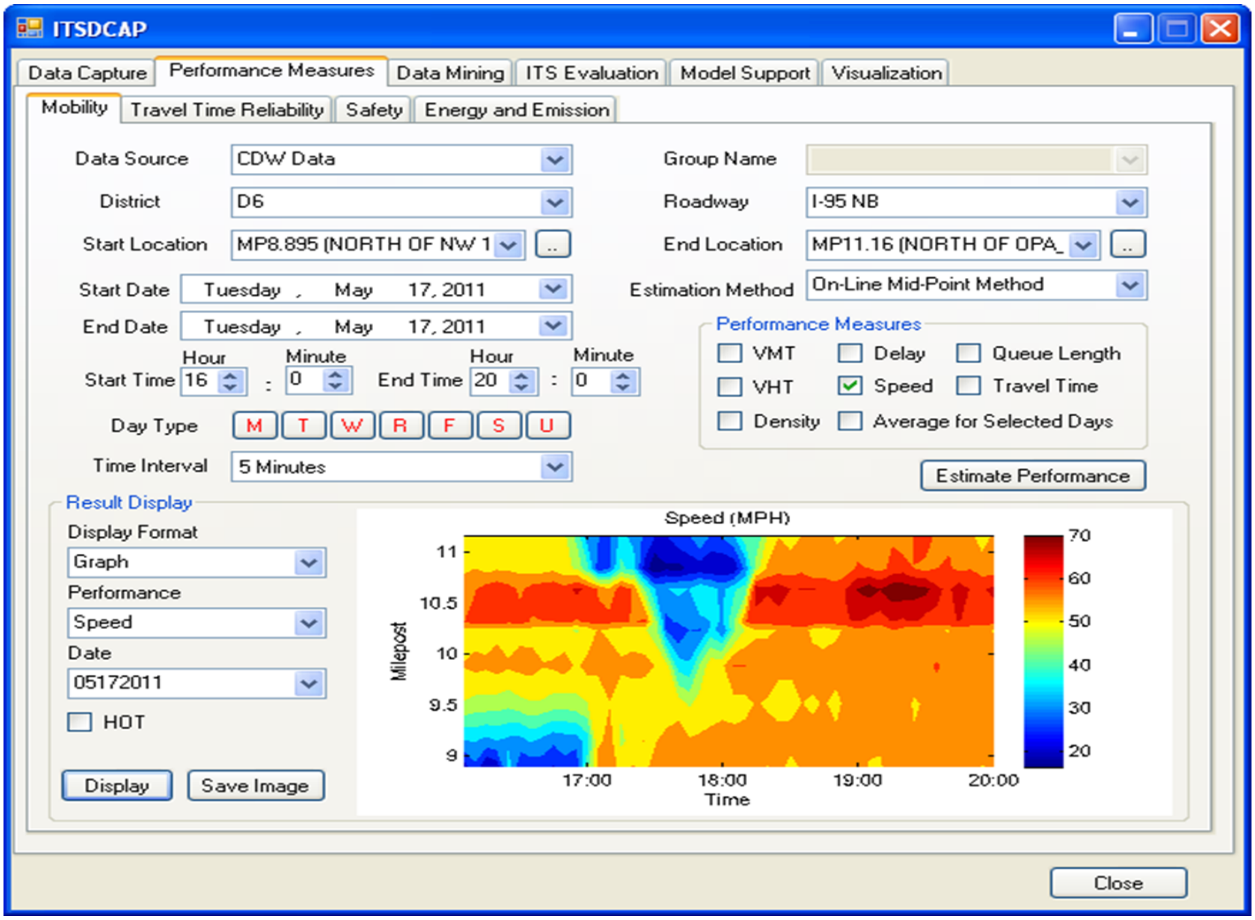
DESCRIPTION	ELEMENT	APPROACH TO INCORPORATING RELIABILITY
Broadest statement. Identifies the purpose of the organization	*Vision*	Reliability included only if it is a top agency priority
Broad statement that identifies how an agency delivers the vision	*Mission*	Reliability may be included if it is a major issue impeding the agency
Short statements describing a small set of the most critical issues that an agency is addressing	*Goals*	Reliability included if a significant issue
Additional specificity for the goals	*Objectives*	Reliability commonly addressed
Steps to implement the goals and objectives	*Policies, Strategies, Actions*	Actions to address reliability included

Figure 1.3. Incorporating reliability into various levels of policy statements.
Source: Cambridge Systematics 2013b.

1.3 Florida DOT Data Analysis Tools

Two tools developed as part of two Florida DOT Research Center projects in the past two years provide a strong platform to support the L38C activities. The two tools are the intelligent transportation systems (ITS) data capture and performance (ITSDCAP) management system and the integrated regional information sharing and decision support (IRISDS) system.

ITSDCAP is a tool developed for the Florida DOT by Florida International University (FIU) to capture data from 13 sources, including SunGuide data, central ITS data warehouses (RITIS and STEWARD), incident data, Florida DOT planning statistics office data, weather data, pricing rates, construction data, crash data from the Florida DOT crash analysis reporting system, weather data, 511 and dynamic message sign (DMS) data, automatic vehicle location data for buses, Bluetooth data, and private-sector data. ITSDCAP modules allow the estimation of various performance measures, support the development of decision support tools, support simulation development and calibration, and allow the visualization of data. The tool supports the extraction and grouping of data based on different criteria for use in the analysis, including user-specified criteria or similarity in traffic patterns, by using clustering analysis. It also allows fusing data from the above sources based on specific needs for integration by using a common spatial and temporal referencing scheme. The tool checks, filters, and imputes the data as needed to ensure data quality. The performance measure module is used to estimate various mobility, reliability, safety, and environmental measures based on the collected data. The tool also allows conducting ITS benefit–cost analysis. Several measures recommended by the L03 project are already incorporated in the calculation of reliability in ITSDCAP. Figure 1.4 shows an example of the user interface of the original desktop tool.



Data Source: CDW Data
District: D6
Start Location: MP8.895 (NORTH OF NW 1
Start Date: Tuesday , May 17, 2011
End Date: Tuesday , May 17, 2011
Start Time: Hour 16 : Minute 0
End Time: Hour 20 : Minute 0
Day Type: M T W R F S U
Time Interval: 5 Minutes
Group Name:
Roadway: I-95 NB
End Location: MP11.16 (NORTH OF OPA_
Estimation Method: On-Line Mid-Point Method

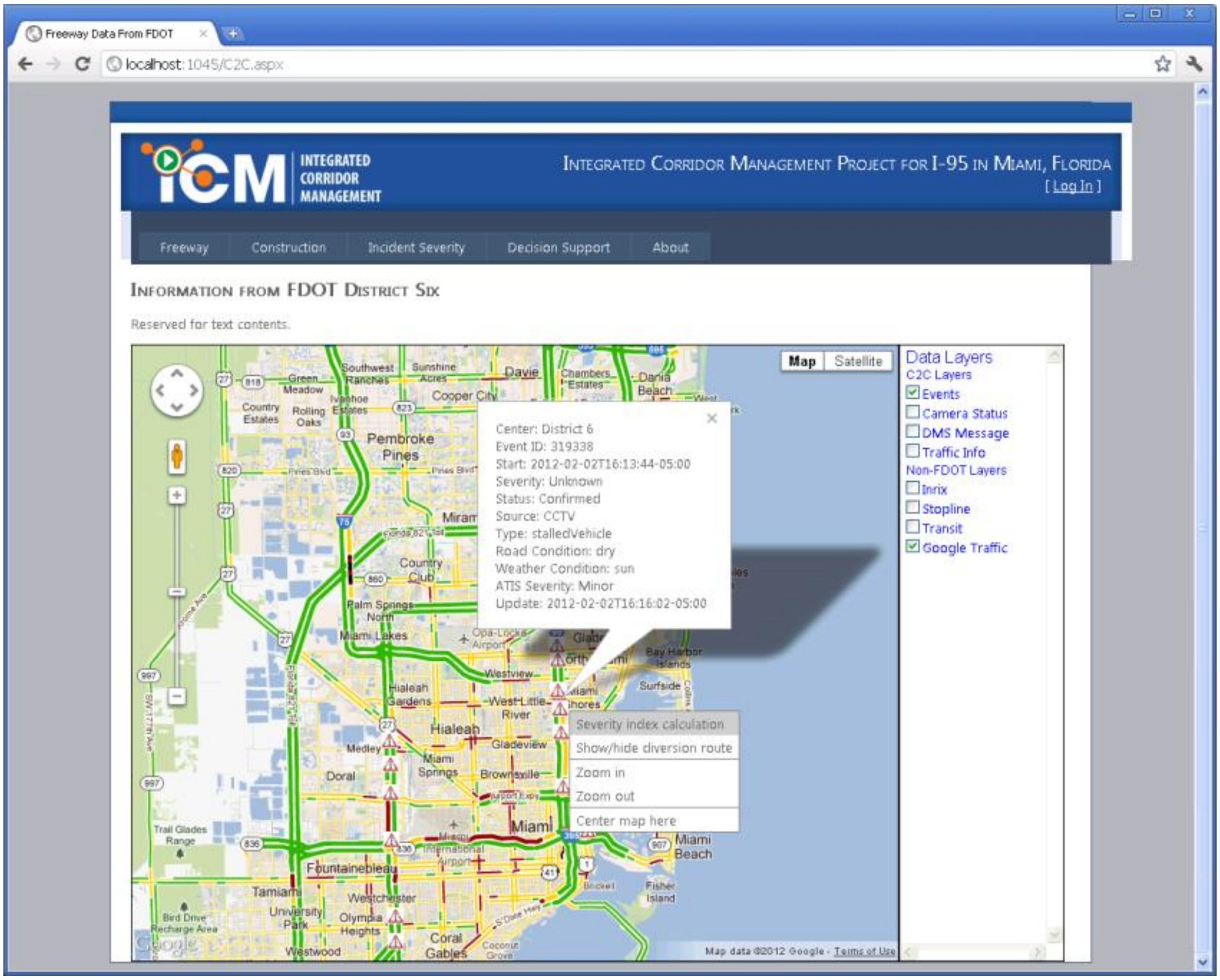
Performance Measures
☐ VMT ☐ Delay ☐ Queue Length
☐ VHT ☑ Speed ☐ Travel Time
☐ Density ☐ Average for Selected Days

Result Display
Display Format: Graph
Performance: Speed
Date: 05172011
☐ HOT

Figure 1.4. Example of ITSDCAP user interface.

IRISDS is a proof-of-concept, web-based system for the provision of a regionally shared information and decision support environment for use by transportation system management agencies in a region in real time. The web-based system receives information in XML data streams using center-to-center communication. Decision support systems have been developed and integrated with the system. One of the system’s major components is the prediction in real time of incident impacts, including incident duration, expected delays, queue length, and probability of secondary incidents. The system is currently in operation for segments of the

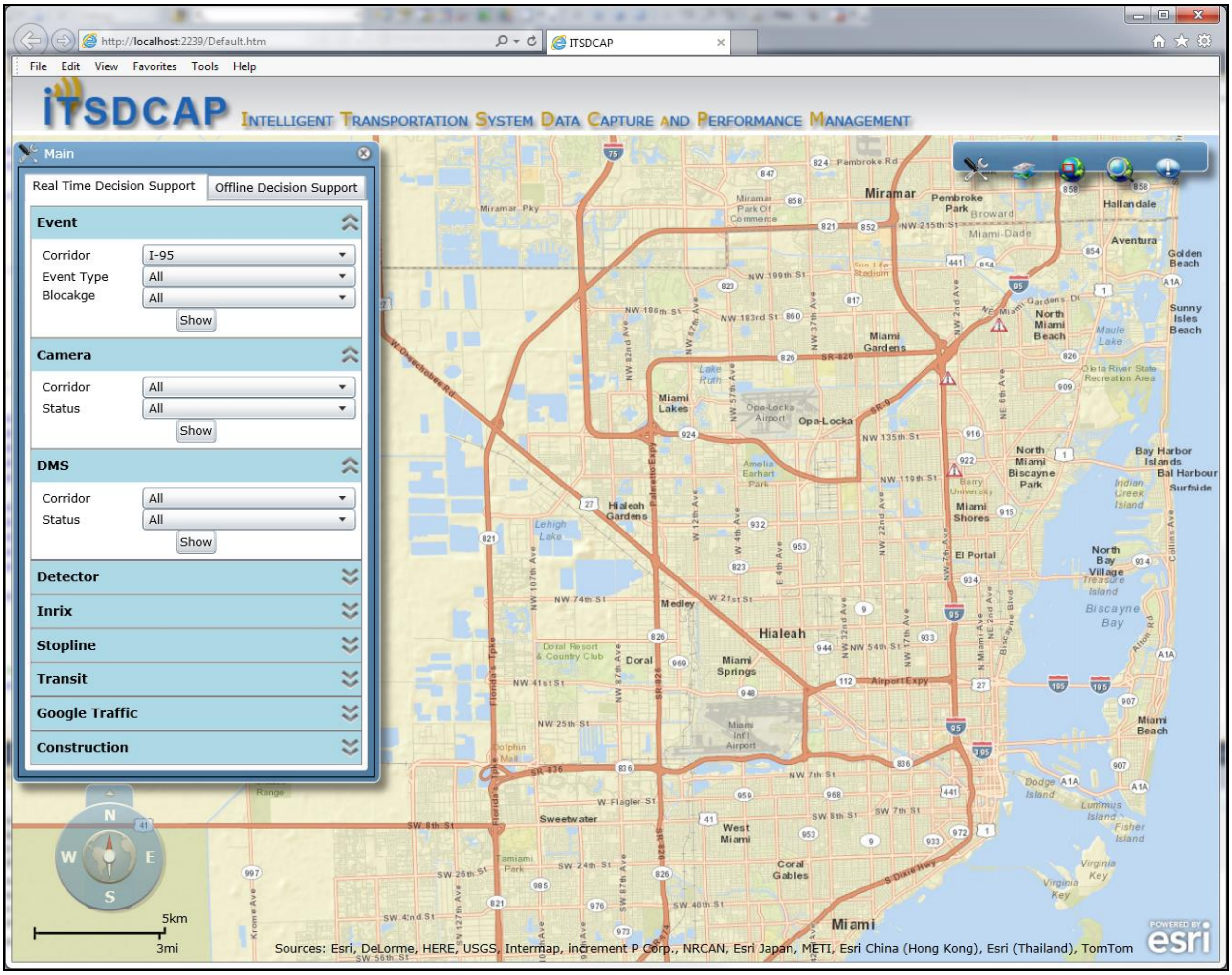
Miami-Dade corridors used in the use cases of this project. Figure 1.5 shows a user interface screen of the original version of IRISDS.



Center: District 6
Event ID: 319338
Start: 2012-02-02T16:13:44-05:00
Severity: Unknown
Status: Confirmed
Source: CCTV
Type: stalledVehicle
Road Condition: dry
Weather Condition: sun
ATIS Severity: Minor
Update: 2012-02-02T16:16:02-05:00

Figure 1.5. Example of IRISDS user interface.

An ongoing Florida DOT project is combining ITSDCAP and IRISDS in an integrated data analysis environment. The goal of the project is to produce a decision support environment that supports the objectives and activities of the transportation system management and operation (TSM&O) program in Florida. The developed environment is web based and can be accessed and used by TSM&O partners to support their offline planning, planning for operations, and real-time operations. In the L38C project, ITSDCAP was used for the extraction and fusion of data from multiple sources to produce inputs to the L02, L07, and L08 procedures. The processes identified by the L38C project were automated as part of the Florida DOT TSM&O decision support system project mentioned above. Incorporation of reliability in real-time operations was performed using IRISDS. Figure 1.6 shows a snapshot of the initial user interface for the improved ITSDCAP.



Corridor: I-95
Event Type: All
Blocakge: All

Corridor: All
Status: All

Corridor: All
Status: All

Figure 1.6. Upgraded ITSDCAP user interface.

1.4 Goal and Objectives

The goal and objectives of the L38C project were aligned with the goal and objectives of the L38 project. The research team of the L38C project conducted pilot testing of products from four SHRP 2 reliability data and analytical projects (products from Projects L02, L05, L07, and L08). The goal was to implement and clearly demonstrate how these SHRP 2 products can be incorporated into the business processes of the Florida DOT and partner agencies. The specific objectives of this project were the same as those defined by the SHRP 2 program for the L38 projects:

- Assist agencies in moving reliability into their business practices through testing of data integration and analytical tools developed by SHRP 2, and
- Provide feedback to SHRP 2 on the applicability and usefulness (benefits and value) of the products tested and suggest potential refinements.

1.5 Project Activities and Document Organization

At the start of the project, an evaluation and implementation plan was developed describing how the products from the four SHRP 2 projects (L02, L05, L07, and L08) would be used in the L38C project to support business processes associated with transportation agency planning and operations activities with a focus on the Florida DOT TSM&O program activities and transportation management center (TMC) operations in Miami-Dade County. The plan also considered other regional processes, as none of these processes can be considered in isolation. The evaluation and implementation plan development was based on L05 project guidelines and information from other tested SHRP 2 products. The plan also considered stakeholder inputs. Extensive outreach and coordination activities were conducted with the project stakeholders and the Florida DOT central office reliability program. The stakeholder inputs were gathered in a stakeholder workshop at the beginning of the project and during several face-to-face meetings with agencies in South Florida. Additional outreach activities were planned to communicate the results to the stakeholders and to further communicate the concepts and values of reliability assessments. The evaluation and implementation plan, presented in Chapter 2, identified the project stakeholders and related business processes that will benefit from reliability estimation, reliability performance measures, analysis scope, setting of reliability performance thresholds (thresholds beyond that which the system considers unreliable), the methods used for assessing reliability, and the method for selection between improvement alternatives. This plan was in line with L05 guidance regarding reliability measurement and use.

The SHRP 2 products were used as a basis for assessing existing reliability deficiencies and improvement alternatives for a limited-access facility with express lanes (ELs) and a parallel arterial facility in the Miami area. The existing reliability of the tested corridors was assessed based on real-world data obtained from multiple sources using the L02 project guidelines and additional measures and visualization techniques combined with other performance measures and assessment techniques. L02 products can be used in data-rich environments with established monitoring systems. In Florida, the limited-access facilities managed by the Florida DOT and toll authorities are instrumented with state-of-the-art ITS monitoring systems with associated data-archiving capabilities. However, urban streets, generally managed by counties and cities, have limited instrumentation, particularly when considering travel time measurements. The Florida DOT has purchased private-sector travel time data from INRIX for a year for some of these facilities. Recently, data from the Nokia Here system also became available. In this study, traffic detector data were used to estimate travel time reliability on limited-access facilities, and INRIX data were used to estimate travel time reliability on arterial streets. Data were collected from multiple sources using the ITSDCAP tool to support the analysis conducted in this project, including the reliability estimation based on monitoring and modeling, as presented in the tested products. The data included traffic parameter, geometry, traffic event, weather, construction, traffic management, and toll pricing data. More details about the collected data are presented in Chapter 2, and the analysis results based on real-world data using L02 and other measures are presented in Chapter 3.

The use of reliability analysis products based on modeling techniques from the L07 and L08 projects allows assessing existing reliability conditions and contributing factors in data-poor environments, and it also allows assessing the impacts of improvement alternatives not currently implemented. The results from these tools were tested and compared with the analysis results obtained based on real-world monitoring systems and private-sector data. This testing and comparison of results of the L07 and L08 reliability tools were also important steps toward validating the quality of the estimates of the impact of improvement alternatives when using these tools for this purpose. The L07 and L08 analysis and associated results are presented in Chapters 4 and 5, respectively.

The reliability thresholds identified in the concept of operation were used to determine the reliability deficiencies based on the results of the analyses. The reliability deficiencies and the impact of each influencing factor on the reliability for different times of day and locations were shared and discussed with the stakeholders of the selected business processes for implementation. Reliability deficiencies were highlighted based on the reliability analysis results, and potential improvement alternatives were identified to address the deficiency issues. The identified set of alternatives and the justifications for these alternatives were reviewed with project stakeholders, and inputs from these stakeholders were used in producing a refined list of improvement alternatives for evaluation. The identified improvement alternatives are presented in Chapter 6. The assessment of the identified alternative strategies required an estimation of the expected improvements in reliability due to the implementations of the identified alternative strategies. This process was performed by using the L08 and/or L07 project products, and the results are also presented in Chapter 6.

Chapter 7 presents assessments of the technical feasibility of the tested products, the understandability and credibility of the results by the decision makers, and the acceptability and implementation potential of the recommendations resulting from applying the products. These assessments were based on inputs from the project stakeholders and the examination of actual decisions made by the involved agencies.

CHAPTER 2

Implementation and Evaluation Plan

This chapter presents an evaluation and implementation plan describing how the products from the four SHRP 2 projects were used in the L38C project to support business processes associated with transportation agency planning and operations activities in Florida. The main focus was on the Florida DOT TSM&O program activities and TMC operations in Miami-Dade County; however, other regional processes were also considered as all these processes are closely related. The evaluation and implementation plan development was based on L05 project guidelines and information from other tested SHRP 2 products and also considered stakeholder inputs.

2.1 Considered Business Processes Categories

One of the important steps in this project was identifying the business processes of the Florida DOT and its partner agencies that could be used for demonstrating the capabilities of the selected SHRP 2 products and the processes that could benefit from the products. Information gathered from the L38C project was shared with the stakeholders associated with these business processes for potential implementation in future efforts.

The L05 project guide and other L05 documents were reviewed and used as a starting point in identifying the business processes in this study. L05 classifies the business processes into the following areas:

- *Long-range planning.* L05 documents recommend steps for using reliability in long-range planning, including the incorporation of reliability in vision and goals, evaluation criteria, methodology, performance measurements, identification of transportation system deficiencies, and selection and approval of strategies. In addition, L05 recommends that when considering strategies in long-range planning, the full range of strategies, including operational improvements, should be considered.
- *Programming.* Programming is the process of selecting transportation projects for implementation over the next few years. The selected projects are listed in the transportation improvement program (TIP) of a metropolitan planning organization (MPO) or a state DOT’s transportation improvement program. L05 documents state that “reliability is most usefully considered within the programming process as a potential means to help prioritize potential future investments at the project level, but can also be useful when identifying potential funding streams or making legislative budget requests.”
- *Corridor planning.* Corridor planning focuses on the transportation needs and improvement strategies of a specific corridor or area. As with the long-range plan, L05 documents describe the incorporation of reliability in the vision and goals, evaluation criteria, methodology, performance measurement, identification of transportation system deficiencies, and selection and approval of strategies.
- *Congestion management process.* The congestion management process (CMP) focuses on integrating a full range of strategies, including operational strategies, into long-range transportation plans (LRTPs) to address congestion and thus reliability problems. L05

documents state that it is natural for this process to address and use reliability as a performance measure.

- *Operations planning.* L05 documents explain that incorporating operations into the planning and programming process can proceed in two ways: (1) by mainstreaming operations within the traditional planning process by assessing operations and capacity projects together and (2) by focusing on a separate operations planning process. The use of reliability analysis allows better estimation of the impacts of operational strategies because improving reliability is one of the most important benefits of these strategies.

There is little experience using LRTP models to estimate reliability directly. Recent research (e.g., SHRP 2 L03) developed sketch planning and travel demand model postprocessing techniques that can be used to estimate travel time, congestion, and reliability performance measures. These methods can be implemented without significant modifications to existing travel demand models and would allow planners to project future reliability, similar to the way other performance measures can be projected. The L05 *Technical Reference* explains how to use transportation planning models and analysis techniques to forecast reliability performance measures (Cambridge Systematics 2013c).

Reliability can be monetized, which may be a promising method for incorporating travel time reliability into the transportation planning process and, in particular, into benefit–cost analysis. Results of several research studies suggest the value of unreliable travel time is between 0.8 and 1.5 times the value of average travel time. The L05 *Guide* and *Technical Reference* explain how to incorporate monetized value into the transportation planning process (Cambridge Systematics 2013b, 2013c).

2.2 Identified Business Processes and Associated Stakeholders

This section identifies the business processes that benefit from the tested products in the L38 project, considering the business process categories outlined in the previous section.

2.2.1 Miami-Dade County Metropolitan Planning Organization

Miami-Dade County MPO processes are as follows:

- *Miami-Dade County long-range transportation plans.* The Miami-Dade County MPO is responsible for the transportation planning process in Miami-Dade County. The MPO is responsible for preparing the LRTP for Miami-Dade County covering a 25-year horizon. The latest approved plan is the 2035 LRTP. An annual update of the plan is conducted, with a major update every three to five years. The MPO is currently working on the 2040 plan. This plan update includes in-depth consideration of intermodal improvement opportunities, freight movement, ITS technologies, and CMP. During the 2040 LRTP development progress, the goal of the plan was changed from “promote transit system reliability” to “promote system reliability” to address the MAP-21 national performance goal and add highway reliability as a measure of effectiveness.

- *Transportation improvement program.* The Miami-Dade MPO is also responsible for developing the five-year TIP for the county, which includes the short-range (five-year) improvements specified in the LRTP. Each year, the TIP is modified by adding a new fifth year. The improvements included in the TIP are identified based on their priorities as obtained from the technical analyses conducted in the preparation of the LRTP.
- *Congestion management process.* The Miami-Dade MPO has an established CMP to monitor the state-of-transportation network in Miami-Dade County. The Miami-Dade CMP plan is currently being updated. Traditionally, the LRTP has focused on capital investment solutions, and the CMP has been used to identify a technology-based operational strategy. The CMP includes methods to monitor and evaluate the performance of the multimodal transportation system, identify the causes of recurring and nonrecurring congestion, identify and evaluate alternative strategies, provide information supporting the implementation of actions, and evaluate the effectiveness of the implemented actions.
- *Unified Planning Work Program special technical studies.* The Unified Planning Work Program includes technical studies that support the transportation planning process. Recent relevant examples include arterial grid network analysis and studies on the tolled managed highways with rapid and enhanced bus routes, ridesharing, and updating the countywide freight plan.

The MPO has also recognized the importance of performance monitoring based on data collected from different agencies in the region and integrating the data collection efforts with its own and other planning efforts, including the LRTP and CMP. The project did not deal directly with the MPO long-range planning and other business processes. The results obtained from this research were shared with the MPO and their LRTP and CMP consultants for potential incorporation in their activities, and feedback was obtained on the usefulness of the information.

2.2.2 Florida DOT Planning Offices

The following Florida DOT planning processes were expected to benefit from the reliability assessment products:

- *Interchange access request.* The purpose of an interchange access request is to demonstrate that a new interchange or a modification of interchanges on existing limited-access facilities is needed and is viable based on various criteria, including traffic analysis. The analysis must document that the existing facilities cannot accommodate the design-year traffic demands and that the need cannot be adequately satisfied by transportation system management (such as ramp metering, public transportation, and managed lane facilities), geometric design, and alternative improvements to the freeway facility. An operational and safety analysis must be conducted to support the request.
- *Highway capacity and level of service.* The Florida DOT's quality/level of service (Q/LOS) handbook and accompanying software have been produced for use in analyzing the roadway capacity and Q/LOS for planning and preliminary analysis. The Florida

DOT sets an acceptable LOS at D in urbanized areas and C outside urbanized areas. LOS is used as the primary measure of current and future mobility needs. The reliability performance measurements specified by the new HCM chapters developed by the L08 project should be considered by the Q/LOS handbook. This change could be critical to incorporating reliability in many business processes because the supporting traffic analysis is in accordance with the Q/LOS handbook.

- *Planning studies.* Planning studies include corridor or subarea studies and focus on defining the needs and issues associated with the study area and developing potential multimodal improvement alternatives for the studied facilities. Reliability should be introduced as a major evaluation criterion of system performance and alternative assessment.

2.2.3 Florida DOT Project Development and Environment Studies

A project development and environment (PD&E) study is conducted to meet the requirements of the National Environmental Policy Act. During the study, the location and conceptual design of feasible build alternatives are determined for transportation improvements and their social, economic, and environmental effects. A no-build alternative, which considers leaving the transportation system in its present state with routine maintenance, remains a viable alternative throughout the study. A PD&E study is finalized when the Federal Highway Administration (FHWA) reviews the documentation and recommendations and then provides a location and design concept acceptance (Florida DOT 2014a).

Florida DOT's *Project Development and Environment Manual* (2014a) provides consistent guidelines so that developed projects can comply with all federal and state laws and conform uniformly in their quality and exactness. Specifically, these guidelines address the following areas:

- *Public involvement;*
- *Data collection*—field reviews, aerial photography, survey coordination, existing roadway characteristics, existing structure characteristics, traffic data, crash data, existing signage inventory, utilities and railroads, transportation plans, soils base map;
- *Needs*—safety and analysis of existing conditions, purpose and need statement;
- *Design analysis*—corridor analysis, traffic analysis, typical section analysis, roadway design alternatives, alternative concept plans, drainage and floodplain analysis, structures, access management, multimodal accommodations, maintenance of traffic analysis, geotechnical coordination, ITS, utilities and railroads;
- *Comparative analysis of alternatives*—comparative analysis and evaluation matrix, selection of preferred alternative(s), conceptual design plans, identification of construction segments, value engineering, construction cost estimates, right-of-way cost estimates, typical section package, design exceptions and variations, project development summary report, support package and engineering report;

- *Environmental analysis and reports*—land use changes, social, economic, mobility, aesthetics, relocation potential;
- *Cultural resources*—archaeological and historic resources and parklands;
- *Natural resources*—wetlands and essential fish habitat, water quality, special designations, wildlife and habitat, permit conditions, farmlands;
- *Physical*—noise, air quality, construction impact analysis, contamination; and
- *Environmental reports*—class of action determination, environmental assessment, finding of no significant impact, draft environmental impact statement, final environmental impact statement.

The above PD&E guidelines are applied to conduct the required processes, analyses, documentation, and public outreach before the design and construction of the selected alternative(s). As with planning studies, reliability should be used as a major evaluation criterion in traffic analyses.

2.2.4 Florida DOT District 6 Traffic Operations

The mission of Florida DOT's traffic engineering and operations office is to "improve safety and mobility through the efficient application of traffic engineering principles and practice" (Florida DOT 2014b). Florida DOT District 6 traffic operations is responsible for the implementation of this mission within Miami-Dade and Monroe Counties. Specifically, traffic operations is responsible for conducting traffic engineering studies and identifying and implementing roadway improvements to enhance traffic operations and safety, as well as delivering ITS services. In addition, the traffic operations office supports the planning, design, and construction offices in the areas of developing roadway improvements to accommodate current and future traffic, evaluating alternative design concepts, reviewing construction plans from a traffic operations and safety perspective, reviewing access (to and from the state highway system) requests from an access management perspective, reviewing traffic control plans for work zones from a traffic management perspective, and reviewing railroad crossings from a safety perspective.

Traffic operations and safety studies are conducted to determine the improvements needed to address abnormal crash patterns, accommodate current and projected traffic volumes, and enhance the safety and performance of the freeways, state roads, and local arterial streets. A study typically consists of collecting traffic data, projecting future traffic volumes, analyzing crash data, performing operational analysis, and identifying the improvements needed to enhance the safety and efficiency of the transportation system. Studies are performed at intersections and roadway segments to determine what improvements are warranted and how they might lead to a better roadway for motorists, cyclists, pedestrians, and other users. The need for traffic signals, improved signal phasing and timing, and speed zones is also determined by traffic studies, which have similar application in the analysis of traffic management in work zones. Typical traffic operations and safety studies may include the following:

- Quantitative assessment of intersections and arterials;

- Signal warrant analysis to determine the need for traffic signals;
- Intersection analysis including intersection inventory, crash analysis, turning movement counts, delay studies, LOS analysis, recommendations for improvements, preliminary cost estimates, estimate of project benefits, and benefit–cost analysis;
- Arterial safety and operational analysis including traffic counts, inventories, crash analysis, arterial analysis, signal optimization, recommendations for improvements, preliminary cost estimates, estimate of project benefits, benefit–cost analysis;
- Left-turn phase warrant analysis including delay study, intersection inventory, crash analysis, LOS analysis;
- Other studies including queue analysis, vehicle gap measurements, conflict analysis, spot speed studies, travel time and delay studies, site distance studies, highway lighting studies, safe curve speed studies, collision diagrams, crash reviews, skid hazard review studies, railroad crossing preemption studies, parking studies and ITS studies;
- Miscellaneous studies including fatal crash reviews, 3R safety reviews, speed zone studies, no-passing zone studies, before and after studies; and
- Review and analysis of traffic control plans for work zones to assess the impact of lane closures on traffic operations, specifically travel time and delay. Recommendations are then developed to mitigate negative impacts on traffic operations, travel time, and delay. In addition, critical locations are identified for monitoring during construction, so that real-time traffic management strategies can be implemented to address congestion and queuing and improve travel time.

The recommendations developed by these studies are submitted through the department’s electronic review comment system to seek input from the Florida DOT District 6’s traffic operations, design, construction, planning, and maintenance offices. Subsequently, the study recommendations, project cost estimates, and anticipated project benefits are finalized based on comments received. The project scope is then presented to the scoping committee for subsequent prioritization, funding, and implementation. Because introducing reliability in the traffic operations study should be considered, the information from the L38C project was shared with the Florida DOT District 6 traffic operations engineer and staff.

2.2.5 Florida DOT District 6 Regional Transportation Management Center

The Florida DOT District 6 regional TMC is situated within the District 6 headquarters campus. This TMC houses the Florida DOT operations staff, who monitor and manage traffic, disseminate information, and dispatch incident management resources 24 hours per day, seven days per week. In the event of a traffic incident, such as a crash or a hazardous materials spill, the operators coordinate with emergency responders and Road Rangers to attend to the incident and provide the emergency and rescue services needed, while clearing the incident as quickly and safely as possible. These activities are coordinated with the Miami-Dade Expressway Authority TMC operations staff and the Florida Highway Patrol (FHP) Troop “E” dispatch within the TMC.

The TMC control room has eight consoles that accommodate operations staff for the primary functions of incident management, EL operations, and ramp signaling operations. One of the eight consoles is dedicated to Miami-Dade Expressway Authority TMC operations. The control room will be reconfigured by doubling the number of workstations to accommodate the growing EL network, Miami-Dade Expressway Authority operations, and other functions.

The well-established business practices of the District 6 Regional TMC are documented in their standard operating guidelines, which include the following sections:

- Control room management,
- TMC systems,
- Service patrol coordination,
- Event management,
- DMSs,
- Systems monitoring and reporting,
- EL operations, and
- Ramp signal operations.

These standard operating guidelines are used by the ITS operations consultant to conduct TMC operations in accordance with contractual performance measures (e.g., TMC control room operator performance, TMC control room event management, TMC standard reporting services, and so forth).

Florida DOT District 6 developed a Florida DOT website that shares and updates summary reports indicating the performance of their ITS operations and ELs (Florida DOT 2014c).

2.2.5.1 ITS Operations

The ITS operations reports include monthly and annual reports for ITS operations and monthly, midyear, annual, and special evaluation reports for EL operations. In addition, monthly reports are provided for travel time reliability (i.e., speeds and volumes**,** TTIs, and travel times).

Various reports (ITS summary reports, DMS usage reports, and 95 Express performance reports) are provided on a monthly basis. These monthly reports are used to monitor performance while serving as a useful tool to refine system operations to address deficiencies and guide decisions yielding continuous improvements. The contents of these reports include the following:

- *ITS summary reports* provide a monthly summary of key milestones, lane-blocking events, Road Ranger assists, 511 traveler information calls, DMS usage by type, TMC operations performance compared to contractual targets, ITS system availability performance, and incident duration breakdown by component activities.
- *DMS usage reports* provide a monthly summary of average number of DMS activations per event, average number of DMS messages per activation, average number of DMS messages per event, comparison of DMS usage for other agencies, DMS by event type,

DMS usage by roadway, number of messages by roadway, and DMS messages by time of day.
- *95 Express performance reports* provide a monthly summary of the number of service trips, toll revenue collected, registered vehicles with toll-exempt trips, volumes and speeds for express versus general-purpose lanes (GPLs), average toll rates by direction and time of day, percentage traveling over 45 mph, ELs remaining open to motorists, percentage time ELs closed for construction or nonrecurring events, transactions by toll amount charged, and other performance bar charts.

Annual reports are provided to document the performance of the ITS and 95 Express programs. Similar to the monthly reports, the annual reports document trends and action plans for continuous improvement. The contents of these reports include the following:

- *District 6 ITS annual reports* provide an annual summary of ITS deployments, TMC operations, incident management, information technology (IT) and ITS maintenance, traveler information, public outreach, benefits to the public, and a look ahead to the next fiscal year.
- *95 Express annual reports* provide an annual summary of operations and traffic statistics; revenue and toll statistics; facility availability; enforcement; and equipment availability, transit, public information, and lessons learned.

Special evaluation reports have been prepared to assess the success of the 95 Express from a transit and public acceptance perspective. These special evaluation reports were subsequently used to recommend improvements to transit operations and to be more attentive to users' needs. The contents of these reports include the following:

- *The 95 Express transit evaluation report* provided a summary of the findings, conclusions, and recommendations based on twelve independent reports on transit operations before and after the opening of the 95 Express.
- *The 95 Express survey summary report* provided a summary of nearly 5,000 respondents to gauge their feedback on the 95 Express operations. The survey was conducted in October 2010, after Phase 1 (A and B) was completed and open to traffic.

Travel time reliability reports, which are provided on a monthly basis, summarize highway performance in terms of speeds and volumes, TTIs, and travel times. The travel time reliability reports provide a baseline tool to measure the reliability of the expressway system within Miami-Dade County by time of day. The contents of these reports include the following:

- *Speed and volume reports* provide a summary of weekday speeds and volumes by time of day for I-95, I-195, I-75, and SR-826.

- *TTI reports* provide a summary of TTIs (in terms of mean TTI) by time of day for I-95, I-195, I-75, and SR-826.
- *Travel time reports* provide a summary of weekday travel times by time of day for I-95, I-195, I-75, and SR-826.

2.2.5.2 IT/ITS Maintenance

The IT/ITS maintenance reports address field equipment quality control, IT/ITS inventory, SunGuide software systems administration, systems documentation, and utility locates. These IT/ITS maintenance reports provide a useful tool to ensure that the systems are properly maintained to achieve system availability requirements. The contents of these reports include the following:

- *Field equipment quality control reports* are based on preventive maintenance inspections and provide pictures and details of ITS field equipment.
- *ITS inventory reports* provide a quarterly update of the complete ITS inventory, added ITS inventory, removed ITS inventory, and inspection findings.
- *IT inventory reports* provide a quarterly update of the complete IT inventory, added IT inventory, removed IT inventory, and inspection findings.
- *SunGuide software monthly reports* provide a monthly report of software issues to be tracked (i.e., critical bugs), SunGuide software configuration, footprints (i.e., open and closed), logic tree tickets (i.e., open and closed), change management board discussions and decisions, and SunGuide review and testing processes.
- *Systems administration monthly reports* provide a monthly report of critical nodes and availability, noncritical nodes and availability, scheduled maintenance outages, responsibilities, video wall, website, daily backups, internet usage, and VPN access.
- *Systems documentation monthly reports* provide a monthly report on TMC hardware inventory (i.e., servers, workstations, network devices), software inventory, patch management, antivirus, and maintenance standard operating guidelines.
- *Utility locates monthly service reports* provide a monthly report on design tickets, contract compliance, SunShine field locate requests, and locate ticket summaries.

2.2.5.3 Speed Profiles on Video Wall

In addition to the weekly, monthly, and annual performance reports, Florida DOT District 6 provides speed profiles for the expressways on the video wall in the TMC control room. These speed profiles provide a graphical comparison of actual speed versus free-flow speed (e.g., 50 mph) for I-95, I-195, I-75, and SR-826. The speed profiles are rotated in cycles so that TMC managers and other operations staff can identify congestion points or segments in real time and then turn the closed-circuit television (CCTV) cameras to those locations to determine and verify the problem and take the appropriate action. A ticker is included below the video wall to indicate the status of live events (e.g., crashes, weather, work zones) that may affect traffic conditions.

2.2.6 Miami-Dade County Traffic Signal Control Center

The Miami-Dade County Traffic Signal Control Center is located at 7100 NW 36th Street within the traffic signals and signs division complex in Miami. The following staff is assigned to the control center: one division manager, one systems manager, 11 traffic engineers, three operators, one technician, and one receptionist. The TMC control room has two consoles that accommodate operations staff. The balance of workstations within the control room is shared by traffic engineers and a technician. A projection screen, with adjacent wall-mounted monitors, is used as a video wall with a static map of Miami-Dade County's roadway network in the background. There are plans to relocate the control center to another Miami-Dade County facility.

There are 2,850 signalized intersections within Miami-Dade County, of which 2,727 are under the Miami-Dade County Public Works signal operation office's control. Each traffic engineer is assigned from 200 to 300 signals (approximately 20 sections) to maintain operations of the system. Traffic engineers are responsible for retiming the signals along one section each month; the balance of their time is focused on addressing problems. Although their standard work week is four days per week, 10 hours per day, they also respond to failures at other times as required. Traffic engineers work approximately half their time in the control center and half their time in the field. Approximately 2,000 traffic signal inquiries are received each month, resulting in approximately 400 traffic signal timing changes each month.

Three operators provide coverage of the control center between Monday and Friday from 6:00 a.m. to midnight and weekends from 10:00 a.m. to 7:00 p.m. Their role is to receive complaints on malfunctioning signals and provide radio communications with the field staff for dispatching and repairs. After hours, calls are received by 311 and 911 and are then forwarded to technicians to address the problems.

Miami-Dade County continues to make significant investments in the upgrade of the communications systems by using a hybrid approach of fiber optics and wireless media. Other features of the signal system include transit signal preemption along the South Dade Busway corridor and limited transit signal priority along Kendall Drive to accommodate the Kendall Cruiser beginning in 2015. In addition, reversible lanes are operated along NW 199th Street, in the vicinity of the Miami Dolphins Stadium, to accommodate peak traffic demands after football games and other special events. Currently there are no traffic-adaptive signal systems; however, their application may be considered in the future within certain corridors as needed.

Miami-Dade County has made a significant investment in the development of advanced traffic management system software to manage their signal system operations. This software provides a robust database for each signal, including signal timing historic data (archived for the past 30 days), maintenance records, signal timing plans, time–space diagrams, intersection drawings, photos of each intersection, event logs, intersection failure reports, and so on. Each signal can accommodate 30 signal timing plans, 24 of which are used for routine operations, five for special events, and one for manual entry. This ability provides the flexibility to download different timing plans (i.e., cycle lengths, splits, offsets) for different seasons, holidays, and unique situations. The Miami-Dade traffic signals and signs division has a procedure manual and help function built into the advanced traffic management system software to provide guidance on signal timing and administrative functions.

The advanced traffic management system software provides operations tools to monitor and track system failures attributed to communications, signal control equipment, timings, and so on. The manager uses the system reporting tools (e.g., malfunction reports, phase modification reports) to manage system performance for each of the traffic engineer's sections. Future upgrades of the software are expected to include other system reports that would highlight travel time and delay savings and associated benefits (e.g., fuel consumption and air pollution emissions).

The potential for including travel time reliability as a performance measure to support operations was well received by management. Using travel time reliability would help traffic engineers to better identify and prioritize signal timing and equipment and communications repairs based on abnormalities in system performance. Travel time reliability data would be generated by traditional detector data, as well as by other sources. Travel time reliability for each roadway segment can be provided by any interval desired by traffic engineers (e.g., five minutes, 15 minutes). In addition, Miami-Dade County has plans to install approximately 200 cameras to monitor traffic conditions along the arterials.

2.2.7 Miami-Dade Transit

Miami-Dade Transit (MDT) operates the 17th largest transit system in the United States and is the largest public transportation system in Florida, operating a fleet of more than 828 buses as well as Metrorail (the 25-mile elevated rail system) and Metromover (the 4.4-mile downtown people mover). MDT's buses travel approximately 2.5 million miles a month, with service throughout Miami-Dade County and commuter express service extending well into Broward County (Miami-Dade County Metropolitan Planning Organization 2014a, 2014b).

During FY 2014, MDT is projected to spend approximately $548 million for the operation of the transit system and support of MDT's other local and regional responsibilities (Miami-Dade County 2013a).

A major initiative to improve Metrobus service efficiency through a restructuring of the Metrobus route system is currently underway. The proposed modified grid system is based on ridership data obtained from the automated passenger counter and Easy Card, as well as coordination with local municipal transit services and the Miami-Dade MPO, to maximize interconnectivity and efficiency.

According to the current transit development plan (Miami-Dade County 2013b), MDT is planning the following improvements:

- *Metrobus service improvements.* Service improvements include rail vehicle and bus replacements, bus enhancements, preventive maintenance, computer-aided dispatch, track and guideway rehabilitation, transit operation system replacement, electric signage information systems, fiber and video improvements, security and safety equipment, maintenance yard improvements, infrastructure renewal, and so forth.
- *New Metrobus routes.* Thirteen new transit routes have been proposed to replace existing routes or add new service.

- *Transit hubs and feeder routes for existing and new routes.* The current bus system generally operates on a modified grid pattern to provide feeder services to Metrorail and Metromover stations. Under the modified grid, bus routes will continue to serve their respective corridors and Metrorail stations, but they will also provide connections to various routes within the general service area at a single location or transit hub. Thirteen transit hubs are proposed throughout Miami-Dade County. Passenger amenities (such as shelters with weather protection and benches) are planned for these locations, and transit riders will be able to purchase transit passes and obtain transit schedule information.
- *Metrorail.* The recent completion of the Orange Line to Miami International Airport represents a milestone achievement for MDT. However, the feasibility of future Metrorail extensions has been a topic of concern given MDT's approved 10-year operating budget and existing revenue sources. Therefore, MDT is considering an expansion plan that involves the development of less costly modal approaches, such as bus rapid transit and express bus service, to the expansion program.
- *Special transportation services.* MDT will begin improved special transportation services that feature IT improvements such as mobile data terminals and radio frequency identification and technology to provide global positioning information to identify vehicle locations. Together, these technologies will provide safety and performance improvements.
- *Bus fleet expansion.* Additional buses will be procured to accommodate service improvements, including 40- and 60-foot buses and 40-foot commuter coach diesel–electric hybrid, clean diesel, compressed natural gas, or other alternative fuel vehicles.
- *Alternative fuels.* Compressed natural gas buses have the potential for significant savings over a diesel or hybrid bus fleet. MDT is working with other county departments on a priority initiative to assess the feasibility and financial impact of transitioning to compressed natural gas fuel for its bus and heavy-truck fleets at various locations and to develop a comprehensive implementation strategy that will optimize cost savings.
- *Infrastructure renewal program needs.* MDT's infrastructure renewal program includes planned investments in areas such as the following to ensure that the transit system operates in a state of good repair: improvements in IT, passenger amenities and facilities, rolling stock, systems, maintenance facilities, safety and security, and track and guideway.

The improvements listed above will provide a strong foundation for applying the travel time reliability performance measure to support the evolving transit developments.

2.2.8 Freight Operations

There are over 130 miles of active railroad tracks, one major airport, and one seaport in Miami-Dade County. These transportation systems represent the infrastructure used to move the highest flow of commodities anywhere in Florida at more than 120 million tons annually. This infrastructure is critical to the regional economy. Although freight movements represent a small portion of the traffic on Miami-Dade County highways, for some of the key freight routes, up to

20% of the traffic is made up of freight truck vehicles (Miami-Dade County Metropolitan Planning Organization 2014a, 2014b).

The Miami-Dade freight plan addresses the county's freight mobility needs and identifies candidate freight improvements that have been incorporated into the 2035 LRTP (Miami-Dade Metropolitan Planning Organization 2014a). The freight plan describes the county's freight system and identifies needed improvements and policies through the year 2035.

Freight needs are similar to those of the commuting public. Freight modes use much of the same infrastructure. Knowing the current and potential issues and conflicts provides insight into mitigating the negative impacts and accentuating the positive. Freight needs are addressed by projects and policies that relate to the requirements of the freight industry and that benefit the region. The candidate freight improvements were assessed, among other priorities, to provide the best infrastructure improvement and maintenance program for the county.

The following 11 goals were developed by the freight transportation advisory committee and the Miami-Dade MPO:

- Support economic development by enhancing freight system connectivity;
- Advance strategic freight initiatives that support job creation and retention to enhance the region's long-term competitive position;
- Enhance freight transportation safety and convenience to ensure mobility and access;
- Provide the secure movement of international and domestic goods;
- Address the varied freight improvement needs of area shippers, carriers, and distributors at both a regional and corridor level;
- Improve multimodal access to enhance freight efficiency throughout the county;
- Promote methods for regional goods movement that are socially and environmentally responsible;
- Educate the public on the importance of freight transportation to the region, as well as the needs and issues of shippers, carriers, and other affected stakeholders;
- Give greater priority and attention to freight in the regional planning process;
- Make public investments that help minimize the cost and improve the reliability of goods movement within county; and
- Implement and maintain freight initiatives that provide long-term returns on public investment.

Candidate freight improvements were identified by developing a consolidated inventory of existing projects and comparing the inventory of projects in relation to needs addressed through data analysis, stakeholder input, and consistency with freight plan and LRTP goals and objectives. Cost-feasible freight improvements included the following:

- *Roadway improvements*—system connectors, signalization and intersection improvements, roadway widening, geometric improvements, slip ramps, grade separations, limited access, and extension improvements to freight hubs;

- *Truck facility improvements*—long-term truck-parking and staging areas;
- *Safety and security enhancements*—freight transportation system upgrades, including grade crossing and signalization improvements;
- *Landside access improvements*—intermodal ramps and truck access to railroad terminals;
- *ITS improvements*—specifically geared toward trucks;
- *PierPass*—feasibility study to examine the impact of implementing congestion mitigation incentives for off-peak operations;
- *Congestion management improvements*—improving turning radii and speeds on Interstate and toll road ramps; and
- *Way-finding signage improvements*—countywide improvements to guide truckers to and from regional freight hubs.

It is anticipated that the improvements listed above will improve the reliability of freight movement within the region as part of a more comprehensive TSM&O program.

2.2.9 Florida DOT TSM&O Program

FHWA defines a TSM&O as “an integrated program to optimize the performance of existing multimodal infrastructure through implementation of systems, services, and projects to preserve capacity and improve the security, safety, and reliability of our transportation system.” On May 20, 2010, the Florida DOT Executive Board endorsed the definition of TSM&O, the TSM&O business plan, and the outline of a strategic plan. The Florida DOT TSM&O program is one of the most advanced programs in the nation.

Florida DOT districts have individual programs that customize the TSM&O concepts and applications to their needs. The mission of the Florida DOT’s District 6 TSM&O program in Miami-Dade County is to “optimize the safety, mobility, and reliability performance outcomes of the South Florida Transportation System through the timely implementation of TSM&O strategies.” As can be seen, reliability is already included in the mission statement. Thus, the products tested in the L38C project had a direct application in supporting the activities of this program. Although the initial implementation was in Miami-Dade County, L38C activities and results were also shared with District 4 TSM&O program partners in Broward and Palm Beach Counties and other Florida DOT district TSM&O coordinators. District 4 TSM&O programs are also very advanced programs that were expected to benefit from the SHRP 2 products.

2.2.10 Florida Multimodal Mobility Performance Measures Program

The Florida DOT multimodal mobility performance measures program is coordinating with various Florida DOT offices (including the transportation statistics office, state transportation development offices, freight and logistics offices, and the Florida DOT district offices) to produce handbooks, procedures, and training material related to multimodal transportation performance measurement. A program plan has been adopted with the following goals:

- Develop and improve measures and reporting techniques;
- Report on mobility measures for MAP-21 and statewide reporting purposes; and
- Provide guidance on mobility performance measures to state and MPO stakeholders.

To achieve these goals, extensive coordination with MPOs and modal and district offices has been conducted. The anticipated outcome is to promote the use of performance measures to evaluate improvement alternatives and when programming and prioritizing projects to improve mobility in Florida.

The program has selected performance measures for statewide reporting, identified how to calculate these measures, and produced a MAP-21 report on mobility measures. The MAP-21 report includes a system performance report on mobility, assessing the percentage of travel operating at acceptable conditions, and MAP-21 national goal areas. The program has established a framework for trip-based travel time reliability, developed a travel time reliability service measure, and is currently implementing the SHRP 2 program’s travel time reliability–based products.

2.3 Selection of Business Processes

Table 2.1 shows the relation of the project activities to the business processes identified in the previous section and how the project activities support these processes.

Table 2.1. Relation between Project Activities and Identified Business Processes

Stakeholder	Process or Stakeholders	L05	C11	L02	L07	L08	Involvement of This Project
MPO	LRTP, TIP, CMP, and UTPW	Yes	Yes	Yes	Yes	No	Share information and results with Miami-Dade MPO and their LRTP and CMP consultants
Florida DOT System Planning	Interchange modification	Yes	No	Yes	No	Yes	Share information with Florida DOT Central Office (Planning Office)
	Q/LOS guidelines	Yes	No	No	No	Yes	
	Corridor/ subarea planning	Yes	No	Yes	No	Yes	Work closely with the Florida DOT District 6 SR-7 corridor study and I-95 master plan teams
Florida DOT PD&E office	PD&E traffic analysis	Yes	No	Yes	No	Yes	Share information with PD&E office and recommend that the Q/LOS guidelines are modified to include reliability
Florida DOT Traffic Operations	Traffic studies	Yes	No	Yes	No	Yes	Communicate results to Florida DOT District 6 traffic operation engineer and staff
	Planning for operations	Yes	Yes	Yes	Yes	Yes	Work extensively with TMC staff on deriving strategies
	TMC operations	Yes	No	Yes	No	No	Detect unreliability threshold in real-time using IRISDS or District 6 TMC tools. Share information with Florida DOT District 4, Miami-Dade Expressway Authority, and Florida Turnpike TMC
	TSM&O	Yes	Yes	Yes	Yes	Yes	Share information with Districts 4 and 6 TSM&O partners and Florida TSM&O coordinators

Stakeholder	Process or Stakeholders	L05	C11	L02	L07	L08	Involvement of This Project
Analysis Tools	Florida DOT	Yes	Yes	Yes	Yes	Yes	Recommend modifications to ITSDCAP, IRISDS, and postprocessors to demand forecasting models
Other Agency Planning for Operations	Miami-Dade Public Works	Yes	Yes	Yes	Yes	Yes	Present SR-7 analysis to Miami-Dade Public Works for potential use in signal control
	Miami-Dade Transit	Yes	Yes	Yes	Yes	Yes	Present SR-7 analysis to MDT for potential use in transit planning
	Florida DOT freight office	Yes	Yes	Yes	Yes	Yes	Share project activities and findings
	Florida multimodal mobility performance measures program	Yes	Yes	Yes	Yes	Yes	Coordinate with the program activities

Below is a discussion of how the L38C project activities are related to the different processes identified in Table 2.1.

2.3.1 Florida DOT TMC Planning for Operations and Operations

The research team worked closely with the Florida DOT District 6 TMC, Florida DOT staff, and their consultant (AECOM) to identify the reliability deficiencies of the I-95 corridor in Miami-Dade County based on real-world point traffic detector measurements, using the SHRP 2 L02 products. Both the general lane and managed lane performance were analyzed. Potential strategies were presented to address the identified contributing factors to these deficiencies, and the impacts of the identified strategies were tested using the L07 and L08 project products (FREEVAL-RL). An updated version of the IRISDS real-time performance measurement and prediction modules and/or the Florida DOT TMC software can be modified to assess the actual travel rate relationship to the desired travel rate in real time and display the derived measures to be used by District 6 TMC operators and other regional agencies that are accessing the IRISDS system. In the future, the tool will also be able to predict unreliability by comparing the real-world traffic detector, incident, weather, and other conditions with a library of conditions that create unreliable travel time conditions.

2.3.1.1 SR-7 Corridor Study

The SR-7 corridor study, an ongoing effort that started in the second half of 2013, is evaluating corridor conditions and recommending improvements for the corridor. Some of the important areas that the project focused on, in addition to capacity improvements, included TSM&O and operational strategies, traffic demand management, encouragement of transit use, safety concerns, and pedestrian and bicycle facilities. The research team worked with the District 6 planning office and their consultant (Jacobs Engineering Group, Inc.) to identify the reliability and other issues associated with the corridor and how reliability could be incorporated in the alternative analysis and the associated decision processes. Reliability on SR-7 was assessed using INRIX data. In addition, the research team used the travel time and traffic volume data collected by the corridor study consultant to develop and calibrate the STREETVAL-RL software, which was used to confirm reliability estimates and to examine the impacts of improvement alternatives on reliability. The L38C project principal investigator participated as a member of the SR-7 project advisory team, and the project principal investigator and coprincipal investigator attended the project advisory team meetings.

2.3.1.2 I-95 Master Plan

The purpose of the master plan is to develop and evaluate improvement concepts and perform a detailed planning-level operational analysis for the I-95 corridor within District 6. The analysis will include the evaluation of all interchanges and interchange influence areas. Multiple improvement alternatives will be developed to address both short-term and long-term operational deficiencies. In addition to capacity improvements, corridor and incident management, active traffic management, and TSM&O concepts (including signal optimization, variable speed limit signs, lane control signs, travel time signs, dynamic storage lanes or merge control, advance warning signs, and transit enhancements) will be evaluated. Multimodal improvements such as signal priority, park-and-ride facility enhancements, and transit-only ramps will also be evaluated as part of the improvement alternatives. The request for proposals for the plan has been issued, and the proposals received are currently being evaluated by District 6. The research team coordinated with the Florida DOT project manager, and the results obtained from the L38C project were shared with the selected team for use in the project.

2.3.2 Florida DOT Data Analysis and Sketch-Planning Tools

Although ITSDCAP has a module that calculates reliability measures for different time periods, incorporating the methods presented in L02 and their applications extended the existing capabilities and allowed the development of additional reliability assessment capabilities for planning, operations, and design applications. Furthermore, as part of IRISDS, the project considered the implementation of real-time warning alerts of unreliability conditions. Finally, recommendations were made for modifications to incorporate reliability in the benefit–cost evaluation modules of the Florida ITS evaluation tool (FITSEVAL), a sketch-planning tool to evaluate 13 types of ITS deployments, also developed for the Florida DOT by FIU researchers. The Florida DOT planning office also developed a travel time reliability model, applied it to all freeways in Florida, and began reporting reliability. This tool was examined in light of the tested products.

2.3.3 Florida Multimodal Mobility Performance Measures Program

The research team coordinated closely with the Florida DOT and their consultant regarding the Florida multimodal mobility performance measures program, which is testing SHRP 2 reliability products. Activities and results from this Florida DOT effort and the L38C effort were reviewed and harmonized to ensure effective and efficient use of reliability estimation methods and tools in Florida.

2.3.4 Other Business Processes

As shown in Table 2.1, the information obtained from the project tasks was shared with the MPO, Miami-Dade Transit, Florida DOT District 6 traffic operations, Miami-Dade County Public Works, Florida DOT central office system planning office, and TSM&O programs for technology transfer purposes and to determine the usefulness of the products to these project stakeholders.

2.4 Stakeholder Issues and Needs

As described in the previous section, the identified stakeholders were contacted to participate in project activities. A stakeholder workshop was conducted at the beginning of the project to determine agency issues and needs related to reliability estimation. Several follow-up meetings were conducted with selected key stakeholders. The results of the project were presented in a technology transfer workshop toward the end of the project, and information was gathered about the usefulness of the data for different stakeholders.

The workshop conducted at the beginning of the project (June 20, 2013) introduced the concept of travel time reliability as a performance measure, how it may support the processes of the stakeholder agencies, and the issues facing the use of reliability by these processes. All the stakeholders identified in the previous section were invited to the workshop, and most attended. The stakeholder agencies that participated in the workshop included the Florida DOT central office, District 6, District 4, Florida Turnpike, Miami-Dade traffic signals and Miami-Dade County, the Miami-Dade Expressway Authority, FHWA, TRB, and FIU. Representatives from the MPO, traffic operation offices, TMCs, planning office, and PD&E offices attended the workshop. Details of the workshop discussion are presented in Appendix A, and highlights of the workshop are summarized below:

- *Data.* Data quality checking is important and requires special consideration, especially for arterial data collection. Installation and maintenance of arterial data collection and monitoring systems are expensive and require staffing resources that may not be available. Arterial data provided by the private sector may be a cost-effective alternative. It may be acceptable to have somewhat less accurate data as long as they provide a cost-feasible solution for a large coverage area.

- *Analysis.* Reliability should be reported by facility, trip, and roadway type. Trip-based reliability is more useful than facility-based reliability; however, it is more difficult to estimate and requires more data. It was suggested that as a test, the reliability of the 10 most common trips in a region be analyzed as case studies. Although the critical periods of highway reliability are typically the morning and evening peaks, freight traffic is typically heavier during the off peaks. Therefore, if the focus is on freight traffic, the off peaks should be considered, as well.
- *Sketch planning.* Sketch-planning tools are needed to identify corridors with potential reliability problems to determine requirements for freeway and arterial management systems. The FITSEVAL sketch-planning tool, developed by FIU for the Florida DOT in 2008, could be a viable platform; however, it does not currently include reliability. The L07 sketch-planning spreadsheet is only applicable to freeways.
- *Combined effects.* The combined effects between incidents, weather, and construction should be considered. Project L11 is a good source for the benefits of reliability and includes evaluation experience that illustrates such interaction (i.e., between maintenance and bad weather).
- *System impacts*. There is a need to consider the interaction between corridors to estimate and predict the impacts on system reliability of events (e.g., incidents, construction) that may occur along other interrelated corridors. The impact of signal phasing and timing on reliability needs to be investigated. The reliability analysis of conditions before and after the applications of advanced strategies should be analyzed and the results documented**.**
- *Congestion management.* Reliability may be important to the Miami-Dade MPO to support their CMP. Existing processes need to be reviewed to incorporate travel time reliability to address MAP-21 requirements.
- *Intermodal planning.* There is a need to associate highway reliability with freight and transit reliability to increase the value and marketability of reliability analysis. This linking will require integrating automatic vehicle location data from these sources with highway data. This data integration is important considering that two of the seven topics of MAP-21 are related to reliability and freight. Including travel time reliability in the short- and long-range transportation planning processes should be a statewide effort, involving Florida DOT districts and MPOs. Transit reliability should be considered, especially the impacts of transit signal priority on transit and arterial operations.
- *PD&E studies.* As part of PD&E studies, the alternatives assessment matrix should include impacts on reliability. Travel time reliability is important for comparing different PD&E study alternatives. Florida DOT District 6 uses the HCM; the inclusion of new reliability chapters in the manual will help with the use of reliability in the process. A pilot study to apply reliability as part of the PD&E study process, along with *PD&E Manual* updates, should be considered with support from the Florida DOT central office. Florida DOT has two projects that are testing travel time reliability in PD&E corridor studies. Including travel time reliability as part of the PD&E process will require training and public outreach efforts.

- *Segmentation*. Spatial segmentation for reliability analysis is important and may be analysis specific. For example, Florida DOT District 4 is currently building EL projects, and segmentation may be needed in accordance with these project operational needs.
- *Work zones*. Reliability in work zones during construction is very important in Florida, particularly for megaprojects.
- *TSM&O*. Performance measurement for multimodal and multifacility arterials analyses, including arterials and benefit–cost analyses that consider reliability, are also important, particularly as part of the evolving TSM&O programs within South Florida. The value of time versus reliability needs to be considered for projects SHRP 2 C11 could help, and FITSEVAL, ITSDCAP, and FHWA benefit–cost analysis tools are options as starting points.
- *Software tools.* Software tools are needed to support the automation of reliability analyses based on data and modeling. These tools should be accessible, relatively easy to use, and accompanied by training. There is a need for a single tool that captures and fuses data from multiple sources and monitors reliability of different modes and facilities managed by different agencies in conjunction with each other. A single tool should report all measures (e.g., mobility, safety, and emissions), not only reliability. As much as possible, real-time and offline performance measurement tools should be separate from existing traffic management software, yet exchange data and information with the SunGuide software in order to avoid degrading its computational performance. The software tools may be in the cloud, allowing access to all agencies. The tools should include visualization of performance to support the various stakeholder decision processes and report travel time reliability for freeways, arterials, and transit systems. ITSDCAP and IRISDS were developed with these needs in mind.
- *TMC operations.* For real-time applications, in which estimation or prediction is made that the conditions of the system are outside the acceptable reliability boundary, the analysis of reliability should be performed every five minutes to allow quick responses to changing traffic conditions. Unreliable conditions can also be disseminated in real time by using 511, DMSs, and freight in-vehicle devices and at truck-parking facilities. Signal system software outputs should include the calculation of reliability measures to share with the SunGuide software, which is focused on freeway systems. Predictive models and decision support system tools are needed to provide operators with suggestions for identifying and selecting potential transportation management strategies.
- *Other needs and applications.* Reliability may also be important to support maintenance of traffic plan procedures and policies. Interaction between travel time reliability and livability should be considered, as there is a strong focus on livability within South Florida, and the linkage of the two strategies would provide synergy in its implementation. There is also a need to learn how to use analysis outputs and conduct evaluations. Agencies should work together to prioritize identified needs in the region by using reliability as one of many performance measures. The impacts of geometric design standards on reliability may also need to be investigated.

The above stakeholder input provided valuable insight into how reliability may be incorporated in the development of policies, short- and long-range transportation plans and work programs, corridor studies, PD&E studies, traffic operations, and TMC operations.

2.5 Identification of Reliability Performance Measures

Various performance metrics have been used to quantify reliability. In fact, the different products tested in this project use different matrices. For example, the L03 project (Cambridge Systematics 2013d) examined a set of six reliability metrics to determine their sensitivities to different types of freeway improvements. The metrics used were the buffer index, on-time performance, 95th percentile planning time index (PTI), 80th percentile TTI, skew statistics index, and misery index. Table 2.2 defines these metrics. The L03 project documentation reported that the 95th percentile travel time or TTI may be too extreme a value to be significantly influenced by operations strategies and that the 80th percentile PTI is more sensitive to these improvements. Thus, the L03 project document posits that the 80th percentile TTI is possibly more appropriate for investigating the reliability impacts of these strategies.

The L02 project recommends using the PDF and CDF of travel time rate in second/mile as the primary reliability measure to identify the reliability performance under different regimes and influencing factors. The L02 project also uses semivariance to determine the unreliability contribution factors such as high demand, bad weather, and incidents. The definition of semivariance is listed in Table 2.2.

The L08 final report reviewed various reliability metrics that can be computed based on travel time distribution parameters, including standard statistical measures (e.g., standard deviation, kurtosis), percentile-based measures (e.g., 80th and 95th percentile travel times, buffer index), on-time measures (e.g., percentage of trips completed within a travel time threshold), and failure measures (e.g., percentage of trips that exceed a travel time threshold). The L08 documentation states that “it is difficult to say which metric should be highlighted as the primary reliability metric; a lot depends on the specific application being used.” However, the L08 project team defined a reliability rating to be used to assess highway facility reliability that is calculated as the percentage of vehicle miles traveled (VMT) with 80th percentile TTI less than 1.33 for freeways and less than 2.5 for arterials (see Table 2.2). The L08 products also discussed the use of the policy index based on the agency’s congestion management goal of operating its freeways at a certain speed, such as 40 mph. The policy index is computed based on the agency’s target speed in place of the free-flow speed, also defined in Table 2.2. The agency’s goal is to maintain the mean annual peak period speed on the facility to be at the target speed or higher; if the policy index exceeds 1.00, then the reliability of the facility will be considered unacceptable.

The L05 guidance encourages agencies to estimate multiple reliability performance measures because different measures capture different aspects of the travel time distribution and may suggest different strategies to employ. The L05 documentation mentioned that “reliability is complex and its proper measurement requires multiple metrics.” It then says that “the use of multiple measures provides a clearer picture as to the size and shape of the travel time distribution. It can be confusing to interpret multiple reliability performance metrics. Some metrics may appear to indicate improvement in reliability between alternatives, while others may not." In this study, multiple metrics were estimated and analyzed to assess the reliability of the corridor according to L05 recommendations. However, it is recognized that having many performance measures that may not point to the same conclusions without good explanations may create confusion for the analysts and the users of analyses.

McLeod et al. (2012) reported that Florida DOT's preferred reporting travel time reliability statistics are the percentage of trips arriving on time and the PTI. For the reliability analysis tool developed for the Florida DOT, *on time* is the amount of time it would take a vehicle to traverse the facility length no less than 10 mph below the free-flow speed in the analysis period. Free-flow speed is the posted speed limit plus 5 mph. The PTI is calculated based on the 95th highest travel time for the relevant time period divided by the free-flow travel time.

Table 2.2. Definitions and Use of Reliability Performance Measures in SHRP 2 Projects

Reliability Performance Metric	Definition	Project Using Measure
Buffer Index	The difference between the 95th percentile travel time and the average travel time, normalized by the average travel time	L03, L08
Failure/On-Time Performance	Percentage of trips with travel times less than • 1.1 × median travel time • 1.25 × median travel time Or percentage of trips with speed less than 50, 45, 40 or 35 mph	L03, L08
95th Percentile PTI	95th percentile of the TTI distribution (95th percentile travel time divided by the free-flow travel time)	L03, L08
80th Percentile TTI	80th percentile of the TTI distribution (80th percentile travel time divided by the free-flow travel time)	L03, L08
Skew Statistics	The ratio of 90th percentile travel time minus the median travel time divided by the median travel time minus the 10th travel time percentile	L03
Misery Index	The average of the highest 5% of travel times divided by the free-flow travel time	L03
PDF of Travel Time Rate	PDF of travel time rate distribution	L02
CDF of Travel Time Rate	CDF of travel time rate distribution	L02
Semivariance	The variance of travel time rate (in second/mile) pegged to the free-flow travel time instead of the mean travel time	L02
Standard Deviation	Usual statistical definition	L08
Kurtosis	Usual statistical definition	L08
Reliability Rating	Percentage of VMT at a TTI less than a certain threshold (e.g., 1.33 for freeway and 2.5 for urban streets)	L08
Policy Index	Mean travel time divided by travel time at target speed	L08
Semistandard Deviation	One-sided standard deviation that is referenced to the free-flow travel time	L08

2.6 Description of Study Facilities

The tested products in this project were implemented to analyze the I-95 corridor GPLs and ELs in the northbound (NB) and southbound (SB) directions and the SR-7/US-441 corridor, which is a parallel facility to the I-95 corridor. Figure 2.1 shows a map of the selected area. The analysis was conducted for 24-hour periods of weekdays.

The analyzed I-95 segment extends from NW 62nd Street to South Biscayne River Drive in the NB direction with a total length of 5.8 miles and from NW 177th Street to NW 18th Street in the SB direction with a length of 12.1 miles; segment lengths were determined by available travel time data. I-95 is a limited-access facility and the most highly traveled corridor in South Florida with over 250,000 vehicles traveling through parts of the corridor daily within Miami-Dade County, a number that is expected to grow. Geometric improvement opportunities are limited as little or no additional right-of-way is available, and existing bridge structures generally cannot accommodate roadway expansion. Extensive traffic and incident management systems have been implemented by Florida DOT District 6 on the corridor. Managed lanes were constructed along the corridor from the Golden Glades Interchange to south of I-195/SR-112. The managed lanes were opened in both directions in 2010. Dynamic pricing is used to manage LOS on the managed lanes. Traffic-adaptive ramp-metering operations are activated for the peak direction in the peak periods using the fuzzy logic algorithm. An advanced incident management system is also implemented that includes traffic detectors, CCTV cameras, DMSs, service patrols, incident response vehicles, and other incident management strategies and policies.

SR-7, an urban arterial, is a state road managed by the Florida DOT; however, the signal control is managed by Miami-Dade County. A major traffic and transit corridor, SR-7 is a vital connection from the northern residential neighborhoods to employment centers within downtown Miami and the hospital district. The corridor segment analyzed in this study consisted of eight signalized intersections between NW 79th and NW 125th Streets. The selection of the number of intersections was due in part to the limit on the number of intersections that can be modeled in STREETVAL. Major traffic demands generate congestion along SR-7. In addition, SR-7 is an alternate route to I-95 during major incidents, causing a significant surge in traffic volumes along the arterial. As with other arterial corridors in the region, SR-7 can be considered a relatively data-poor environment.

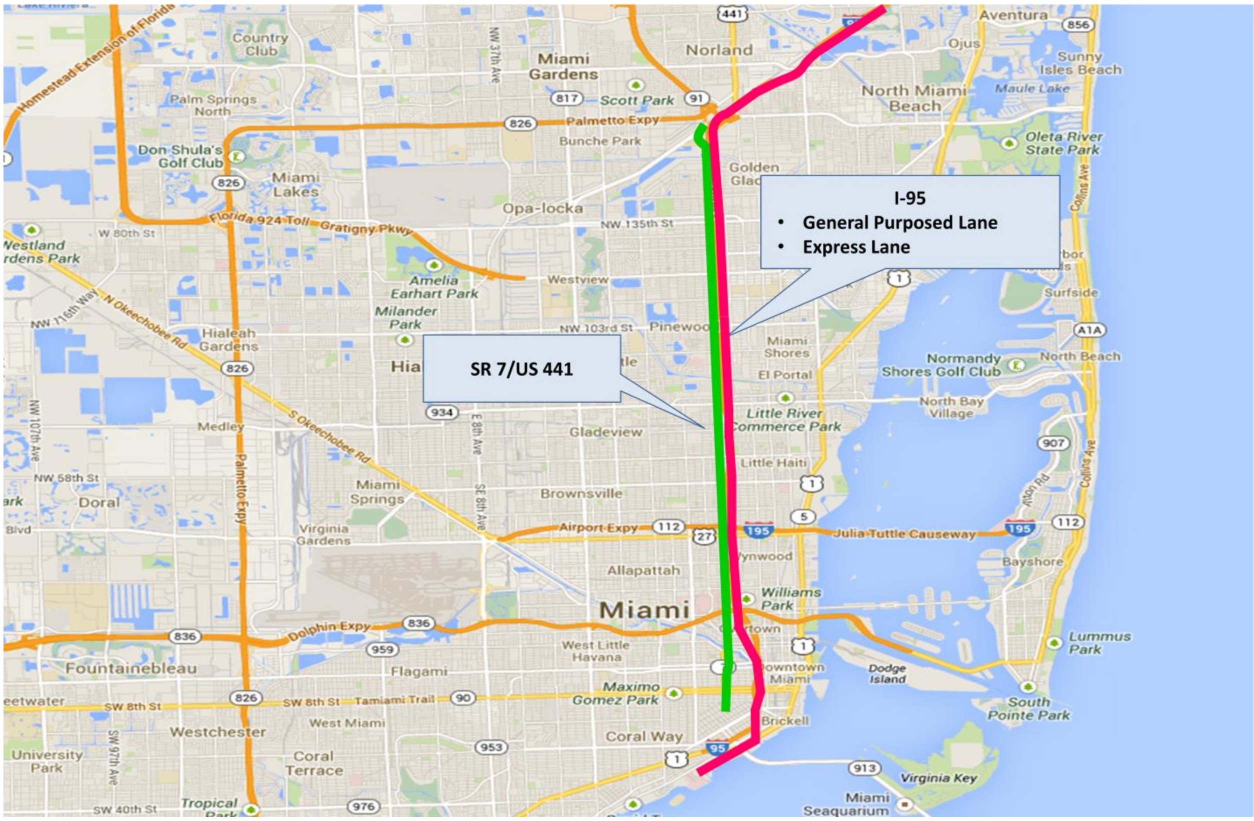


Figure 2.1. Study facilities.

2.7 Data Collection

Data collection included the collection and fusion of data from multiple sources to support the reliability analyses of this project. For data-rich environments with monitoring systems, real-world travel time data were used to estimate reliability for different periods under different regimes based on estimates of travel time using real-world measurements. The collected data were also used to support the reliability modeling using L07 and L08 procedures and tools. The collected data included traffic flow parameter and performance data, geometry data, event data, and traffic management data. The data were collected and imported to the ITSDCAP data analysis tool, as previously described. The main items that were collected are as follows:

- *SunGuide travel time estimate data*. Traffic measurements were collected by the traffic sensor system of SunGuide. In the SunGuide system, the aggregated traffic sensor system data are stored in the Oracle database for report generation, and the raw data are saved in a text file in a comma-separated file format. This file contains one record per lane for each detection station at a 20-second polling interval. Each traffic sensor system data record included the following information: time stamp, detection station name, lane number, speed, occupancy, and raw count. The travel time data provided estimates of travel time for travel time links associated with DMSs calculated based on traffic sensor system speed measurements. One year of travel time data collected between January 1 and December 31, 2012, for the I-95 NB and SB GPLs and ELs were retrieved from the SunGuide system.

- *Statewide ITS data warehouse data*. The Florida DOT statewide data warehouse retrieves point traffic detector data from district TMCs and processes and archives the data for users to download through a web link. The user can download traffic volumes, speeds, and occupancies at different aggregation levels. Five-minute aggregation level detector data for I-95 in 2012 were downloaded from the RITIS website that is maintained by the University of Maryland.
- *SunGuide incident management database*. This database included detailed incident information stored in the SunGuide Oracle database, including incident time stamps (such as detection, notification, arrivals, and departures), incident ID, responding agencies, event details, chronicles of the event, and environmental information. The detection time stamp is the time when an incident is reported to the TMC and input into the SunGuide system. The notification time stamps are recorded per responding agency and refer to the time when such responding agencies are notified. The arrival and departure time stamps are also recorded per responding agency and refer to the time when responding agencies arrive and depart from the incident site. The latest version of the SunGuide incident database till March 2013 was obtained from the District 6 TMC.
- *Florida Highway Patrol incident database.* FHP incident data are stored through Signal Four Analytics, a traffic crash database environment developed for the FHP. This program gathered information from FHP reports on a daily basis. Crash occurrence time, location, severity, weather, and pavement conditions are archived in the database. This database provided incident information between August 6, 2010, and August 5, 2013, for SR-7 that was not available in the SunGuide incident management database.
- *INRIX data*. INRIX data were available for the investigated limited-access highways (I-95) for more than one year, because these facilities are covered by the I-95 Corridor Coalition. INRIX data collected between August 6, 2012, and August 5, 2013, were also obtained for SR-7.
- *Weather data*. After examining the weather data type and data sources used in the previous studies, such as the L02 and L08 projects, weather data were retrieved from quality-controlled local climatological data from the National Climatic Data Center. These weather data included detailed temperature and precipitations information. In this study, the data between August 6, 2011, and August 5, 2013, were downloaded for the Miami Opa Locka Airport station.
- *SR-7 intersection turning movement counts*. The intersection turning movement counts, including vehicle count, truck percentage, and pedestrian counts, were obtained from a recent SR-7 corridor study prepared for the Florida DOT.
- *Signal control data*. SR-7 signal control information was downloaded from the Miami-Dade County signal control system website.
- *Geometry data*. Geometry data were obtained from aerials, field observations, Florida DOT databases, and previous Miami-Dade County studies.

The data in the list above were preprocessed as needed and fused for the analysis. Modification of the data capture and preprocessing modules of the ITSDCAP tool was conducted to capture additional data items not captured by the tool, and also to conduct additional preprocessing required for the analysis of this project.

2.8 Assessment of Reliability Based on Real-World Data

System reliability, for the study segments, was assessed using L02 guidance and other measures based on real-world speed and travel time data. For the I-95 GPLs and EL, the estimates were based on data collected from infrastructure-based traffic detectors (true-presence microwave detectors) located at one-third to one-half mile spacing. For SR-7, infrastructure devices were not available to provide data for use in travel time estimation. Thus, travel time data from a private-sector data provider (INRIX) were used in estimating the travel time reliability of SR-7. The reliability was estimated based on one year of point detector data in 2012 for I-95 and one year of INRIX data from August 6, 2012, to August 5, 2013, depending on data availability.

The travel time measurements were combined with nonrecurrent event data (e.g., weather, incidents, construction, and special events) to estimate the impacts of these factors on incidents. The incident data for I-95 were obtained from the detailed SunGuide incident database maintained by the Florida DOT. For SR-7, incident data were not available from the transportation management agencies. Thus, they were obtained from the FHP crash database, which lacked the details required for estimating the incident impact, such as the number and duration of lane blockages and even the direction of the incidents.

Reliability was assessed based on various reliability measures, as discussed in the previous section. The ITSDCAP tool allowed the estimation of several reliability measures based on real-world data, including the standard deviation/variance, buffer index, failure/on-time performance, TTI based on the 95th, 90th, or 80th percentile, skew statistics index, and misery index. Additional metrics based on L02, L08, and the Florida DOT planning office recommendations were also calculated and compared in this effort. These additional metrics included the semivariance measure and travel time rate probability and cumulative distribution used in L02; the reliability rating (proportion of VMT with TTI below a given threshold) and policy index, as discussed in the L08 products section; the TTI CDF used in L07; and the on-time performance based on target speed, as defined by the Florida DOT central office. Additional visualization techniques such as bar charts of the travel time, TTI, and speed percentiles for different regimes were used to communicate the results to project stakeholders.

Additional data analysis and visualization techniques of various performance measures were produced to visualize the reliability by time of day at the five-minute aggregation level and for 24 hours of the day. Data analyses were performed for different combinations of the influencing factors to isolate the impacts of these factors. The analysis at five-minute intervals was needed when performing planning for operations analysis to determine the exact times at which the roadway segments become unreliable and thus recommend the activation of active management strategies at those times.

The L02 recommendations of establishing reliability regimes were used to categorize the impacts of various contributing factors on the reliability of the system. By examining the results under different regimes, it was possible to identify the contributing factors to the unreliability of the analyzed segments. Initially, this project used L02 recommendations of categorizing the data by congestion level. However, it was later decided than binning the data by time of day considering different causes of congestion at different times of the day was more appropriate as it allowed analyzing the reliability of the specific condition under consideration.

Other approaches to bin data by regime were also used. For example, instead of having only one incident category, as in L02, incidents were subcategorized by duration and/or number of lanes blocked, and the rain events were categorized by rain intensity. In addition, overlapped incident plus weather conditions were analyzed.

When determining the contribution of an event type or a combination of event types on reliability, L02 used the semivariance measure. This contribution is a function of the multiplication of the average impact of a single event and the frequency of the event of that type. However, some events may be severe but rare. Although its overall contribution is low, agencies may still be interested in knowing the average impact of a single event on reliability. Thus, in addition to estimating the contribution of an event on reliability based on the semistandard deviation, the severity of a single event was also calculated based on its normalized semivariance (NSV), which is calculated as the semistandard deviation divided by the frequency of the event.

2.9 Testing L07 and L08 Products to Assess Existing Reliability

L02 products can be used in data-rich environments with established monitoring systems. In Florida, the limited-access facilities managed by the Florida DOT and toll authorities are instrumented with state-of-the-art ITS monitoring systems with associated data-archiving capabilities. However, urban streets, generally managed by counties and cities, have limited instrumentation, particularly with regard to travel time measurements, although the Florida DOT has purchased private-sector travel time data for one year from INRIX for some of these facilities and has recently contracted to get NAVTEQ HERE data. The L03, L07, C11, and L08 project products provide an opportunity to estimate the travel time reliability of these data-poor data environments based on limited traffic and network data. In addition, such tools are needed to assess improvement alternatives. However, it is important to further validate the results from these tools.

In this study, the reliability measures estimated using the L08 and L07 project tools for selected segments of the facilities were compared with those estimated based on system monitoring, as described in the previous section. Further examination was made of the sensitivity of the analysis results by varying input parameters to the models.

2.10 Identifying Reliability Deficiencies

Reliability deficiencies should be assessed by comparing segment and facility reliability to threshold values and highlighting the segments and facilities with reliabilities that are worse than the threshold. The reliability measures should be examined to determine the time periods with unacceptable reliability and the contributing factors to these unreliable conditions. The identification of reliability thresholds is required to make the reliability measures meaningful to system stakeholders when trying to identify reliability issues with the transportation system. However, up to now little guidance has been provided to agencies in determining these thresholds. The L05 guidance and L08 documentation suggest that these thresholds should be based on local policies; however, initial values can be identified based on other similar corridors in the nation, state, or region.

This identification of the target performance thresholds and the specific performance measures are challenging issues that need to be addressed in reliability analysis. In this study, a review of the tested products was conducted to determine their guidance regarding the identification of the performance thresholds and reliability deficiencies. Any identified threshold values were refined based on stakeholder inputs, as discussed in the L05 project guidelines. The results were shared with the project stakeholders to provide a better understanding of the reliability issues of the system. A recommendation of the L05 project is to convert reliability performance into good, fair, and poor categories, as the converted measure allows communication of results more easily. However, the L05 project guidelines also state that when setting reliability performance thresholds, the perception of system users needs to be considered, because this perception varies significantly across locations, roadway types, users, times of day, and days of the week. Thus, the L05 guidelines suggest that the setting of the thresholds requires an iterative approach to adjust the threshold up and down, based on agency and stakeholder understanding of reliability deficiencies. Tables 2.3 and 2.4 and Figures 2.2, 2.3, and 2.4 present examples of reliability values presented in the L05 and L08 products that can be used in setting initial reliability performance thresholds.

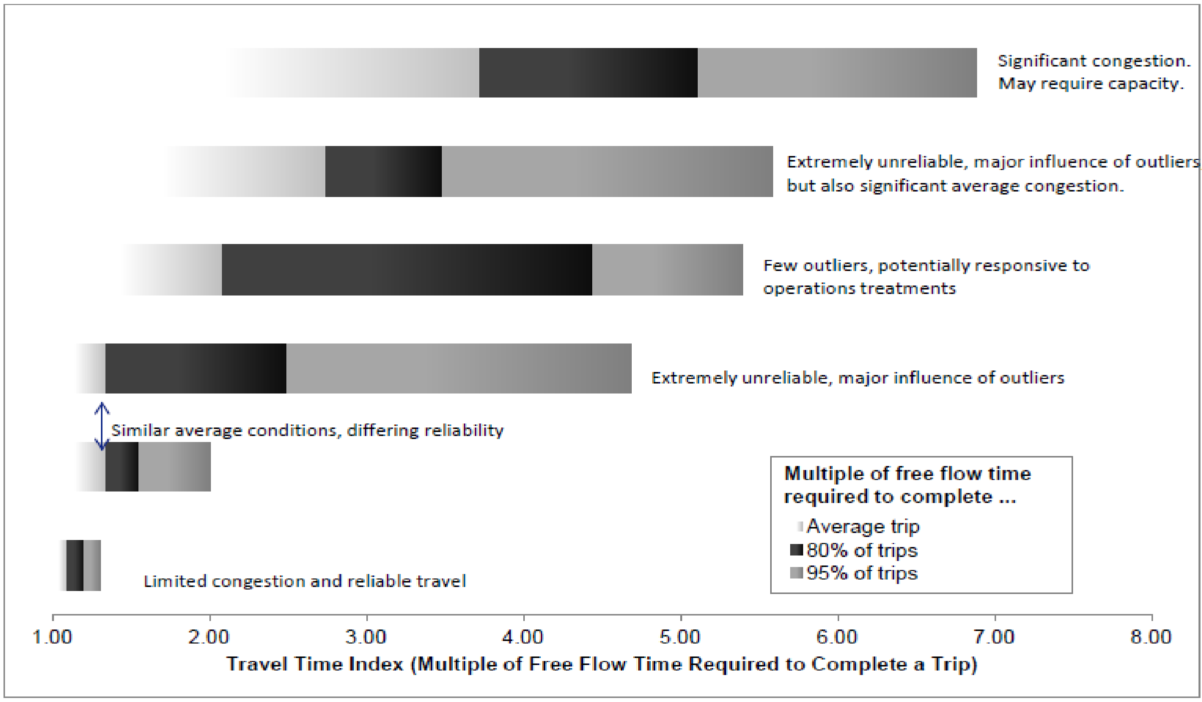


Figure 2.2. Variation in reliability measures for example corridors.

Source: Cambridge Systematics (2013b).

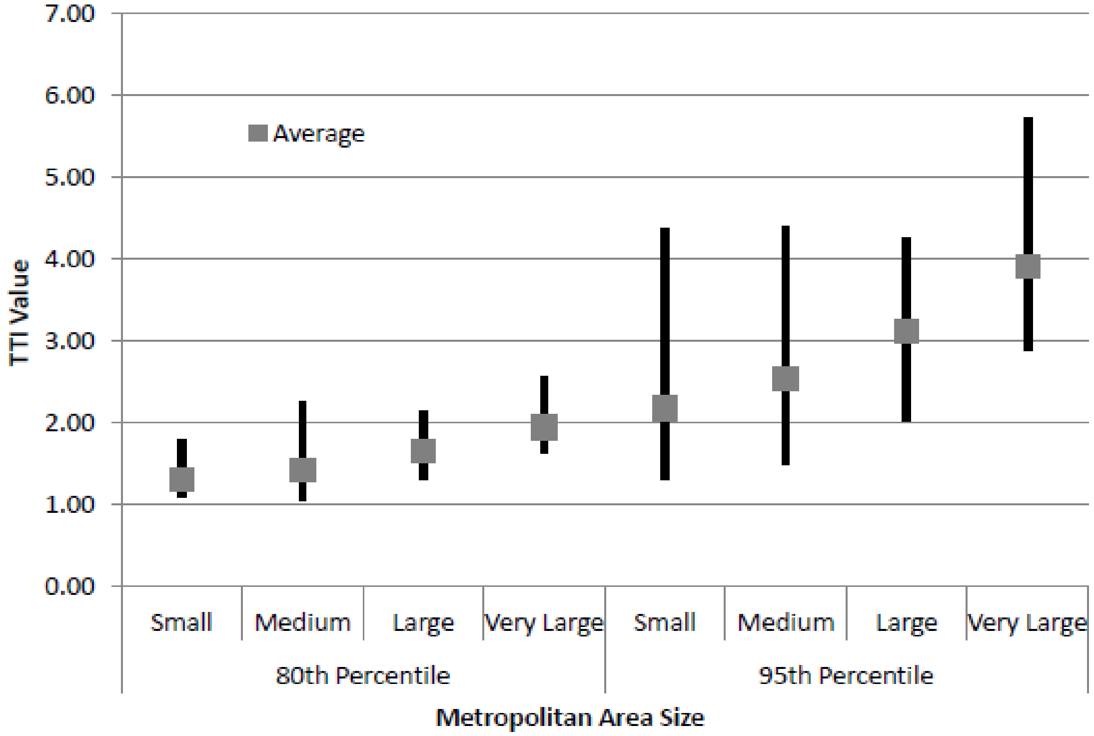


Figure 2.3. Reliability variation by area size.

Source: Cambridge Systematics (2013b).

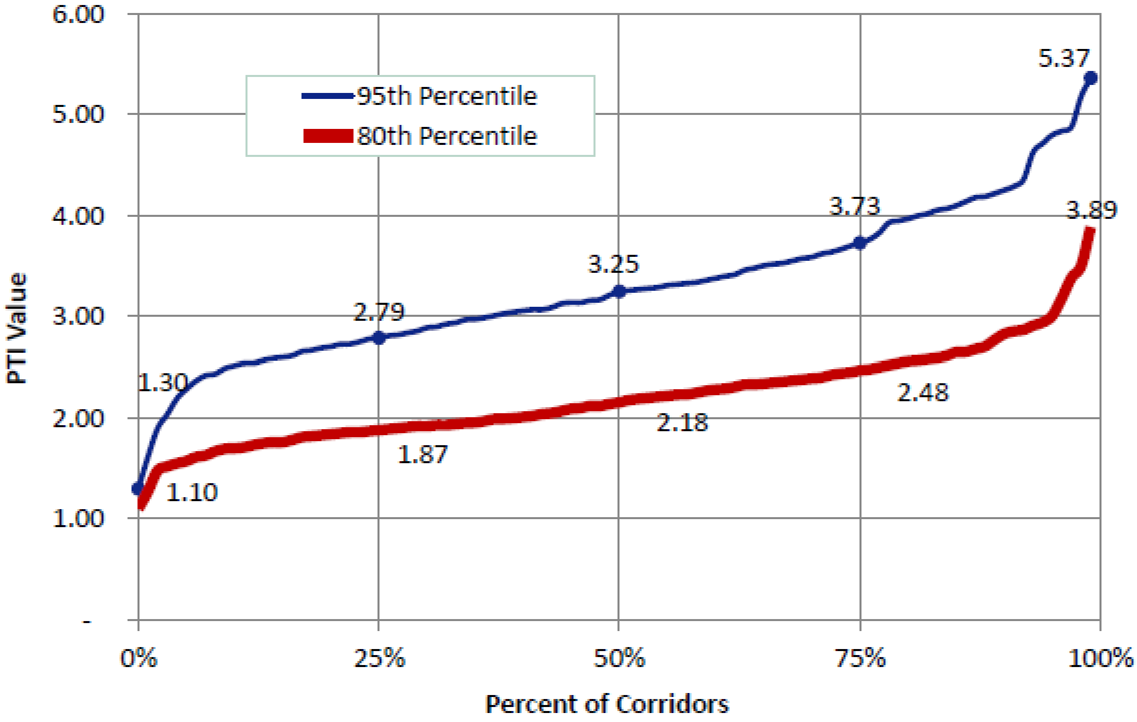


Figure 2.4. Distribution of PTI for the 328 most congested corridors in the United States.

Source: Cambridge Systematics (2013b).

The L02 project recommends comparing the actual versus desired travel time windows. The travel time rate PDFs under different regimes and the desired travel rates were derived based on real-world data. Reliability was measured by the percentage of trips with actual travel rates within the allowable desired travel rate window.

McLeod et al. (2012) reported that the Florida DOT's preferred travel time reliability measure is based on a target speed of 10 mph less than the posted speed limit or a policy target speed of 40 mph. The comparison of reliability measures based on the target speed against the value of 1.0 was used to determine whether the reliability performance was acceptable.

Table 2.3. Reliability Statistics for a Cross-Section of Florida Freeways

Location	**50% TTI**	**80% TTI**	**90% TTI**	**95% TTI (PTI)**	**Policy Index Alt. 1**	**Policy Index Alt. 2**	**Buffer Time Index**	**Misery Index**
I-95 NB at NW 19th St	1.00	1.36	1.69	2.01	1.27	1.75	2.02	2.22
I-95 SB at NW 19th St	1.08	1.19	1.58	2.01	1.27	1.75	1.86	2.48
I-95 NB, S of Atlantic Blvd	1.03	1.28	1.73	2.23	1.27	1.75	2.16	2.74
I-95 SB, S of Atlantic Blvd	1.10	1.36	1.89	2.37	1.27	1.75	2.15	2.93
SR-826 NB at NW 66th St	2.40	2.82	3.07	3.35	1.33	1.50	1.39	3.69
SR-826 SB at NW 66th St	1.01	1.28	2.63	4.06	1.33	1.50	4.02	4.62
SR-826 WB, W of NW 67th Ave	1.04	1.08	1.21	1.77	1.33	1.50	1.70	2.10
SR-826 EB, W of NW 67th Ave	0.98	1.00	1.02	1.04	1.33	1.50	1.07	1.10
I-4 EB, W of World Dr	0.97	1.04	1.06	1.08	1.27	1.75	1.12	1.12
I-4 WB, W of World Dr	1.02	1.09	1.49	1.90	1.27	1.75	1.86	2.22
I-4 EB, W of Central Florida Pkwy	1.06	1.13	1.18	1.31	1.27	1.75	1.24	1.56
I-4 WB, W of Central Florida Pkwy	1.05	1.36	1.63	1.81	1.27	1.75	1.72	2.03
I-275 NB, N of MLK Jr Blvd	1.45	1.71	1.91	2.16	1.33	1.50	1.49	2.58
I-275 SB, N of MLK Jr Blvd	0.97	1.01	1.04	1.12	1.33	1.50	1.15	1.28
I-275 NB, N of Fletcher Blvd	1.05	1.07	1.11	1.21	1.33	1.50	1.16	1.35
I-275 SB, N of Fletcher Blvd	0.96	0.98	0.99	1.00	1.33	1.50	1.04	1.01
I-10 EB, E of Lane Ave	0.93	0.96	0.98	0.99	1.33	1.50	1.07	1.01
I-10 WB, E of Lane Ave	0.97	1.10	1.24	1.46	1.33	1.50	1.51	1.87
I-95 NB, S of Spring Glen Rd	1.04	1.09	1.26	1.77	1.27	1.75	1.70	2.00
I-95 SB, S of Spring Glen Rd	1.16	1.30	1.42	1.60	1.27	1.75	1.38	1.88
Minimum	0.93	0.96	0.98	0.99	1.27	1.50	1.04	1.01
Average	1.11	1.26	1.51	1.81	1.30	1.63	1.64	2.09
Maximum	2.40	2.82	3.07	4.06	1.33	1.75	4.02	4.62

Source: Proposed HCM 2010 Chapter 37.

Table 2.4. Rankings of U.S. Facilities by Mean TTI and PTI (AM Peak, Midday, and PM Peak Combined)

Percentile Rank	Freeways			Urban Streets		
	TTI	Mean TTI	PTI	TTI	Mean TTI	PTI
Minimum	1.01	1.02	1.07	1.03	1.06	1.23
Worst 95%	1.02	1.05	1.09	1.09	1.12	1.27
Worst 90%	1.02	1.06	1.13	1.13	1.15	1.29
Worst 85%	1.04	1.06	1.14	1.15	1.16	1.32
Worst 80%	1.05	1.08	1.17	1.17	1.20	1.33
Worst 75%	1.05	1.08	1.22	1.19	1.20	1.35
Worst 70%	1.05	1.09	1.25	1.19	1.22	1.36
Worst 65%	1.06	1.10	1.30	1.20	1.22	1.39
Worst 60%	1.07	1.12	1.34	1.20	1.23	1.41
Worst 55%	1.08	1.15	1.39	1.21	1.23	1.42
Worst 50%	1.10	1.16	1.47	1.23	1.26	1.44
Worst 45%	1.11	1.19	1.57	1.24	1.27	1.47
Worst 40%	1.13	1.23	1.73	1.25	1.28	1.49
Worst 35%	1.14	1.30	1.84	1.25	1.29	1.52
Worst 30%	1.17	1.33	1.97	1.26	1.30	1.54
Worst 25%	1.20	1.39	2.24	1.30	1.34	1.60
Worst 20%	1.26	1.43	2.71	1.33	1.36	1.63
Worst 15%	1.31	1.51	2.90	1.35	1.38	1.70
Worst 10%	1.59	1.78	3.34	1.39	1.47	1.84
Worst 5%	1.75	1.97	3.60	1.45	1.54	1.98
Maximum	2.55	2.73	4.73	1.60	1.66	2.55

Source: Proposed HCM 2010 Chapter 37.

2.11 Assessment of the Identified Strategies Using L07 and L08

The research team, in conjunction with project stakeholders, examined the results from the reliability analysis in the previous tasks and identified alternative strategies to address reliability issues. The research team worked with the TMC staff and consultant, the SR-7 corridor study project management and consultant, and other stakeholders to identify alternative solutions to the identified problems. Capacity, active traffic and demand management, and operational improvements were considered.

The selection of the identified alternative strategies required an assessment of the expected improvements due to the implementation of the identified alternative strategies. Depending on the selected strategy, this assessment was performed using the L08 and/or L07 products.

2.12 Evaluation of the Functionality and Outcomes of the Product Testing

The research team presented the results from the reliability and alternative analysis to the Florida DOT Districts 4 and 6 TSM&O core groups and TMC staffs, Florida TSM&O coordinators, TMC staff, the SR-7 project advisory team, I-95 master plan project manager, MPO, and Miami-Dade County staff. Discussions with the agencies addressed the identified reliability problems, the recommended countermeasures, and the results from the analysis.

This task included the evaluation of the technical feasibility of the products, the understandability and credibility of the results by decision makers, and the acceptability and implementation potential of the recommendations resulting from the products. This assessment was based on interviews with project stakeholders and examination of actual decisions made by the involved agencies.

CHAPTER 3

Analysis of Existing Reliability Based on Data

3.1 Introduction

The existing reliability of the tested facilities was assessed based on real-world data obtained from multiple sources by using the L02 project guidelines and additional measures and visualization techniques combined with other performance measures and assessment techniques. For the I-95 GPL and EL, the estimates were based on data collected from infrastructure-based traffic detectors (true-presence microwave detectors) located at one-third to one-half mile spacing. Infrastructure devices were not available for SR-7 to provide data for use in travel time estimation. Therefore, travel time data from a private-sector data provider (INRIX) were used in estimating the travel time reliability of SR-7. The travel time measurements were combined with nonrecurrent event data (e.g., weather, incidents, construction, and special events) to estimate the impacts of these factors on reliability. This chapter presents the reliability analysis only for the I-95 NB GPL. Due to the large number of graphs and in order to improve the readability of the report, the analyses of the I-95 NB EL, I-95 SB GPL, I-95 SB EL, SR-7 NB, and SR-7 SB are presented in Appendices B, C, D, E, and F, respectively. However, a summary of the results of the analysis of all segments is presented in this chapter.

3.2 I-95 Northbound General-Purpose Lane Analysis

3.2.1 Overall Reliability Performance

Initially, this project used L02 recommendations of categorizing the data by congestion level. However, it was later decided to bin the data by time of day as considering different causes of congestion at different times of the day was more appropriate because it allowed analyzing the reliability of the specific condition under consideration.

Figures 3.1, 3.2, and 3.3 present an assessment of the overall system performance for the I-95 NB GPL for different times of the day. The travel time rate CDF in Figure 3.1 clearly shows the unreliability of travel during the PM peak periods. The PM peak period was subdivided into two peaks, PM1 from 3:00 to 5:00 p.m. and PM2 from 5:00 to 7:00 p.m., to reflect the differences in the observed congestion patterns and the different causes of congestion in these two periods. In Figure 3.1, it appears that the 95th percentile travel time rate in the PM peak was close to 162 second/mile (about 21 mph) compared to about 62 second/mile (58 mph) for free-flow conditions, reflecting a 95th percentile TTI of 2.6 and indicating highly unreliable travel during the PM peak. The reliability was good in the remaining periods, although the 95th percentile travel time rate appeared to be somewhat high in the after-PM (APM) period between 7:00 and 10:00 p.m., resulting in a TTI of about 1.75. MD in the figure refers to the midday period, and MN refers to the midnight and early morning period.

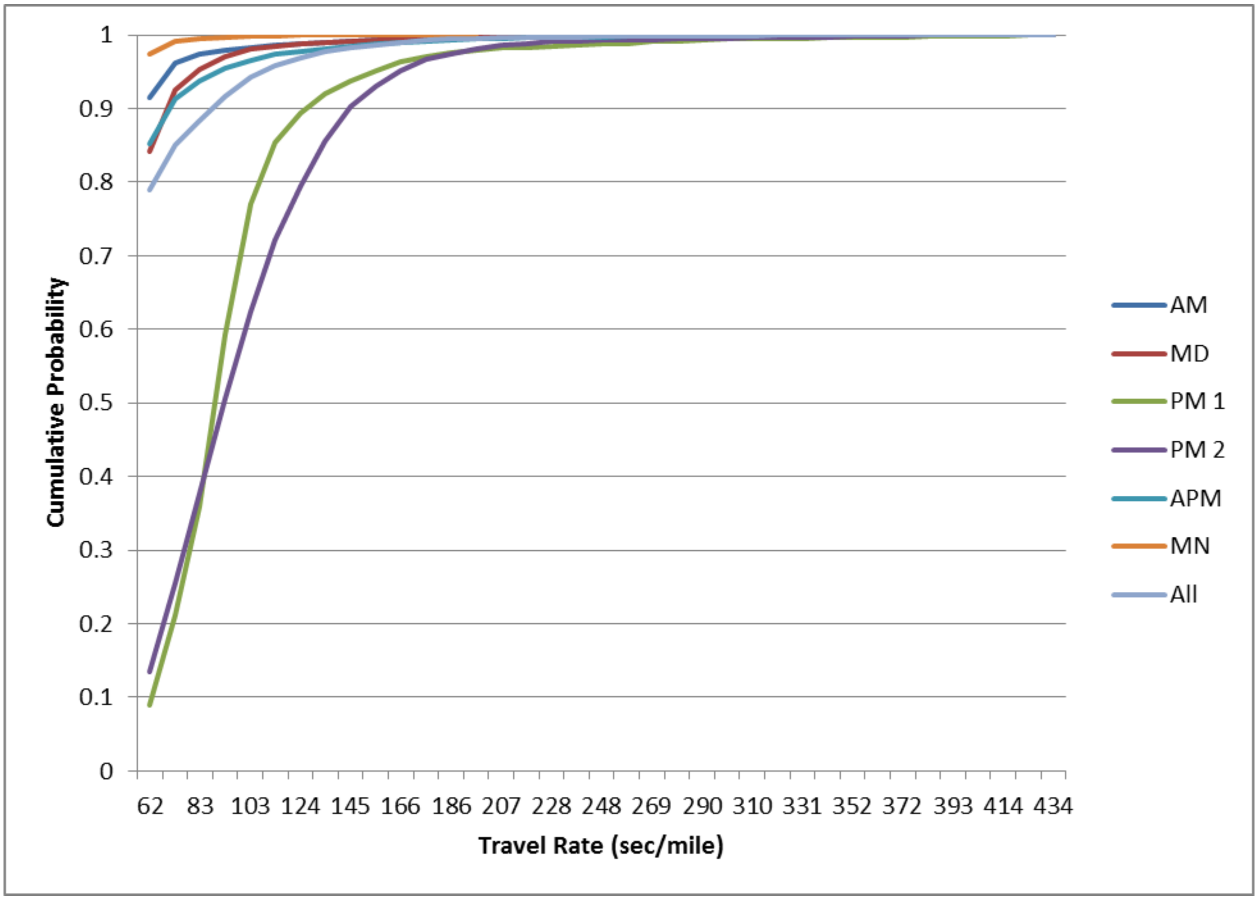


Figure 3.1. CDFs for I-95 NB GPL.

The percentage of unreliability contribution (see Figure 3.2) shows that the unreliability in the PM1 and PM2 peaks as measured by the semivariance contributed to 29% and 45%, respectively, of the overall unreliability of the daily operations, with a total of 74% for the combination of these two peaks. The remaining AM, midday, and APM periods contributed to 5%, 11%, and 9%, respectively, of the total unreliability according to the semivariance measure. Some of the unreliability of the midday and APM periods occurred at the boundary of the PM peak period.

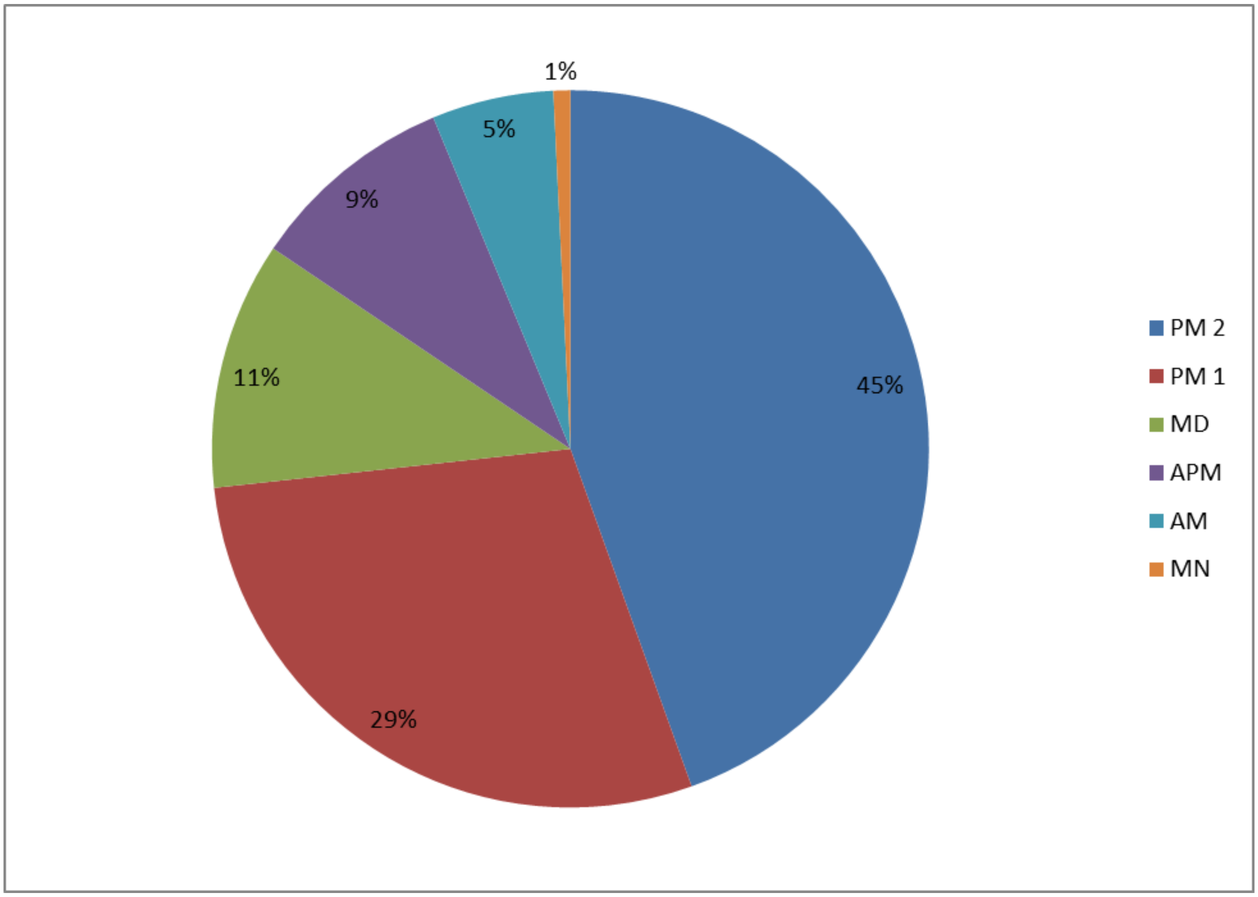
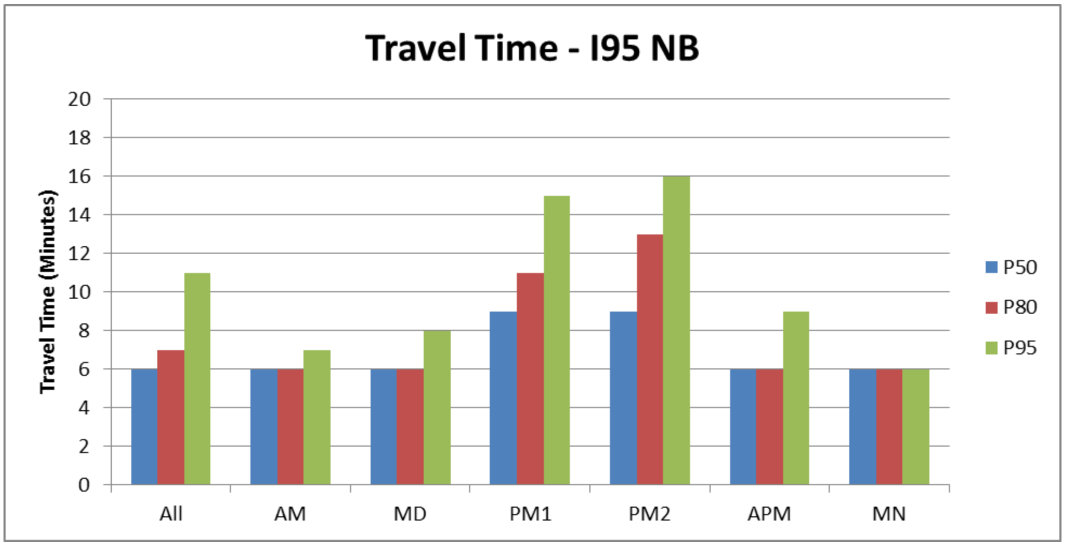
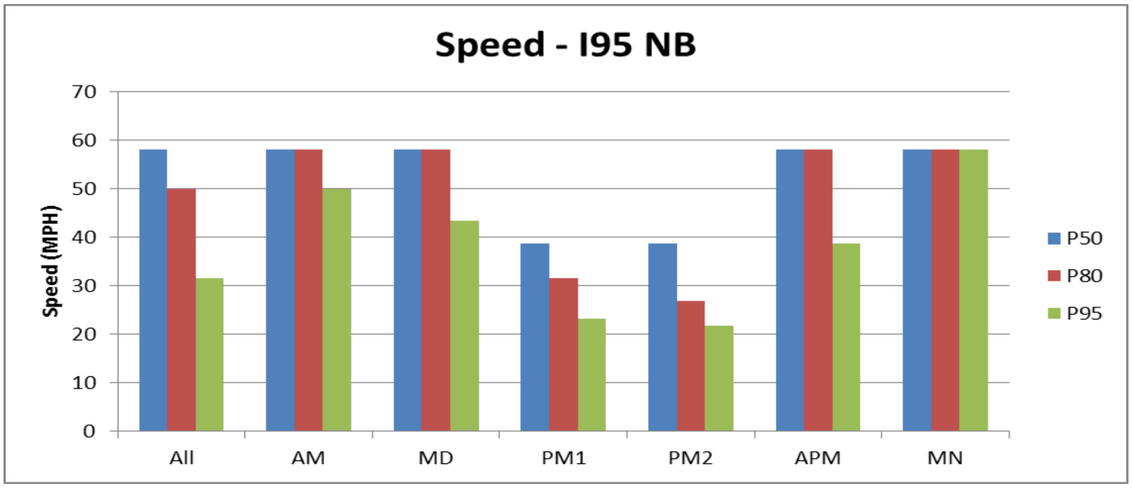


Figure 3.2. Percentage of unreliability contribution for I-95 NB GPL.

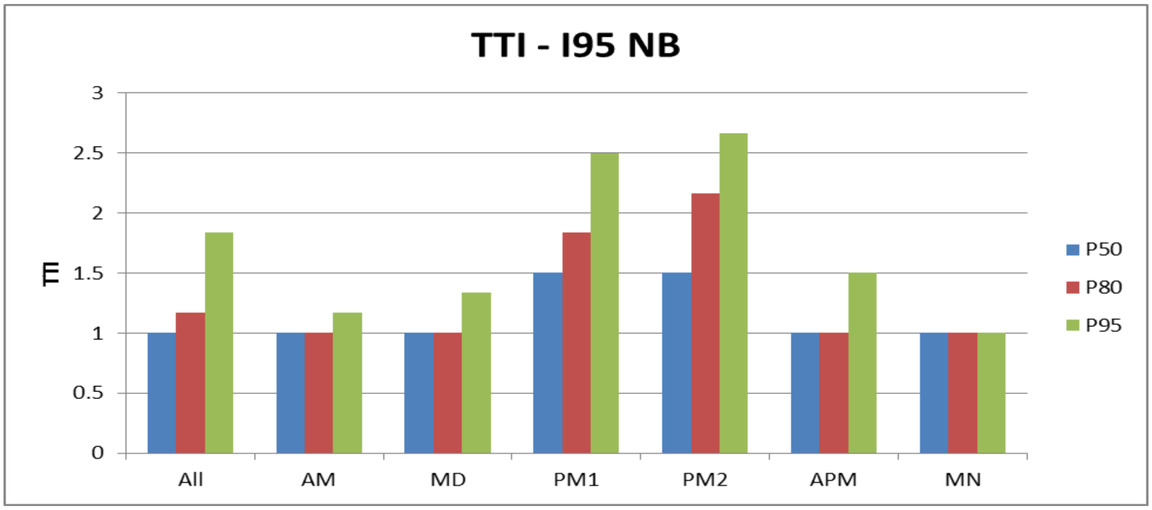
The CDF curves in Figure 3.1 are crowded, so to provide a more straightforward visualization of reliability results, the travel time, speed, and TTI that correspond to the 50th, 80th, and 95th percentiles of CDFs for different times of day are presented in Figure 3.3. The results show that the travel time under the 50th and 80th percentile travel time was about six minutes for most of the day. However, the 50th percentile travel time increased to nine minutes and the 80th percentile increased to 13 minutes for the PM peak. The travel time for the 95th percentile condition increased from seven to eight minutes to 16 minutes. The corresponding 95th percentile speed in the PM peak was around 20 mph, and the TTI was around 2.6.



(a)



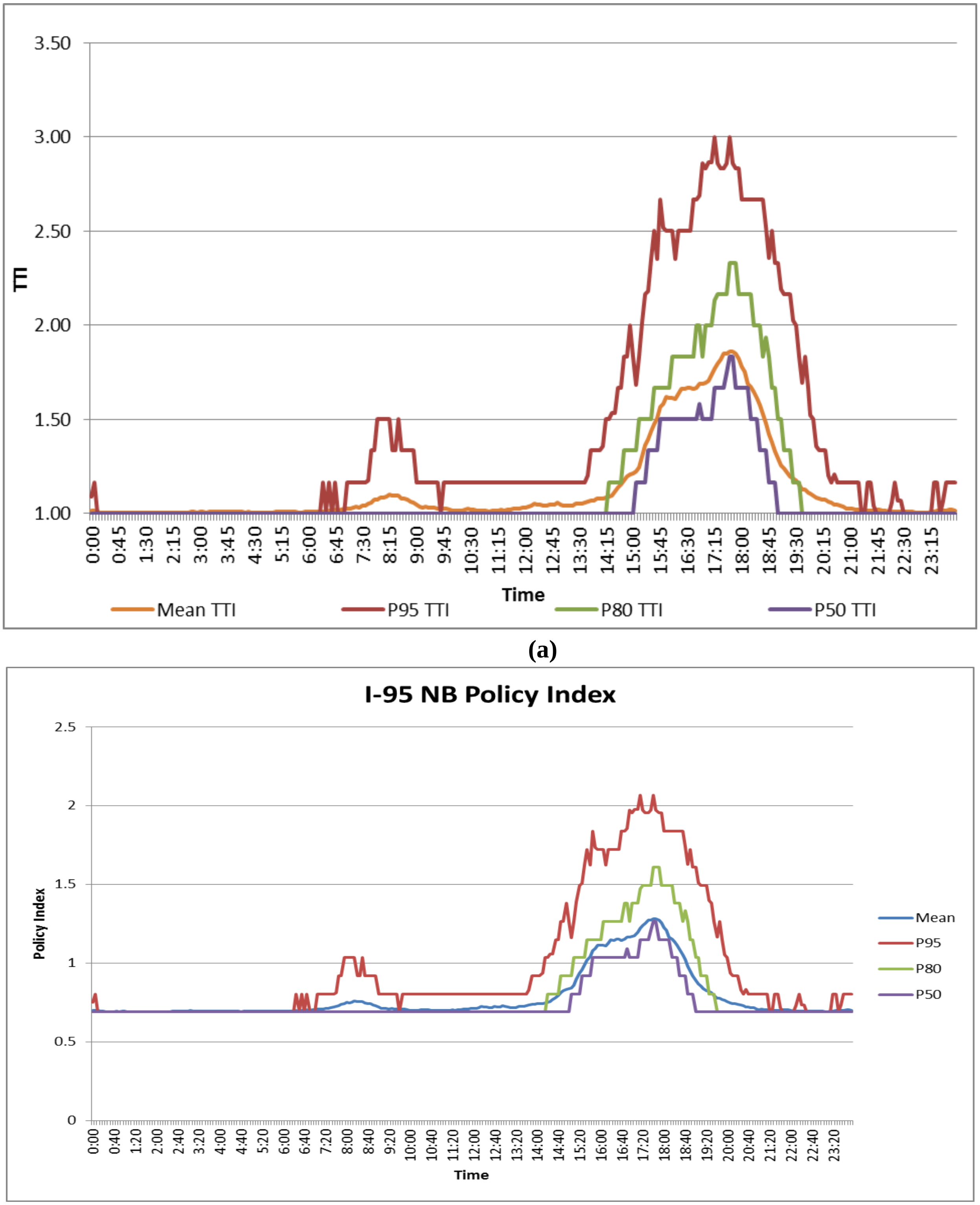
(b)



(c)

Figure 3.3. I-95 NB GPL (a) travel time, (b) speed, and (c) TTI.

The variation of the TTI by five-minute intervals shown in Figure 3.4a confirms that, excluding the PM peak periods, the 95th percentile TTI was good for most of the day, except in the AM peak between 7:30 and 8:45 a.m., when it reached 1.4 to 1.5. This figure also shows that the 80th and 95th percentile TTIs started increasing between 2:00 and 3:00 p.m., reaching 1.9 and 2.5, respectively, by 4:00 p.m. Between 4:45 and 6:45 p.m., the 80th and 95th percentile TTIs increased to 2.3 and 3.0, respectively, then started decreasing sharply, reaching 1.0 and 1.4 by 8:00 p.m. The median travel time was 1.5 to 1.8 of the free-flow travel time in the PM peak periods between 3:30 and 6:30 p.m. Between 9:00 a.m. and 1:45 p.m. and after 9:00 p.m., the 95th percentile TTI ranged between 1.00 and 1.20. These results indicate that the period between 3:00 and 8:00 p.m. could be considered unreliable, with major influence of outliers according to L05 guidance. Figure 3.4a shows that the AM peak was moderately unreliable, while the rest of the day was reliable. The policy index was also calculated assuming a target speed of 40 mph, as shown in Figure 3.4b. This measure confirms that the period between about 2:00 and 7:00 p.m. was unreliable.



(a)

(b)

Figure 3.4. I-95 NB GPL (a) TTIs and (b) policy index variation by time of day.

Figure 3.5 shows that the on-time performance (both the 1.1 and 1.25 on-time performance) was close to or above 90% between 8:00 a.m. and 2:00 p.m., but dropped from 52% to 62% and 60% to 75%, respectively, between 2:00 and 7:30 p.m., with the highest drop appearing to be between 5:00 and 6:45 p.m. As stated earlier, the Florida DOT central planning office prefers the use of on-time performance and PTI to assess reliability. The misery index, semistandard deviation (shown as Semi-SD in Figure 3.6), and buffer index were worst between 3:00 and 7:00 p.m., although they were also relatively high between 7:00 and 8:30 p.m., as shown in Figure 3.6. The high values in the after-PM peak period possibly reflect the observed higher severity of crashes during this period, as discussed below. The misery index reflects the average travel time of the worst 5% of travel, indicating the high impacts of severe events.

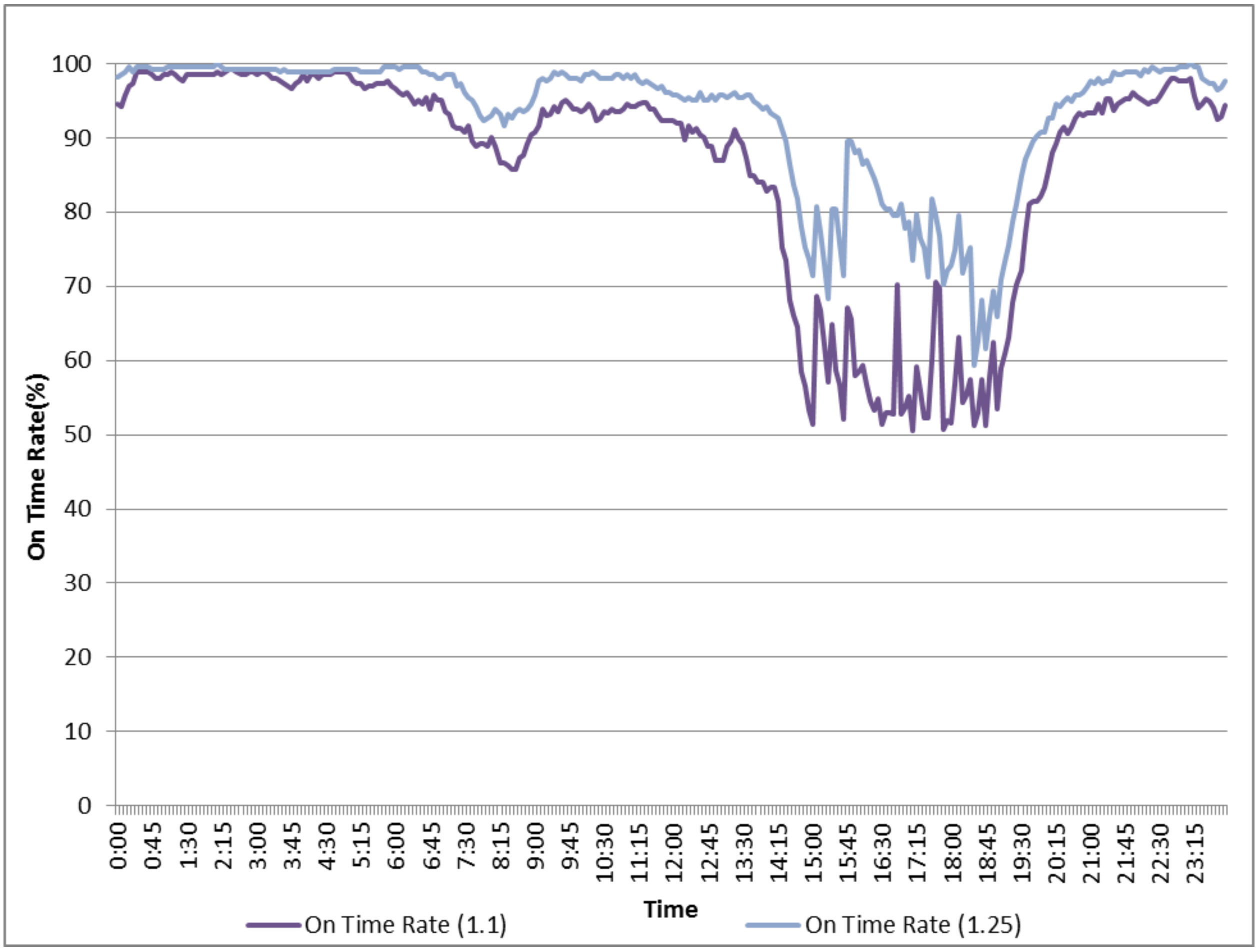


Figure 3.5. I-95 NB GPL on-time performance.

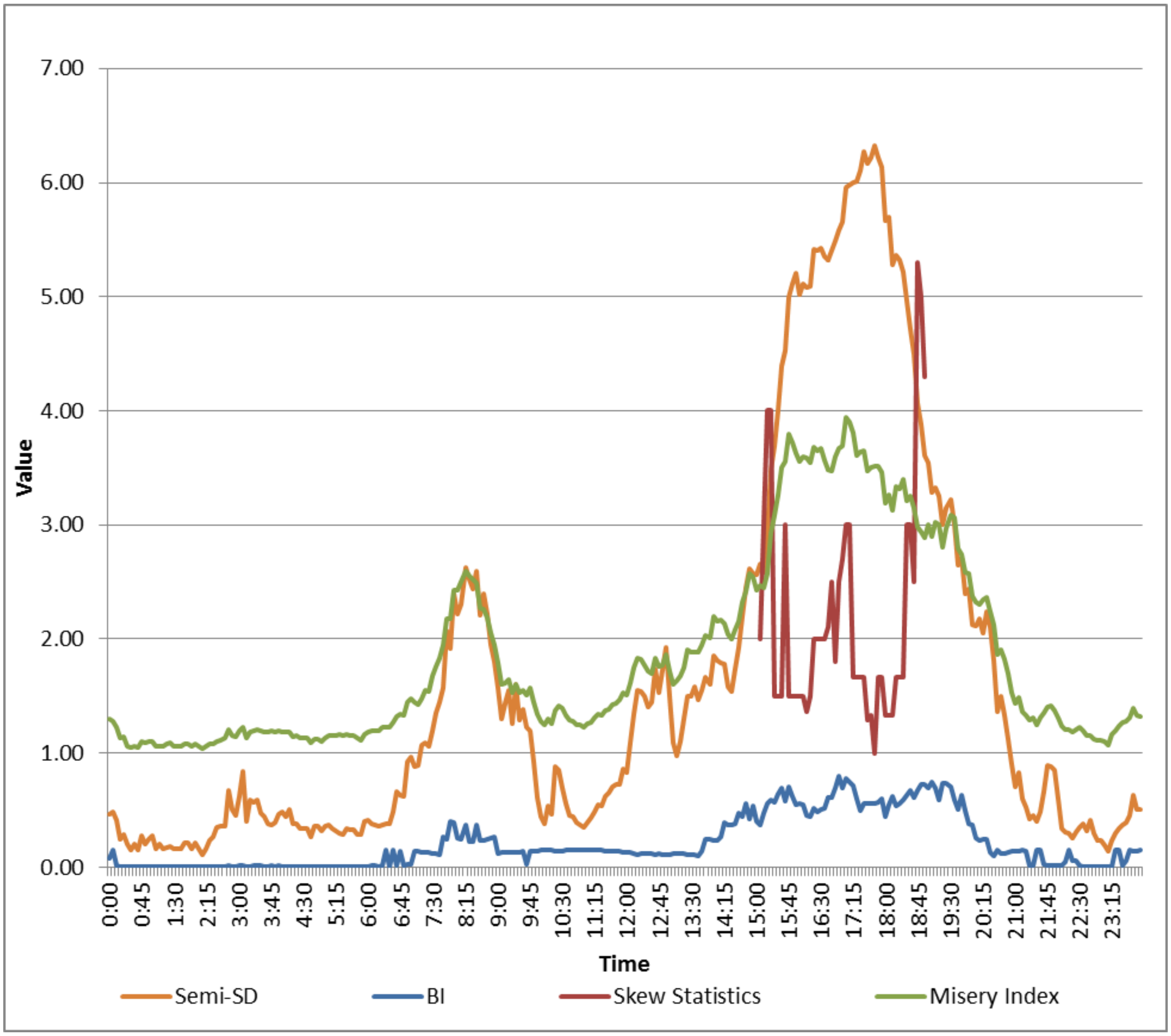


Figure 3.6. I-95 NB GPL other performance measures.

Figures 3.7 and 3.8, respectively, show the five-minute variation of VMT and vehicle hours traveled (VHT) in 24 hours. Figure 3.7 shows that I-95 NB GPL had a relatively high VMT from 7:00 a.m. to 7:00 p.m., even though there was a slight drop in VMT during the midday. However, the curve in Figure 3.8 shows a big difference in VHT during different times of the day.

In addition to the reliability measures mentioned above, the reliability rating defined in L08 as the percentage of VMT with a TTI less than 1.33 was also calculated. Figure 3.9 presents the percentage of VMT under given values of TTIs. The results in this figure indicate that for the whole day only 54% of VMT had a 95th percentile TTI less than 1.33. If the thresholds are increased to 1.5 and 2, these percentages increase to 67% and 74%, respectively.

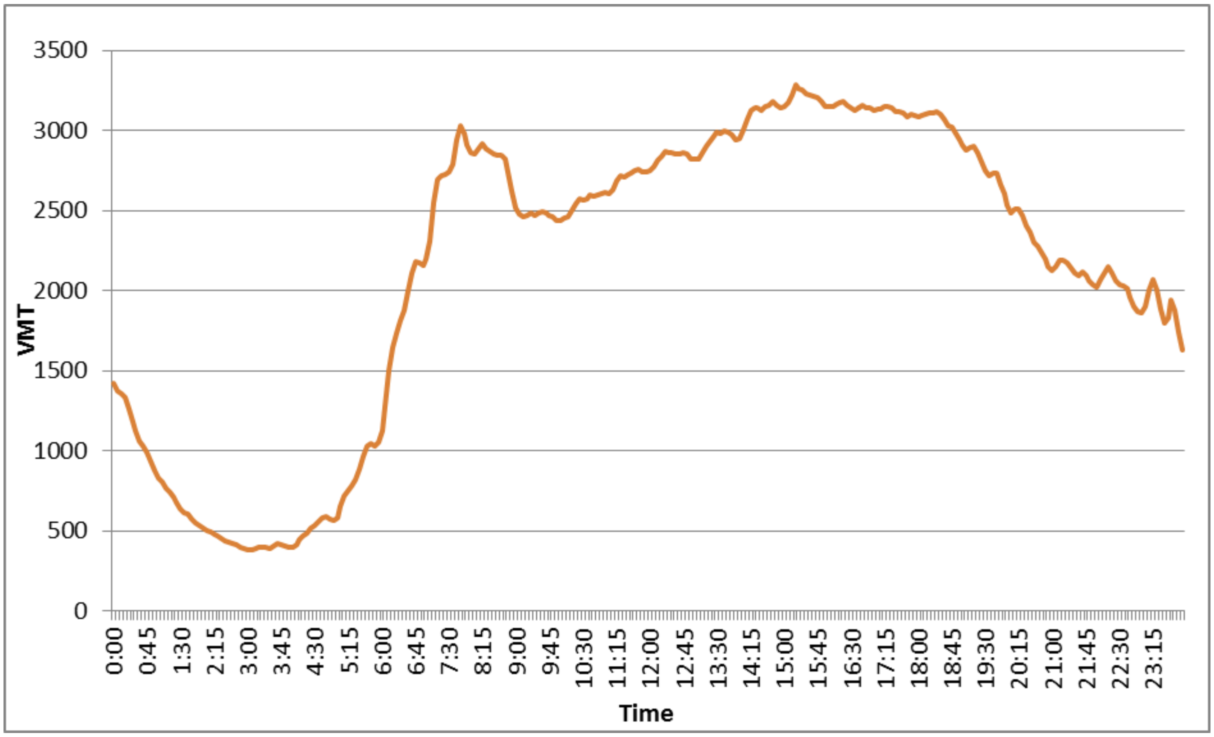


Figure 3.7. I-95 NB GPL VMT variation by time of day.

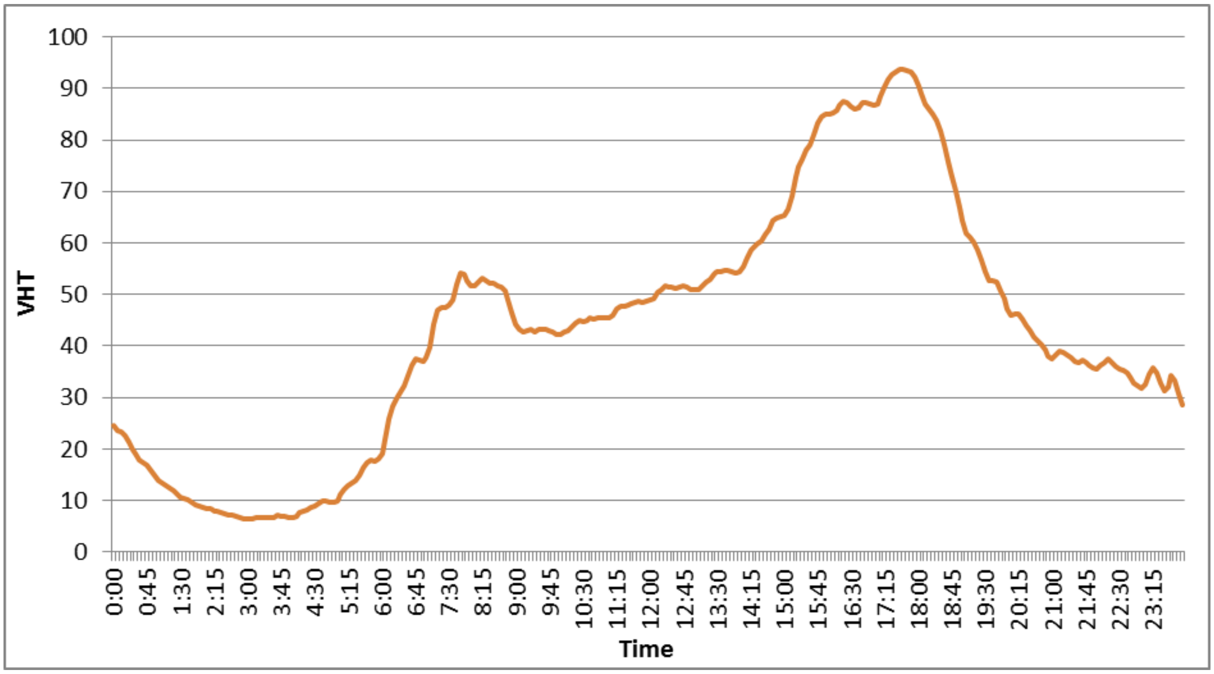
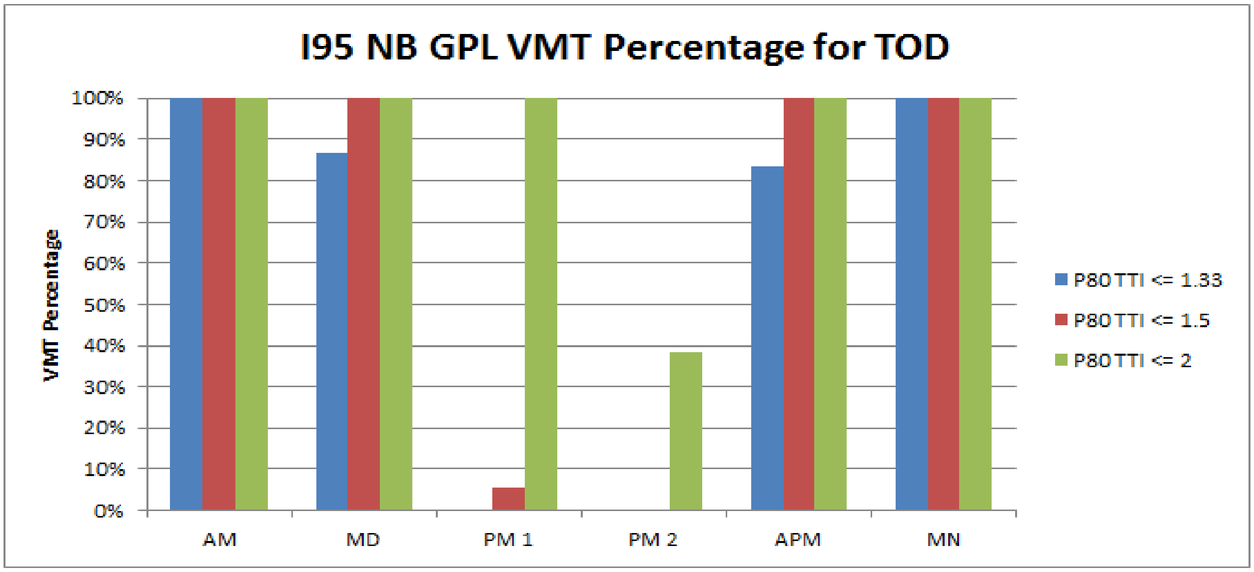
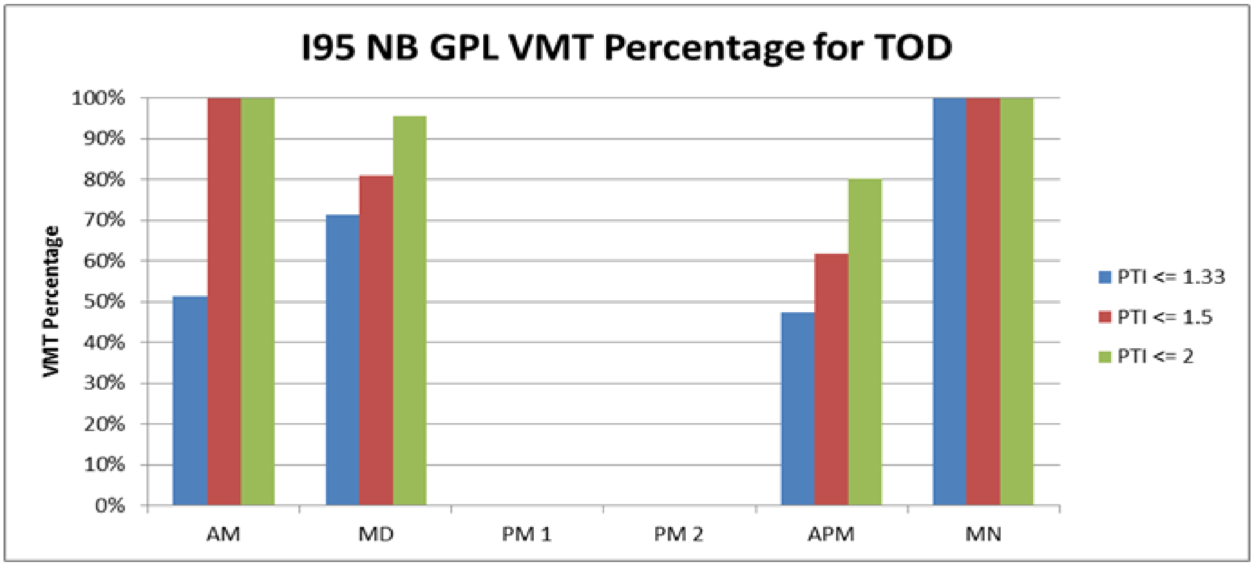


Figure 3.8. I-95 NB GPL VHT variation by time of day.



(a)



(b)

Figure 3.9. I-95 NB GPL reliability rating for comparison based on (a) 80th and (b) 95th percentile TTI.

3.2.2 Contributions of Influential Factors

The impacts of various factors on travel time reliability were examined in this study following the procedures outlined in the L02 project. Figure 3.10 presents the CDF distributions for travel time rate under different traffic conditions. Tables 3.1, 3.2, and 3.3, respectively, summarize the percentages of occurrence, severity, and overall contribution of the no-event traffic condition (including normal traffic and high-demand conditions), incident, weather, and incident plus weather to travel time reliability.

An important observation from Table 3.3 is that the no-event periods contributed significantly to the unreliability of the system in the PM peak (10% in PM1 and 21% in PM2, with a total of 31% of the whole day). This level of contribution indicates serious issues with the recurrent operation. It should be mentioned that in reality the contribution of recurrent congestion was higher as even during incident intervals in the congested peak, part of the congestion or unreliability was due to the congestion due to recurrent capacity constraints.

The reliability analysis also indicated that incidents were a major contributor to travel time reliability for most of the day. Table 3.3 indicates that the five-minute intervals with incidents contributed to 15% and 21% of the unreliability of the day during the PM1 and PM2 periods. However, after correcting for the no-event congestion contribution during the incidents, the contribution of incidents appeared to be 10% and 8.4% of the daily unreliability during the PM1 and PM2 periods, respectively. These percentages are the same contribution as the no-event in the PM1 period (10%) but lower than the no-event contribution during the PM2 period (8.4% versus 21%), again indicating the severity of the recurrent congestion during the PM2 period. However, Table 3.2 shows that a single average incident event caused more damage than a single average no-event. During the rest of the day, the impacts of incidents based on the semivariance were clearly lower.

Weather events were relatively rare compared to incident occurrence, and the overall contribution of weather was much smaller than that due to incident and no-event high-demand conditions, as shown in Table 3.1 and Table 3.3. However, a single weather event impact measured in NSV was almost the same as the impact of a single incident in the PM1 and PM2 periods (see Table 3.2).

Incidents plus weather events were even rarer than weather events; therefore, their contributions to the overall reliability were low. However, the incident plus weather combination generated the worst conditions, as indicated by the travel time distributions shown in Figure 3.10 and the NSV values shown in Table 3.2. This table shows that during PM1 and PM2, the NSV during incident plus weather events was about twice the NSV during incident conditions and also about twice the NSV during rainy conditions. It is interesting to see that the impact of a single incident plus weather event was also very high in the AM peak and relatively high in the midday period.

Table 3.1. Percentage of Occurrence

Time Period	Nonevent	Incident	Weather	Incident + Weather	Total
AM	10%	2%	1%	0%	13%
MD	20%	6%	1%	0%	27%
PM1	4%	2%	0%	0%	6%
PM2	5%	3%	0%	0%	8%
APM	9%	3%	0%	0%	12%
MN	27%	4%	1%	0%	33%

Table 3.2. Percentage of Severity

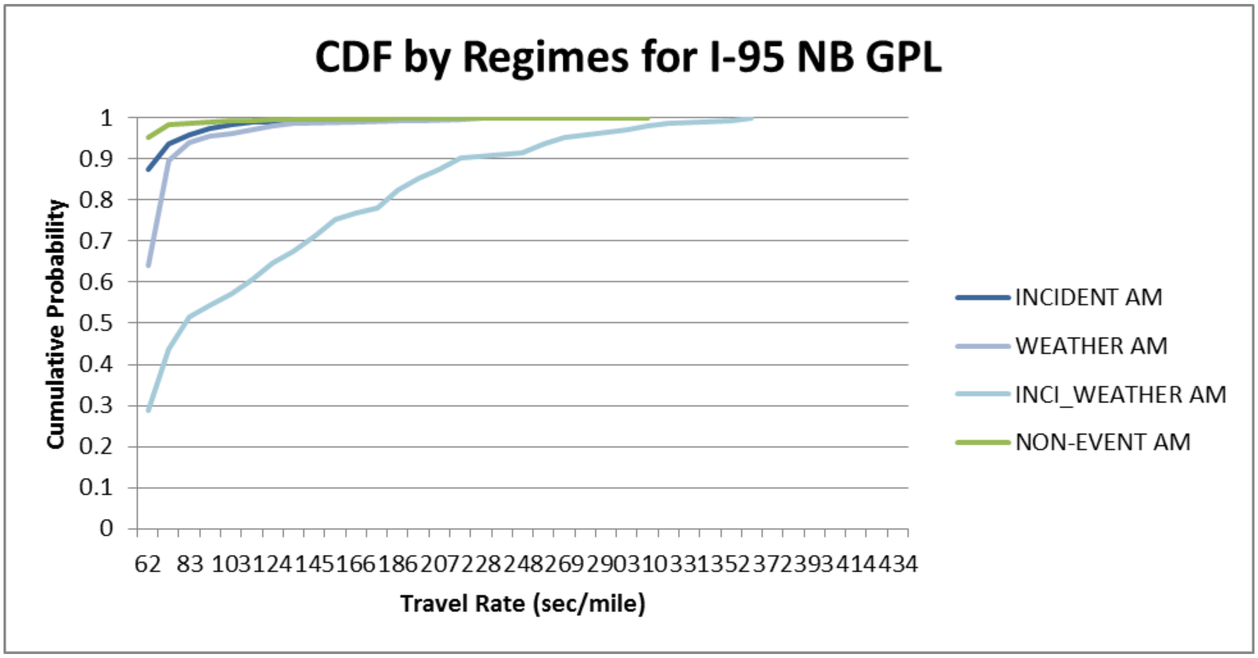
Time Period	Nonevent	Incident	Weather	Incident + Weather	Total
AM	0%	0%	1%	17%	19%
MD	0%	1%	1%	5%	7%
PM1	3%	9%	7%	17%	35%
PM2	5%	8%	8%	14%	35%
APM	0%	3%	0%	1%	4%
MN	0%	0%	0%	0%	0%

Table 3.3. Percentage of Unreliability Contribution

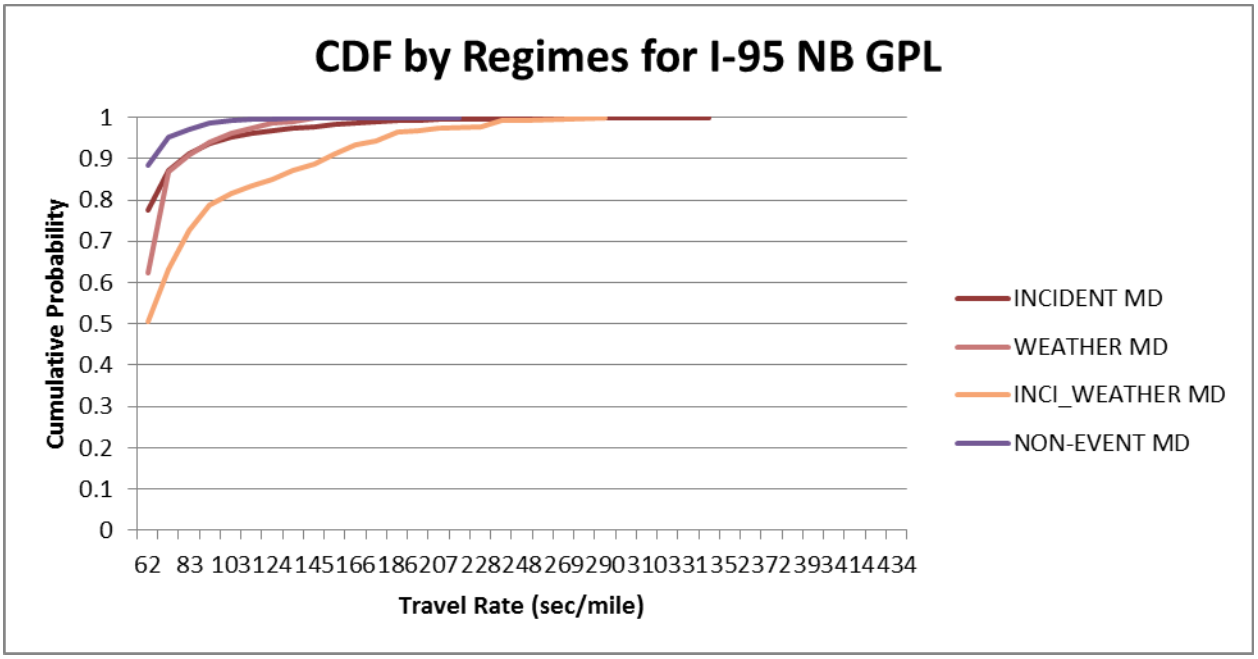
Time Period	Nonevent	Incident	Weather	Incident + Weather	Total
AM	2%	1%	0%	3%	5%
MD	3%	6%	1%	2%	11%
PM1	10%	15%	1%	2%	29%
PM2	21%	21%	2%	1%	45%
APM	2%	7%	0%	0%	9%
MN	1%	0%	0%	0%	1%

Figure 3.10 CDFs confirm that the worst conditions in each peak occurred during incident plus bad weather events and that the no-event conditions during the PM1 and particularly the PM2 peaks were bad. Incident and weather impacts were also clear.

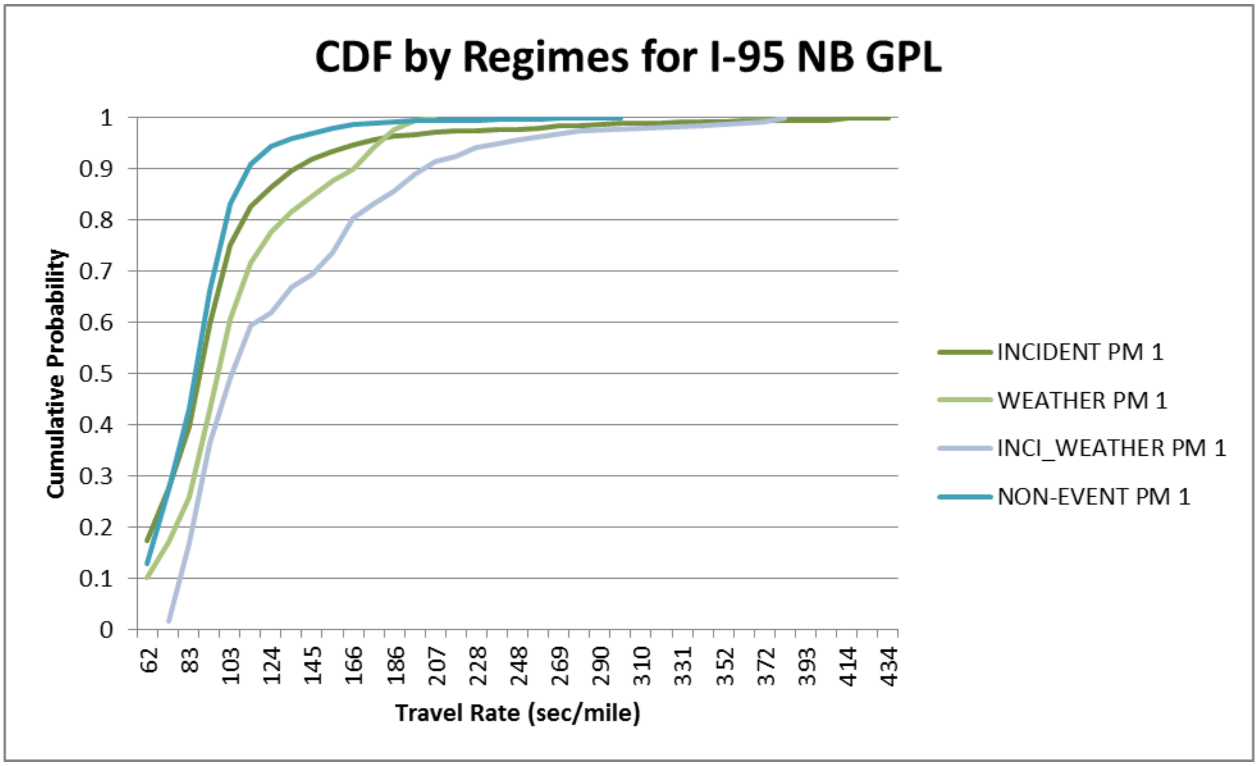
In addition to showing the results in CDF format, Figure 3.11, Figure 3.12, and Figure 3.13 summarize results in additional ways for the purpose of helping transportation agencies better visualize the results. Figure 3.11 shows the values of travel time for 50th, 80th, and 95th percentiles, and Figure 3.12 and Figure 3.13 show the corresponding speeds and TTIs, respectively.


CDF by Regimes for I-95 NB GPL
Cumulative Probability
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
62 83 103 124 145 166 186 207 228 248 269 290 310 331 352 372 393 414 434
Travel Rate (sec/mile)
INCIDENT AM
WEATHER AM
INCI_WEATHER AM
NON-EVENT AM

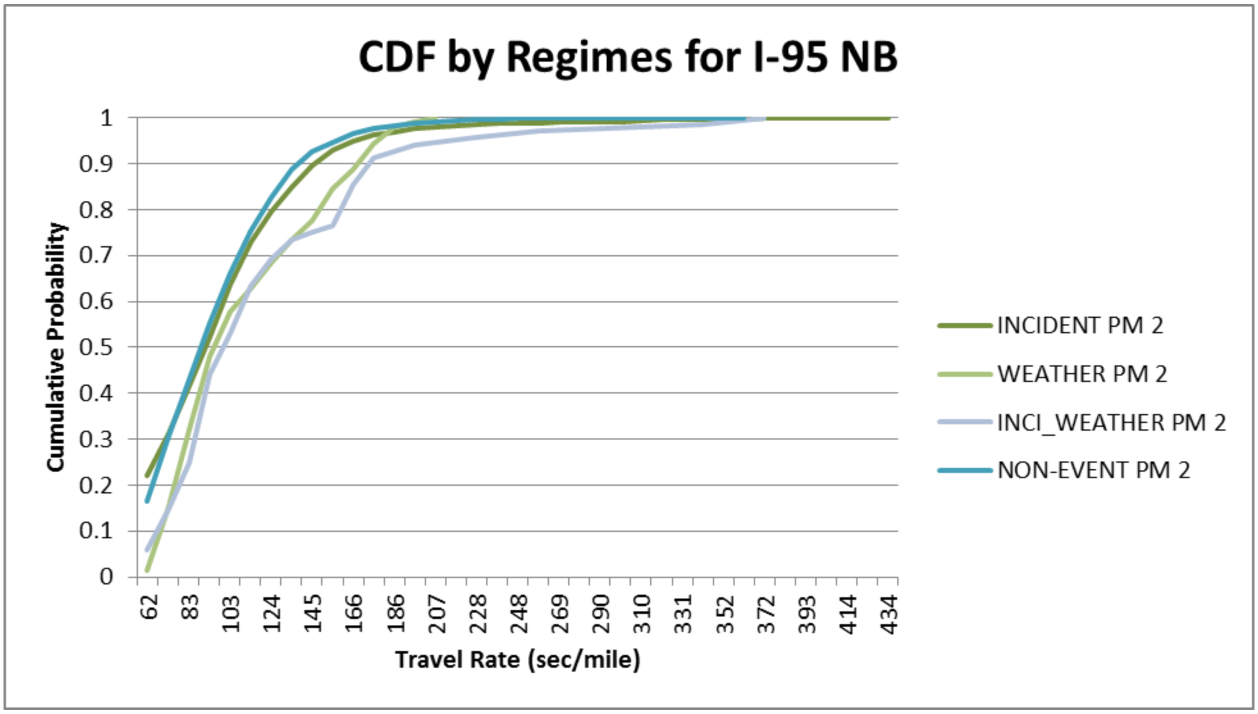
(a)


CDF by Regimes for I-95 NB GPL
Cumulative Probability
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
62 83 103 124 145 166 186 207 228 248 269 290 310 331 352 372 393 414 434
Travel Rate (sec/mile)
INCIDENT MD
WEATHER MD
INCI_WEATHER MD
NON-EVENT MD

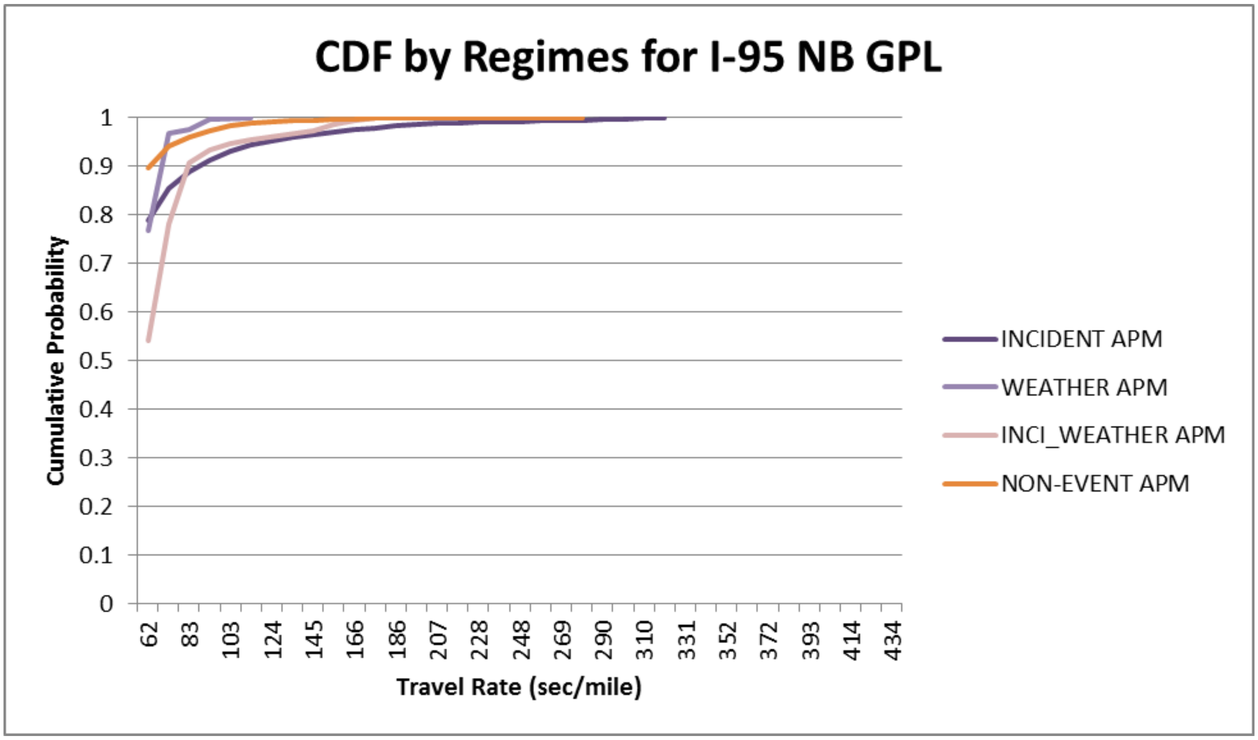
(b)


CDF by Regimes for I-95 NB GPL
Cumulative Probability
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
62
83
103
124
145
166
186
207
228
248
269
290
310
331
352
372
393
414
434
Travel Rate (sec/mile)
INCIDENT PM 1
WEATHER PM 1
INCI_WEATHER PM 1
NON-EVENT PM 1

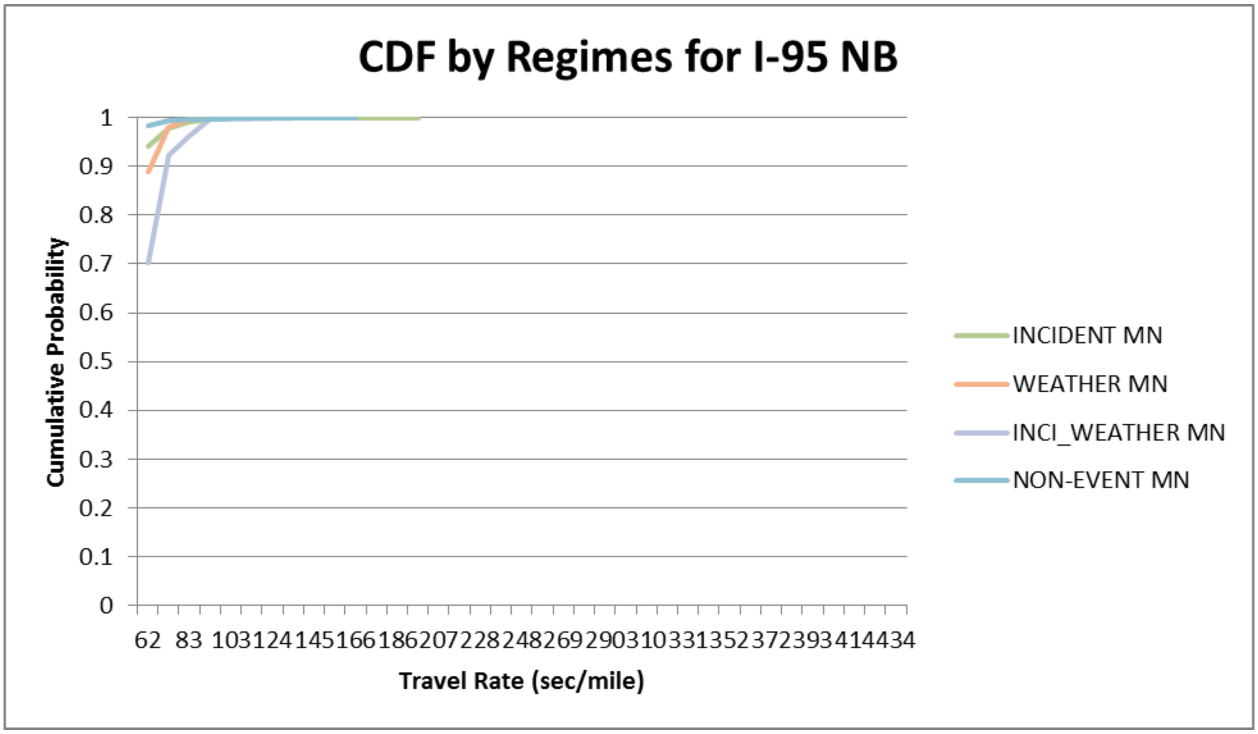
(c)


CDF by Regimes for I-95 NB
Cumulative Probability
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
62
83
103
124
145
166
186
207
228
248
269
290
310
331
352
372
393
414
434
Travel Rate (sec/mile)
INCIDENT PM 2
WEATHER PM 2
INCI_WEATHER PM 2
NON-EVENT PM 2

(d)

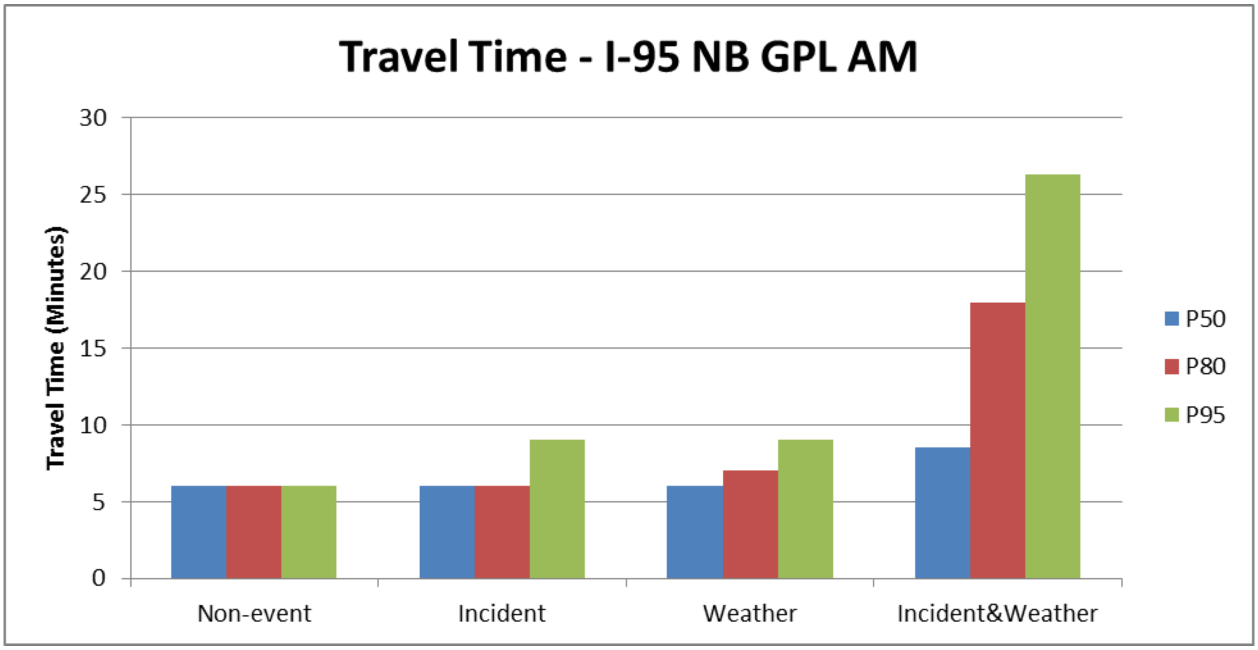


(e)

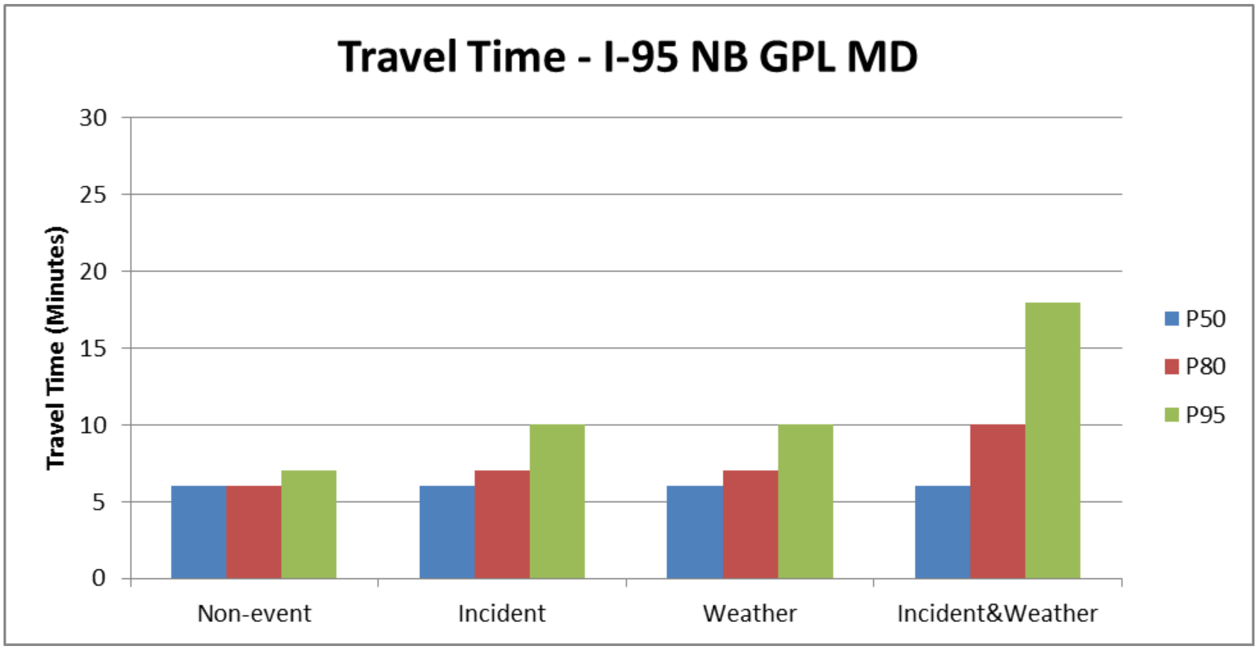


(f)

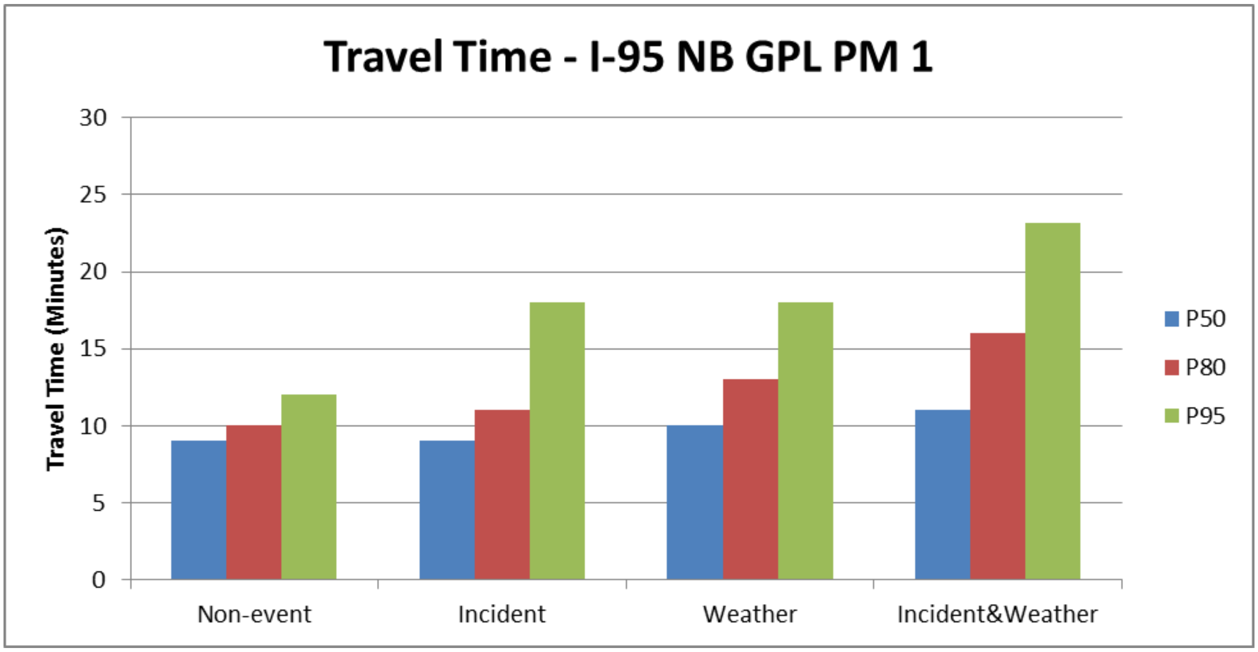
Figure 3.10. CDF by regimes for I-95 NB GPL for (a) AM peak, (b) MD, (c) PM1, (d) PM2, (e) APM peak, and (f) MN periods.


Travel Time - I-95 NB GPL AM
Travel Time (Minutes)
30
25
20
15
10
5
0
Non-event
Incident
Weather
Incident&Weather
P50
P80
P95

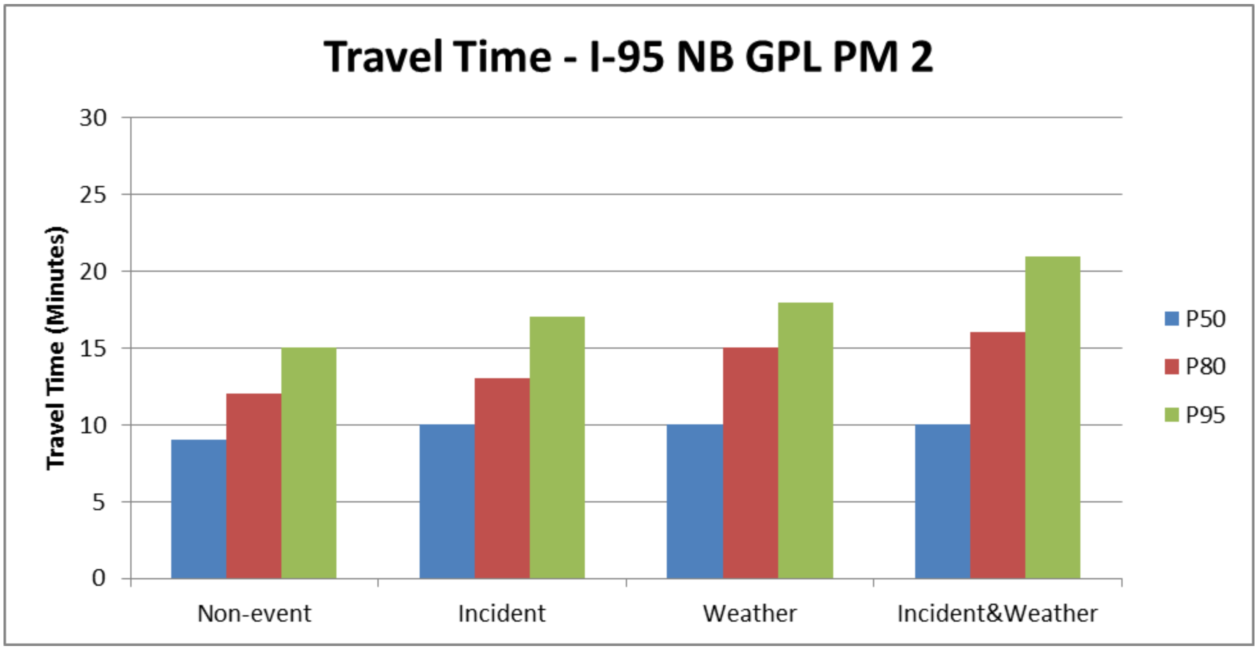
(a)


Travel Time - I-95 NB GPL MD
Travel Time (Minutes)
30
25
20
15
10
5
0
Non-event
Incident
Weather
Incident&Weather
P50
P80
P95

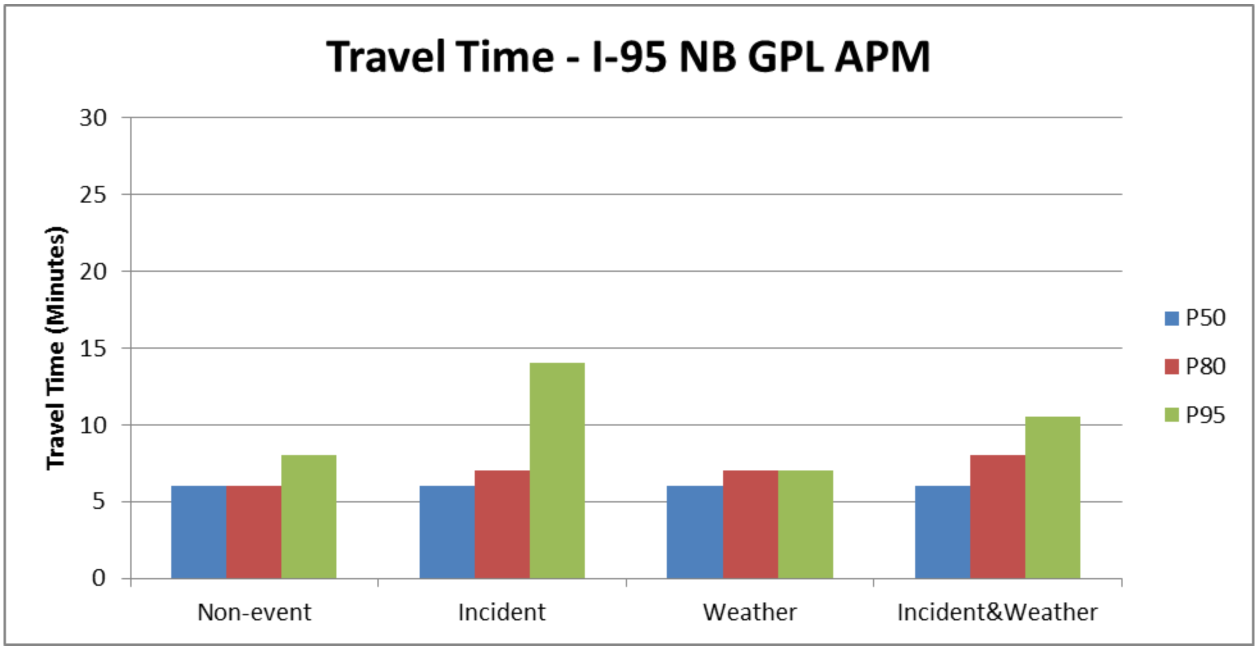
(b)


Travel Time - I-95 NB GPL PM 1
Travel Time (Minutes)
30
25
20
15
10
5
0
Non-event
Incident
Weather
Incident&Weather
P50
P80
P95

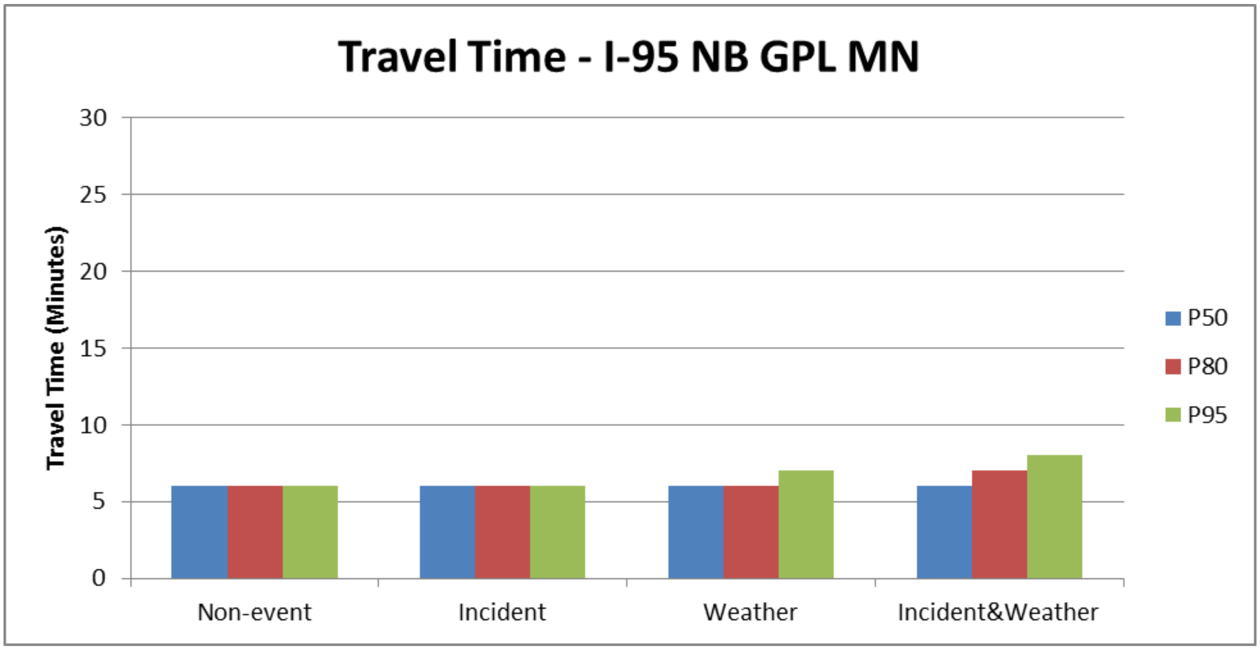
(c)


Travel Time - I-95 NB GPL PM 2
Travel Time (Minutes)
30
25
20
15
10
5
0
Non-event
Incident
Weather
Incident&Weather
P50
P80
P95

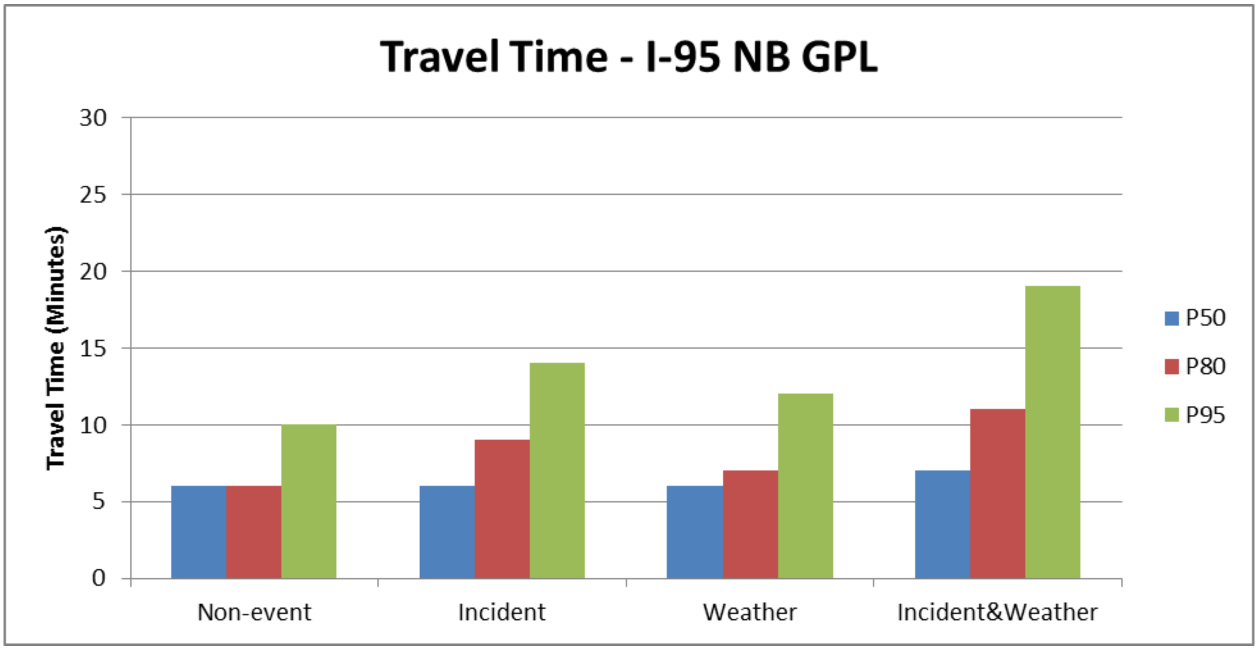
(d)


Travel Time - I-95 NB GPL APM
Travel Time (Minutes)
30
25
20
15
10
5
0
Non-event
Incident
Weather
Incident&Weather
P50
P80
P95

(e)

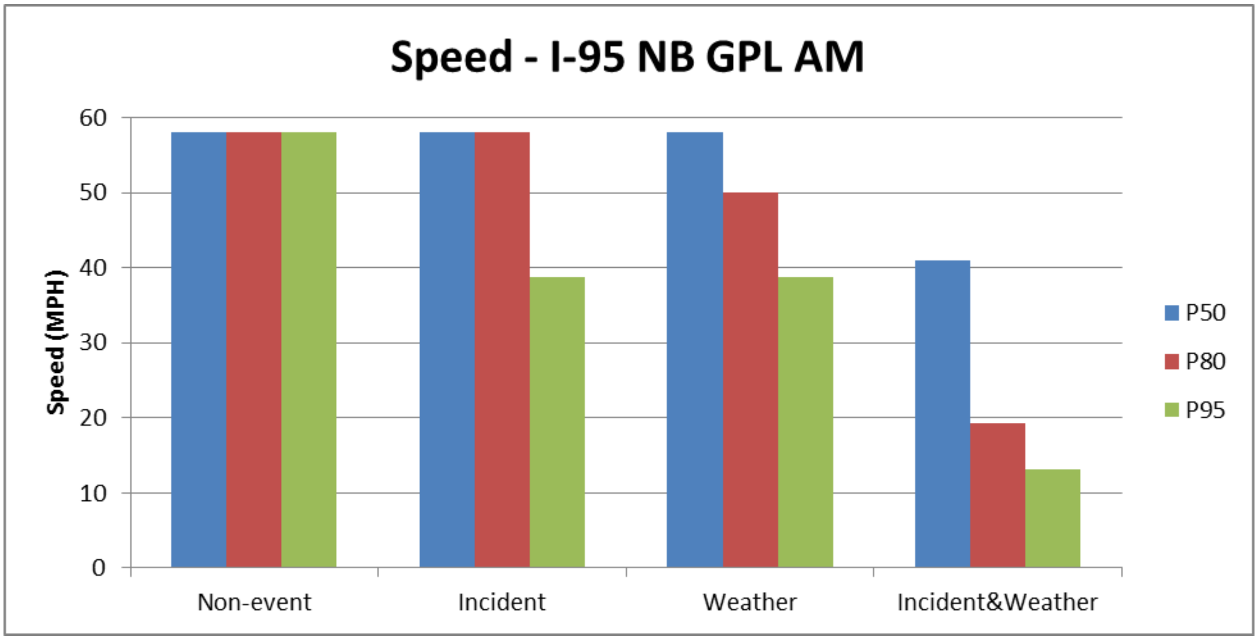

Travel Time - I-95 NB GPL MN
Travel Time (Minutes)
30
25
20
15
10
5
0
Non-event
Incident
Weather
Incident&Weather
P50
P80
P95

(f)

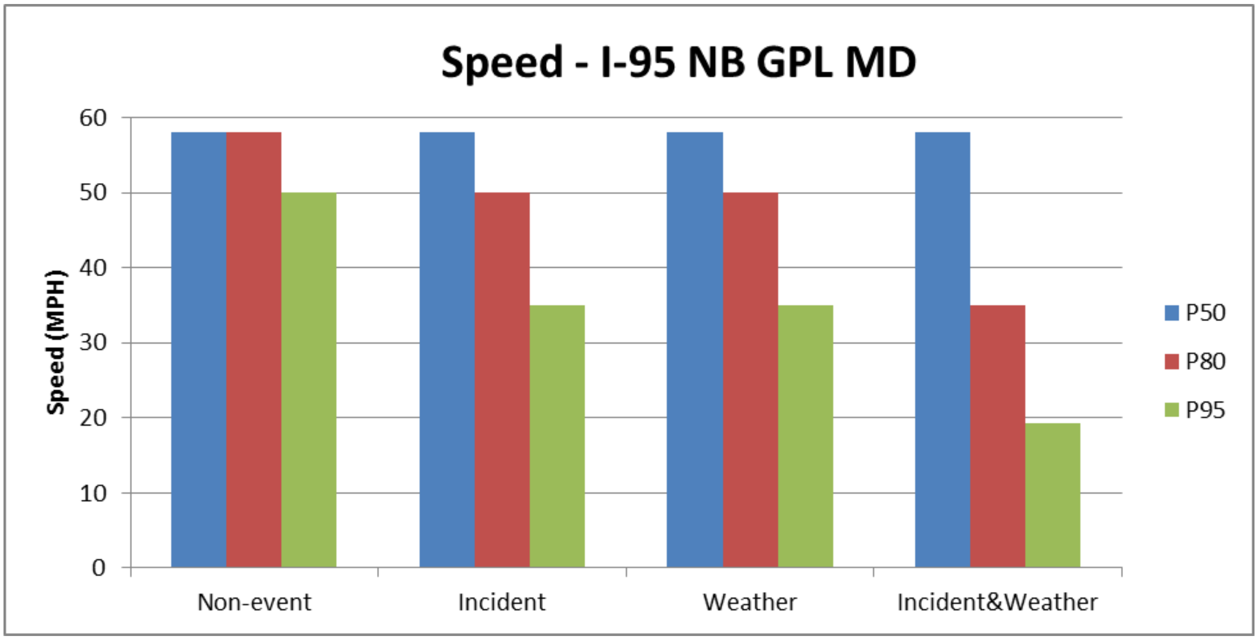


(g)

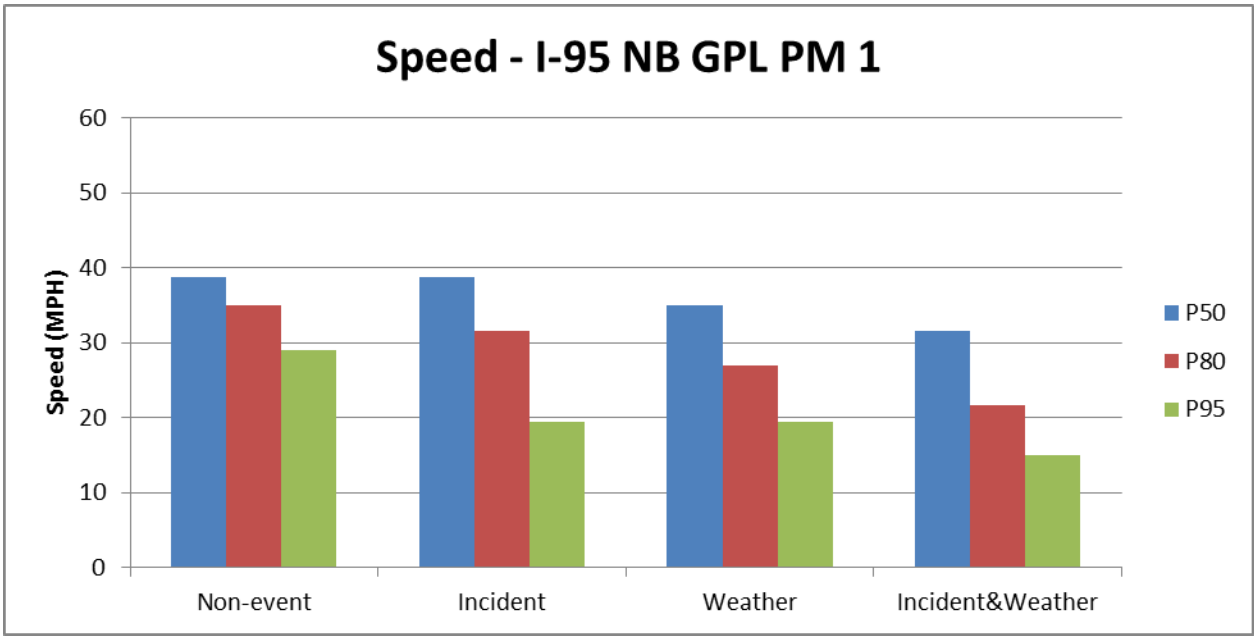
Figure 3.11. I-95 NB GPL travel times for (a) AM peak, (b) MD, (c) PM1, (d) PM2, (e) APM, (f) MN, and (g) all time periods.


Speed - I-95 NB GPL AM
Speed (MPH)
0
10
20
30
40
50
60
Non-event
Incident
Weather
Incident&Weather
P50
P80
P95

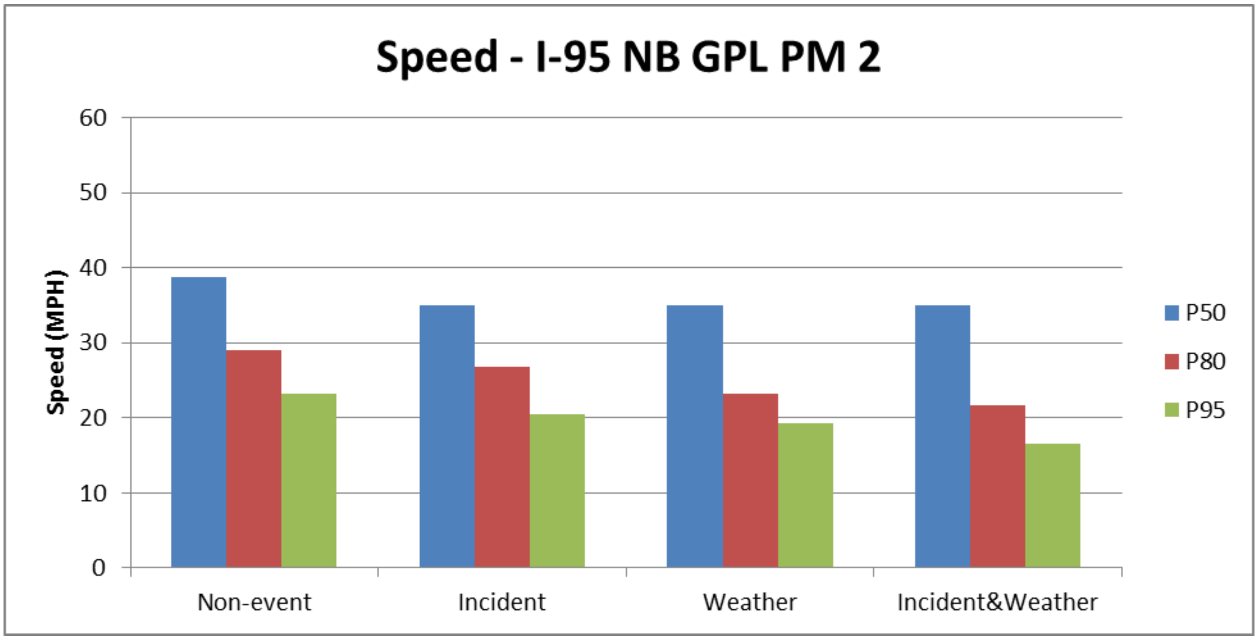
(a)


Speed - I-95 NB GPL MD
Speed (MPH)
0
10
20
30
40
50
60
Non-event
Incident
Weather
Incident&Weather
P50
P80
P95

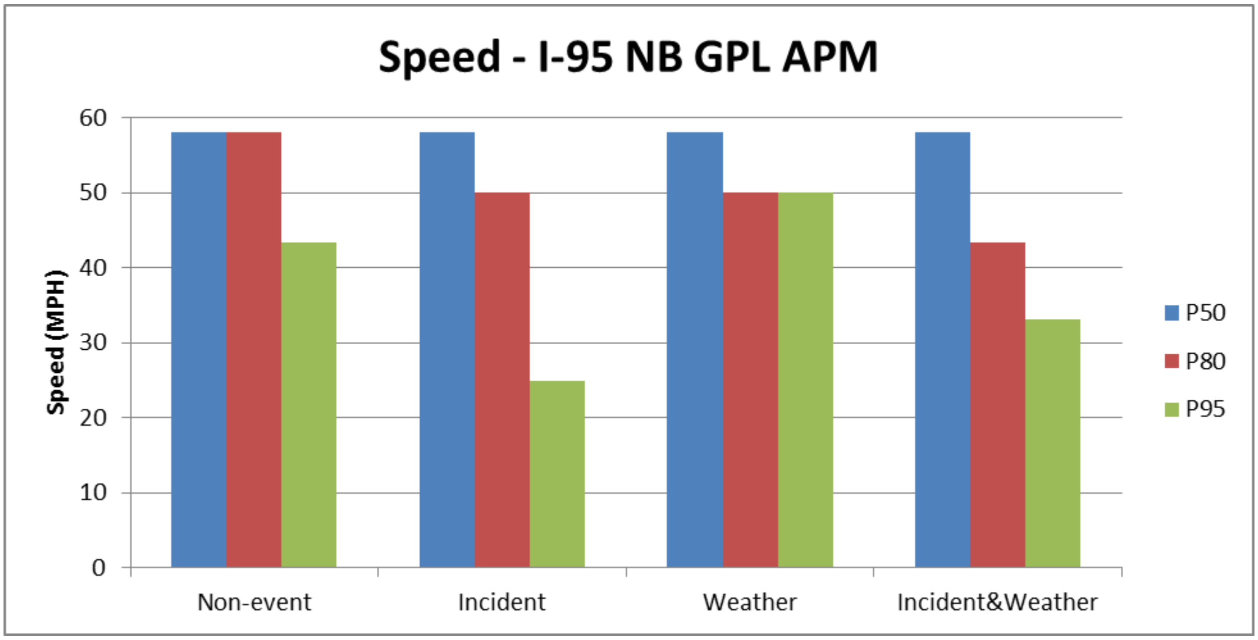
(b)


Speed - I-95 NB GPL PM 1
Speed (MPH)
60
50
40
30
20
10
0
Non-event
Incident
Weather
Incident&Weather
P50
P80
P95

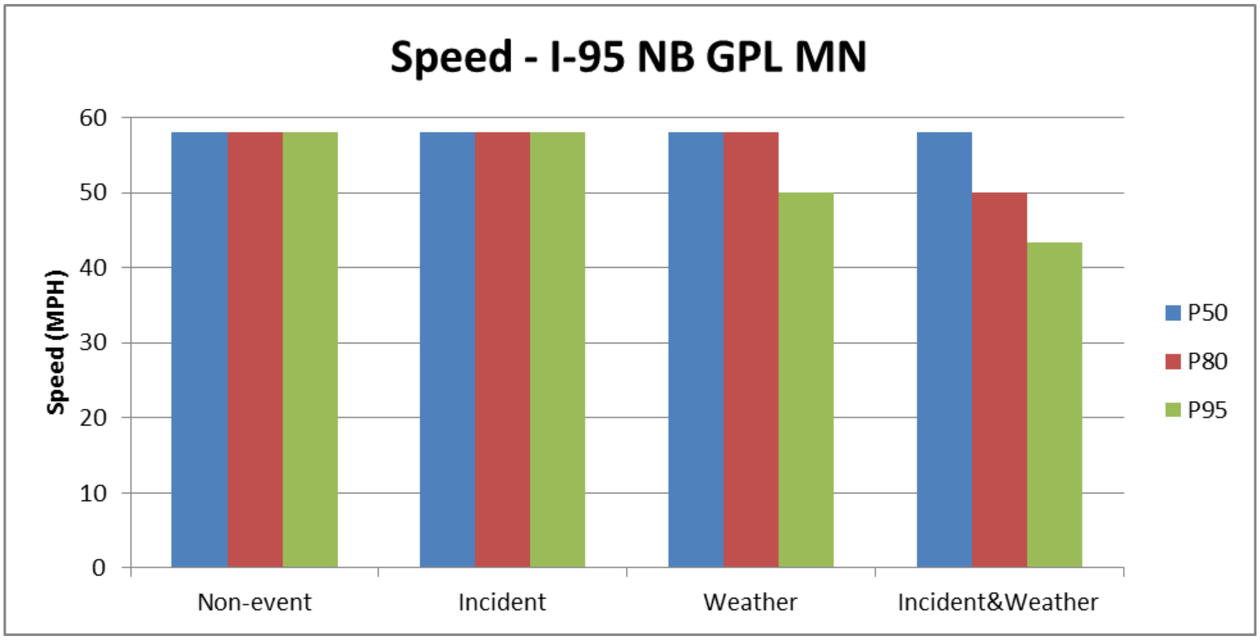
(c)


Speed - I-95 NB GPL PM 2
Speed (MPH)
60
50
40
30
20
10
0
Non-event
Incident
Weather
Incident&Weather
P50
P80
P95

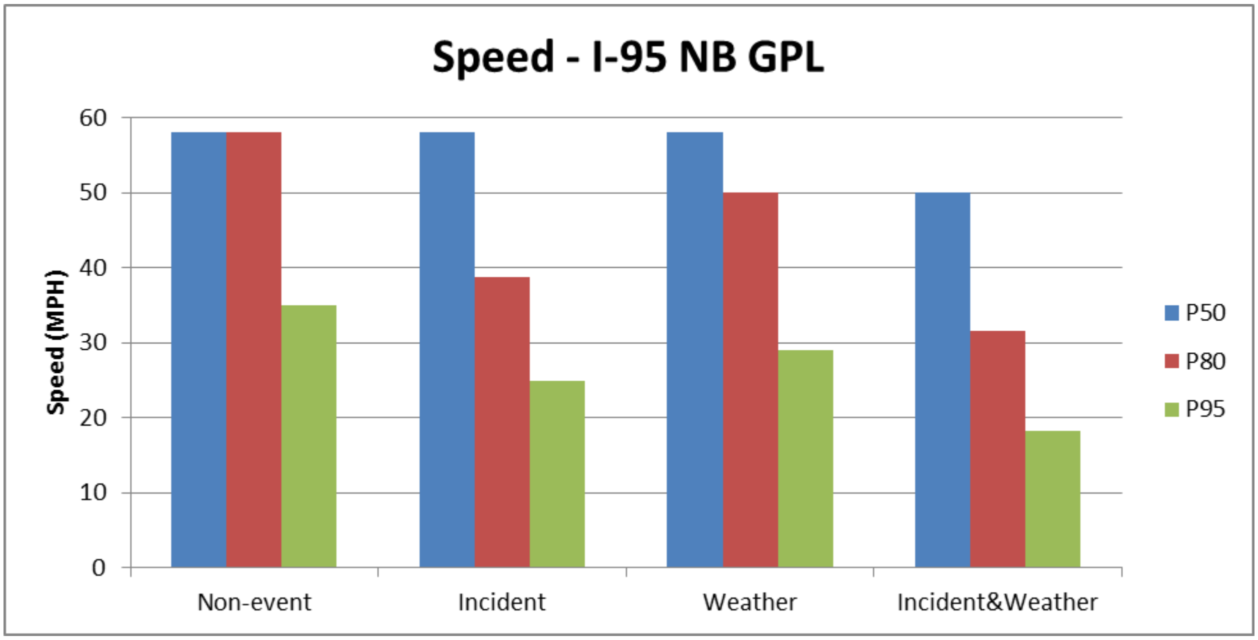
(d)


Speed - I-95 NB GPL APM
Speed (MPH)
60
50
40
30
20
10
0
Non-event
Incident
Weather
Incident&Weather
P50
P80
P95

(e)

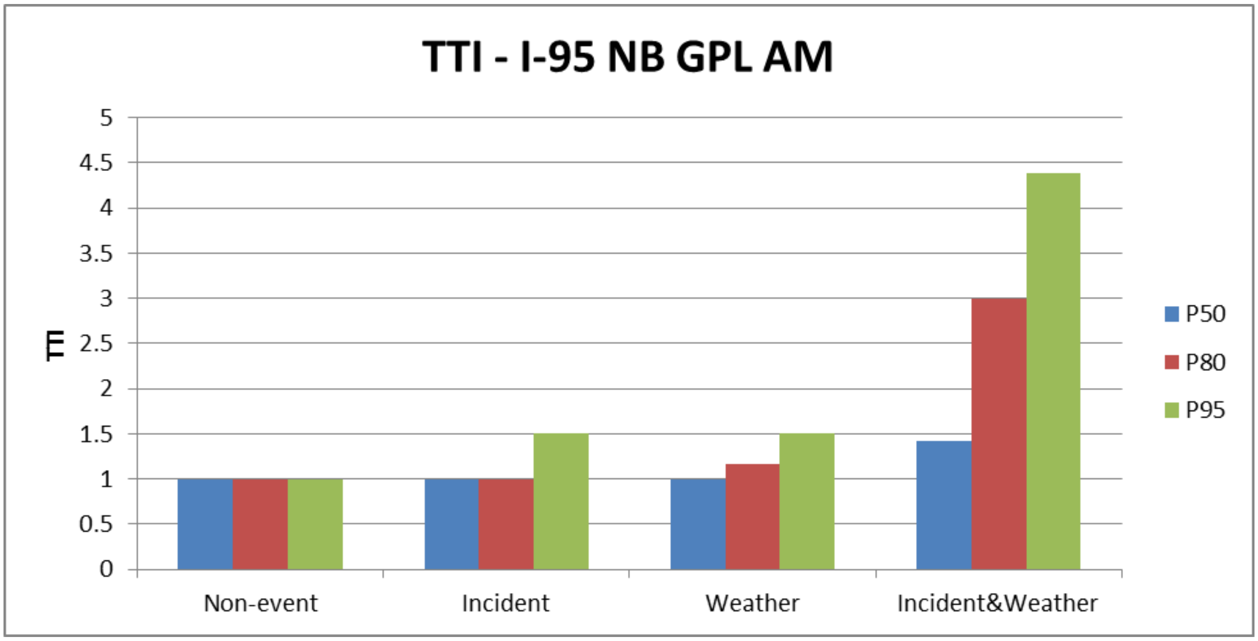

Speed - I-95 NB GPL MN
Speed (MPH)
60
50
40
30
20
10
0
Non-event
Incident
Weather
Incident&Weather
P50
P80
P95

(f)

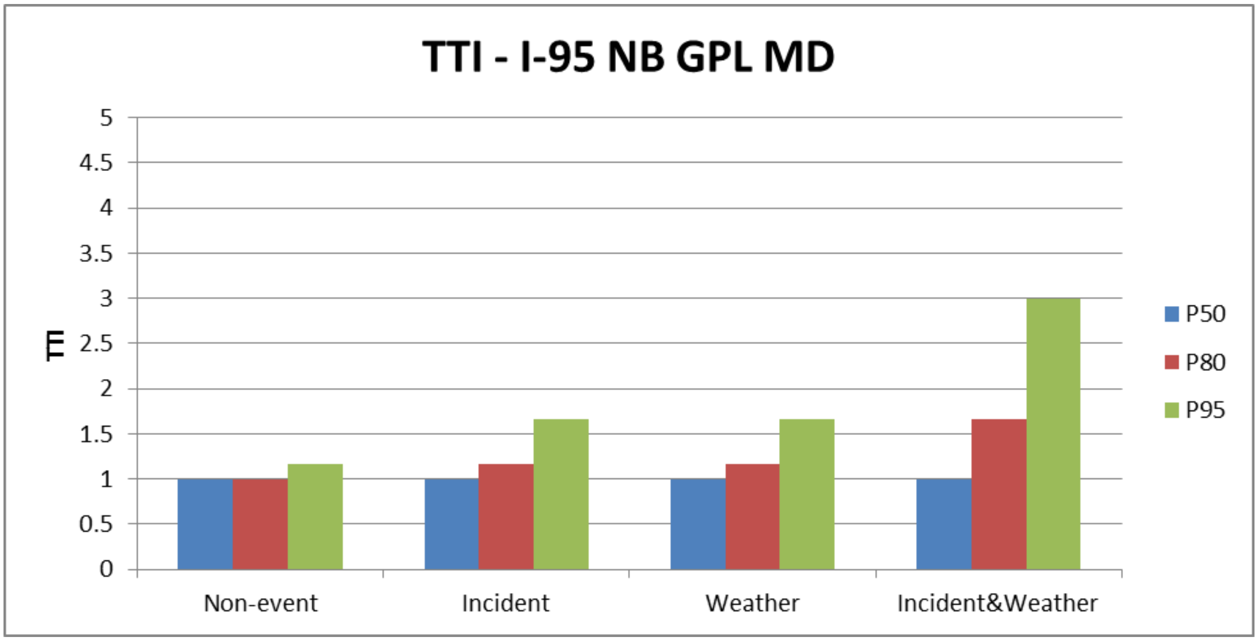


(g)

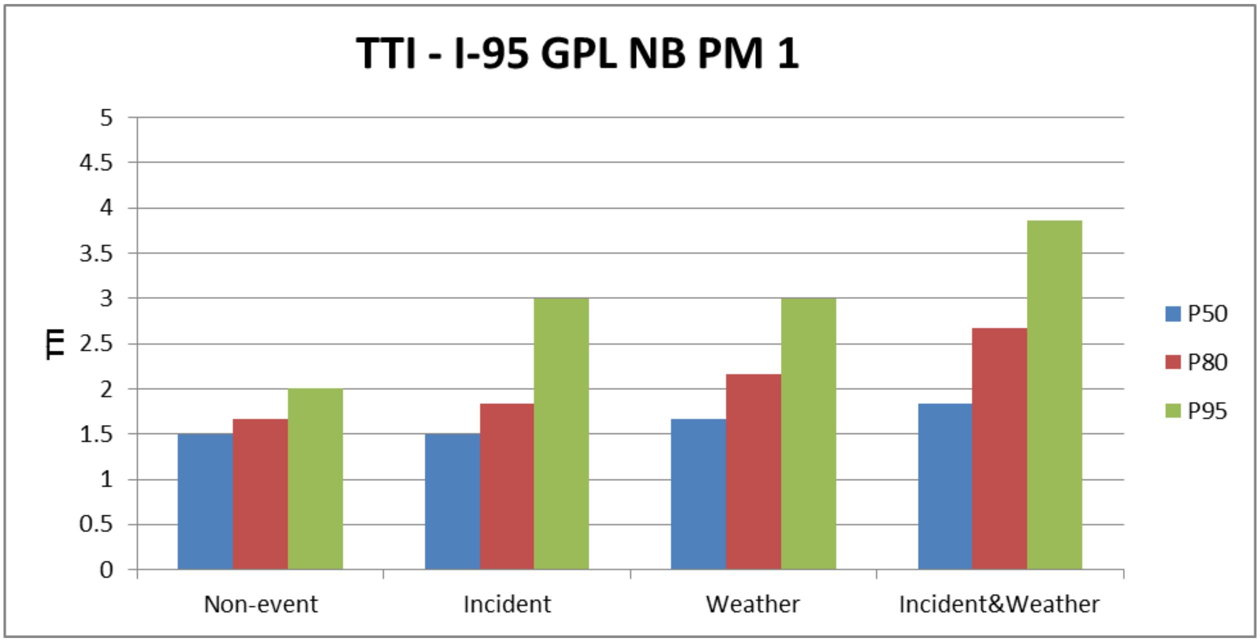
Figure 3.12. I-95 NB GPL speeds for AM peak, (b) MD, (c) PM1, (d) PM2, (e) APM, (f) MN, and (g) all time periods.


TTI - I-95 NB GPL AM
TTI
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
Non-event
Incident
Weather
Incident&Weather
P50
P80
P95

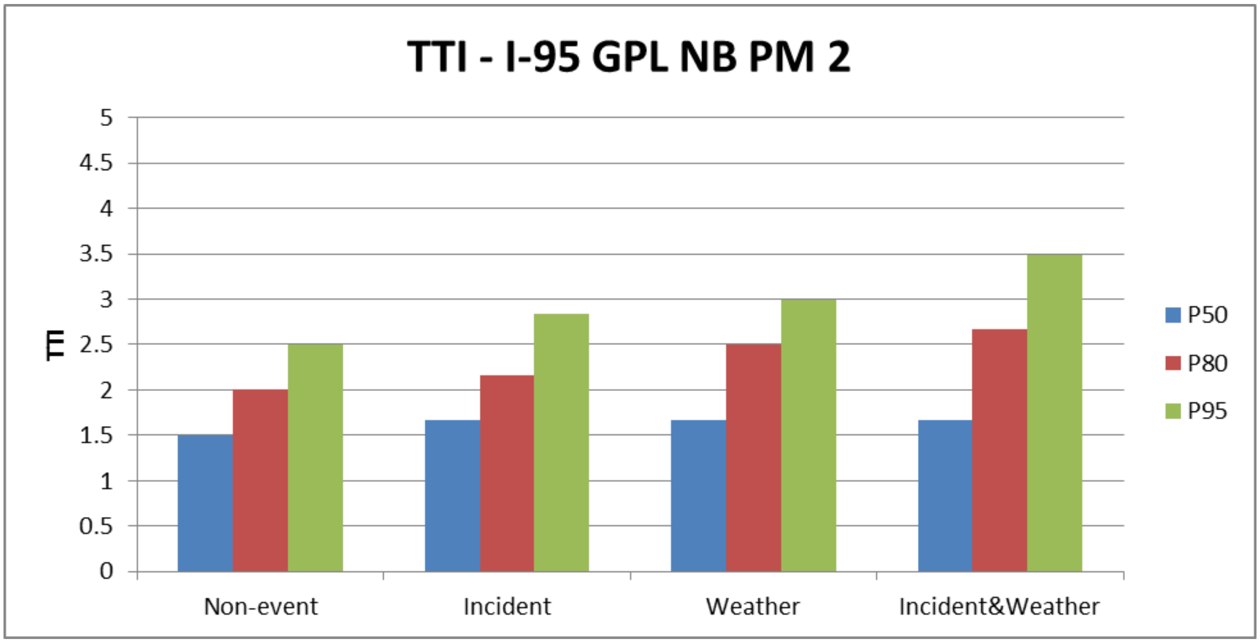
(a)


TTI - I-95 NB GPL MD
TTI
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
Non-event
Incident
Weather
Incident&Weather
P50
P80
P95

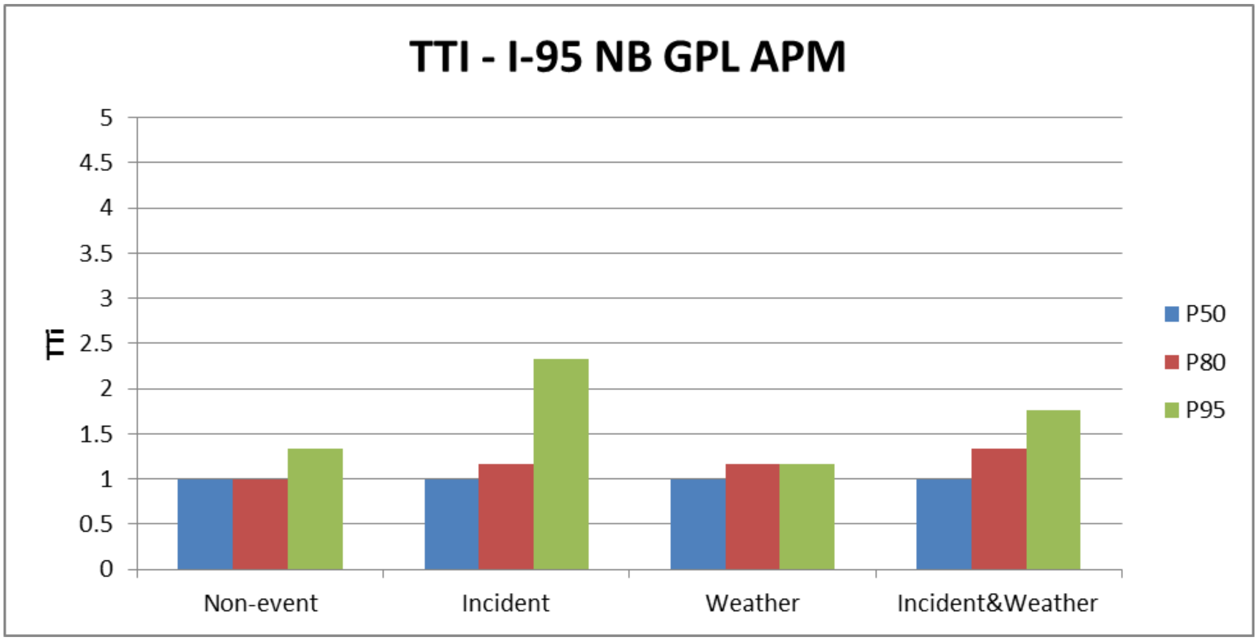
(b)


TTI - I-95 GPL NB PM 1
TTI
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
Non-event
Incident
Weather
Incident&Weather
P50
P80
P95

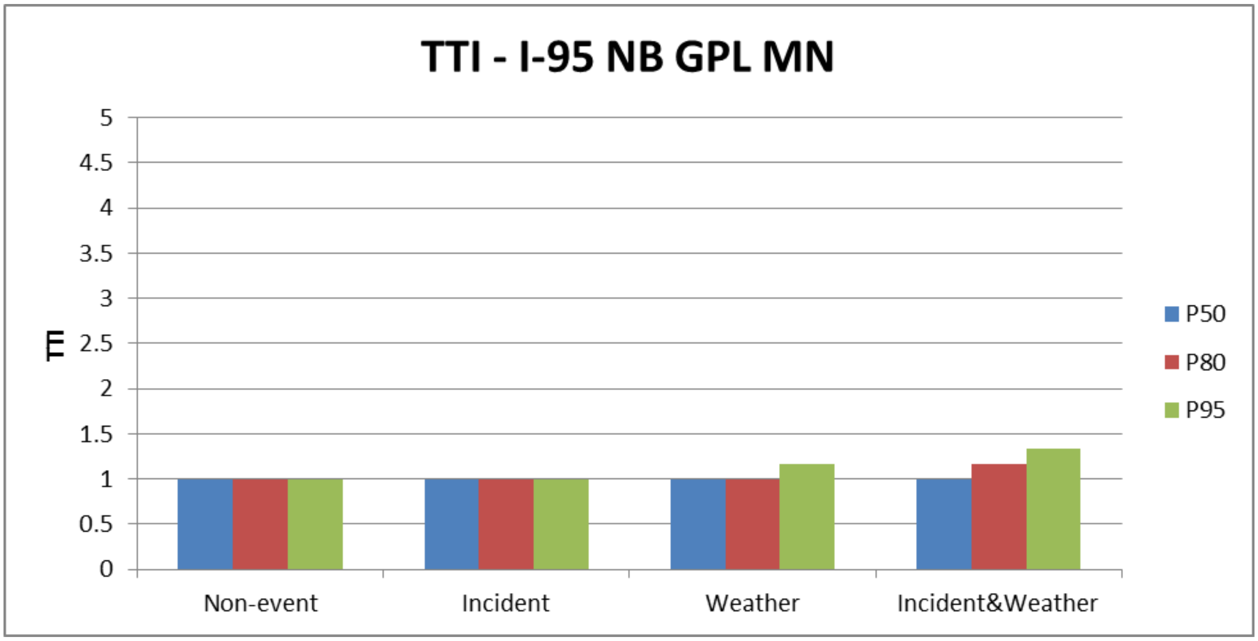
(c)


TTI - I-95 GPL NB PM 2
TTI
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
Non-event
Incident
Weather
Incident&Weather
P50
P80
P95

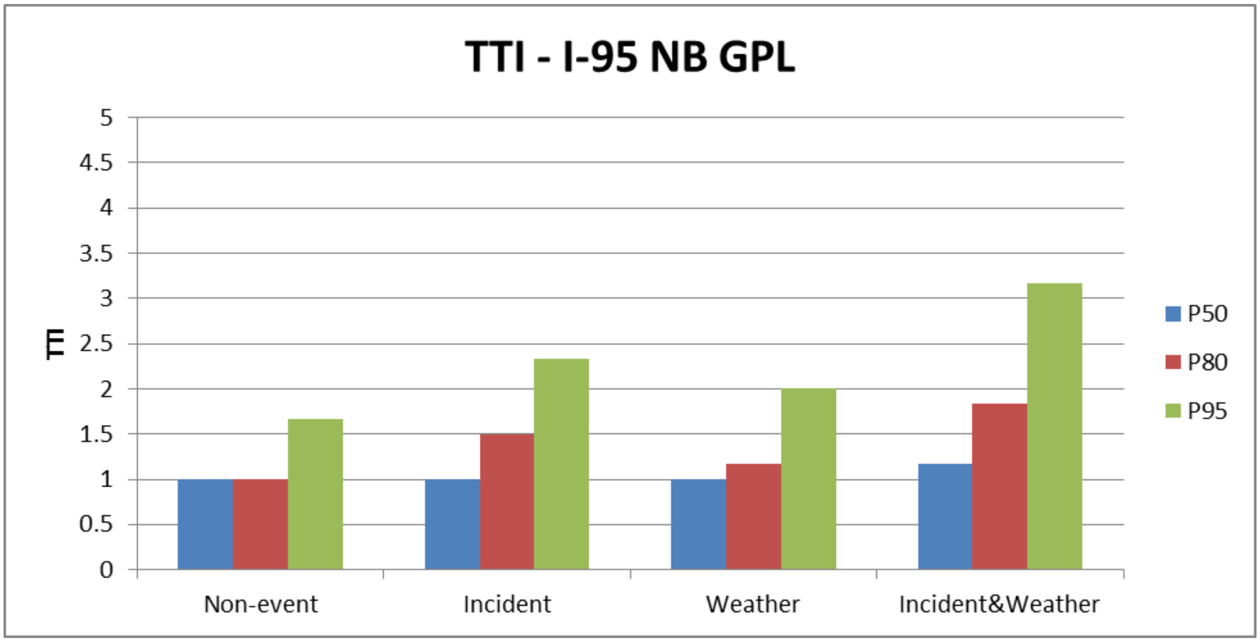
(d)


TTI - I-95 NB GPL APM
TTI
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
Non-event
Incident
Weather
Incident&Weather
P50
P80
P95

(e)


TTI - I-95 NB GPL MN
TTI
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
Non-event
Incident
Weather
Incident&Weather
P50
P80
P95

(f)



(g)

Figure 3.13 I-95 NB GPL TTIs for (a) AM peak, (b) MD, (c) PM1, (d) PM2, (e) APM, (f) MN, and (g) all time periods.

In addition to the above visualization and analysis techniques, other reliability performance measures were estimated for every five minutes of the day. These estimations were done based on TMC operation staff requirements for fine-grained analysis of reliability. The additional measures included the mean and 50th, 80th, and 95th percentile TTIs; semistandard deviation; buffer index; skew statistics; on-time performance (based on 1.1 and 1.25 thresholds); and the misery index, as shown in Figure 3.14 to Figure 3.23, respectively.

The variation of the mean TTI by five-minute intervals during the 24 hours of the day (see Figure 3.14) shows that with no incidents and when the demand did not exceed the high-demand threshold, the mean TTI was 1.3 to 1.4 (i.e., 30% to 40% higher in travel time than the free-flow travel time) between 3:00 and 5:00 p.m., increased to about 1.45 between 5:00 and 5:35 p.m., and then dropped to 1.15 by 6:20 p.m. During higher-demand days, the mean TTI between 3:00 and 5:00 p.m. was about 1.54 but increased to 1.78 between 5:00 and 6:30 p.m. Therefore, higher-demand days not only increased the TTI but also elongated the period during which the TTI was high.

A similar trend can be seen in Figure 3.17 for the 95th percentile TTI. The high-demand contribution to the 95th percentile TTI was small until 5:00 p.m., indicating that the worst 5% travel was caused mainly by other events. Between 5:00 and 7:00 p.m., however, the high demand increased the 95th percentile TTI from 2.35 for normal-demand congested conditions to 2.70. Incidents appeared to be the main contributors to the 95th percentile TTI in the early PM peak and the rest of the day. However, between 5:00 and 7:00 p.m., the impact of high demand during the no-event day was significant. Figure 3.13 also confirms that during the normal-demand period, the 95 percentile TTI still had a high value. This figure also shows that there was some effect of weather on reliability, particularly during PM1 and PM2, but to a lesser degree than incidents and high demand.

Another interesting finding from the figures is that the impacts of the influencing factors on the 95th percentile TTI and 80th percentile TTI were much higher than the impacts of the influencing factors on the median or mean TTI. This finding is important as it allows stronger justifications of advanced strategies to address factors such as incidents, weather, and fluctuations in demands. For example, when considering the mean TTI at 4:00 p.m., the value was 1.41 under normal demand and no-event and 1.62 under all conditions combined (a difference of about 15%). The corresponding values for the 95 percentile TTI were 1.9 and 2.5, respectively (a difference of about 31%).

Another observation is that the TTIs were still high even for normal conditions, indicating the potential impacts of external factors not accounted for in the analysis such as backups from off-ramps and downstream incidents, events on the ELs or opposing traffic, diversion from other routes, seasonal variations, and unrecorded weather and special events. This observation is important because it may explain that the FREEVAL-RL tool may sometimes underestimate unreliability because it does not account for all real-world events, as shown in a later chapter.

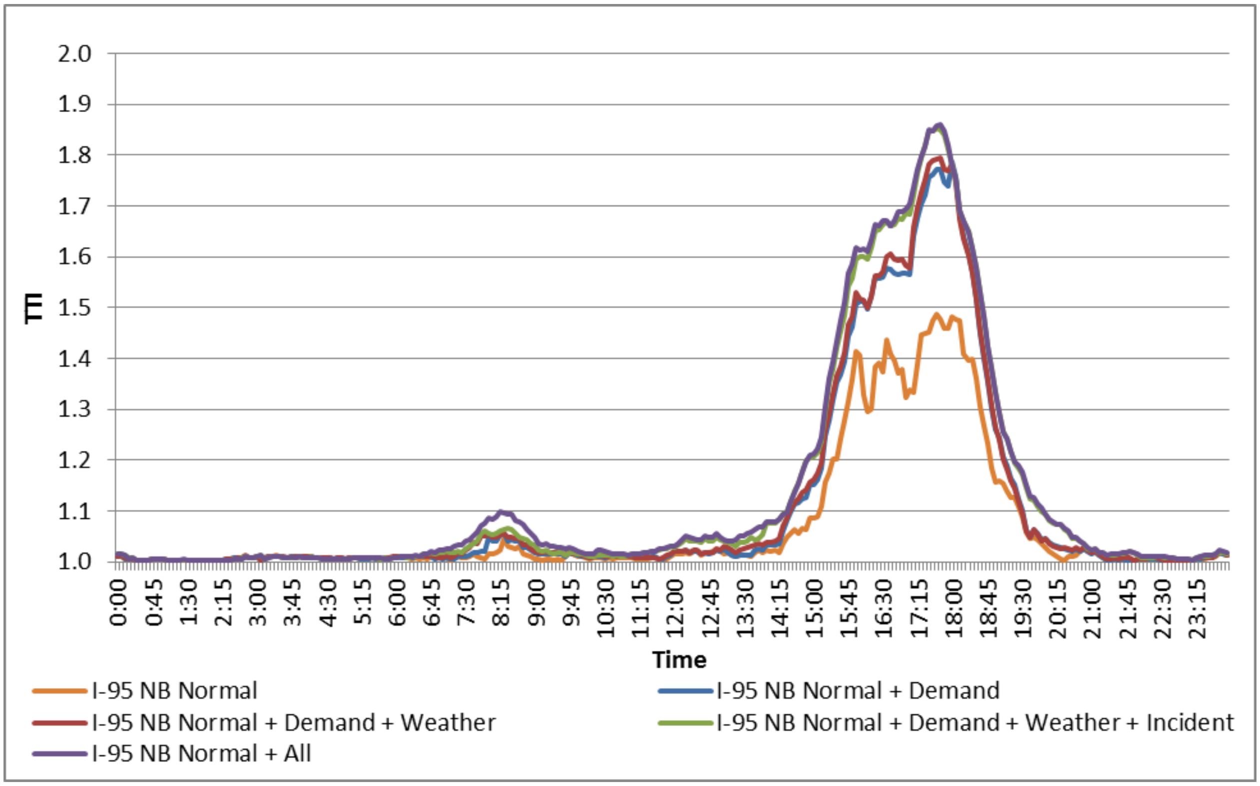


Figure 3.14. Mean TTI comparison for I-95 NB GPL.

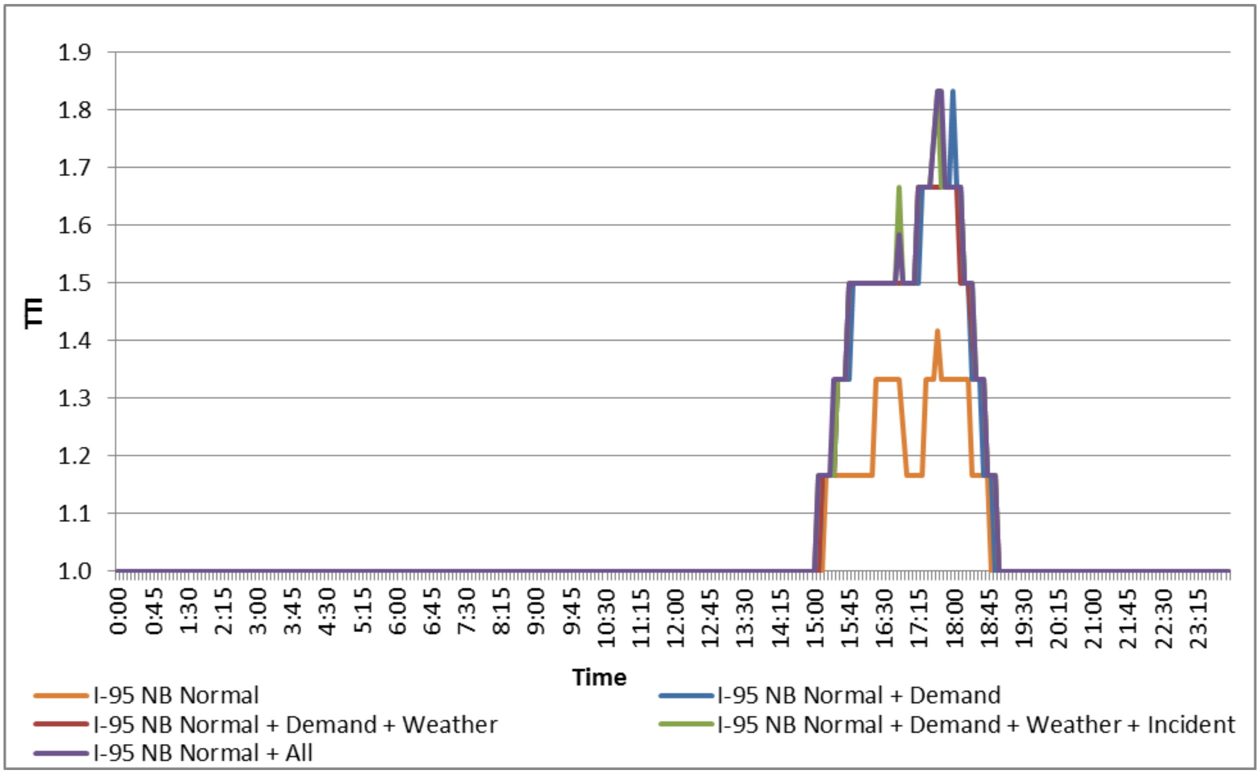


Figure 3.15. 50th percentile TTI comparison for I-95 NB GPL.

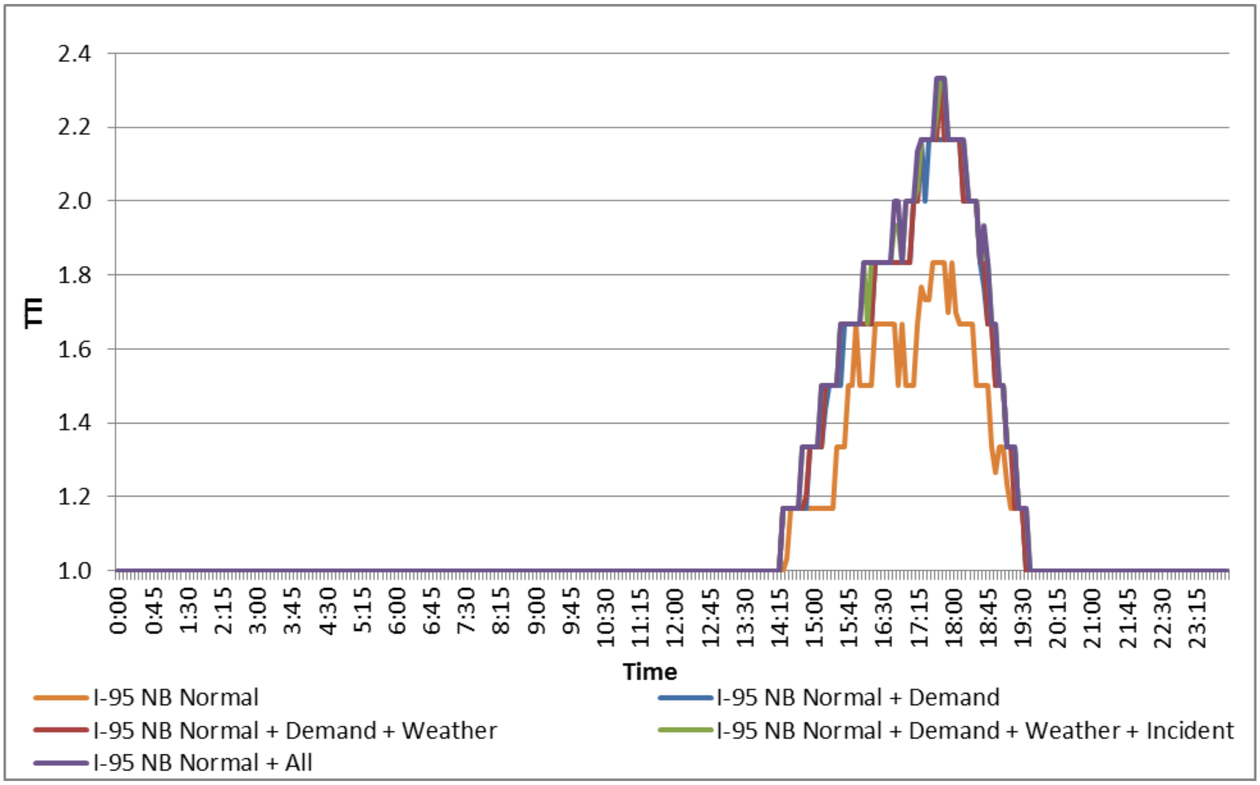


Figure 3.16. 80th percentile TTI comparison for I-95 NB GPL.

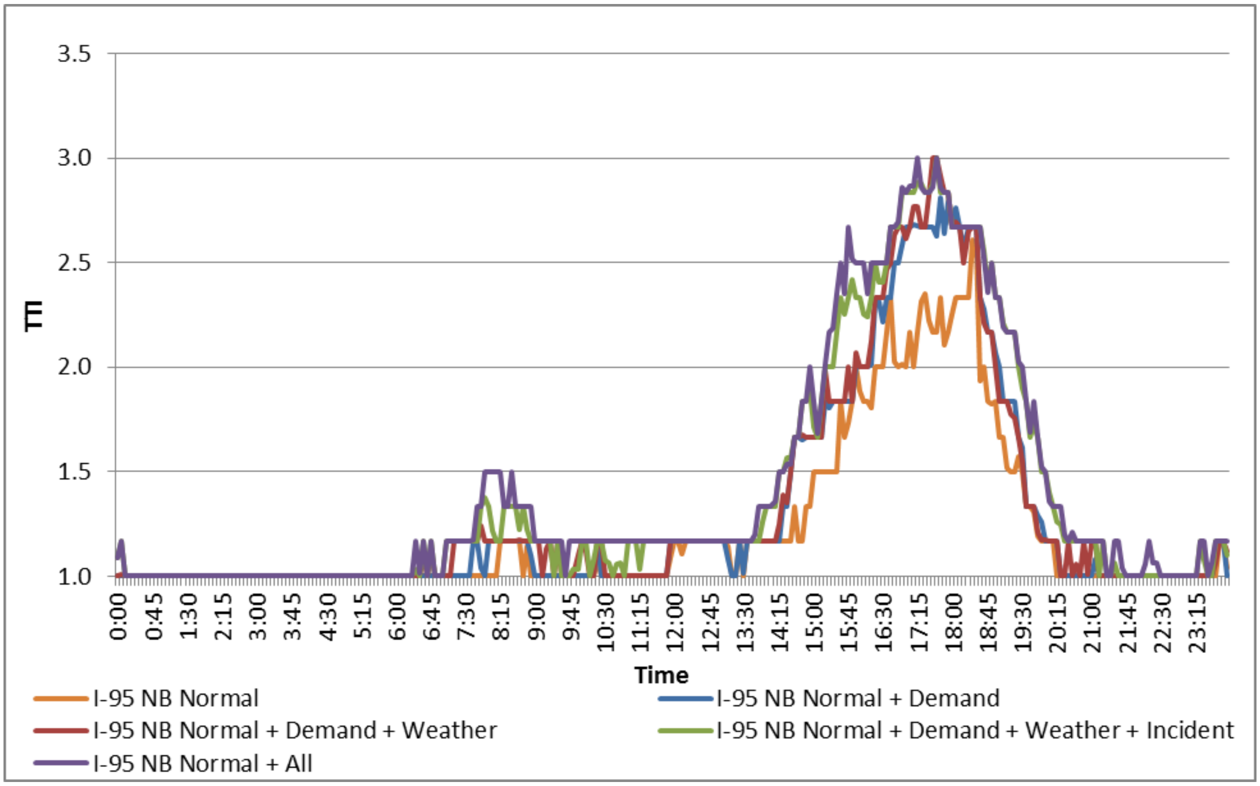


Figure 3.17. 95th percentile TTI comparison for I-95 NB GPL.

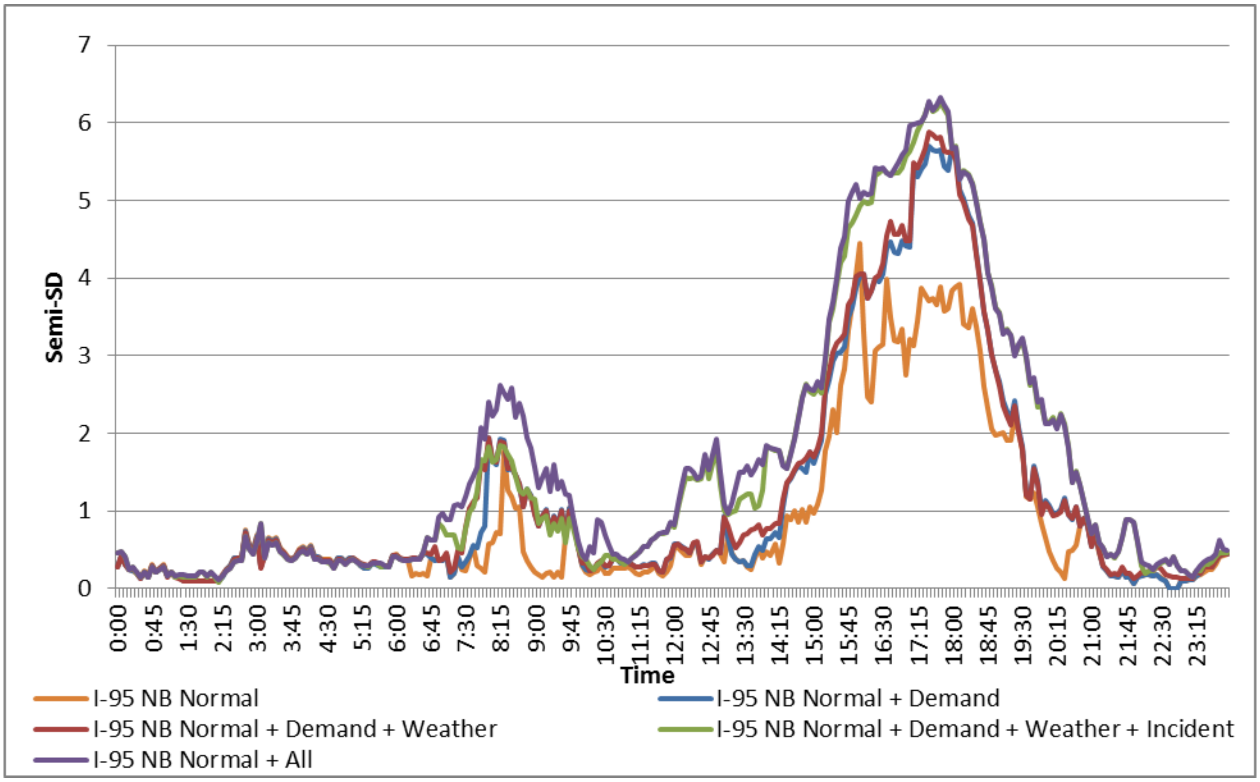


Figure 3.18. Semistandard deviation comparison for I-95 NB GPL.

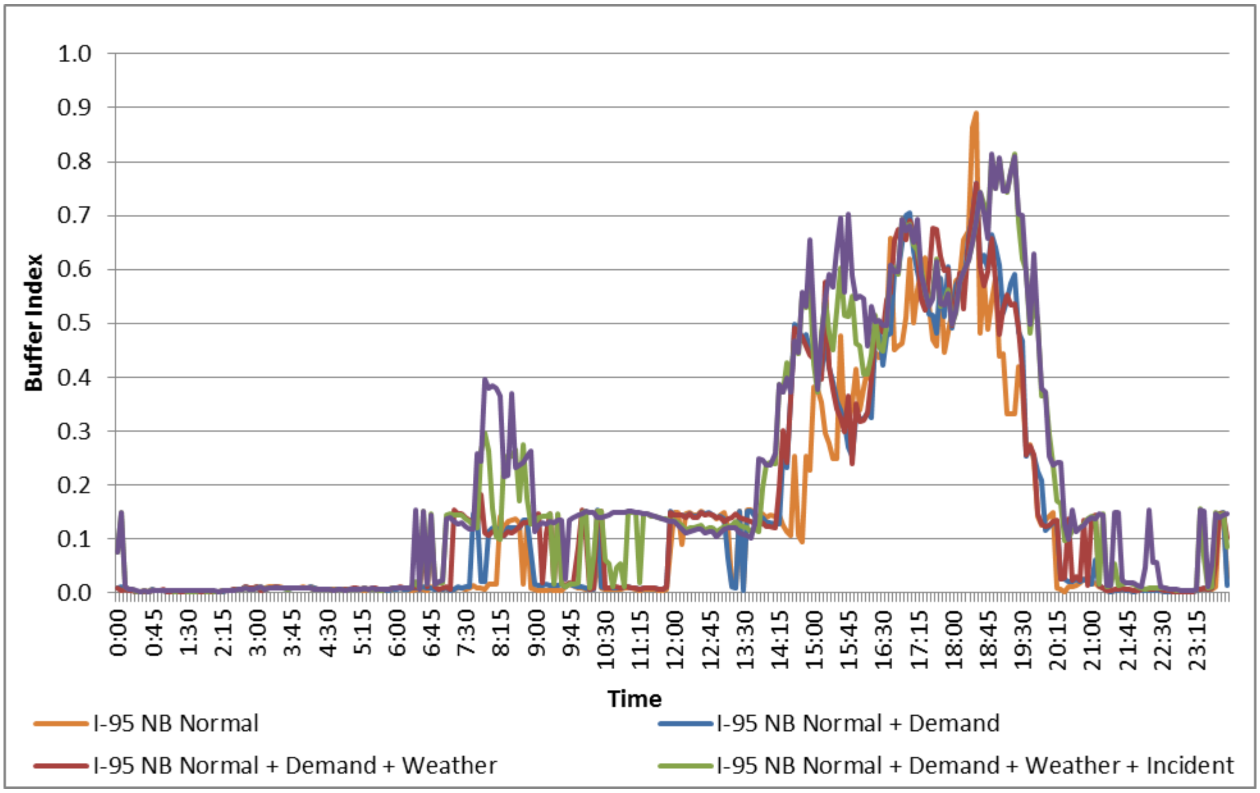


Figure 3.19. Buffer index comparison for I-95 NB GPL.

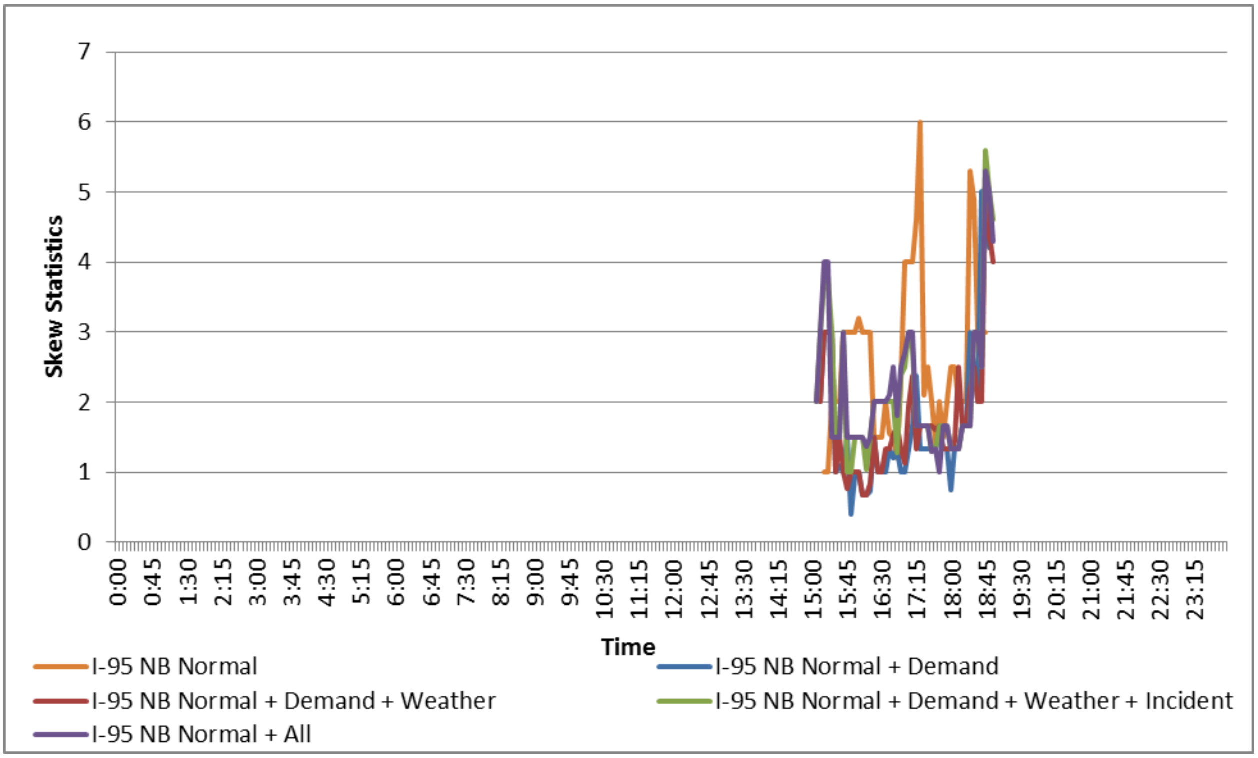


Figure 3.20. Skew statistics comparison for I-95 NB GPL.

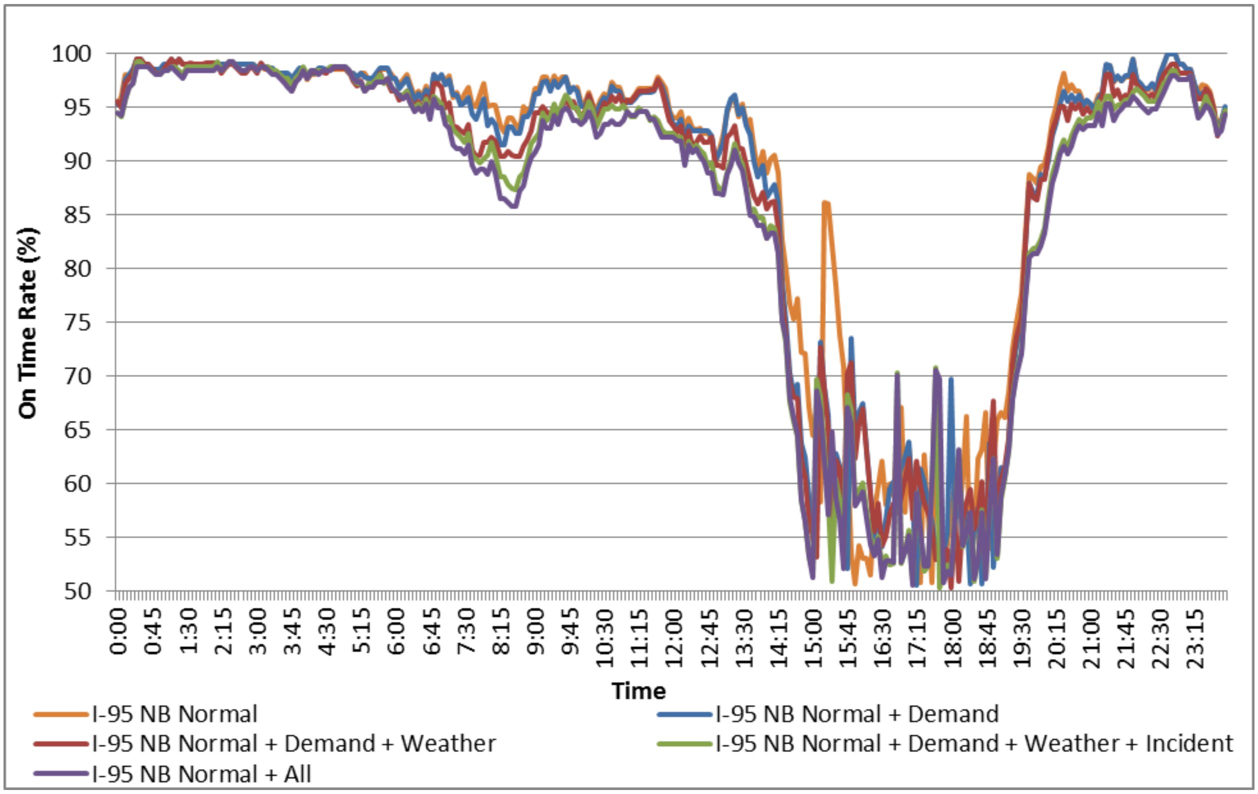


Figure 3.21. On-time performance comparison (based on 1.1) for I-95 NB GPL.

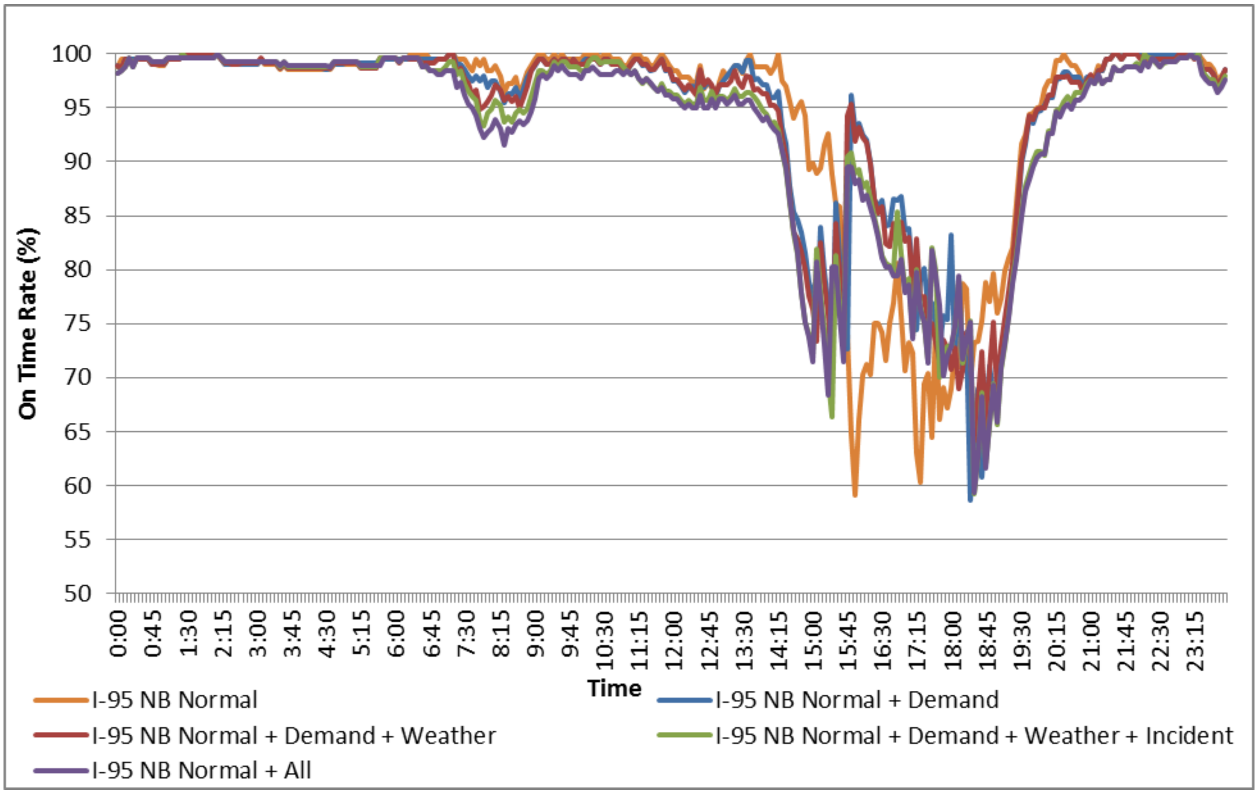


Figure 3.22. On-time performance comparison (based on 1.25) for I-95 NB GPL.

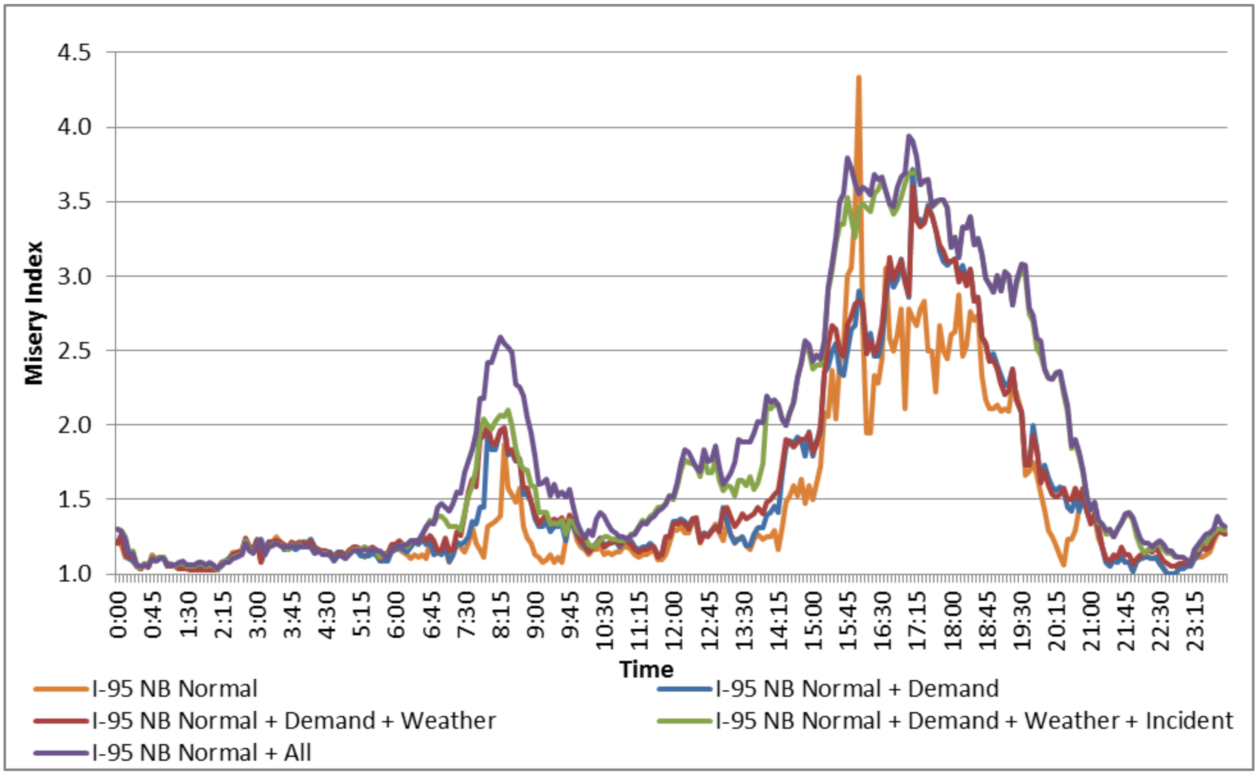


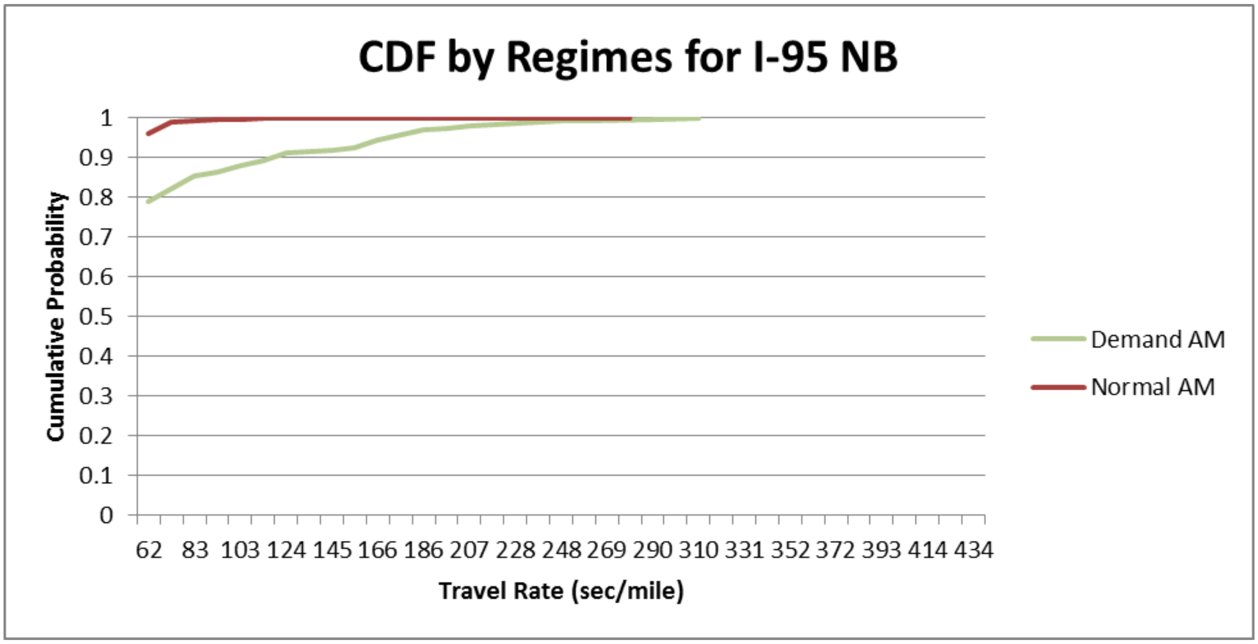
Figure 3.23. Misery index comparison for I-95 NB GPL.

The detailed impacts of high demand, incident, and weather were further analyzed in this study, and the corresponding results are presented in the next section.

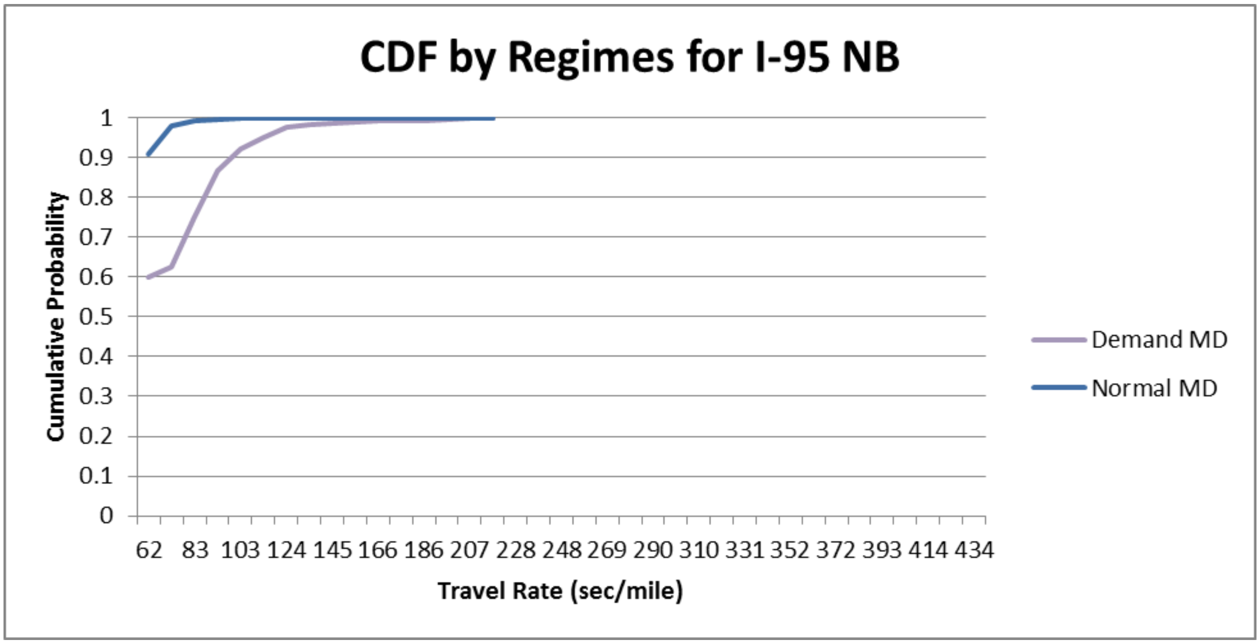
3.2.3 Impact of Normal versus High Demands

The no-event period was further classified into two categories, high-demand and normal-demand periods, to study the impacts of high demand. The categorizing was performed based on the procedure developed in the L02 project to determine the threshold that differentiates normal demands from high demands. The travel time rate CDF curves and the associated percentiles in Figure 3.24 show significant impacts of high demand, particularly during the PM2 periods. This finding indicates that implementing active traffic and demand management when a certain threshold of demand is exceeded has the potential of improving system reliability. It is interesting to note again, however, that based on the CDF curves, even with normal demand in the PM peak periods, the 95th percentile travel time rate was about twice the free-flow travel time rate, probably indicating that there were impacts of events from outside of the system or events not accounted for.

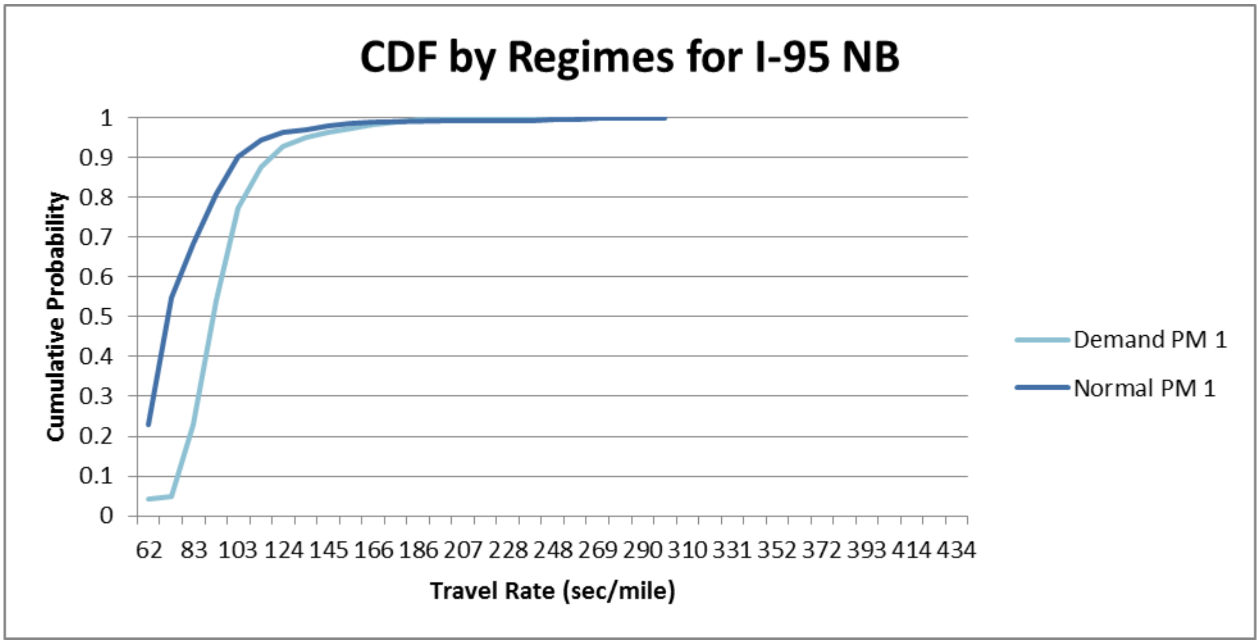
The occurrence, severity, and unreliability contribution results as shown in Table 3.4, Table 3.5, and Table 3.6 indicate that the five-minute intervals with high demand based on the derived threshold contributed significantly to the unreliability of the no-event period. The contribution of high-demand intervals to whole-day unreliability was 18% and 41% in PM1 and PM2, respectively, compared to 8% and 13% corresponding values for the normal-demand periods (Table 3.6). When normalized by frequency to determine the severity of the impact of a single interval, the high-demand interval NSV was 17% and 36% in the PM1 and PM2 periods, compared to corresponding 9% and 9% for normal-demand intervals, respectively (Table 3.5).



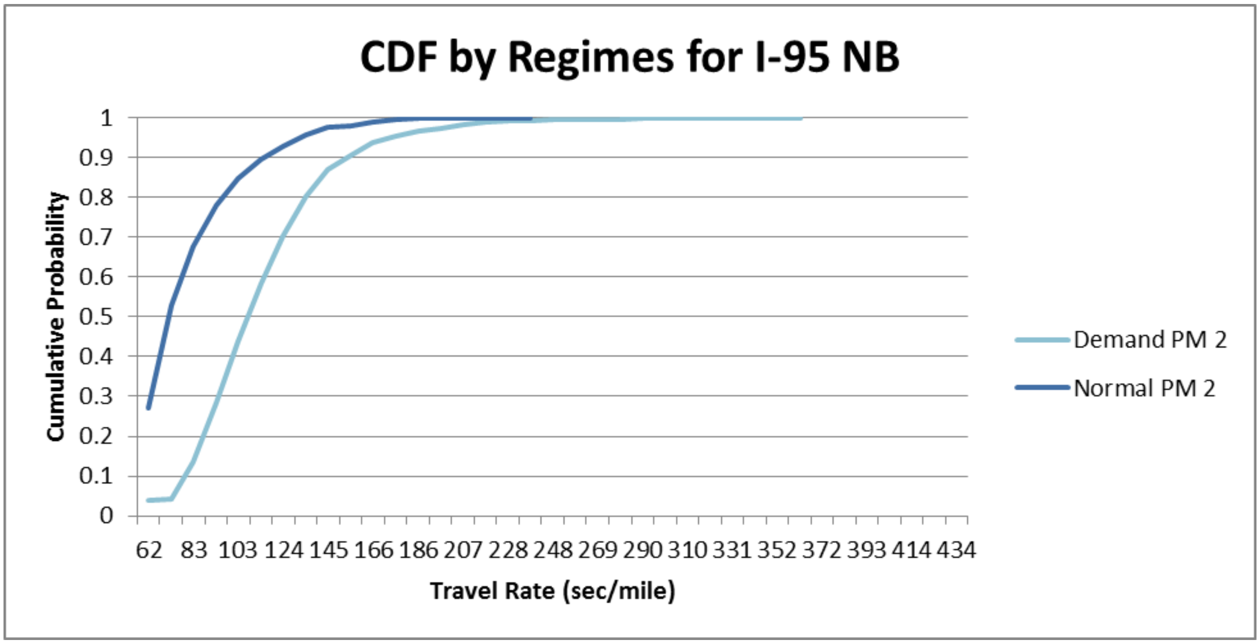
(a)



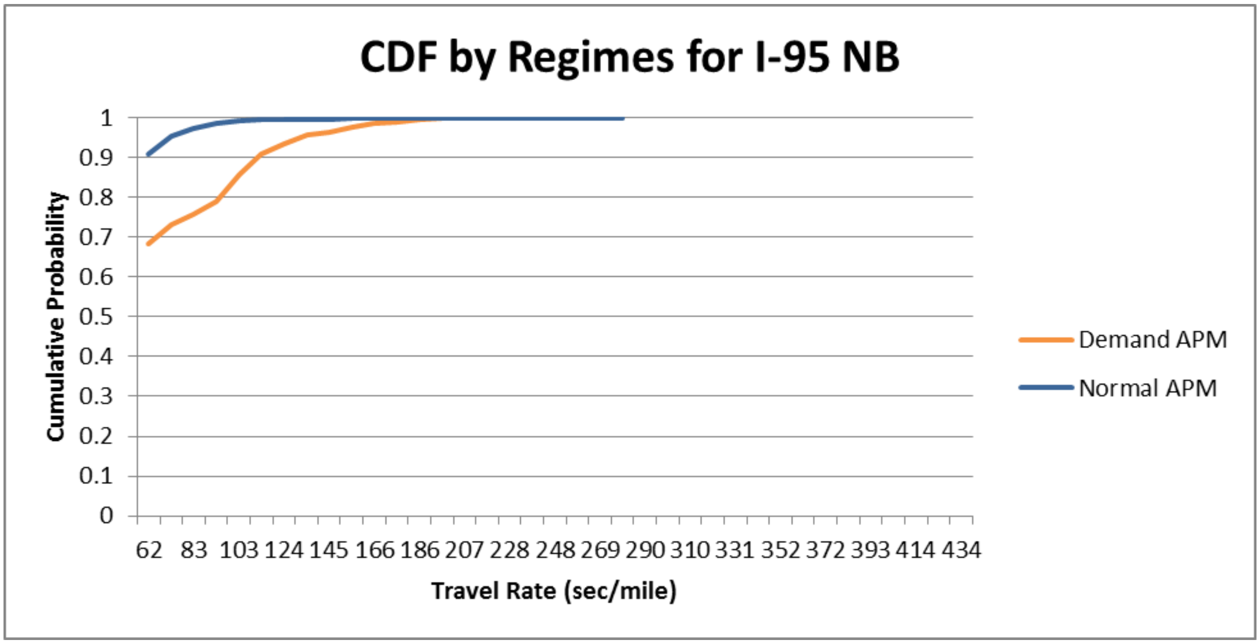
(b)


CDF by Regimes for I-95 NB
Cumulative Probability
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
62 83 103 124 145 166 186 207 228 248 269 290 310 331 352 372 393 414 434
Travel Rate (sec/mile)
Demand PM 1
Normal PM 1

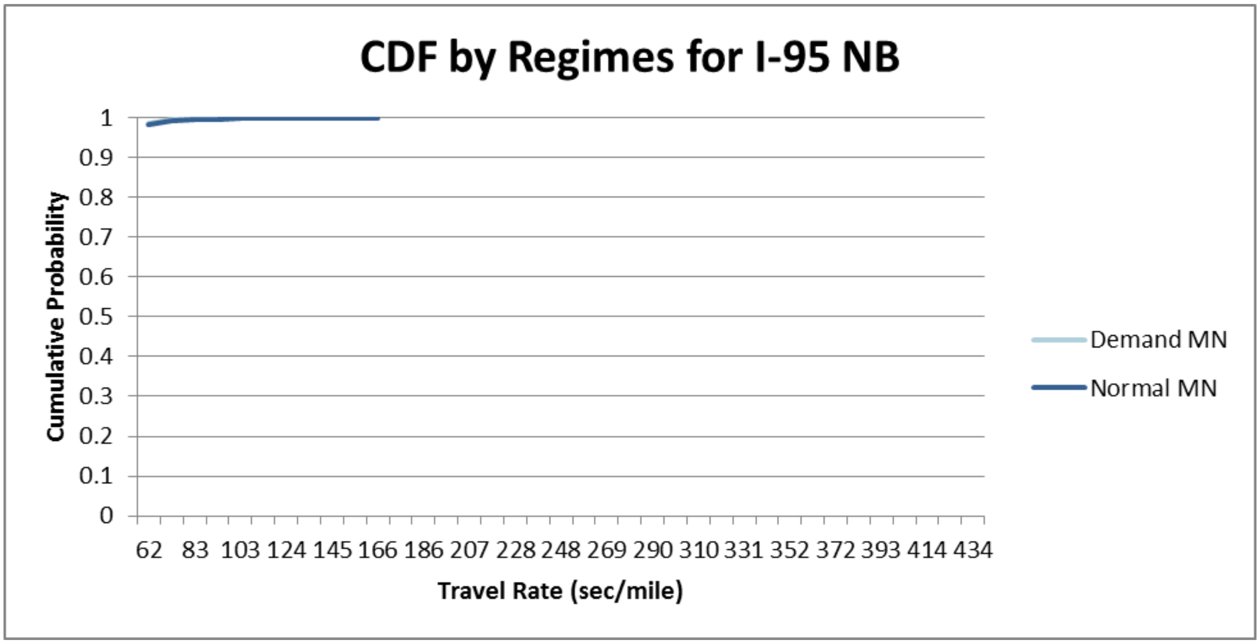
(c)


CDF by Regimes for I-95 NB
Cumulative Probability
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
62 83 103 124 145 166 186 207 228 248 269 290 310 331 352 372 393 414 434
Travel Rate (sec/mile)
Demand PM 2
Normal PM 2

(d)



(e)



(f)

Figure 3.24. CDF by regimes for I-95 NB GPL for normal and demand (a) AM, (b) MD, (c) PM1, (d) PM2, (e) APM, and (f) MN time periods.

Table 3.4. Percentage of Occurrence

Time Period	Demand	Normal	Total
AM	1%	13%	13%
MD	2%	25%	27%
PM1	3%	2%	5%
PM2	3%	4%	7%
APM	1%	11%	12%
MN	2%	35%	37%

Table 3.5. Percentage of Severity

Time Period	Demand	Normal	Total
AM	11%	0%	12%
MD	7%	0%	7%
PM1	17%	9%	26%
PM2	36%	9%	45%
APM	10%	1%	10%
MN	0%	0%	0%

Table 3.6. Percentage of Unreliability Contribution

Time Period	Demand	Normal	Total
AM	3%	2%	4%
MD	4%	3%	7%
PM1	18%	8%	27%
PM2	41%	13%	54%
APM	2%	4%	6%
MN	0%	1%	1%

To select capacity improvements and/or active traffic management strategies, it is not sufficient to identify congestion and unreliability values and perform a general analysis of the contributing factors. Analyzing the data and visualizing the bottleneck impacts using contour (heat) maps, as shown in Figure 3.25, indicated that the main issues in the PM1 peak were two capacity problems on NW 79th Street and NW 103rd Street. The capacities on these links were found to be lower that of the capacity reported by the HCM. For the PM2 period, the main issue was a backup from the off-ramp to the Florida Turnpike.

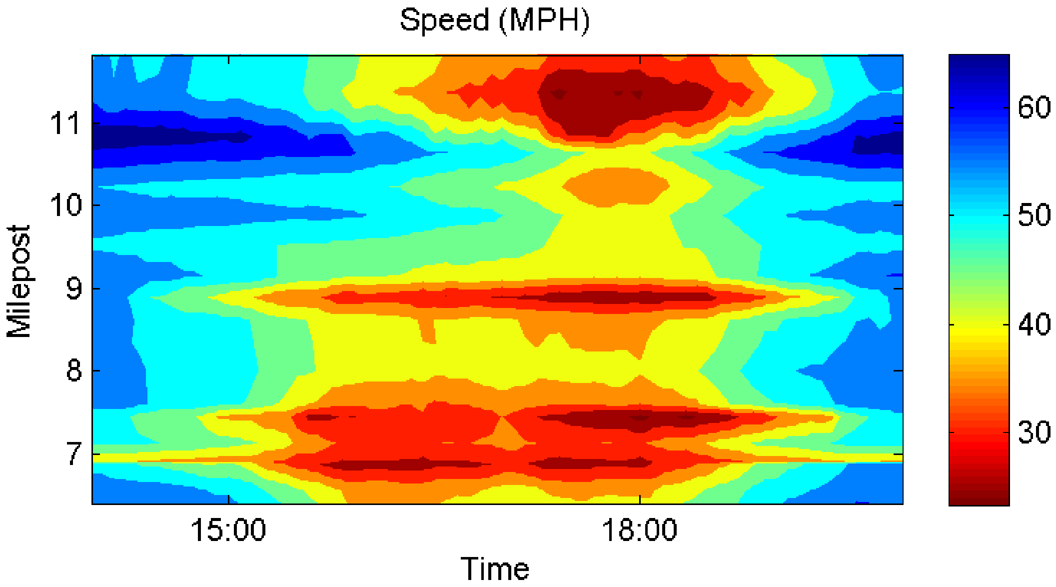


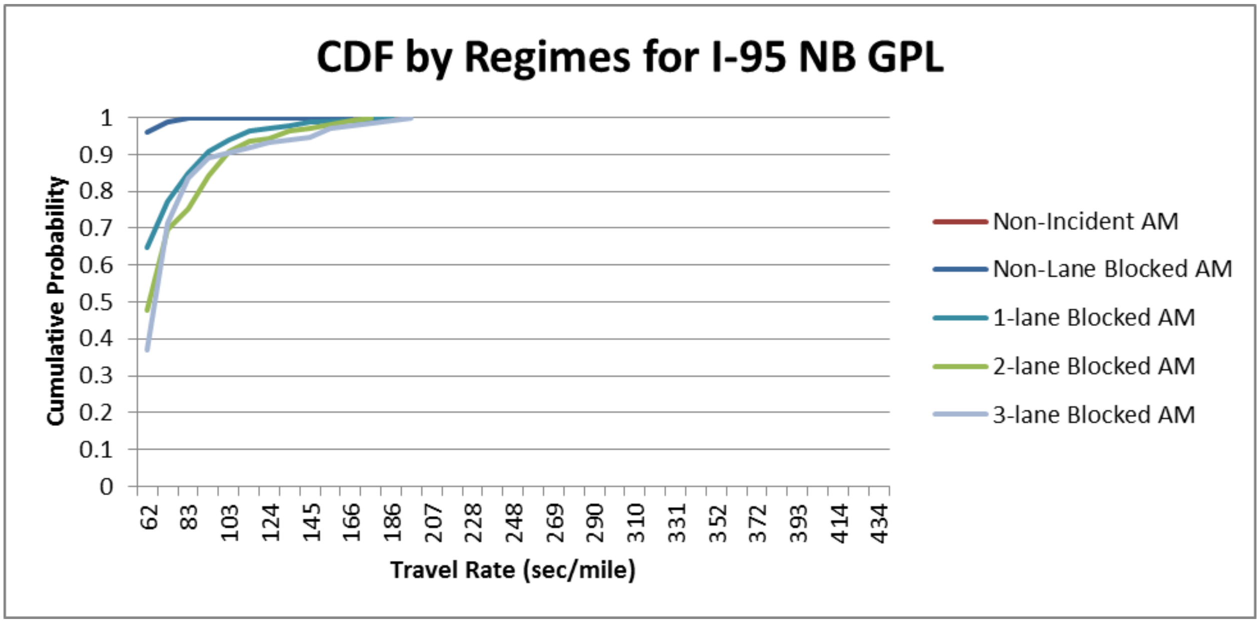
Figure 3.25. I-95 NB GPL speed contour map during the PM peak period.

3.2.4 Incident Severity Impacts

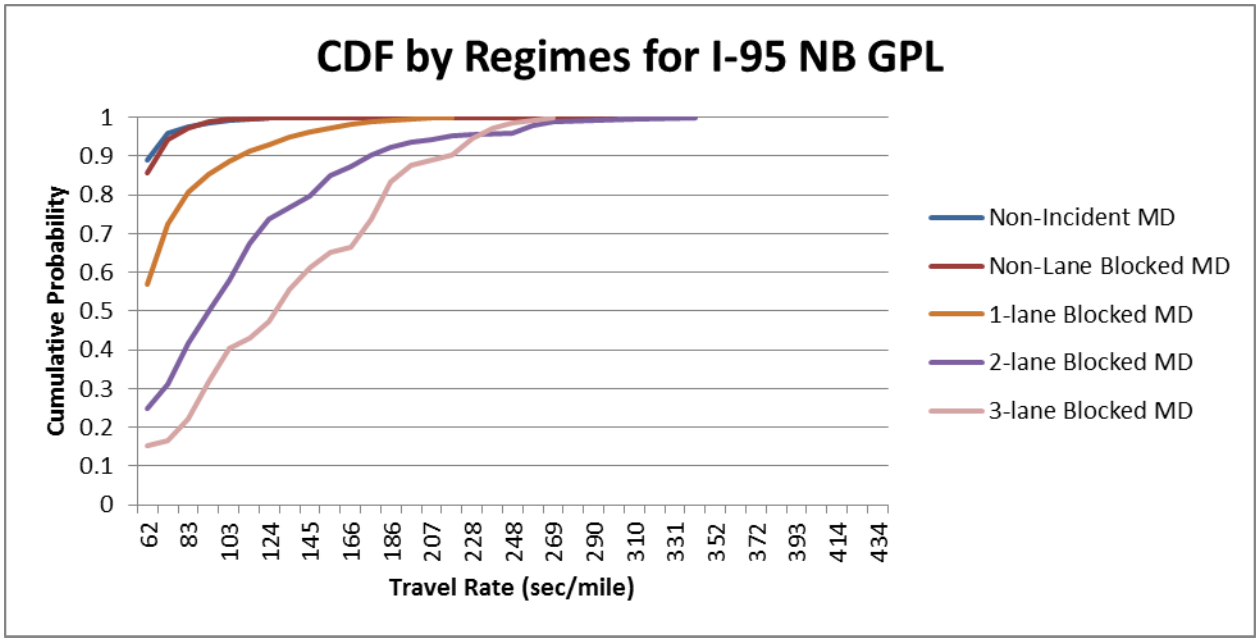
The incident impacts were further analyzed by the level of lane blockage for the AM, midday, PM, and APM periods. The CDF results, presented in Figure 3.26, show that the contribution of lane blockage incidents, as expected, was much higher than a single average incident. This finding is also reflected by the travel time rate CDFs, which show the highest tilt of two or more (2+) lane–blocking incidents during the PM peak, then 2+ lane–blocking incidents in the APM peaks, followed by 2+ lane–blocking incidents during the midday, one-lane–blocking incidents during the PM, and one-lane–blocking incidents in the midday and APM periods. The I-95 NB GPL incident that occurred under the good weather conditions in the AM peak did not seem to have had a significant influence.

Tables 3.7 to 3.9, respectively, present the occurrence, severity, and unreliability contribution of different lane-blocking incidents. It is seen from Table 3.9 that the contribution of lane-blocking incidents was twice as much as non-lane-blocking incidents, although non-lane-blocking incident frequency was much higher than that of lane blockage frequency. On a single-event basis, the NSV indicated the high impacts of 2+ lane blockage. Additional analysis results not shown in this report indicated that crash incidents were generally more damaging than other (noncrash) incidents. During the PM period, the damage due to a single noncrash incident was about 50% of the damage caused by a crash incident. However, the overall impact on reliability was equivalent due to the higher frequency of noncrash incidents.

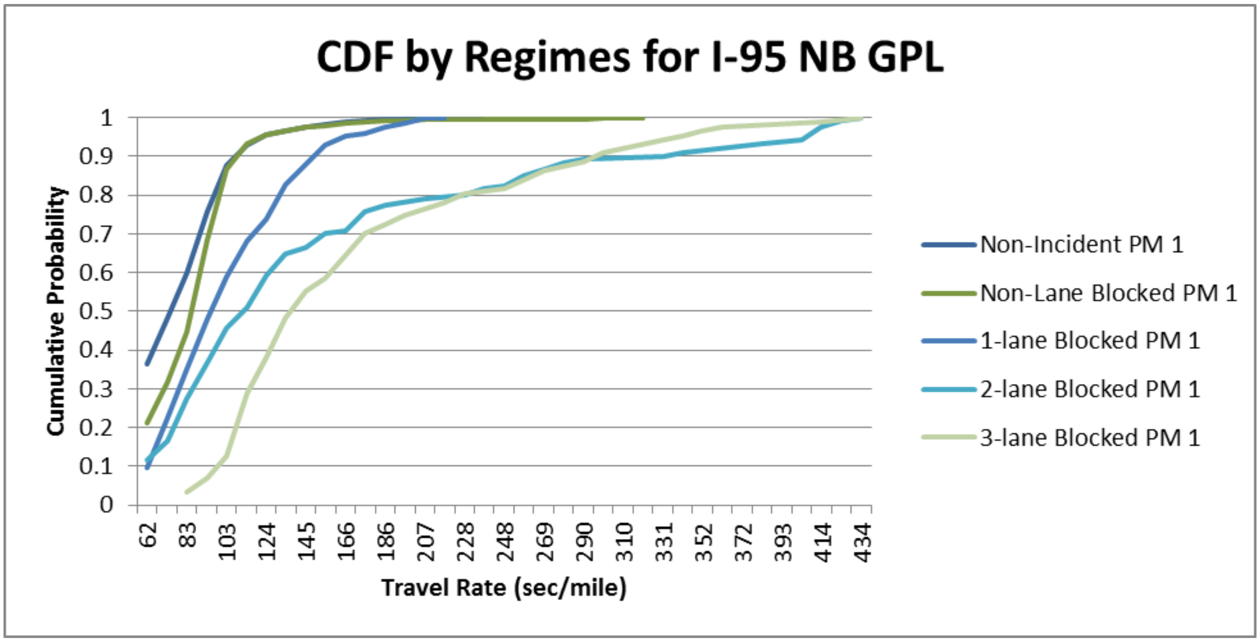
To better understand the incident impacts, the temporal and spatial incident frequency variation needs to be determined to allow better selection of advanced incident management strategies. These variations can be visualized as shown in Figures 3.27 and Figure 3.28, which show that the crash incident frequency was clearly the highest in the PM peak period from 4:40 to 7:00 p.m. The noncrash incidents were high most of the day, but they had a relatively flat peak between 2:00 and 8:00 p.m. These figures also show that, when the investigated facility was segmented to three segments, the highest frequency of incidents occurred at Segment 3, which was the most downstream segment (between NW 103 Street and the turnpike exit). Segment 2 (between NW 79th Street and NW 103rd Street) had the second-highest crash incident frequency.



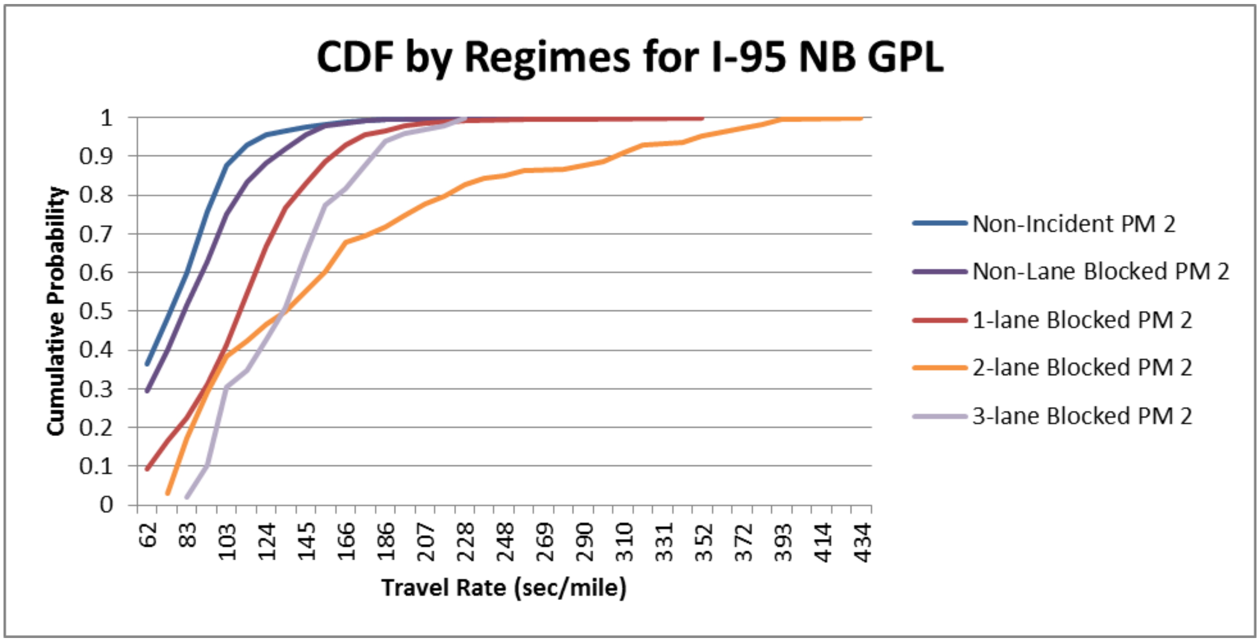
(a)



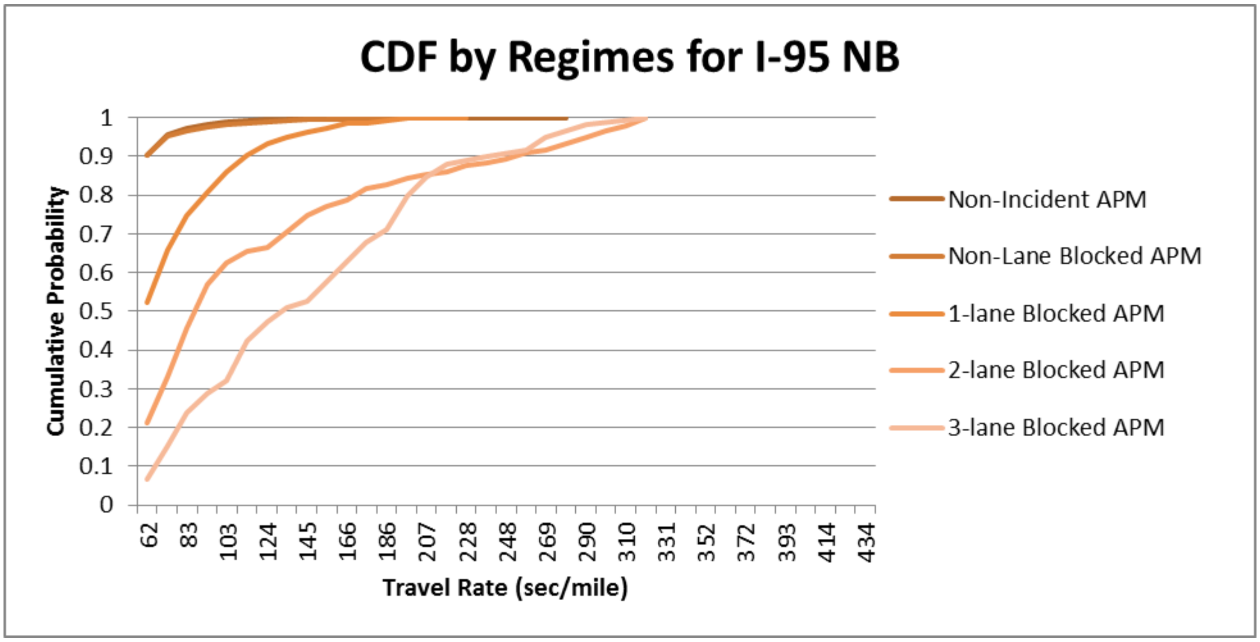
(b)


CDF by Regimes for I-95 NB GPL
Cumulative Probability
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
62
83
103
124
145
166
186
207
228
248
269
290
310
331
352
372
393
414
434
Travel Rate (sec/mile)
Non-Incident PM 1
Non-Lane Blocked PM 1
1-lane Blocked PM 1
2-lane Blocked PM 1
3-lane Blocked PM 1

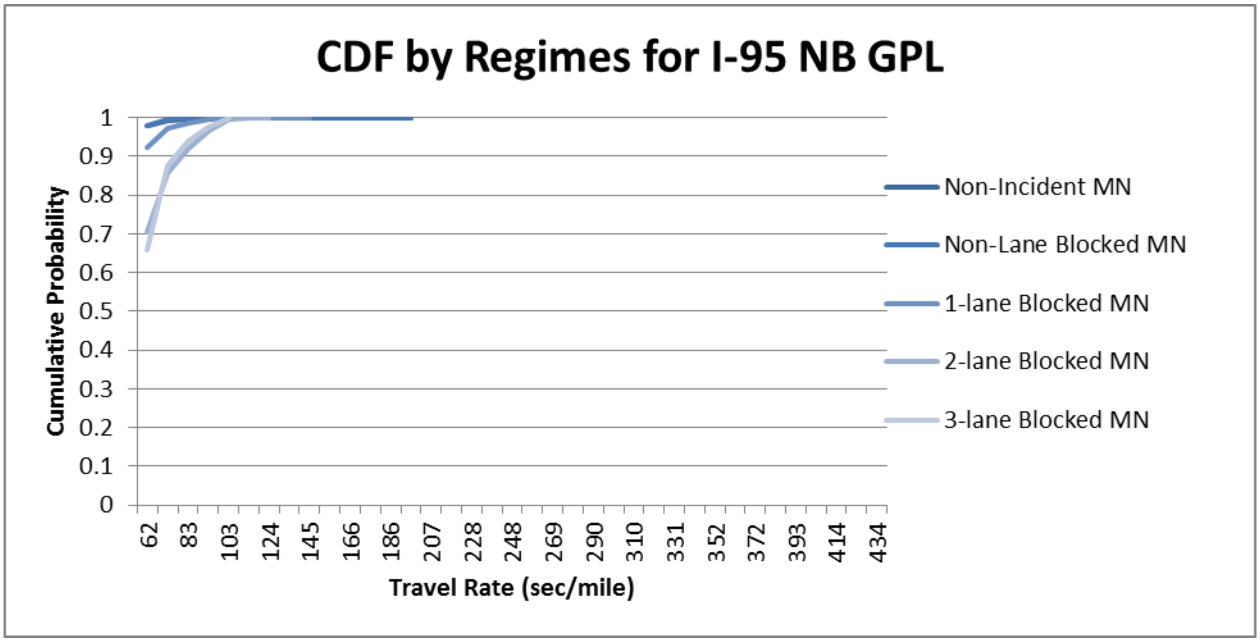
(c)


CDF by Regimes for I-95 NB GPL
Cumulative Probability
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
62
83
103
124
145
166
186
207
228
248
269
290
310
331
352
372
393
414
434
Travel Rate (sec/mile)
Non-Incident PM 2
Non-Lane Blocked PM 2
1-lane Blocked PM 2
2-lane Blocked PM 2
3-lane Blocked PM 2

(d)



(e)



(f)

Figure 3.26. CDF by regimes for I-95 NB GPL for (a) AM, (b) MD, (c) PM1, (d) PM2, (e) APM, and (f) MN periods.

Table 3.7. Percentage of Occurrence

Time Period	Nonincident	0 Lanes Blocked	1 Lane Blocked	2 Lanes Blocked	3+ Lanes Blocked	Total
AM	10.6%	1.6%	0.3%	0.1%	0.0%	12.6%
MD	21.2%	4.8%	0.9%	0.2%	0.0%	27.1%
PM1	4.1%	1.5%	0.4%	0.1%	0.1%	6.2%
PM2	5.2%	2.0%	0.8%	0.2%	0.1%	8.3%
APM	9.3%	2.4%	0.5%	0.2%	0.1%	12.4%
MN	29.0%	3.7%	0.4%	0.2%	0.1%	33.4%

Table 3.8. Percentage of Severity

Time Period	Nonincident	0 Lanes Blocked	1 Lane Blocked	2 Lanes Blocked	3+ Lanes Blocked	Total
AM	0.1%	0.0%	0.4%	1.0%	8.6%	10.1%
MD	0.1%	0.1%	0.8%	5.2%	8.2%	14.2%
PM1	1.1%	1.2%	2.1%	20.3%	13.5%	37.2%
PM2	1.7%	1.4%	3.3%	11.8%	4.5%	21.0%
APM	0.1%	0.1%	0.9%	8.6%	7.8%	17.4%
MN	0.0%	0.0%	0.0%	0.1%	0.0%	0.1%

Table 3.9. Percentage of Unreliability Contribution

Time Period	Nonincident	0 Lanes Blocked	1 Lane Blocked	2 Lanes Blocked	3+ Lanes Blocked	Total
AM	4.1%	0.1%	0.7%	0.4%	0.2%	1.3%
MD	6.7%	2.4%	3.3%	4.8%	1.4%	11.9%
PM1	23.1%	8.9%	4.4%	9.7%	7.3%	30.2%
PM2	44.9%	14.2%	13.2%	13.5%	1.5%	42.4%
APM	4.6%	1.5%	2.1%	7.0%	3.1%	13.8%
MN	1.1%	0.1%	0.1%	0.1%	0.0%	0.3%

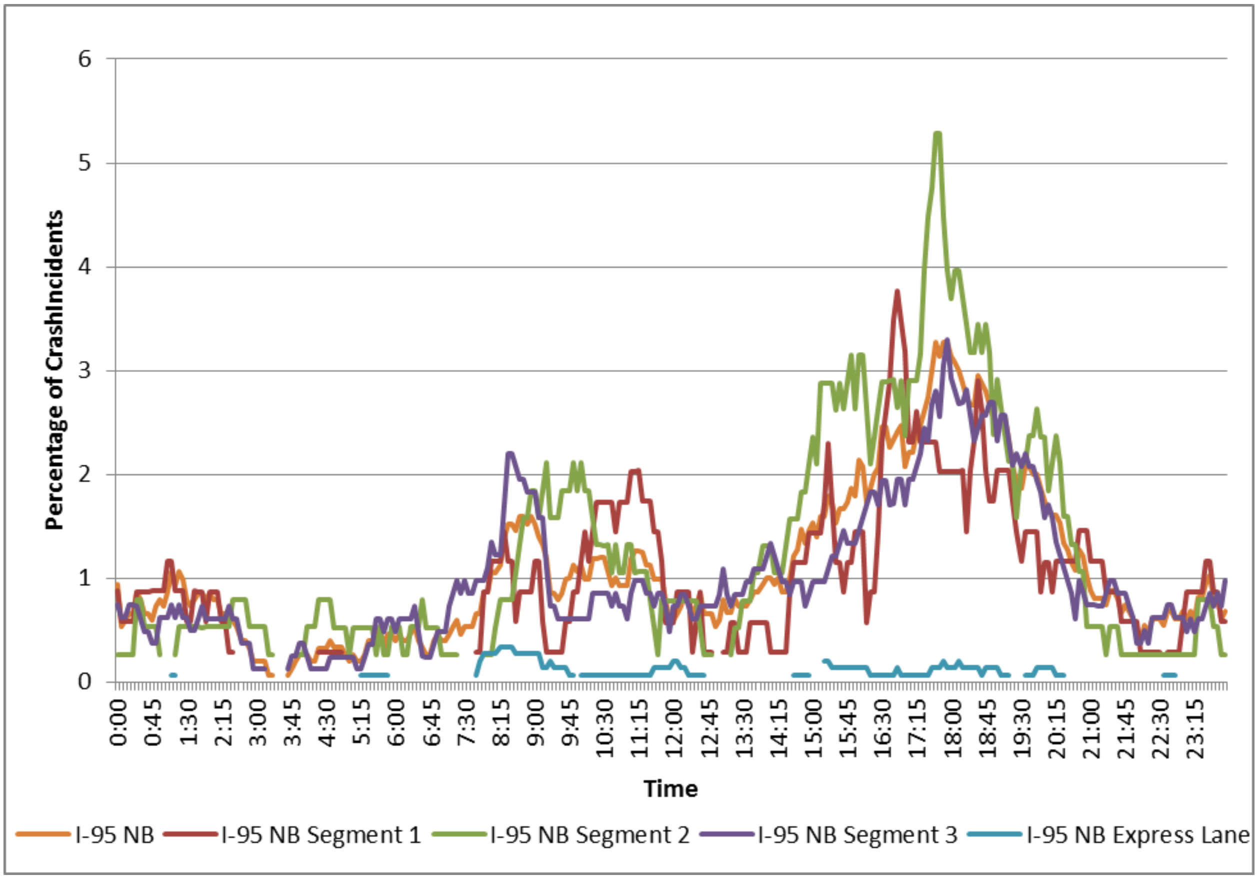


Figure 3.27. Percentage of crash incidents per mile comparison.

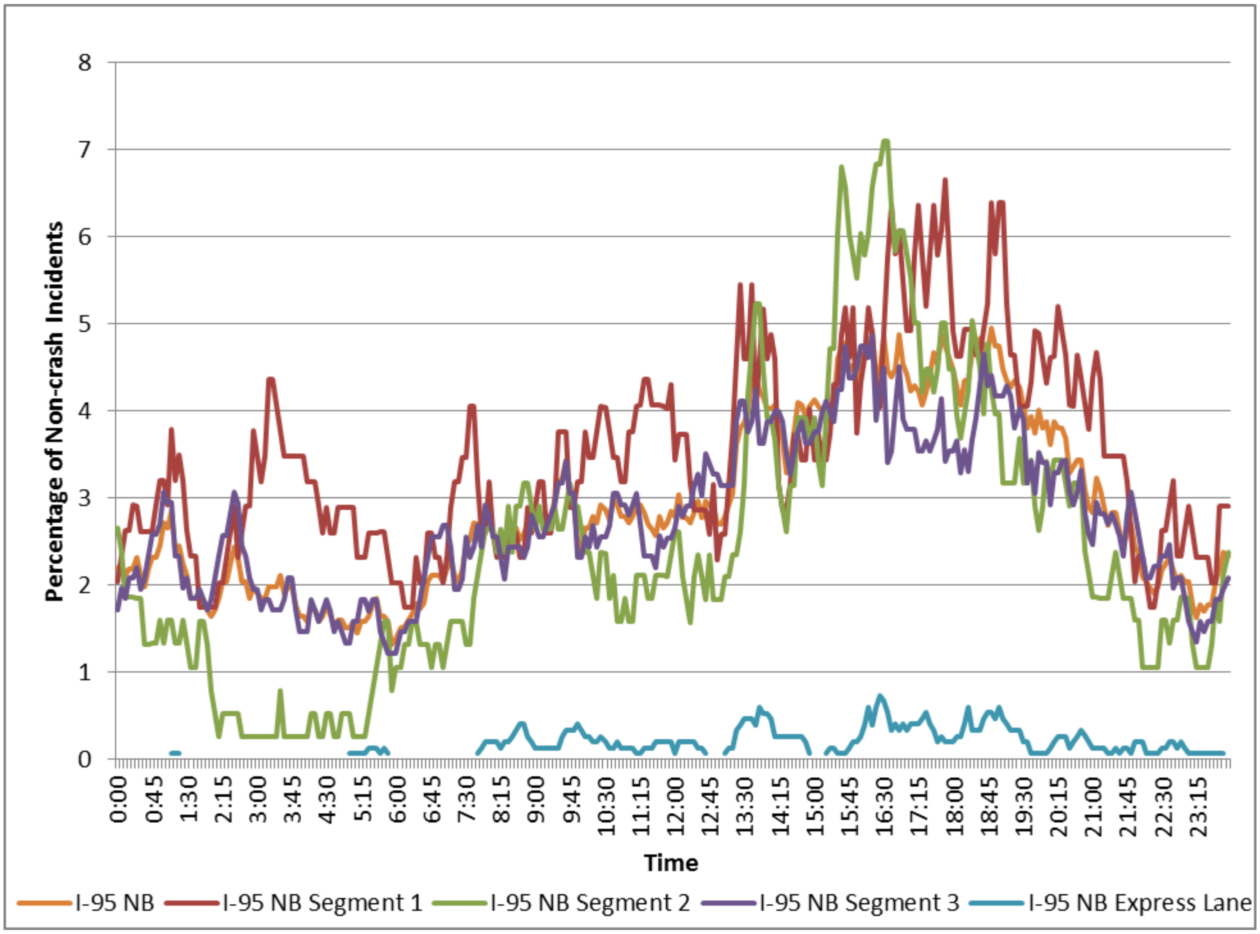


Figure 3.28. Percentage of noncrash incidents per mile comparison.

Figure 3.29 presents the 95th percentile TTI under three scenarios. Scenario 1 includes all traffic conditions (shown as I-95 NB ALL in the figure). Scenario 2 corresponds to the traffic conditions without lane-blocking incidents (shown as I-95 NB ALL – Lane-Blocked Incidents in the figure). Scenario 3 refers to the conditions after further removal of all remaining incidents (shown as I-95 NB ALL - Incidents in the figure). Figure 3.29 further indicates the significant impacts of lane-blocking incidents on the PTI (95th percentile TTI) between 2:30 and 8:00 p.m. During PM1 (3:00 to 5:00 p.m.), the 95th percentile TTI increased from about 2.0 to about 2.5 due to lane-blocking events. In PM2 (5:00 to 7:00 p.m.), the conditions without incidents were already unreliable mainly due to backups from the turnpike, yet incidents increased the peak 95th percentile from 2.6 to 3.0. Lane-blocking incidents also resulted in an increase in the mean TTI, but to a lesser degree (e.g., from 1.58 to 1.68 at 4:00 p.m.), as shown in Figure 3.30. However, only small impacts of lane-blocking incidents can be observed from Figures 3.31 and 3.32 on the median and 80th percentile TTIs. The higher impacts of incidents on the 95th percentile clearly indicate the need to consider reliability when assessing the impacts of incidents and incident management benefits.

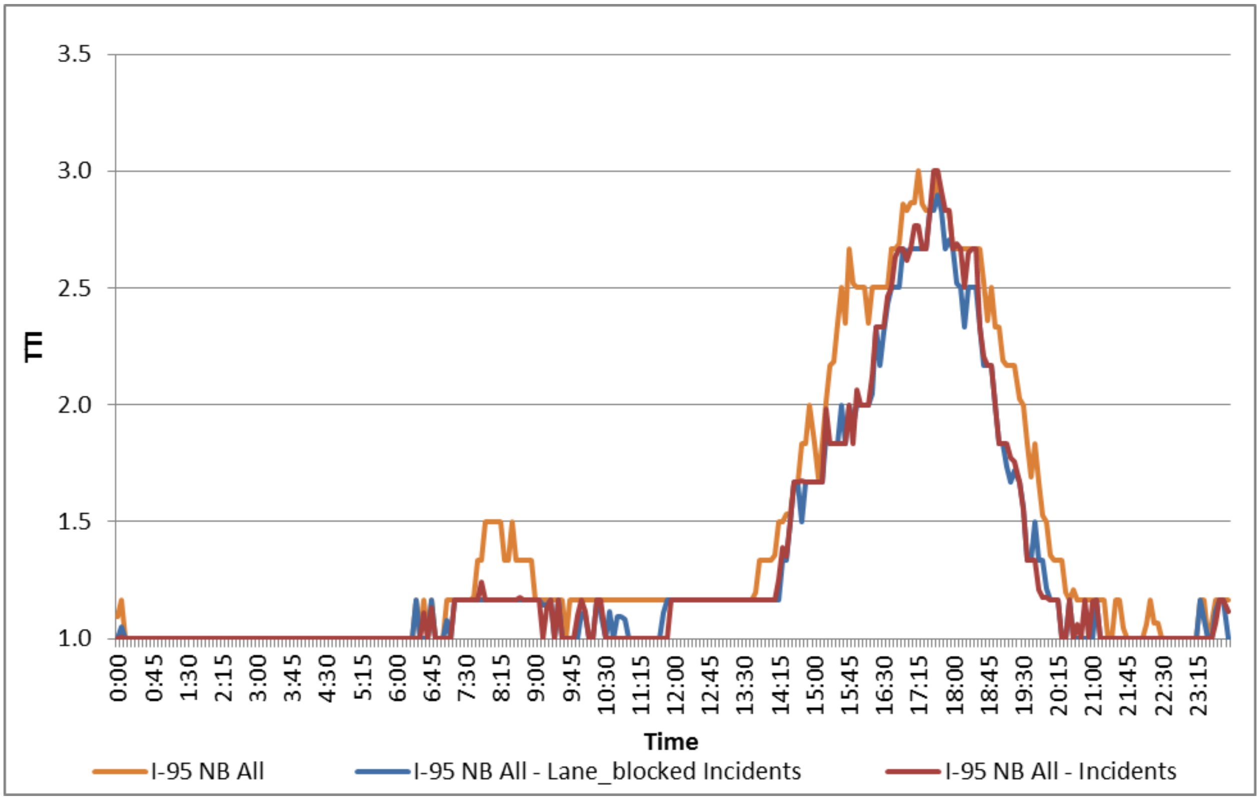


Figure 3.29. 95th percentile TTI and lane-blocking incidents comparison for I-95 NB GPL.

Figures 3.33 to 3.36 present the impacts of lane-blocking incident duration on reliability performance measures. It appears from these figures that higher-duration incidents did not contribute to unreliability more than shorter-duration incidents. All lane-blocking incidents, even those with durations less than 30 minutes, had a high impact on reliability. This effect may have been due in part to the higher frequency of these shorter-incident duration events.

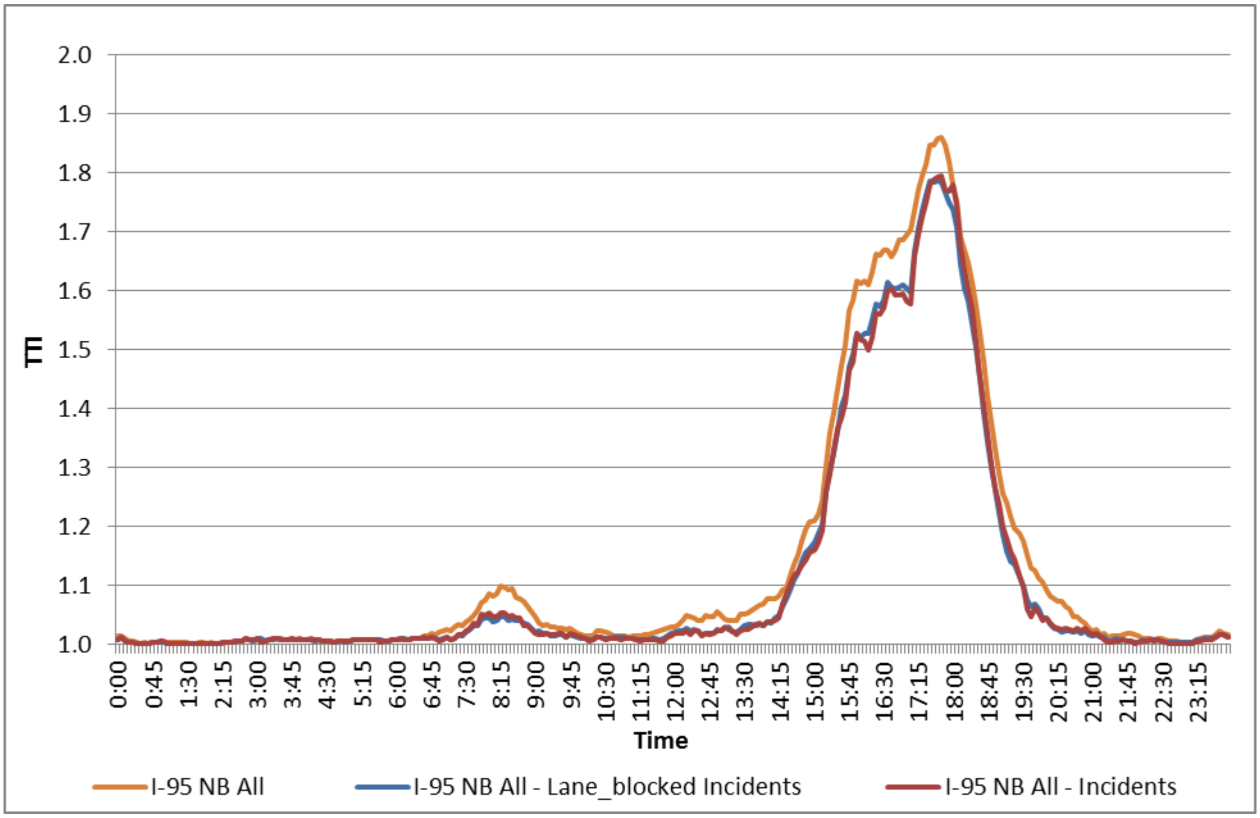


Figure 3.30. Mean TTI and lane-blocking incidents comparison for I-95 NB GPL.

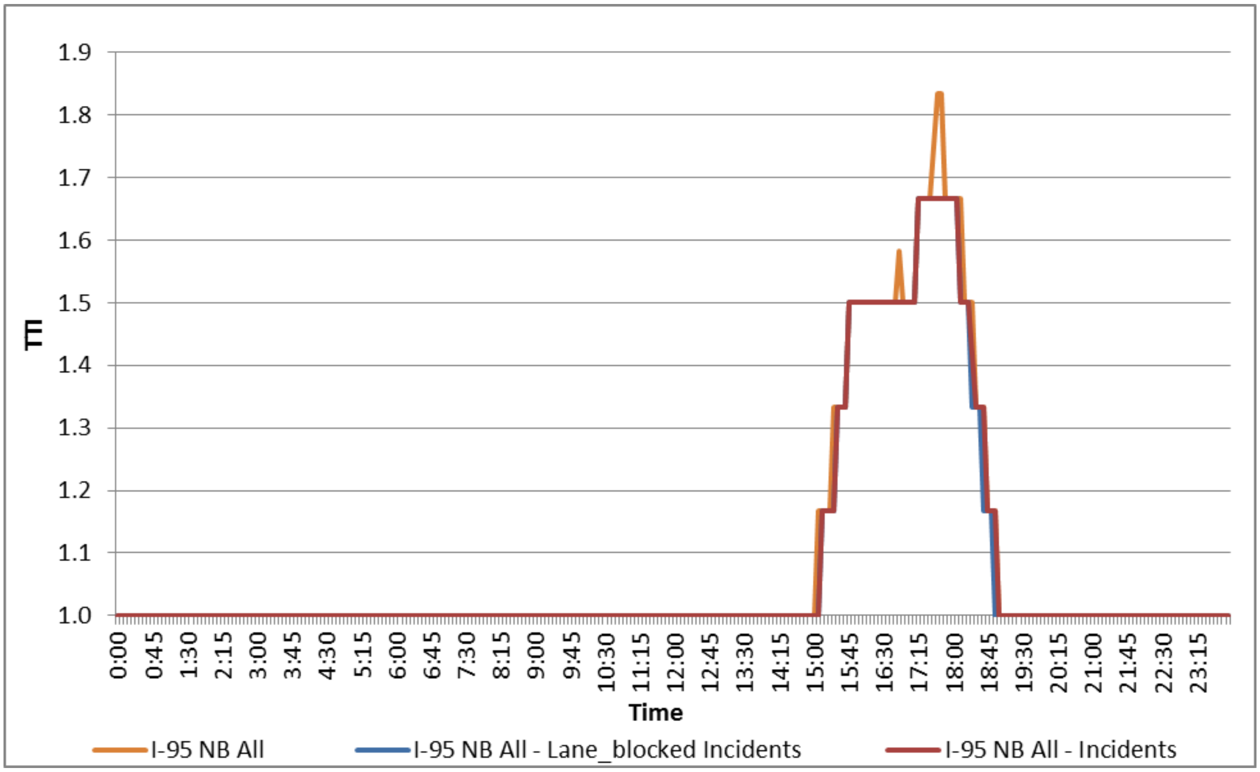


Figure 3.31. 50th percentile TTI and lane-blocking incidents comparison for I-95 NB GPL.

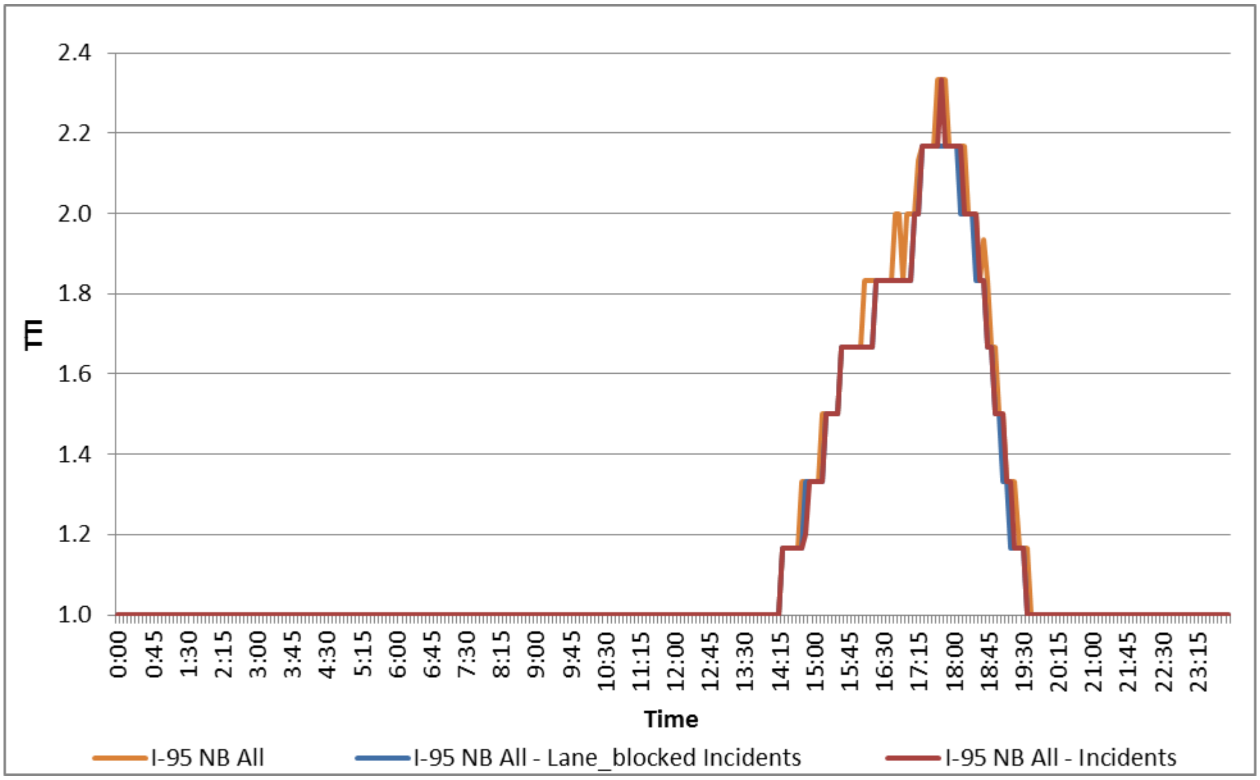


Figure 3.32. 80th percentile TTI and lane-blocking incidents comparison for I-95 NB GPL.

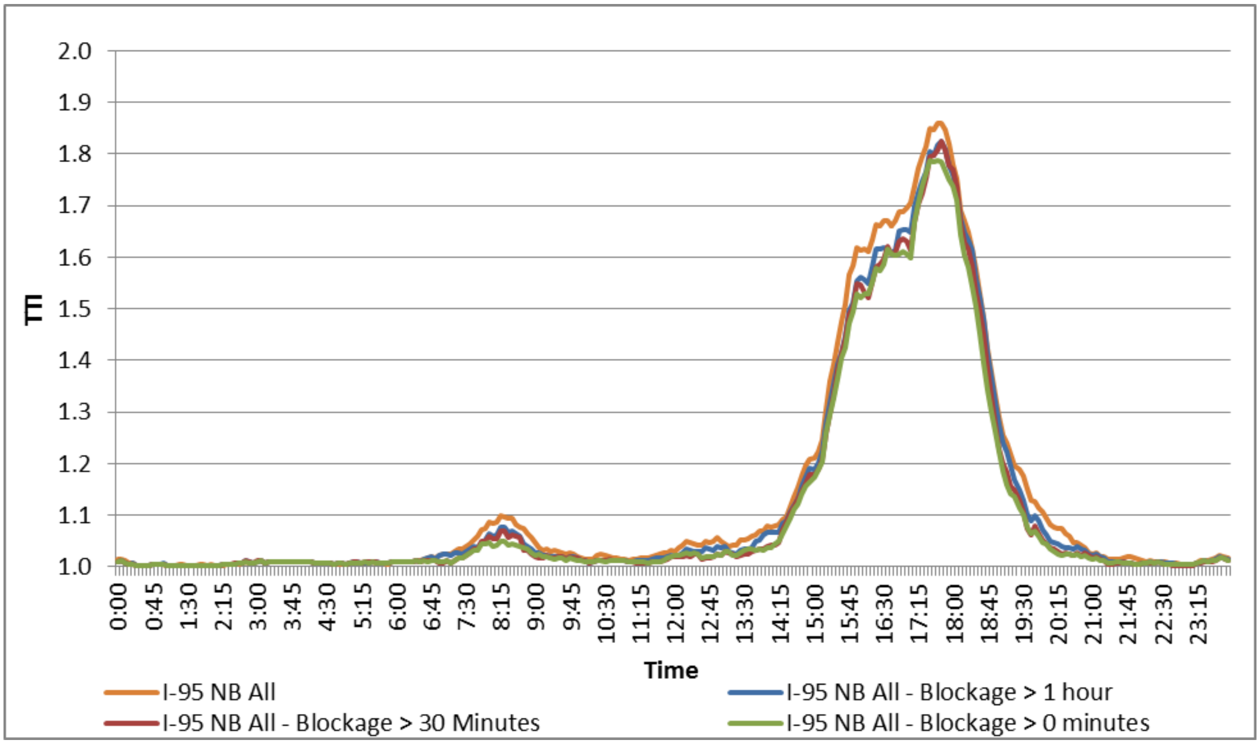


Figure 3.33. Mean TTI and incident duration comparison for I-95 NB GPL.

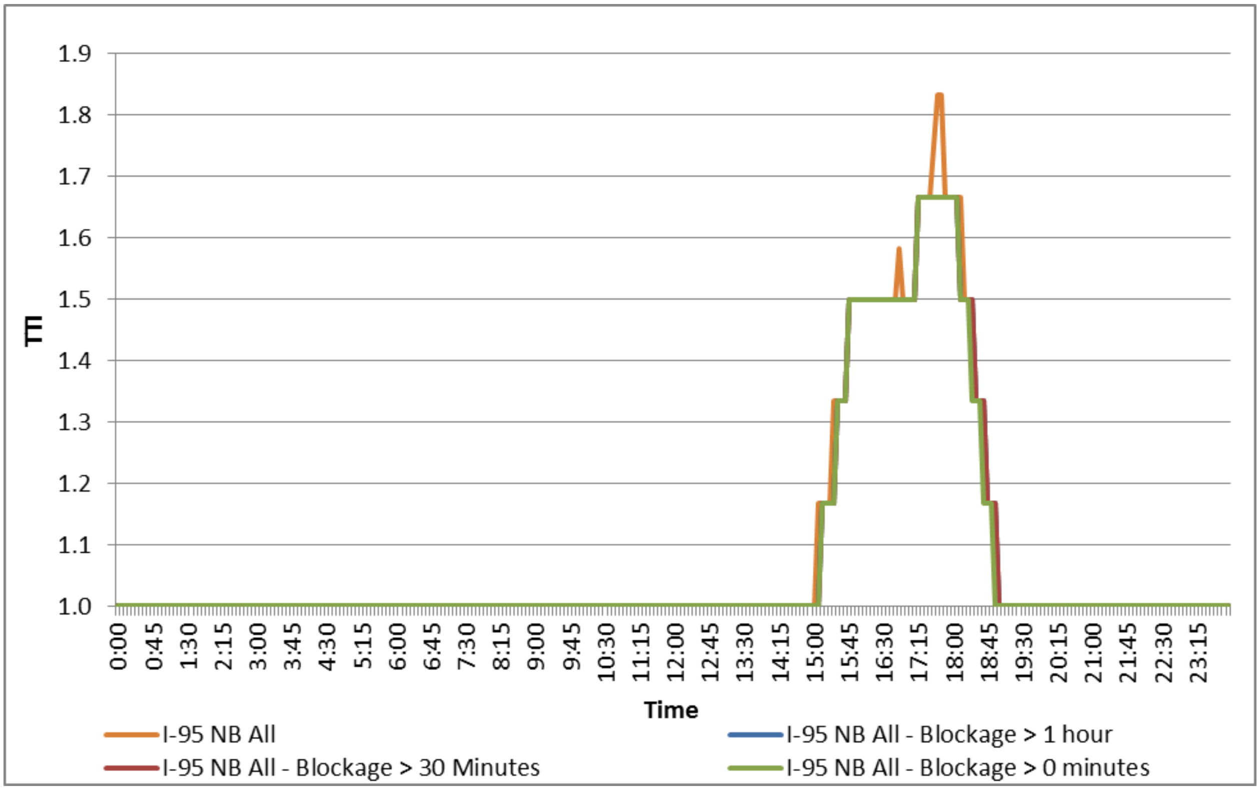


Figure 3.34. 50th percentile TTI and incident duration comparison for I-95 NB GPL.

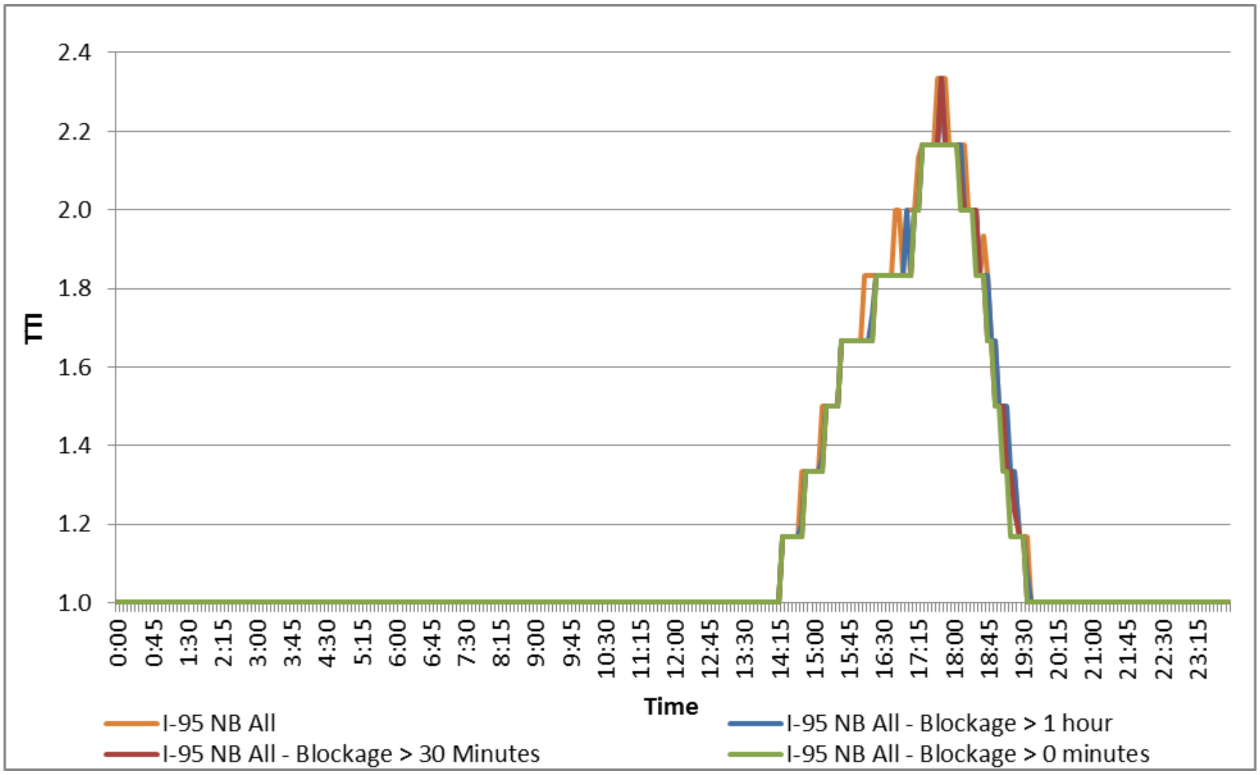


Figure 3.35. 80th percentile TTI and incident duration comparison for I-95 NB GPL.

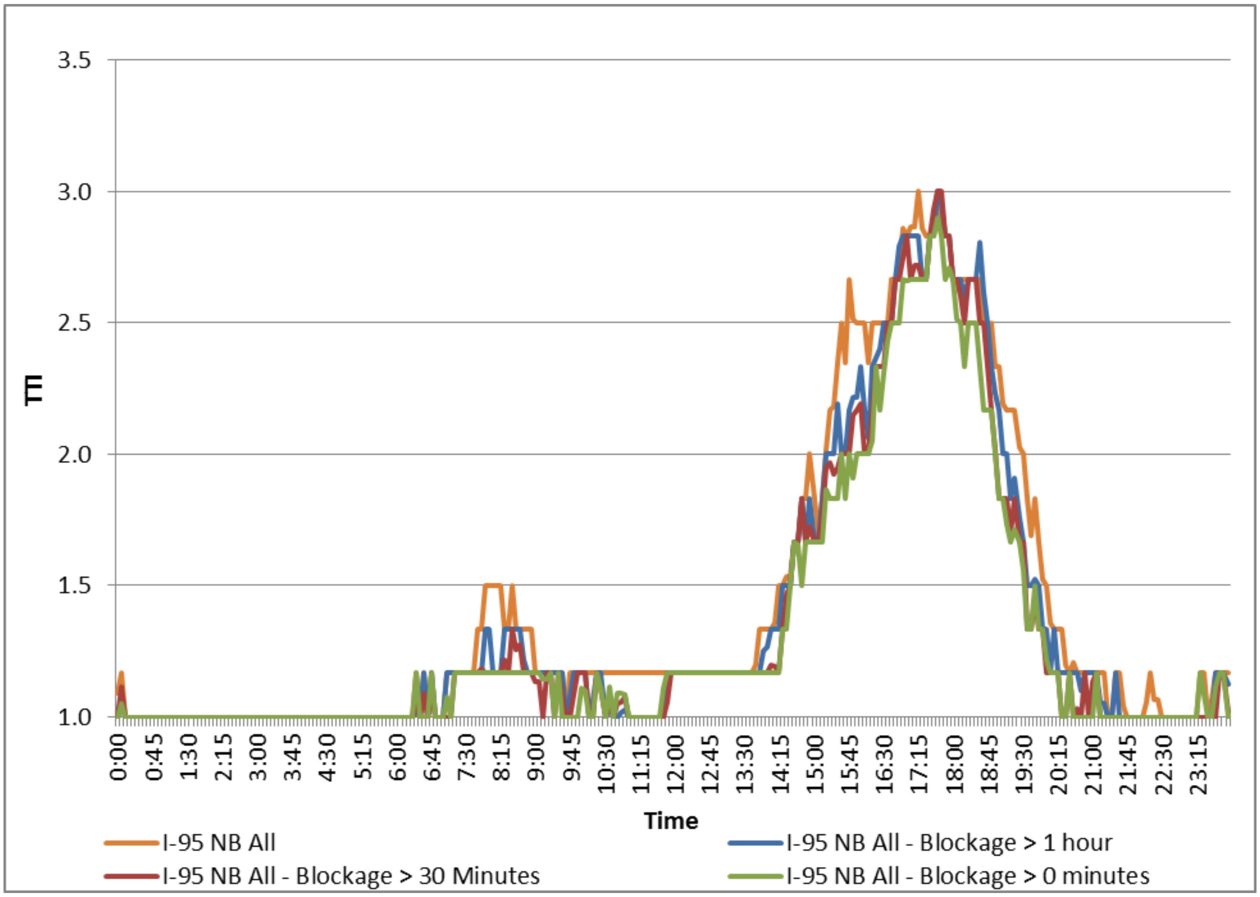
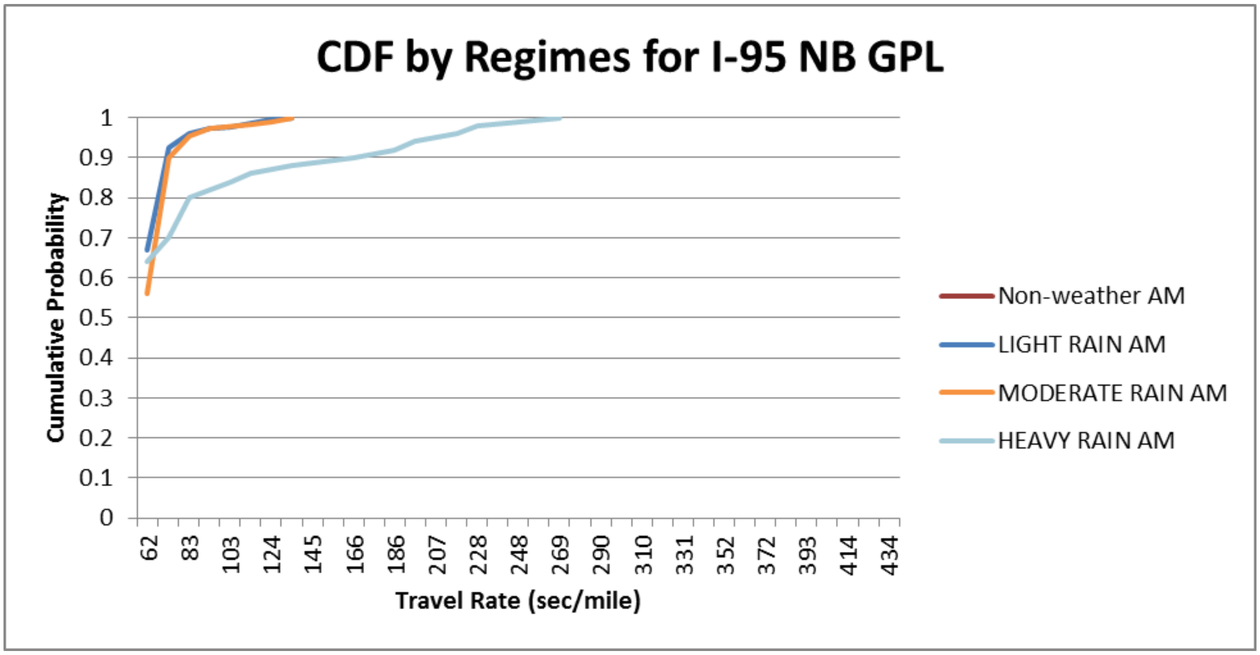


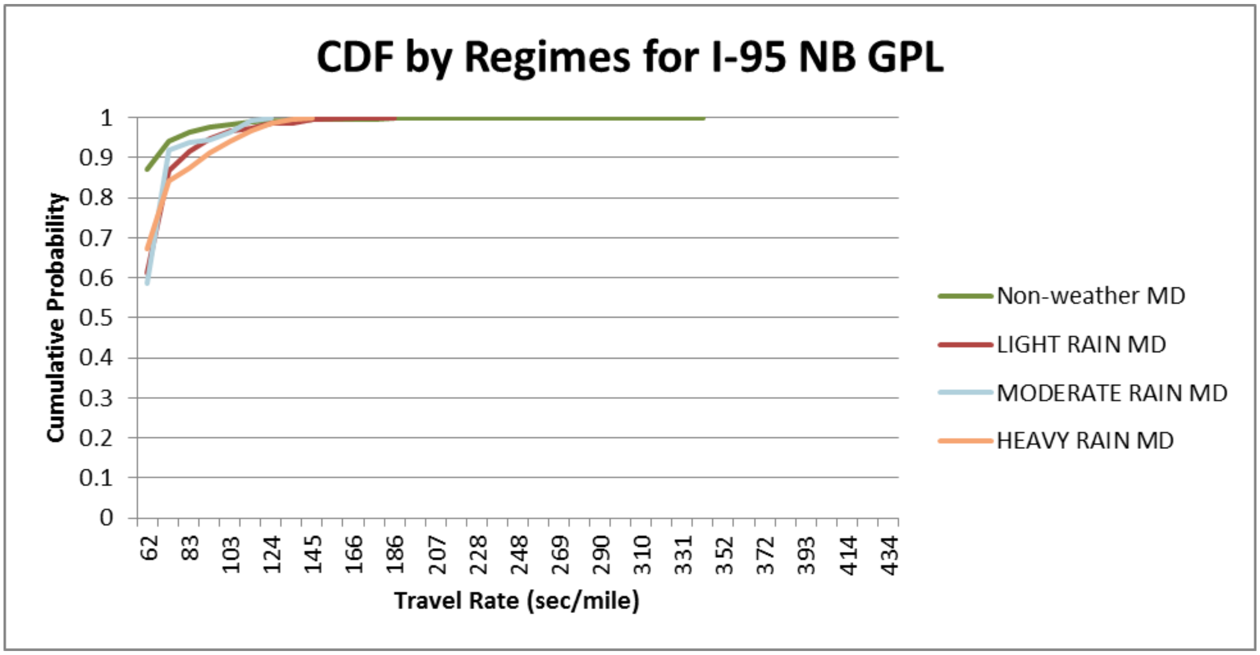
Figure 3.36. 95th percentile TTI and incident duration comparison for I-95 NB GPL.

3.2.5 Weather Impacts

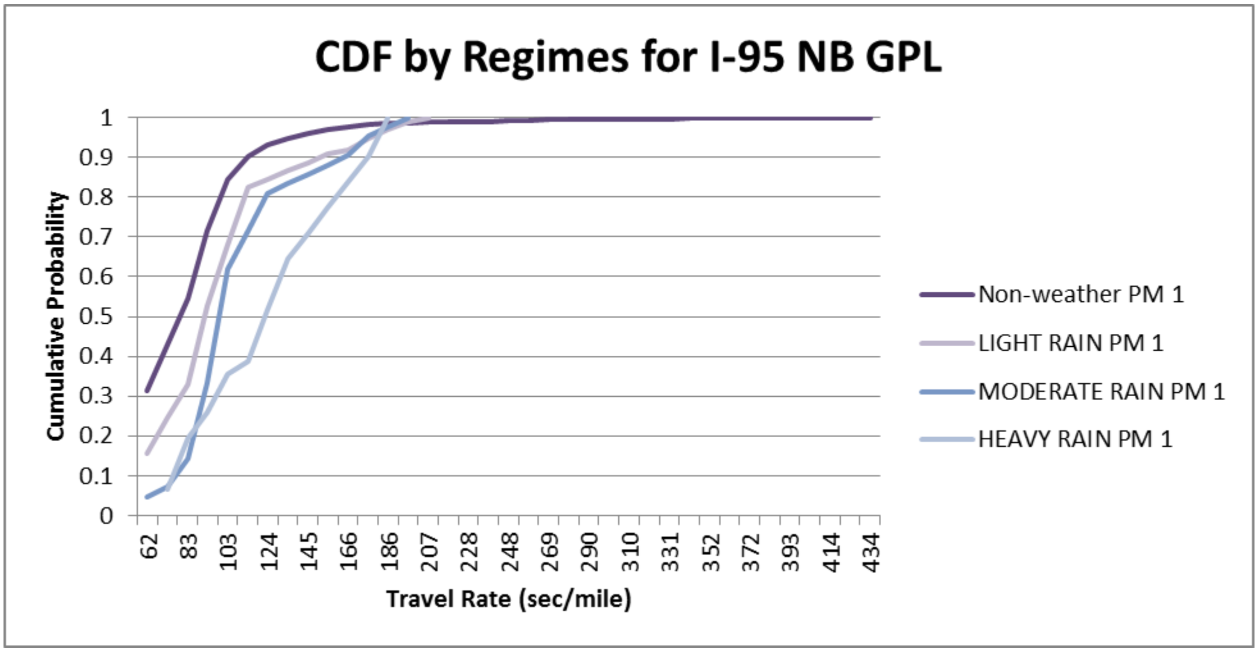
Further analysis was conducted to examine the impacts of the severity of precipitation on travel time reliability; the results are presented in Figures 3.37 to 3.41 and Tables 3.10, 3.11, and 3.12. As shown in these tables and figures, a single moderate-to-heavy rain event caused a significant impact, with resulting NSV that was 20% to 50% higher than the no-weather event in the PM peak. Table 3.11 also seems to indicate that heavy rain in the AM peak also caused high contribution per event. However, as stated earlier, the overall contribution of weather to unreliability appeared to be relatively small due to the low number of rain events compared, for example, to incident events. Another important factor to be considered is that the weather stations from which the weather service information providers collect data are distributed around the region and were not located at the study facility. This distribution of weather data may have reduced the accuracy of the assessment of weather events on reliability.


CDF by Regimes for I-95 NB GPL
Cumulative Probability
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
62
83
103
124
145
166
186
207
228
248
269
290
310
331
352
372
393
414
434
Travel Rate (sec/mile)
Non-weather AM
LIGHT RAIN AM
MODERATE RAIN AM
HEAVY RAIN AM

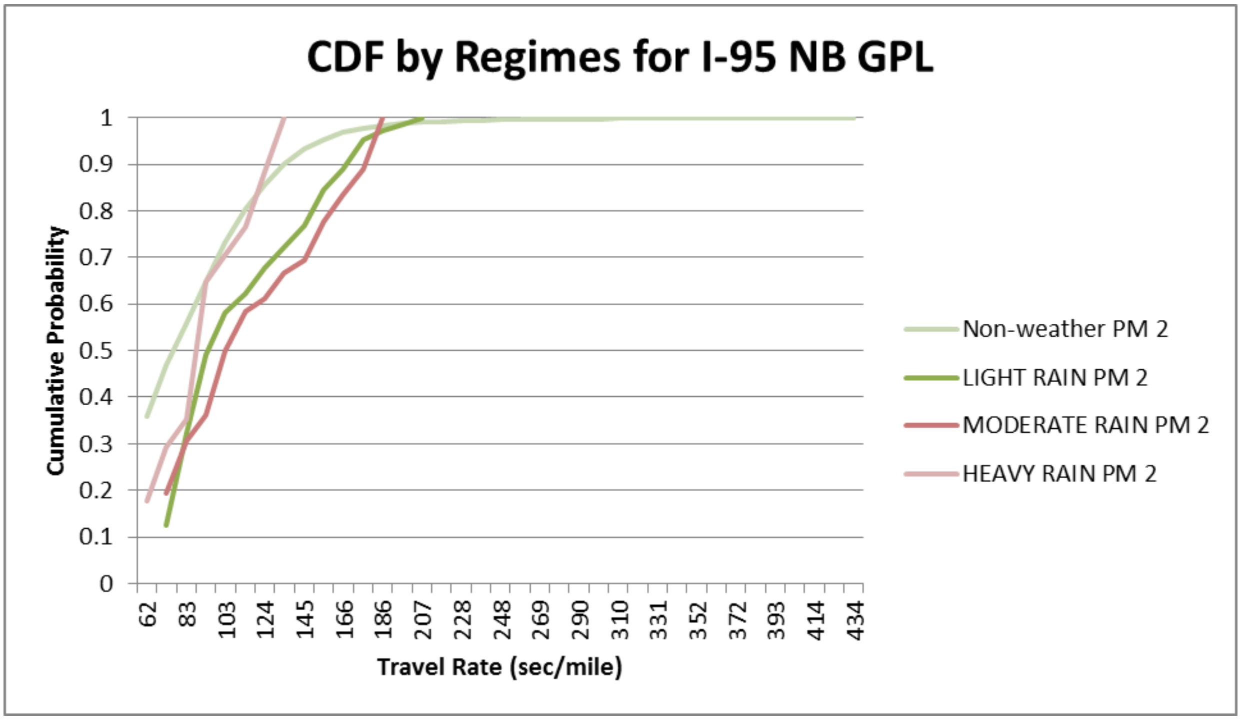
(a)


CDF by Regimes for I-95 NB GPL
Cumulative Probability
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
62
83
103
124
145
166
186
207
228
248
269
290
310
331
352
372
393
414
434
Travel Rate (sec/mile)
Non-weather MD
LIGHT RAIN MD
MODERATE RAIN MD
HEAVY RAIN MD

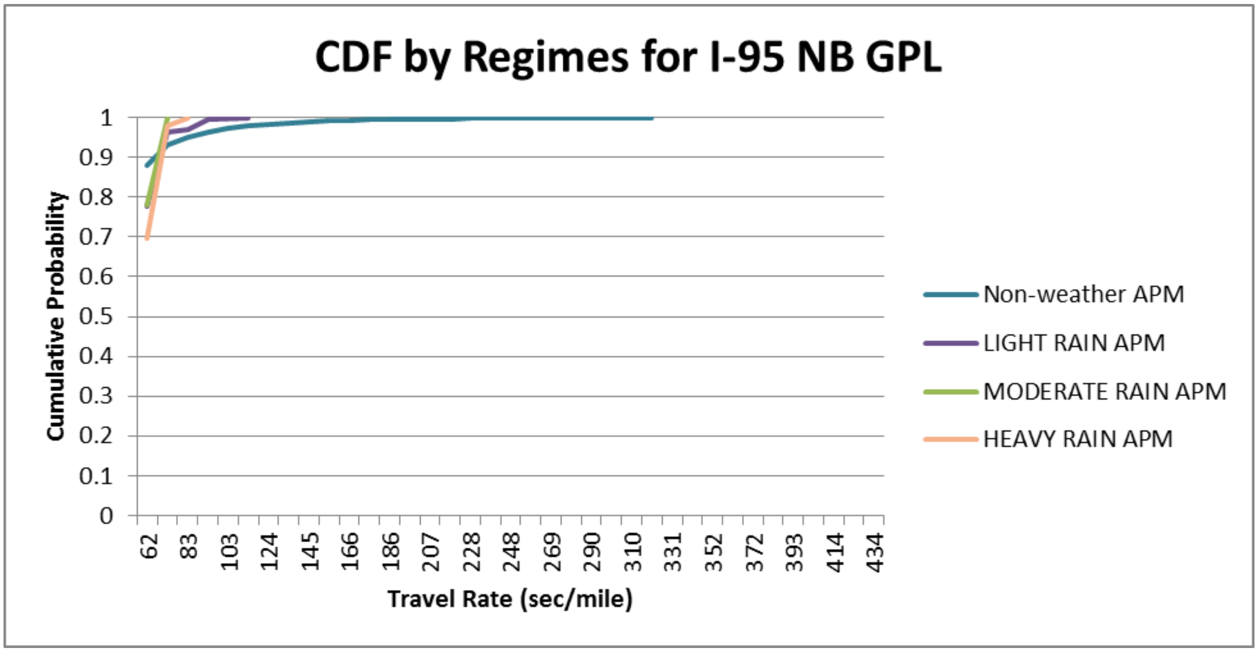
(b)


CDF by Regimes for I-95 NB GPL
Cumulative Probability
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
62
83
103
124
145
166
186
207
228
248
269
290
310
331
352
372
393
414
434
Travel Rate (sec/mile)
Non-weather PM 1
LIGHT RAIN PM 1
MODERATE RAIN PM 1
HEAVY RAIN PM 1

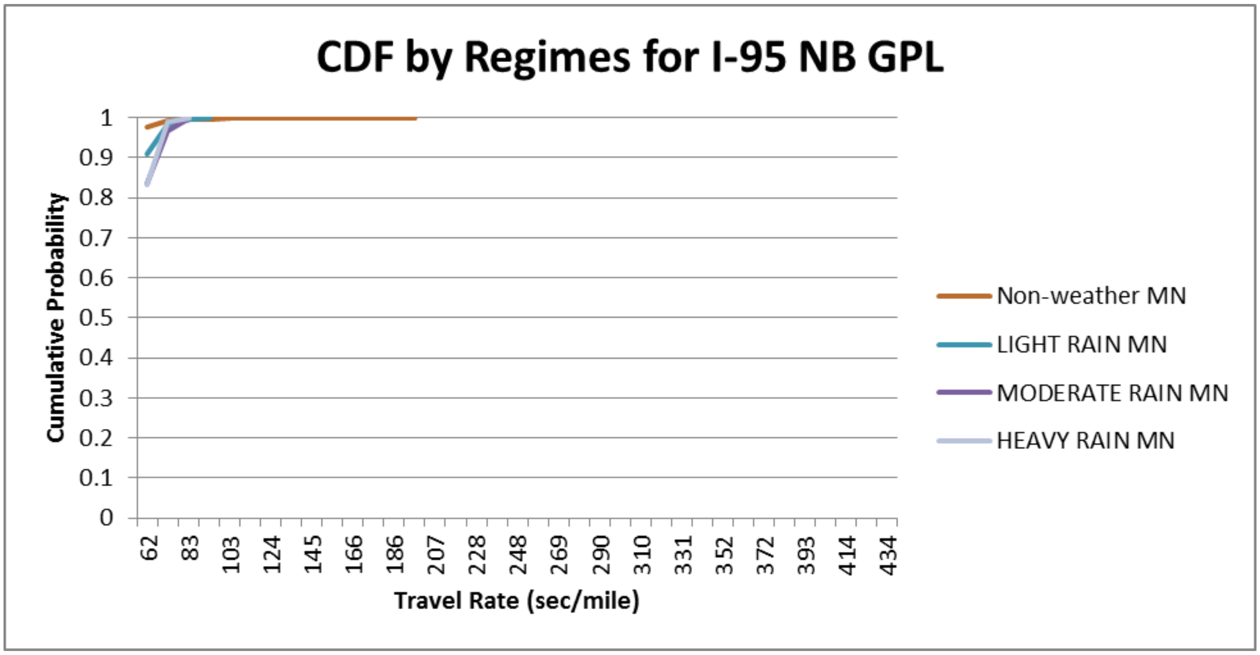
(c)


CDF by Regimes for I-95 NB GPL
Cumulative Probability
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
62
83
103
124
145
166
186
207
228
248
269
290
310
331
352
372
393
414
434
Travel Rate (sec/mile)
Non-weather PM 2
LIGHT RAIN PM 2
MODERATE RAIN PM 2
HEAVY RAIN PM 2

(d)



(e)



(f)

Figure 3.37. CDF by regimes for I-95 NB GPL for (a) AM, (b) MD, (c) PM1, (d) PM2, (e) APM, and (f) MN periods.

Table 3.10. Percentage of Occurrence

Time Period	Nonweather	Light Rain	Moderate Rain	Heavy Rain	Total
AM	12%	0%	0%	0%	13%
MD	26%	1%	0%	0%	27%
PM1	6%	0%	0%	0%	6%
PM2	8%	0%	0%	0%	8%
APM	12%	0%	0%	0%	12%
MN	32%	1%	0%	0%	33%

Table 3.11. Percentage of Severity

Time Period	Nonweather	Light Rain	Moderate Rain	Heavy Rain	Total
AM	0%	0%	1%	9%	10%
MD	1%	1%	1%	1%	3%
PM1	8%	8%	10%	17%	43%
PM2	10%	12%	15%	5%	41%
APM	1%	0%	0%	0%	2%
MN	0%	0%	0%	0%	0%

Table 3.12. Percentage of Unreliability Contribution

Time Period	Nonweather	Light Rain	Moderate Rain	Heavy Rain	Total
AM	2%	0%	0%	0%	3%
MD	9%	0%	0%	0%	10%
PM1	27%	1%	0%	0%	29%
PM2	45%	1%	0%	0%	47%
APM	10%	0%	0%	0%	10%
MN	1%	0%	0%	0%	1%

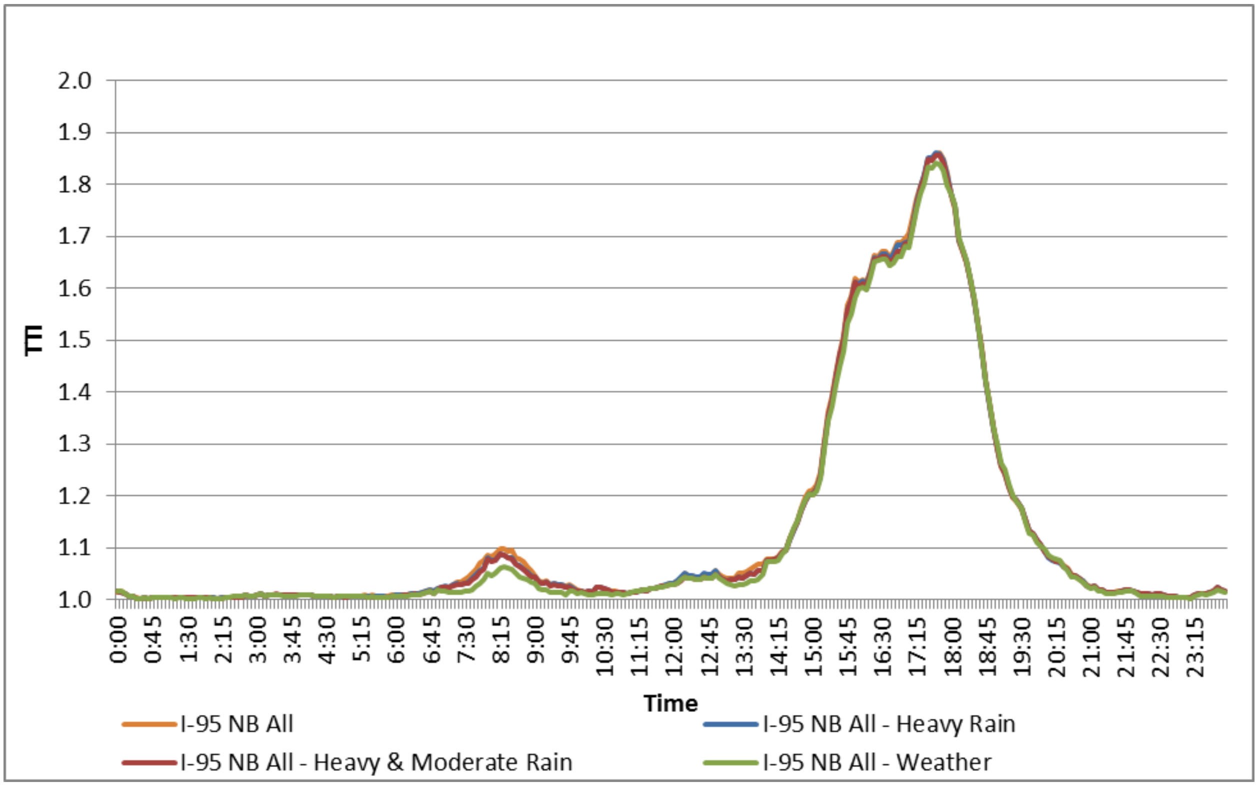


Figure 3.38. Mean TTI and weather comparison for I-95 NB GPL.

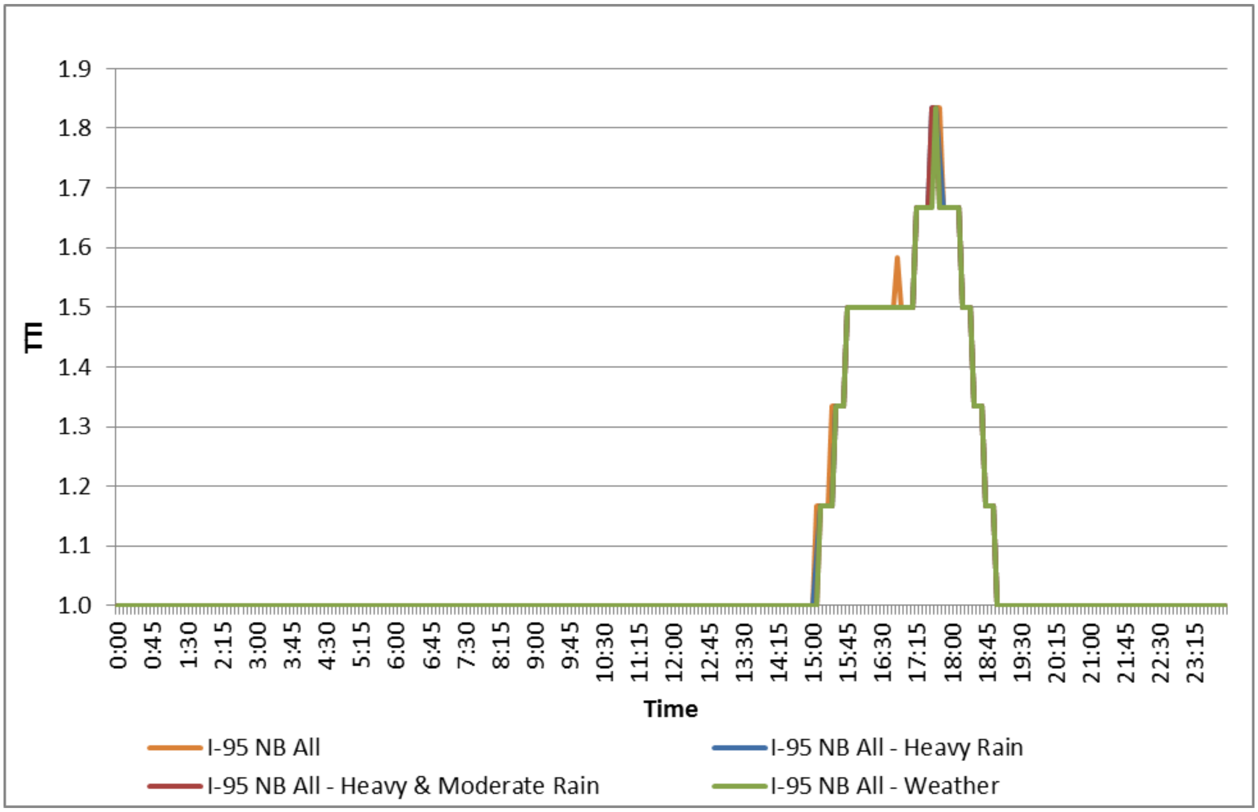


Figure 3.39. 50th percentile TTI and weather comparison for I-95 NB GPL.

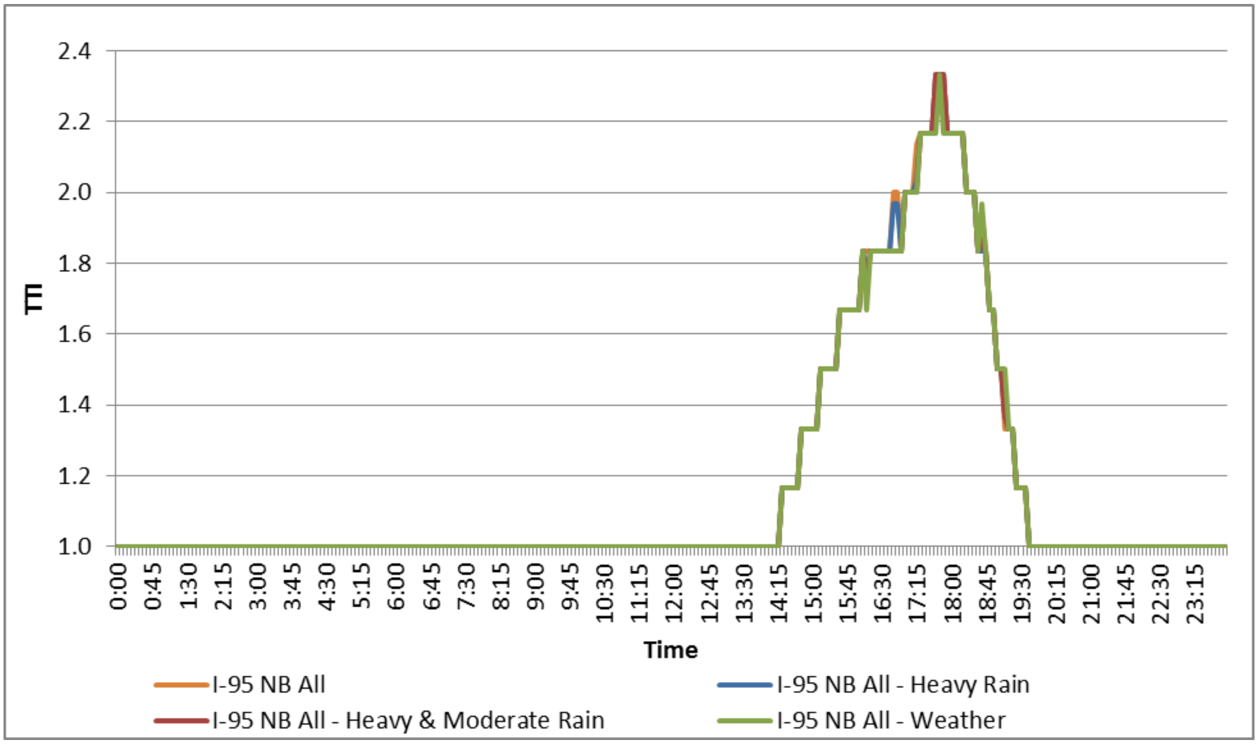


Figure 3.40. 80th percentile TTI and weather comparison for I-95 NB GPL.

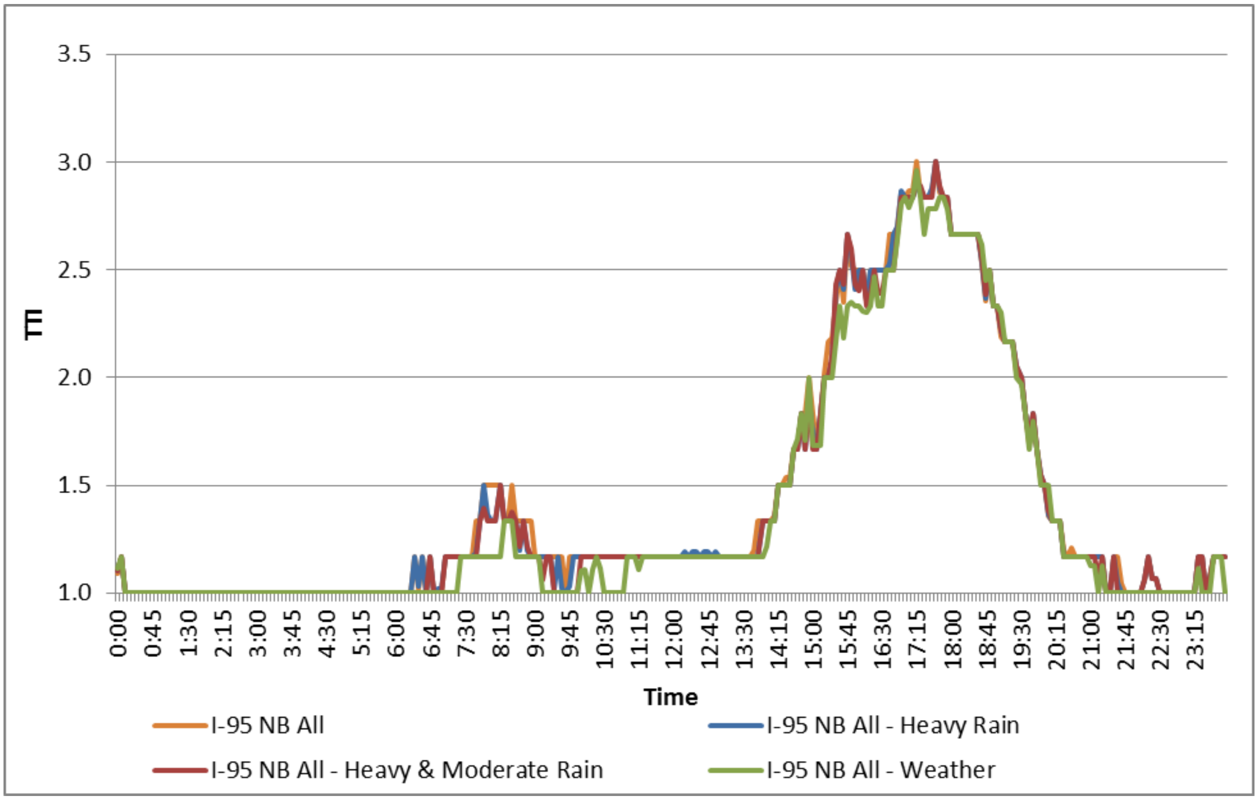


Figure 3.41. 95th percentile TTI and weather comparison for I-95 NB GPL.

3.3 Summary of I-95 Northbound General-Purpose Lane Performance

Based on the results presented in the previous section, it can be concluded that the I-95 NB GPL segment was extremely unreliable in the PM peak. This period of unreliability extended from about 2:00 to 8:00 p.m. Most of the unreliability in the day occurred in the PM peaks, with the unreliability between 3:00 and 5:00 p.m. and between 5:00 and 7:00 p.m. contributing 29% and 45%, respectively, of the overall daily unreliability of the NB GPL in the day (a combined contribution of 74%). This overall unreliability did not consider the additional unreliability on the shoulders between 2:00 and 3:00 p.m. and between 7:00 and 8:00 p.m. The 50th, 80th, and 95th percentile TTIs for the GPL PM peak were 1.5, 2.1, and 2.6, respectively. The analysis of detector data indicated that during earlier parts of the peak, between 3:00 and 5:00 p.m., the reliability of the system was influenced by two capacity-constrained locations at NW 79th Street and NW 103rd Street.

Between 5:00 and 7:00 p.m., a more severe capacity problem occurred due to the off-ramp to the Florida Turnpike and the turnpike toll plaza downstream of that ramp. Due to the different congestion patterns and causes in the PM peak, as explained above, the PM peak was subdivided into two periods for the purposes of analysis.

It was found that higher-demand days not only increased the TTI, but also elongated the period during which the TTI was high. This finding indicates that implementing active traffic and demand management when a certain threshold of demand is exceeded has the potential of improving system reliability. It is interesting to note, however, that based on the CDF curves, even with normal demand in the PM peak periods, the 95th percentile travel time rate was about twice the free-flow travel time rate, probably indicating that there were impacts of events from outside the system or events not accounted for.

In addition to these capacity-constrained problems, incidents contributed significantly to unreliability during most of the day. The contribution of lane-blocking incidents, as expected, was much higher than a single average incident. The contribution of lane-blocking incidents was twice as much as non-lane-blocking incidents, although non-lane-blocking incident frequency was much higher than that of lane blockage frequency. On a single-event basis, an average 2+ lane–blocking incidents had a very high relative impact. Additional analysis results indicated that crash incidents were generally more damaging than other (noncrash) incidents. During the PM period, the damage due to a single noncrash incident was about 50% of the damage caused by a crash incident. However, the overall impact on reliability was equivalent due to the higher frequency of noncrash incidents. The proportion of severe incidents appeared to be higher in the APM peak, possibly due to dark conditions, and increased in speed differential due to the dissipations of some queues and the lingering of others.

Weather events (rain) were relatively rare compared to incident occurrence, and the overall contribution of weather was much smaller than that due to incidents and the PM peak no-event high-demand conditions. However, the impact of a single weather event, particularly moderate- to heavy-intensity rain events, was almost the same as that of a single incident in the PM peak. Incidents plus weather events were even rarer than weather events. Thus, their contributions to the overall reliability were low. However, a single incident plus weather event generated on average the worst conditions and on a single-incident basis produced twice the impact of an incident in dry weather conditions. It is interesting to see that the impact of a single incident plus weather event was also very high in the AM peak and relatively high in the midday period.

3.4 Summary of I-95 Northbound Express Lane Performance

The results of the I-95 NB EL analysis are presented in Appendix B. The I-95 NB EL was unreliable in the PM peak, but for a shorter period than the GPL. Most of the unreliability occurred in the PM1 and PM2 peaks, when the unreliability between 3:00 and 5:00 p.m. and between 5:00 and 7:00 p.m. contributed to 32% and 47%, respectively, of the overall daily unreliability of the NB EL in the day (a combined contribution of 79%). Between 5:00 and 7:00 p.m., the 50th, 80th, and 95th percentile TTIs were about 1.1, 1.5, and 2.7. Between 3:00 and 5:00 p.m., the 50th, 80th, and 95th percentile values were 1.1, 1.2, and 2.2. These results indicate that the median travel time of the EL was good. However, the 95th percentile TTI was relatively high between 3:00 and 7:00 p.m., and the 80th percentile TTI was somewhat high between 5:00 and 7:00 p.m.

Compared to the GPL values, the 80th percentile TTI had a shorter peak period on the EL (from 4:30 to 6:00 p.m. compared to 3:00 to 7:00 p.m.). The maximum 80th percentile TTI value for EL during the PM peak was also lower than that on the GPL (peak of 1.75 versus 2.2). Although the peak 95th percentile TTIs of the EL and GPL were similar (95th percentile TTI values between 2.5 and 3.0) in the PM peak, the peak 95th percentile TTI for the EL occurred between 4:15 and 6:15 p.m., while that for the GPL occurred between 3:15 and 7:30 p.m.

The no-event period contribution to the unreliability of the NB EL in the PM peak period was significantly smaller than the contribution of the no-event period for the GPL. However, the no-event periods, particularly when the demand exceeded the high-demand threshold, still had a significant influence on reliability, indicating that more aggressive pricing policies between 5:00 and 7:00 p.m., when the demand exceeded the high-volume threshold, would have the potential to improve the reliability of the system. Analyzing the data and visualizing the bottleneck impacts by using contour (heat) maps indicated that the main capacity-constrained congestion issues in the PM peak on the EL were at approximately the same locations as those of the GPL (NW 79th Street, NW 103rd Street, and the Florida Turnpike exit).

The reliability analysis also indicated that incident intervals were the major contributors to unreliability. Although the incident frequency was lower on the EL than on the GPL, the EL contribution to unreliability was very high in the PM peak period due to the high severity per incident when one lane of the EL was blocked, and even more when both lanes were blocked. This finding needs to be explored further to determine how these impacts can be reduced, especially considering the geometric constraints of the EL, which may increase the impacts of incidents. Rainy conditions combined with incidents also increased the impacts of a single event. The overall contribution of weather events to reliability was small.

3.5 Summary of I-95 Southbound General-Purpose Lane Performance

The results of the I-95 SB GPL analysis are presented in Appendix C. The SB GPL was unreliable from 7:00 to about 10:30 a.m. Forty-six percent of the unreliability of the day occurred between 7:00 and 9:00 a.m., and it appeared that additional significant contribution occurred between 9:00 and 10:30 a.m. Between 7:00 and 9:00 a.m., the 50th, 80th, and 95th TTIs were 1.4, 1.7, and 2.5, respectively. The maximum five-minute 50th, 80th, and 95th percentile values during the AM peak were 1.6, 2.0, and 2.7 to 3.0, respectively. The midday period (assumed between 9:00 a.m. and 3:00 p.m.) also had a relatively high 95th percentile TTI at about 1.9. Five-minute reliability analysis indicated that the main unreliability in the midday peak occurred between 9:00 and 11:00 a.m., at least in part due to the extension of the AM peak congestion beyond 9:00 a.m. on some days.

The contribution of the no-event periods to the unreliability of the SB direction during the AM peak period was smaller than the contribution in the NB direction during the PM peak. However, the no-event periods, particularly when the demand exceeded the high-demand threshold, still had a significant influence on reliability. Analyzing the data and visualizing the bottleneck impacts by using contour (heat) maps indicated that the main capacity-constrained congestion issue in the AM peak was located at three merging areas (Miami Garden Drive, the NW 103rd Street ramp, and at the exit of the EL). During the no-event periods between 7:00 and 9:00 a.m., the contribution of a single event with high demand was three times as much as that with normal demand.

The reliability analysis also indicated that incidents were a major contributor to reliability most of the day. Significant effects of these incidents were also observed in the midday and PM peak. The percentage incident contribution to unreliability of the GPL was much higher in the SB direction in the midday and AM peak periods compared to the NB PM peak period. A higher number of incidents appear to have occurred in the SB direction, particularly in the AM and PM peaks, compared to the NB direction, which increased the impact on reliability. This difference could be due to the more complex weaving and merging maneuvers in the SB direction. Safety analysis should be conducted to determine the causes. The analysis also indicated that although the frequency of lane-blocking incidents was lower than non-lane-blocking incidents, their contribution was higher than shoulder incidents in the AM peak and particularly in the midday peak. The contribution of one-lane–blocking incidents, and particularly with 2+ lane blockages, was much higher than shoulder incidents.

Incident plus weather events did not significantly influence overall reliability because of the low frequency of these incidents. However, the impact of a single such incident in the AM peak, and to a lesser degree in the midday and PM peak, was high. In the AM peak, the impact of a single incident plus weather event was twice as great as a single incident and 3.75 times as great as a single no-event interval. The PM peak period between 5:00 and 7:00 p.m., considered off-peak for the SB direction, during incident plus weather conditions in the SB direction was as bad as during the AM peak. The overall contribution of weather events to reliability was small due to the low frequency of these events; however, a single moderate-to-heavy-rain event had a significant influence.

3.6 Summary of I-95 Southbound Express Lane Performance

The results of the I-95 SB EL analysis are presented in Appendix D. The SB EL was unreliable in the AM peak. However, the reliability was significantly better than the SB GPL, and the unreliability lasted for a shorter period of time. A large proportion of the unreliability occurred in the AM peak and midday. However, the midday unreliability appeared to occur at the shoulder of the AM peak, from 9:00 to 10:00 a.m. Between 7:30 and 9:30 a.m., the 50th, 80th, and 95th TTIs were 1.08, 1.2, and 1.7, respectively.

The main contributing factor to unreliability in the EL in the SB direction was an incident in the AM peak and, to a lesser degree, the midday peak. In the AM peak, the contribution of a single incident event was very high, indicating that, as with the NB EL, the geometry and operational constraints on the EL increased the incident impacts.

3.7 Summary of SR-7 Northbound Performance

The results of the SR-7 NB analysis are presented in Appendix E. SR-7 is a data-poor environment. Therefore, data from INRIX were used in analyzing the reliability of the facility based on real-world data. The analysis clearly showed that the PM peak traffic experienced the most unreliable travel time, followed by the travel times during the midday and the after-PM peak period. The semivariance of travel time rate for the PM peak when considering a single-instant contribution was close to double the midday and evening values. However, because there are more hours in the midday, the overall contribution to unreliability was higher in the midday, followed closely by the PM peak. The 50th, 80th, and 95th percentile TTIs in the PM peak were 1.50, 1.63, and 1.90, respectively. The maximum 95th percentile TTI was approximately 2.0, indicating a travel time twice the free-flow travel time. For the midday, the three TTIs were 1.40, 1.46, and 1.55, respectively; the three indexes were close to each other. Similar results were noted for the other periods. These findings may be due to the nature of the operation on SR-7 or a function of the data used in the analysis (INRIX data).

On a single-event basis, normal conditions, bad weather conditions, and conditions with crashes with a longer duration than 30 minutes appeared to have had the highest influence on reliability. However, when taking occurrence into consideration, the normal conditions during the midday and PM periods had larger contributions to overall unreliability along SR-7 NB. The analysis also showed that the I-95 lane-blocking events slightly increased the semivariance of travel time rates along SR-7 NB in the PM peak period.

3.8 Summary of SR-7 Southbound Performance

The results of the SR-7 SB analysis are presented in Appendix F. The analysis indicated that the reliability performance was similar for different periods of the day, with the AM peak showing only slightly higher single-event impact than the PM peak and midday peak. Because of the longer period of the midday, the overall contribution to unreliability of the midday was the highest. The 50th, 80th, and 95th TTIs in the AM peak were 1.40, 1.50, and 1.80, respectively. For the midday, the three TTIs were 1.45, 1.49, and 1.63, respectively. For the PM peak, the three indexes were 1.46, 1.49, and 1.51. Again, all indexes seemed to be close to each other, possibly due to the nature of the operation on the facility or the nature of the data used.

The analysis results showed that the occurrence of crashes caused slight increases in the unreliability of SR-7 SB traffic. It appeared that weather events and crashes had comparable impacts on unreliability. The percentage of semivariance was also high during the midday period, which indicates that further improvement in the existing roadway configuration and signal timing may need to be considered.

CHAPTER 4
L07 Product Tests

4.1 Introduction and Background

Project L07 focused on the estimation of the effect of physical design treatments on freeway travel time reliability and the cost-effectiveness of these treatments. The L07 analysis was based on the reliability estimation methods developed in the L03 project and can be considered as a sketch planning–level analysis that is not as detailed as the L08 procedures. Therefore, it may not be appropriate to support detailed operational analysis, but rather to give an overall estimation of the benefits of specific types of improvements at the planning stage. In addition, the L07 project analysis is only applicable to freeway segments and currently cannot be used for arterial streets.

In this chapter, the results from the L07 sketch-planning spreadsheet are examined for the I-95 NB GPL segment and compared with the analysis results obtained based on the real-world monitoring system discussed in Chapter 3. The analysis is done for both the full I-95 NB GPL segment and also for times when that segment was divided into three subsegments.

4.2 L03 Reliability Models

The L07 reliability analysis was based on procedures developed in the L03 project to estimate reliability. TTI was used as the measure of reliability. For a data-rich environment, the models developed in the L03 project quantify the effect of incidents and work zones on reliability by predicting several percentiles of the TTI distribution based on three key variables:

- Lane hours lost (LHL) due to incidents and work zones, which is calculated as the average number of lanes blocked per incident (or work zone) multiplied by the average duration per incident (or work zone) and the total number of incidents (or work zones) during the time slice and study period of interest;
- Critical demand-to-capacity ratio (dccrit), which is defined as the ratio of demand to capacity during the most critical hour of the time slice and study period; and
- Hours of rainfall exceeding 0.05 inch (R0.05") during the time slice and study period of interest.

The relationships developed in the L03 project have the following general functional form (Equation 4.1), with the coefficient values for calculating different TTI percentiles as presented in Table 4.1:

$$TTI_{n\%} = e^{(j_n LHL + k_n dc_{crit} + l_n R_{0.05''})} \qquad (4.1)$$

where

$TTI_{n\%}$ = $nth\ percentile\ TTI\ value$, and

j_n, k_n, l_n = $coefficients\ for\ nth\ percentile$.

Table 4.1. Coefficients Used in Project L03 Reliability Models for Peak Hour

N (percentile)	j_n	k_n	l_n
10	0.07643	0.00405	0.00000
50	0.29097	0.01380	0.00000
80	0.52013	0.01544	0.00000
95	0.63071	0.01219	0.04744
99	1.13062	0.01242	0.00000

Note: The coefficients used to calculate the mean TTI are 0.27886 for j_n, 0.01089 for k_n, and 0.02935 for l_n.

4.3 Data Collection and Analysis

4.3.1 Input Data

In order to test the reliability evaluation tool of the L07 project, a number of data items were needed as inputs to the tool. As stated earlier, the analysis was conducted for the entire analyzed I-95 NB GPL segment and also for times when the segment was divided into three subsegments. The three subsegments are defined in Table 4.2.

Table 4.2. Basic Information for Study Segments

Segment	Starting Location	Ending Location	Length (mile)	No. of Lanes
Segment 1	NW 62nd Street	NW 78th Street	0.98	4
Segment 2	NW 78th Street	NW 101st Street	1.45	4
Segment 3	NW 101st Street	NW 155th Street	3.46	4

4.3.1.1 Lane Hours Lost

LHL is a variable that reflects the duration and lane blockage severity of incidents and work zones. In this study, LHL due to incidents was calculated based on data from the SunGuide incident management database.

There are two types of incident blockages: lane-blocking incidents and shoulder-blocking incidents. LHL due to lane-blocking incidents was calculated as the actual number of blocked lanes due to incidents multiplied by the blockage duration. The expression for LHL for lane-blocking incidents is given by Equation 4.2:

$$LHL = \frac{1}{60}\sum_j N_{blockage,j} * T_{incident,j} \qquad (4.2)$$

where $N_{blockage,j} = number\ of\ lanes\ blocked\ by\ incident\ j$ and

$T_{incident,j} = blockage\ duration\ of\ incident\ j$.

LHL due to shoulder blockage can also contribute to incident impacts. This contribution was accounted for by calculating the equivalent lane blockage due to reduced capacity as a result of shoulder blockage multiplied by the blockage duration. The formula is given by Equation 4.3:

$$LHL = \frac{1}{60} \sum_j P_{reduce,i} N_{all\ lanes} T_{incident,j} \qquad (4.3)$$

where

$P_{reduce,i}$ = $percentage\ of\ reduced\ highway\ capacity\ due\ to\ incident\ type\ i,$

$N_{all\ lanes}$ = $the\ number\ of\ all\ the\ lanes\ in\ study\ segment,$ and

$T_{incident,j}$ = $blockage\ duration\ of\ incident\ j.$

The values for the reduced percentage of highway capacity used in the above equation were obtained based on the HCM estimates presented in Table 4.3 (HCM 2010).

Table 4.3. Proportion of Freeway Segment Capacity Available Under Incident Condition

No. of Lanes per Direction	Shoulder Disablement	Shoulder Accident	One Lane Blocked	Two Lanes Blocked	Three Lanes Blocked
2	0.95	0.81	0.35	0.00	Not applicable
3	0.99	0.83	0.49	0.17	0.00
4	0.99	0.85	0.58	0.25	0.13
5	0.99	0.87	0.65	0.40	0.20
6	0.99	0.89	0.71	0.50	0.26
7	0.99	0.91	0.75	0.57	0.36

Source: HCM 2010.

4.3.1.2 Critical Demand-to-Capacity Ratio

Another important independent variable in TTI estimation is the critical demand-to-capacity ratio. The main challenge involved in estimating this parameter is that, in a congested period, the observed traffic volume passing a specific section is capacity constrained. The traffic detectors provide traffic volume measurements (the number of vehicles that pass a given point), not demand (the number of vehicles that want to pass the point, including those that are queued because of capacity constraints). These two parameters are different in congested conditions. The L03 project recommended a procedure to estimate demand during the congested period. This procedure was applied in this study by using a mean speed of 40 mph as a threshold to activate the congested demand–estimation procedure.

4.3.1.3 Hours of Rainfall Exceeding 0.05 inch

The L07 tool provides default values of hourly rainfall based on 10 years (2000 through 2010) of hourly precipitation data at 387 weather stations across the United States. The number of hours with rainfall exceeding 0.05 inch reported in the data was used in the reliability estimation of this study. The snowfall statistics were not relevant to Miami.

4.3.2 Analysis of Results

To test the accuracy of the TTI prediction model, the TTI calculated based on real-world data, as discussed in Chapter 3, was compared with the TTI estimated by the L07 tool for the total length of the I-95 NB GPL facility (5.89 miles) and for each segment. The results are presented in Figures 4.1 to 4.4. In these figures MIN refers to the minimum TTI and MAX refers to the maximum TTI during the 24 hours of the day. It can be observed from these figures that there were significant differences in the comparisons of the estimated TTIs for different segments. The TTI L07 estimates for Segment 1 were lower than the real-world TTIs, and the TTI estimates for Segment 3 and the whole facility were higher than the real-world TTI values. Figure 4.3 shows that the estimated cumulative TTI curve for Segment 2 had a good fit with the real-world TTI curve. Figures 4.5 through 4.8 show the comparison for different percentile TTIs for each segment by time of day. The results in Figures 4.1 to 4.8 indicate that when using the reliability estimation default models, the L07 procedure did not produce estimates that were close to the real-world values, except for Segment 2. Thus, the parameters of the models used had to be obtained for local conditions, as described next.

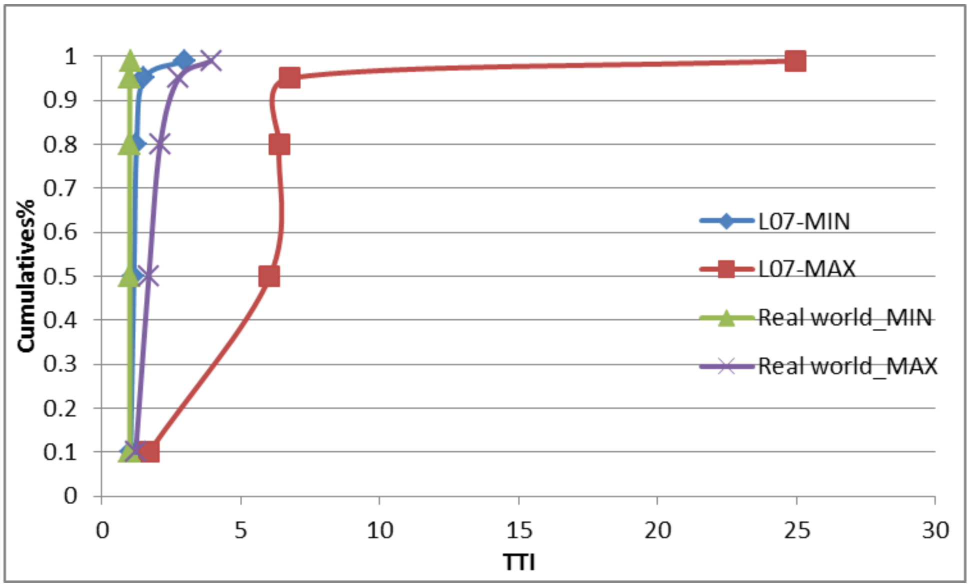


Figure 4.1. Cumulative TTIs for the whole facility for I-95 NB GPL.

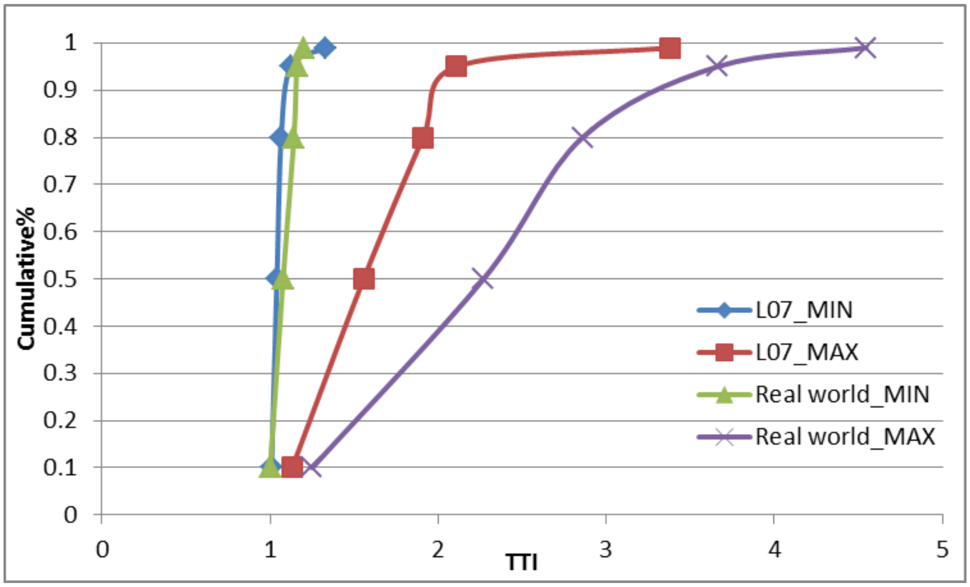


Figure 4.2. Cumulative TTIs for Segment 1 of I-95 NB GPL.

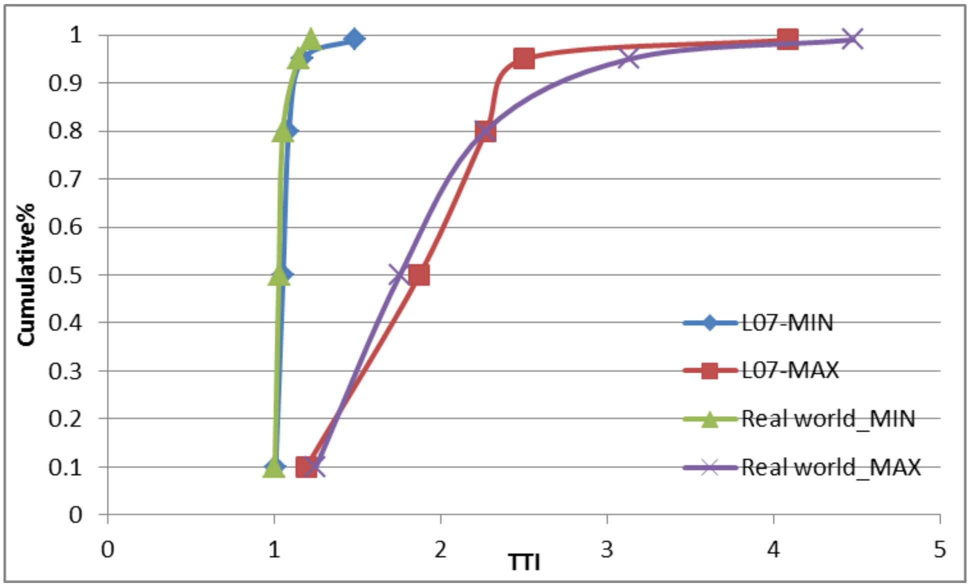


Figure 4.3. Cumulative TTIs for Segment 2 of I-95 NB GPL.

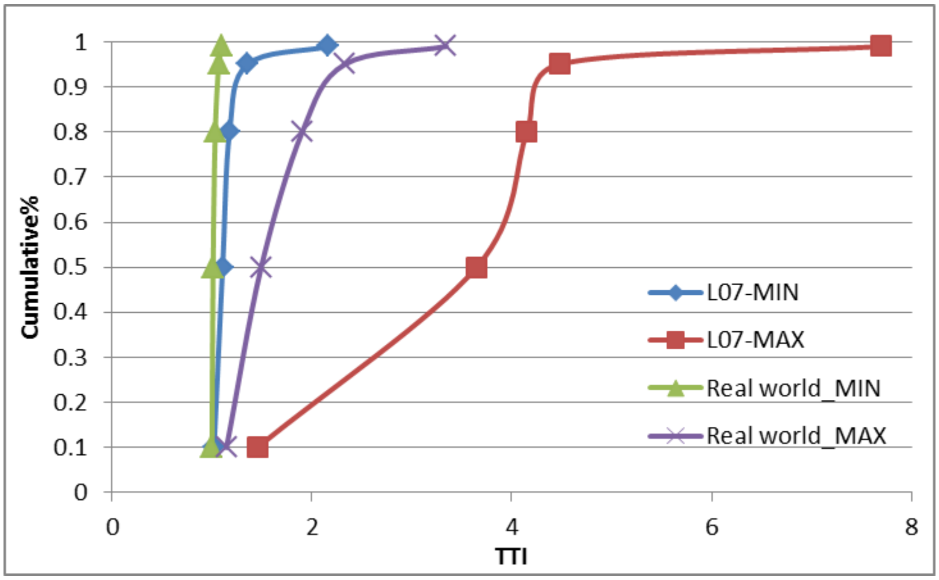


Figure 4.4. Cumulative TTIs for Segment 3 of I-95 NB GPL.

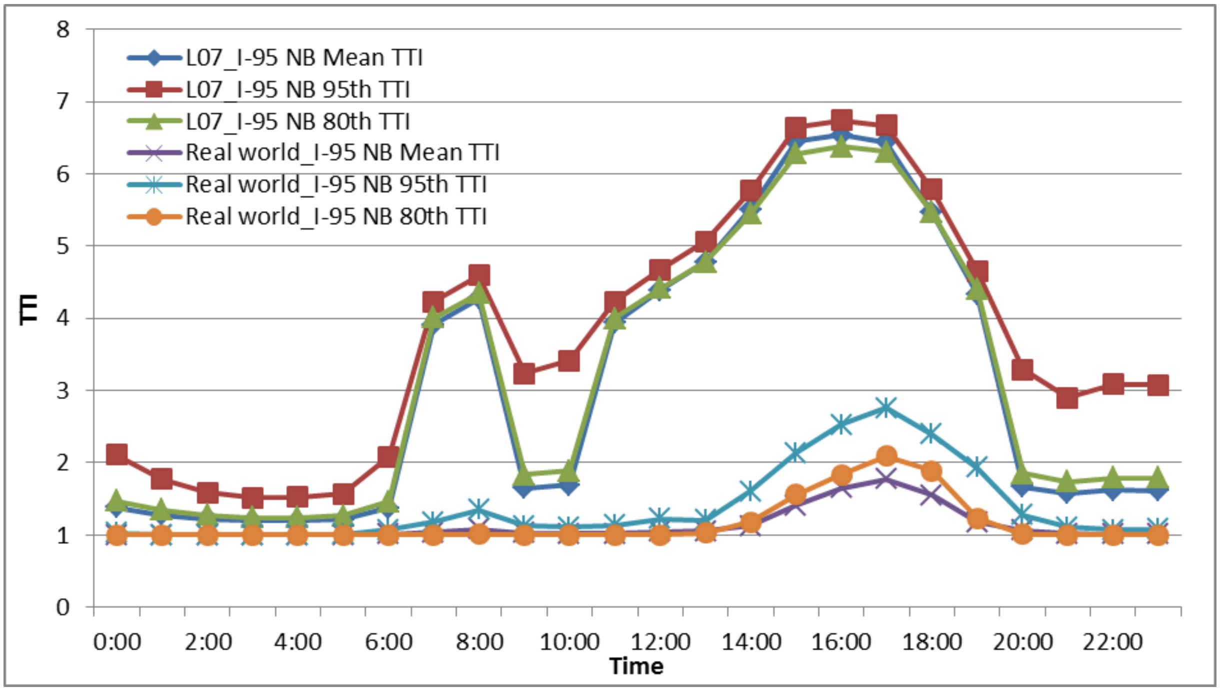


Figure 4.5. Comparison of mean, 95th percentile, and 80th percentile TTIs for the whole facility for I-95 NB GPL.

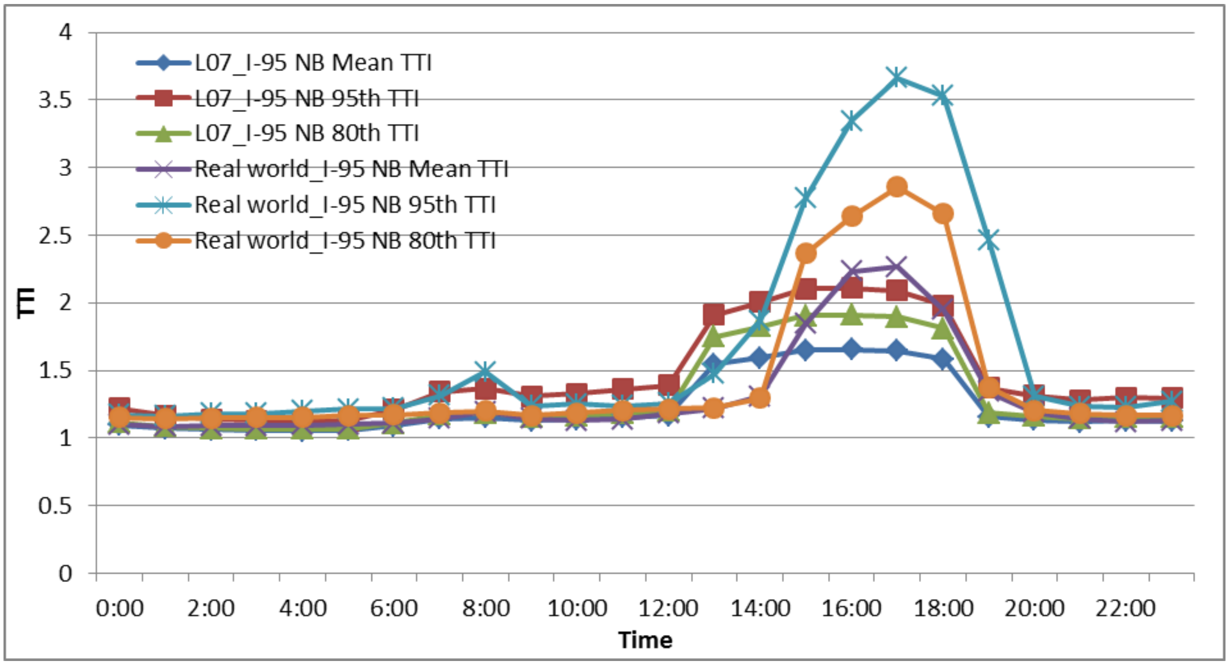


Figure 4.6. Comparison of mean, 95th percentile, and 80th percentile TTIs for Segment 1 of I-95 NB GPL.

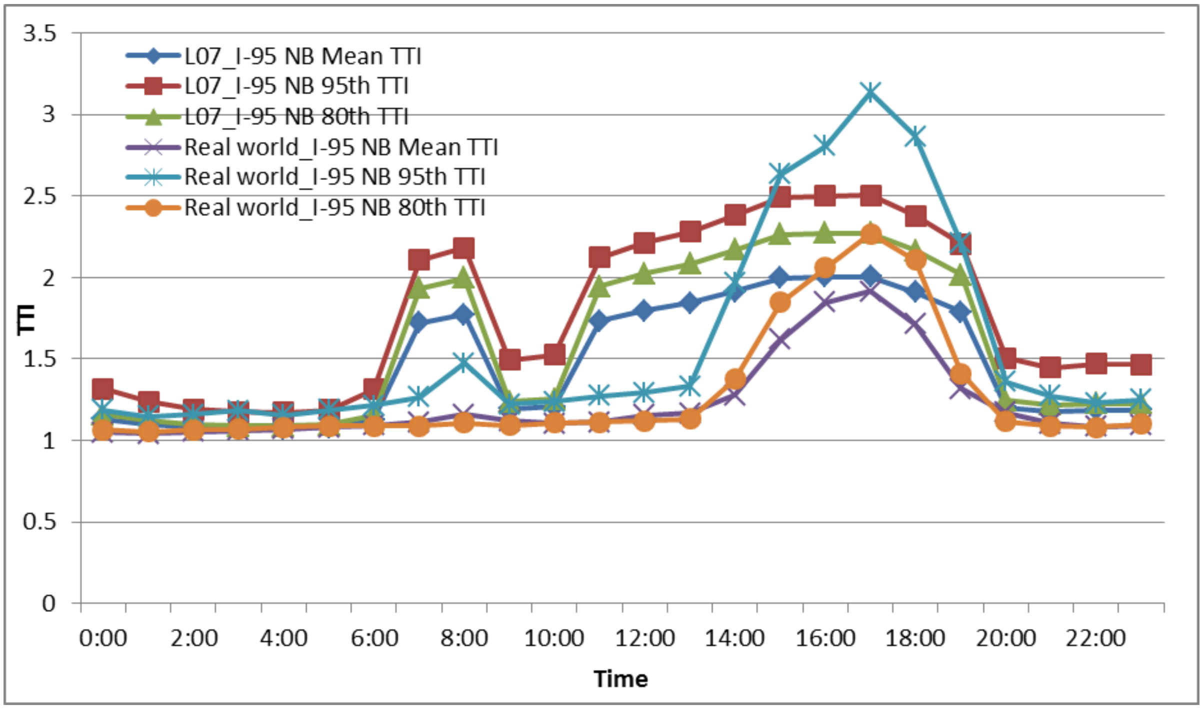


Figure 4.7 Comparison of mean, 95th percentile, and 80th percentile TTIs for Segment 2 of I-95 NB GPL.

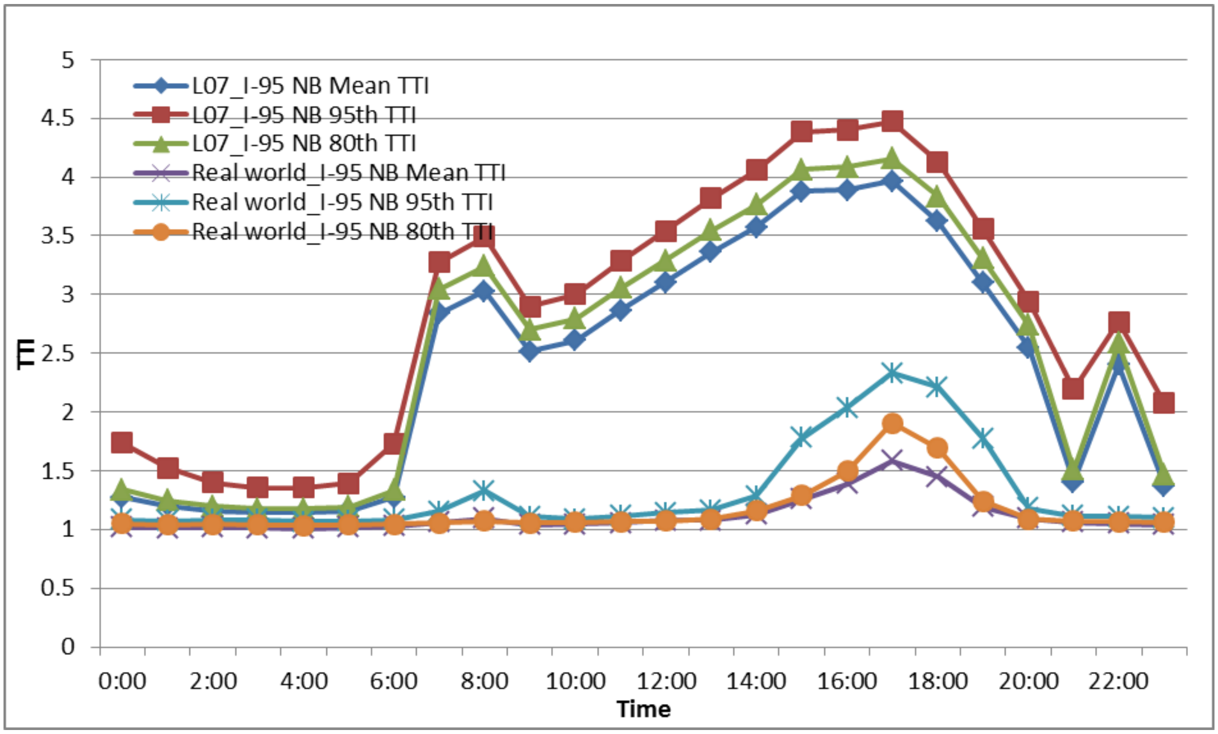


Figure 4.8. Comparison of mean, 95th percentile, and 80th percentile TTIs for Segment 3 of I-95 NB GPL.

4.4 Parameter Estimation Based on Local Conditions

As mentioned in Section 4.3, the default TTI model used in L07 did not produce a good estimation of the TTIs for the I-95 NB GPL. This section presents the derivation of the parameters of the TTI estimation model based on local data. Different regression expressions were investigated, and a new variable, segment length, was added into the regression model, as discussed below.

4.4.1 Variable Analysis

Different percentile TTIs were estimated by the L03 and L07 models based on demand, incidents, and weather. Preliminary analysis based on the limited investigated case studies indicated that segment length may have played a role in the accuracy of the estimates based on the default models. The L07 TTI estimates for the shorter segments were lower than the real-world TTIs, and the TTI estimates for the longer segments were higher than the real-world TTIs. These findings are possibly due to the development of default regression models for a certain range of segment lengths. In this study, segment length was added as an independent variable in the TTI estimation model to determine its impacts on the results.

Scatterplots for variables are presented in Figure 4.9 and Figure 4.10. These figures show that there was a positive relation between the TTI values and dc_{crit}, $R_{0.05''}$, and LHL in the three segments, while there was a negative relationship between the TTI values and segment length. Moreover, the TTI for each segment seemed to vary with different independent variables. Thus, individual models for each of the three segments were produced in addition to a global model for the three segments.

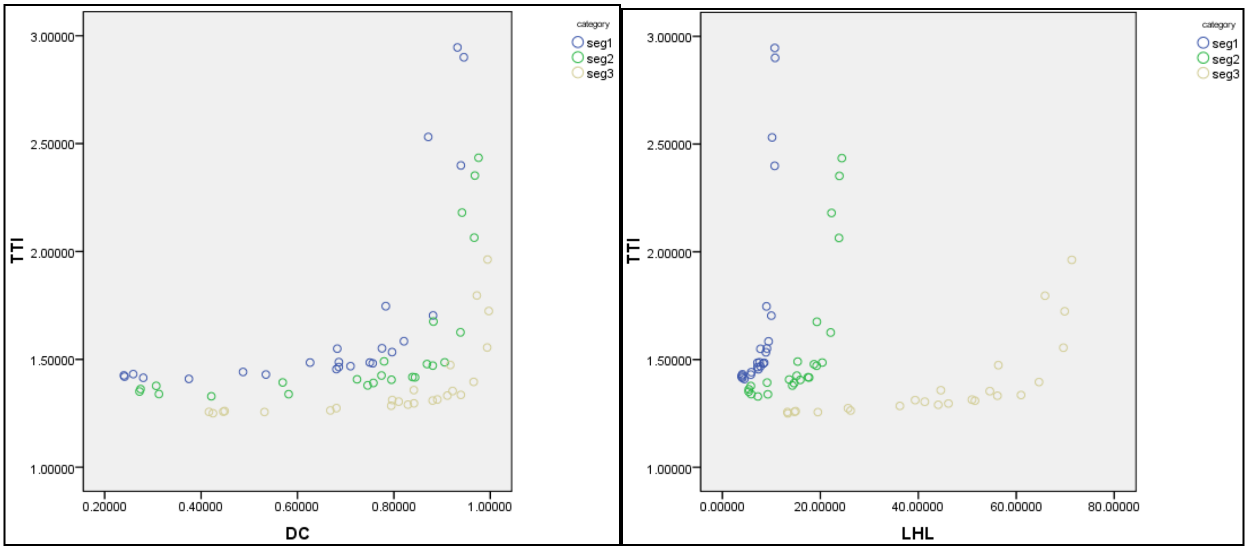


Figure 4.9. Scatterplots for dc_{crit} and LHL.

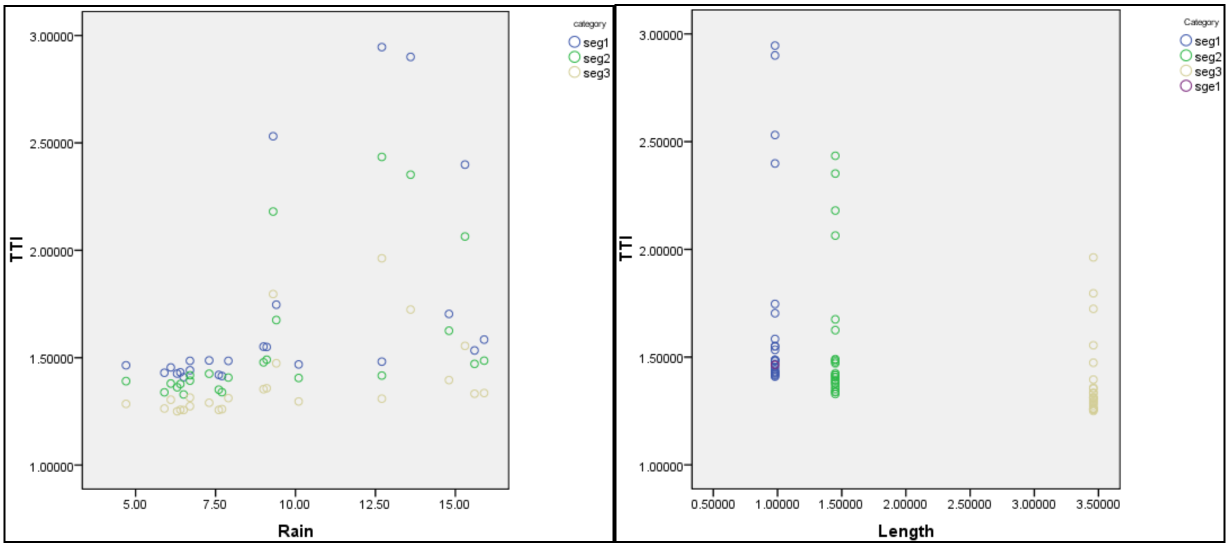


Figure 4.10. Scatterplots for precipitation and segment length.

4.4.2 Regression Analysis Results

4.4.2.1 Global Model

Regression models were produced for each individual segment in addition to the global model for all the segments. The global model was developed based on data from all three segments investigated in this study. Linear, quadratic, and exponential forms were tested for the regression model. The exponential function was selected as the main regression model form due to its better performance. A comparison was made between TTI values estimated by the different models as follows:

- *Global Model 1*—uses the exponential function and coefficients used in the L07 tool;
- *Global Model 2*—uses the exponential function used in the L07 tool and coefficients based on local data for I-95;
- *Global Model 3*—uses the exponential function with the addition of a constant term;
- *Global Model 4*—similar to Global Model 3, but with the addition of segment length as an independent variable in the regression mode; and
- *Global Model 5*—the same independent variables as Global Model 3, but using a combined quadratic function and exponential function.

The detailed expression for each model is presented in Table 4.4, which shows that using local data, adding constant coefficients, and to a lesser degree adding segment length as an independent variable improved the results. Using the combined quadratic function and exponential function also improved the results slightly over using an exponential expression by itself.

Table 4.4. Comparison between Global Regression Models Fit of Real-World Data

Model	**R^2**	**Format**	**RMSE**	**CV (%)**
Global 1	NA	$TTI = e^{a1*dc+a2*LHL+a3*Rain}$	0.955236	78.5
Global 2	0.251	$TTI = e^{a1*dc+a2*LHL+a3*Rain}$	0.241055	19.8
Global 3	0.921	$TTI = e^{b1*dc+b2*LHL+b3*Rain+b4} + b5$	0.078249	6.4
Global 4	0.928	$TTI = e^{b1*dc+b2*LHL+b3*Rain+b4*Length+b5} + b6$	0.074652	6.1
Global 5	0.948	$TTI = e^{b1*dc+b2*LHL+b3*Rain+b4} + b5*Length + b6*Length^2 + b7$	0.063624	5.2

Note: RMSE = root mean square error; CV = coefficient of variation.

4.4.2.2 Individual Models

As mentioned in Section 4.4.1 on variable analysis, individual regression models were also produced for each segment. However, it was not applicable to add the length variable in the individual segment regression model. Therefore, only the models using the form of the regression model used in the L07 tool and the exponential function with added constant coefficients were compared. The individual regression models are described as follows:

- *Individual Model 1 for Segment 1*—uses the exponential function used in the L07 tool and coefficients based on local I-95 data;
- *Individual Model 2 for Segment 1*—uses the exponential function with the addition of constant coefficients;
- *Individual Model 1 for Segment 2*—uses the exponential function used in the L07 tool and coefficients based on local I-95 data;
- *Individual Model 2 for Segment 2*—uses the exponential function but with the constant terms;
- *Individual Model 1 for Segment 3*—uses the exponential function used in the L07 tool and coefficients based on local I-95 data; and
- *Individual Model 2 for Segment 3*—uses the exponential function but with the constant terms.

The expressions for each regression model are listed in Table 4.5. Table 4.5 shows that the exponential regression model with constant terms fit the local data better and significantly increased the R^2. The coefficients for the global and segment regression models that had R^2 larger than 0.9 are shown in Table 4.6.

Table 4.5. Comparison between Different Individual Regression Models

Model	R^2	Format	RMSE	CV
Segment 1	0.708	$TTI = e^{a1*dc+a2*LHL+a3*Rain}$	0.192441	14.7%
	0.990	$TTI = e^{b1*dc+b2*LHL+b3*Rain+b4} + b5$	0.035533	2.7%
Segment 2	0.725	$TTI = e^{a1*dc+a2*LHL+a3*Rain}$	0.134105	10.9%
	0.970	$TTI = e^{b1*dc+b2*LHL+b3*Rain+b4} + b5$	0.442901	3.6%
Segment 3	0.665	$TTI = e^{a1*dc+a2*LHL+a3*Rain}$	0.087111	7.8%
	0.977	$TTI = e^{b1*dc+b2*LHL+b3*Rain+b4} + b5$	0.022445	2.0%

Table 4.6. Coefficients for Regression Models

Model	*b*1	*b*2	*b*3	*b*4	*b*5	*b*6	*b*7
Global 3	17.788	–0.054	–0.111	–15.986	1.054		
Global 4	15.554	–0.008	–0.109	0.558	–13.549	1.052	
Global 5	17.564	–0.041	–0.113	–15.896	–0.347	0.066	1.397
Segment 1	7.220	1.249	–0.168	–12.694	1.108		
Segment 2	–2.220	0.559	–0.128	–4.421	1.057		
Segment 3	4.655	0.185	–0.197	–10.143	1.026		

Figures 4.11 through 4.13 compare the results from different regression models to real-world data. As expected, individual segment models fit the real-world data best for the segment for which the model was developed. However, global models were also able to provide good fits for the data. Global Model 5 was considered the best model in that it fit the data well for all segments. This observation indicates that deriving a model based on local data for the whole facility is sufficient if individual segment models are not to be derived.

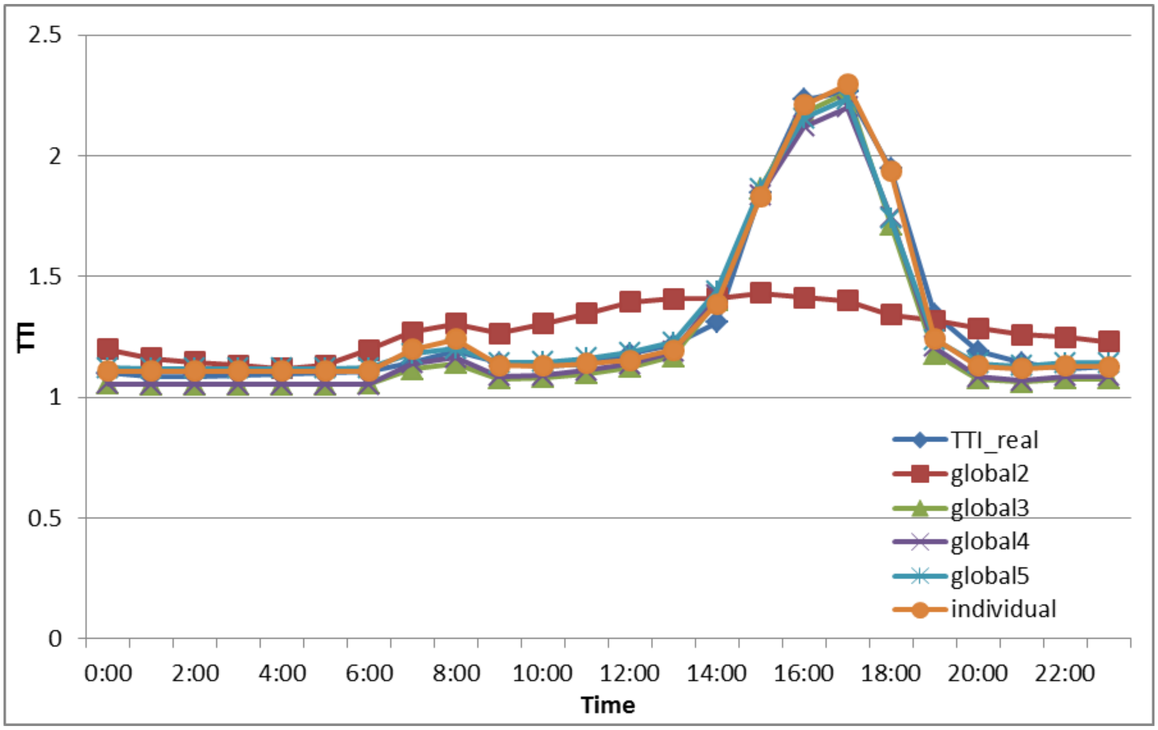


Figure 4.11. Comparison of regression models for Segment 1.

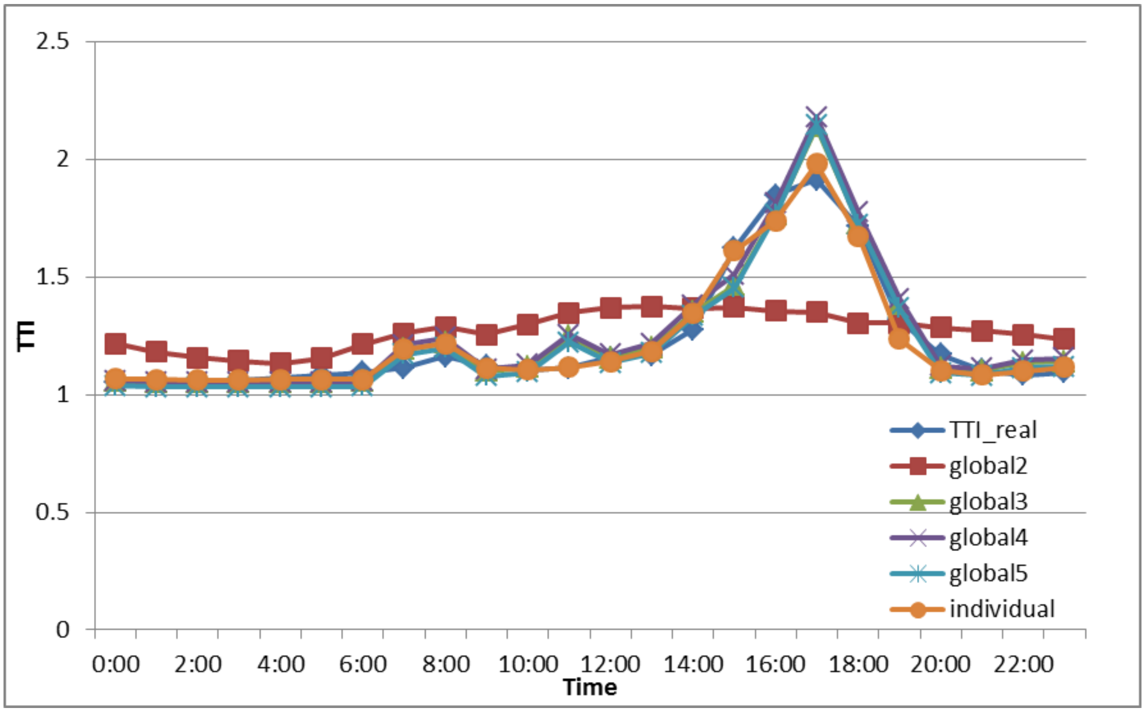


Figure 4.12. Comparison of regression models for Segment 2.

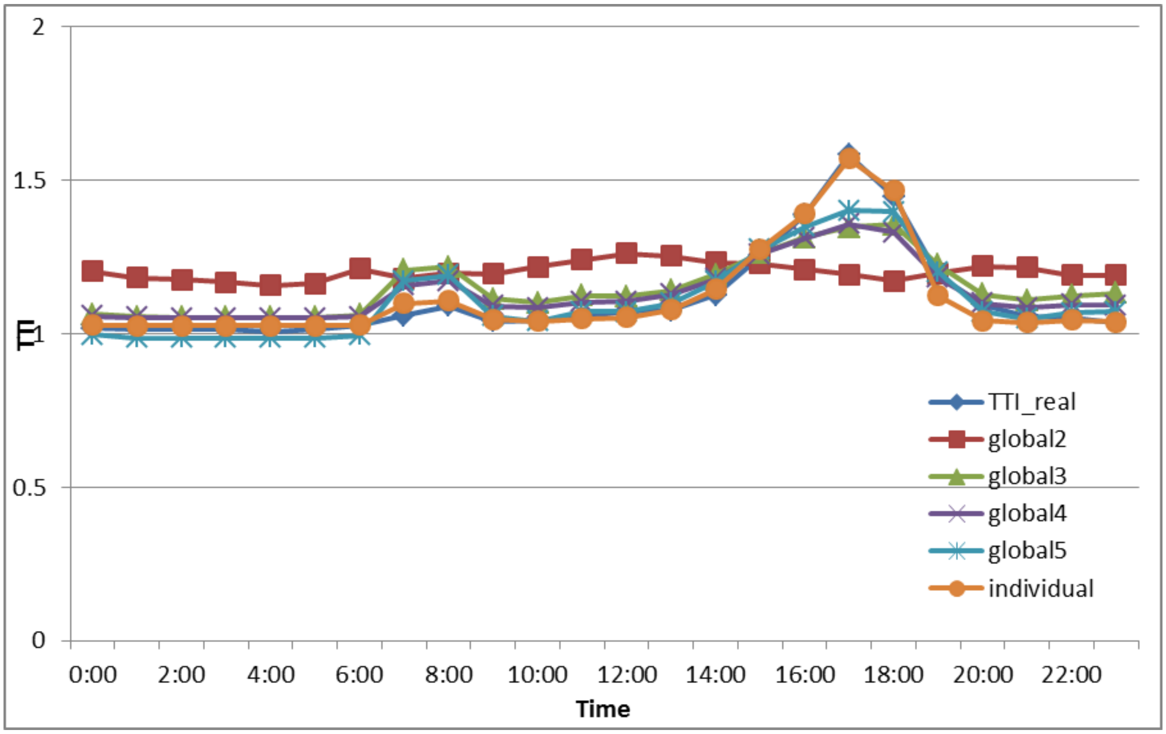


Figure 4.13. Comparison of regression models for Segment 3.

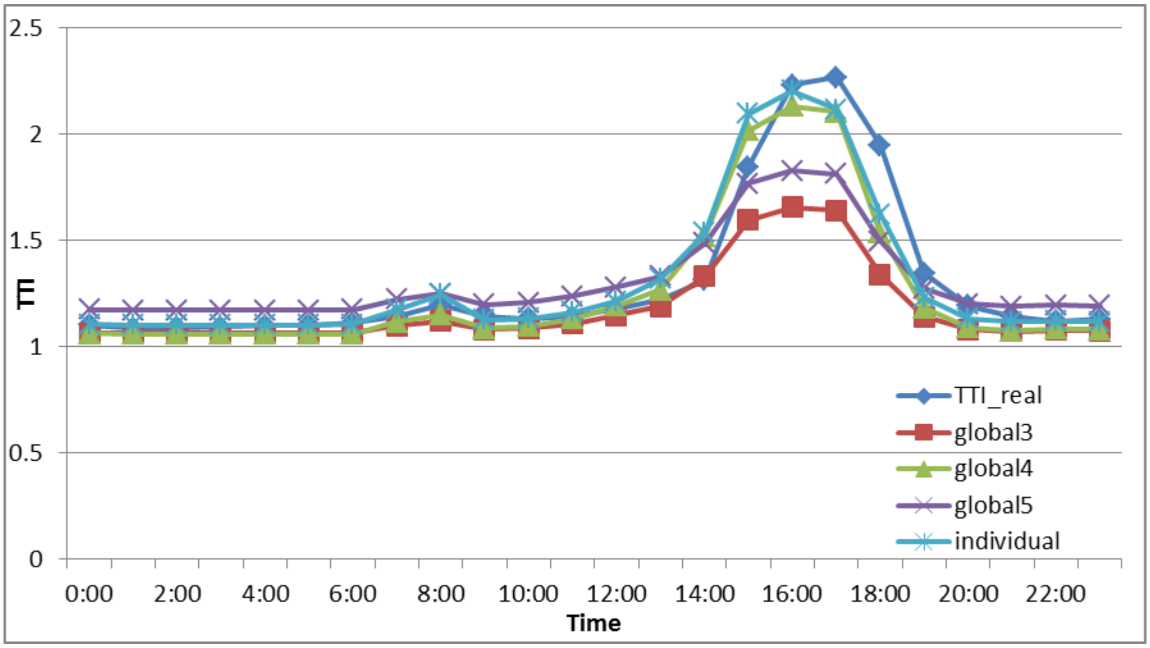


Figure 4.14. Comparison of regression models for Segment 1.

4.4.3 Validation for Regression Model

In the derived regression models, the LHL, dc_{crit}, and $R_{0.05''}$ variables should be positively related to the TTI values, meaning that the coefficients should also be positive in the exponential regression model. Some of the regression models reported above did not follow this expectation. The regression analysis was repeated by adding constraints for those coefficients to have no negative values. The updated regression analysis for the mean TTI is described below as an example. Tables 4.7 and 4.8 demonstrate the modification of coefficients for global and individual models. Figures 4.14 to 4.16 show an updated comparison with real-world data. As shown in these tables and figures, the R^2 and goodness of fit, as measured by the root mean square error, were lower after the update compared to those before the update, and some of the model coefficients became zero. However, the updated Global Model 4, for example, still produced estimates that had relatively good correspondence with the TTI values based on real-world data, as shown in Figures 4.14 to 4.16. Further research on this issue is needed.

Table 4.7. Modification for Regression Coefficients of Global Models

Model	R^2	*b*1	*b*2	*b*3	*b*4	*b*5	*b*6	*b*7
Model 3	0.921	17.788	–0.054	–0.111	–15.986	1.054		
Modified	0.584	13.147	0.000	0.000	–13.786	1.060		
Model 4	0.928	15.554	–0.008	–0.109	0.558	–13.549	1.052	
Modified	0.884	14.020	0.000	0.000	–0.619	–13.470	1.058	
Model 5	0.948	17.564	–0.041	–0.113	–15.896	–0.347	0.066	1.397
Modified	0.757	12.101	0.000	0.000	–12.632	–0.410	0.066	1.509

Table 4.8. Modification for Regression Coefficients of Individual Models

Model	R^2	*b*1	*b*2	*b*3	*b*4	*b*5
Segment 1	0.990	7.220	1.249	–0.168	–12.694	1.108
Modified	0.910	0.000	1.584	0.000	–9.786	1.101
Segment 2	0.970	–2.220	0.559	–0.128	–4.421	1.057
Modified	0.925	10.528	0.135	0.000	–12.885	1.062
Segment 3	0.977	4.655	0.185	–0.197	–10.143	1.026
Modified	0.823	9.018	0.087	0.000	–13.579	1.024

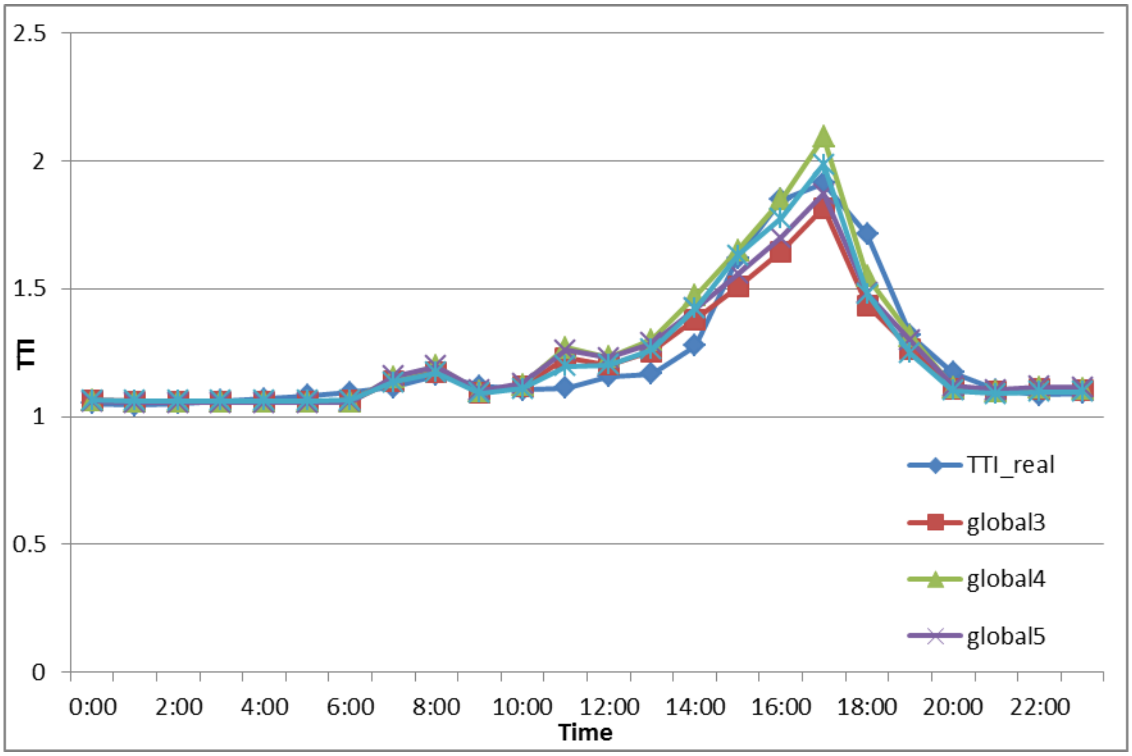


Figure 4.15. Comparison of regression models for Segment 2.

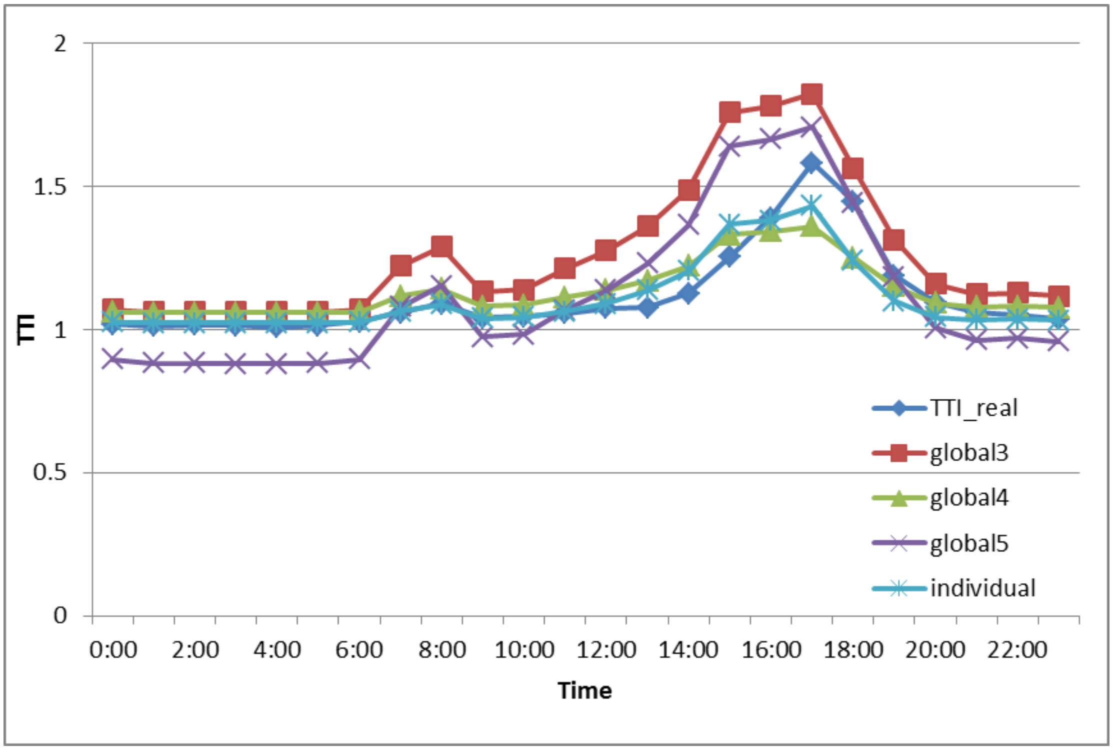


Figure 4.16. Comparison of regression models for Segment 3.

Similar analysis was also conducted for other TTI percentiles in addition to mean TTI. Tables 4.9 and 4.10 show the regression coefficients and R^2 values for different models without constraining the coefficient signs to positive values and after constraining the signs to positive values, respectively.

Table 4.9. Coefficients for Different Models before Validation

Global Model 4: $TTI = e^{b1*dc+b2*LHL+b3*Rain+b4*Length+b5} + b6$

Percentile	R^2	*b*1	*b*2	*b*3	*b*4	*b*5	*b*6
10	0.904	10.216	0.057	–0.021	–1.165	–10.791	1.013
50	0.918	22.356	–0.077	–0.116	0.058	20.471	1.051
80	0.894	17.613	–0.024	–0.150	–0.433	–14.701	1.063
95	0.904	12.414	0.027	–0.125	–0.832	–9.382	1.083
99	0.831	6.386	0.048	–0.045	–0.894	–0.041	1.095
Mean	0.928	15.554	–0.008	–0.109	0.558	–13.549	1.052

Global Model 5: $TTI = e^{b1*dc+b2*LHL+b3*Rain+b4} + b5 * Length + b6 * Length^2 + b7$

Percentile	R^2	*b*1	*b*2	*b*3	*b*4	*b*5	*b*6	*b*7
10	0.911	15.162	–0.029	–0.017	–16.418	0.037	–0.011	0.997
50	0.846	20.378	–0.152	–0.174	–17.164	0.065	–0.013	1.001
80	0.918	18.824	–0.045	–0.152	–16.233	–0.699	0.141	1.715
95	0.904	15.428	–0.033	–0.128	–12.819	–0.597	0.107	1.718
99	0.814	8.951	–0.018	–0.045	–7.095	–0.571	0.073	1.843
Mean	0.948	17.564	–0.041	–0.113	–15.896	–0.347	0.066	1.397

Individual model for Segment 1: $TTI = e^{b1*dc+b2*LHL+b3*Rain+b4} + b5$

Percentile	R^2	*b*1	*b*2	*b*3	*b*4	*b*5
10	0.969	13.655	–0.420	–0.028	–12.285	1.008
50	0.996	–6.197	4.265	–0.228	–17.093	1.101
80	0.975	–1.068	2.475	–0.223	–10.846	1.147
95	0.952	12.607	0.093	–0.185	–9.967	1.133
99	0.886	–4.256	0.932	–0.025	0.302	0.068
Mean	0.990	7.220	1.249	–0.168	–12.694	1.108

Individual model for Segment 2: $TTI = e^{b1*dc+b2*LHL+b3*Rain+b4} + b5$

Percentile	R^2	*b*1	*b*2	*b*3	*b*4	*b*5
10	0.872	12.639	0.133	–0.004	–16.428	1.035
50	0.958	–12.440	1.047	–0.182	–0.592	1.046
80	0.968	–8.184	0.803	–0.185	–0.796	1.041
95	0.941	–0.744	0.432	–0.116	–3.340	1.101
99	0.851	–1.297	0.186	–0.027	0.419	0.106
Mean	0.970	–2.220	0.559	–0.128	–4.421	1.057

Individual model for Segment 3: $TTI = e^{b1*dc+b2*LHL+b3*Rain+b4} + b5$

Percentile	R^2	*b*1	*b*2	*b*3	*b*4	*b*5
10	0.931	–5.148	0.253	–0.111	–5.192	1.006
50	0.980	–20.766	0.508	–0.275	4.153	1.032
80	0.983	–9.543	0.387	–0.287	–1.873	1.049
95	0.953	52.466	–0.243	–0.192	–41.800	1.074
99	0.893	74.582	–0.540	–0.044	–54.379	1.114
Mean	0.977	4.655	0.185	–0.197	–10.143	1.026

Table 4.10. Coefficients for Different Models after Validation

Global Model 4: $TTI = e^{b1*dc+b2*LHL+b3*Rain+b4*Length+b5} + b6$

Percentile	R^2	*b*1	*b*2	*b*3	*b*4	*b*5	*b*6
10	0.581	0.500	0.000	0.013	–0.075	–1.555	0.749
50	0.864	17.445	0.000	0.000	–2.457	–15.568	1.071
80	0.825	14.865	0.000	0.000	–0.658	–13.912	1.072
95	0.827	10.477	0.029	0.000	–0.832	–9.139	1.105
99	0.814	5.481	0.049	0.000	–0.894	–3.758	1.105
Mean	0.884	14.020	0.000	0.000	–0.619	–13.470	1.058

Global Model 5: $TTI = e^{b1*dc+b2*LHL+b3*Rain+b4} + b5 * Length + b6 * Length^2 + b7$

Percentile	R^2	*b*1	*b*2	*b*3	*b*4	*b*5	*b*6	*b*7
10	0.564	0.271	0.000	0.009	–0.954	0.029	–0.011	0.536
50	0.685	13.978	0.000	0.000	–14.684	–0.447	0.078	1.514
80	0.698	12.802	0.000	0.000	–12.987	–0.782	0.139	1.880
95	0.733	10.757	0.000	0.000	–10.426	–0.626	0.087	1.864
99	0.757	6.791	0.000	0.000	–5.864	–0.594	0.046	1.986
Mean	0.757	12.101	0.000	0.000	–12.632	–0.410	0.066	1.509

Individual model for Segment 1: $TTI = e^{b1*dc+b2*LHL+b3*Rain+b4} + b5$

Percentile	R^2	*b*1	*b*2	*b*3	*b*4	*b*5
10	0.791	0.000	0.246	0.015	–3.180	0.930
50	0.921	16.961	0.517	0.000	–20.256	1.095
80	0.857	0.000	1.641	0.000	–9.751	1.135
95	0.821	0.000	1.123	0.000	–6.167	1.133
99	0.841	0.000	0.579	0.000	–2.328	0.922
Mean	0.910	0.000	1.584	0.000	–9.786	1.101

Individual model for Segment 2: $TTI = e^{b1*dc+b2*LHL+b3*Rain+b4} + b5$

Percentile	R^2	*b*1	*b*2	*b*3	*b*4	*b*5
10	0.625	0.000	0.044	0.000	–1.727	0.817
50	0.910	8.326	0.318	0.000	–13.488	1.047
80	0.890	11.483	0.122	0.000	–13.318	1.047
95	0.885	9.529	0.097	0.000	–10.451	1.134
99	0.833	0.000	0.175	0.000	–1.276	0.789
Mean	0.925	10.528	0.135	0.000	–12.885	1.062

Individual model for Segment 3: $TTI = e^{b1*dc+b2*LHL+b3*Rain+b4} + b5$

Percentile	R^2	*b*1	*b*2	*b*3	*b*4	*b*5
10	0.639	0.000	0.006	0.000	–0.949	0.589
50	0.789	0.000	0.228	0.000	–10.039	1.034
80	0.751	0.000	0.222	0.000	–9.081	1.049
95	0.793	16.848	0.000	0.000	–17.221	1.066
99	0.761	11.081	0.000	0.000	–10.675	1.106
Mean	0.823	9.018	0.087	0.000	–13.579	1.024

4.5 Summary

The L07 tool was applied in this study to investigate the travel time reliability along the I-95 NB segments. The analysis results showed that the TTI prediction model used in the L07 tool was more sensitive to the incident’s number and duration than other variables, such as traffic demand or weather. Large differences were also found when comparing the model results to the real-world data. Calibration of the TTI prediction model based on local data produced a better estimation of the local travel time reliabilities. Inclusion of segment length in the equation may produce a better TTI estimation model, and this possibility should be investigated further.

CHAPTER 5

L08 Procedure for Freeway and Urban Street Facilities

5.1 Introduction

Project L08 developed reliability assessment methods and tools based on the HCM freeway and urban street facility procedures and computational engines (Kittelson & Associates et al. 2012). This chapter presents an investigation of the application of these procedures to estimate the reliability of I-95 NB and SB GPLs and SR-7/US-441 roadway segments. Of particular interest is examining the impacts of input parameters to the traffic flow model and the scenario generation module incorporated as part of the computational engines of the HCM-based reliability estimation procedure of freeway and urban street facilities.

5.2 Freeway Facilities

5.2.1 Reliability Estimation Methodology

The base computational engine of the freeway facility procedure is referred to as FREEVAL (Rouphail et al. 2011). This computational engine was extended in the L08 project to allow the estimation of travel time reliability according to procedures developed in the project. The extended version, referred to as FREEVAL-RL, allows the consideration of the impacts of factors that contribute to facility unreliability, including incidents, weather, work zones, special events, and demand variation (Sajjadi et al. 2013a). The consideration of these additional factors was accomplished by the addition of a second computational engine, referred to as the scenario generator, which enumerates different operational conditions of a freeway facility based on the probability of their occurrence. Each scenario is created by adjusting demand, capacity, and/or free-flow speed in each analysis period in a seed file that includes base condition inputs, which are basically the same inputs required for the base FREEVAL computational engine. A number of additional enhancements were introduced to FREEVAL, as reported by Sajjadi et al. (2013a), including considering the capacity drop during queue discharge; adding a speed adjustment factor to account for the speed change under the nonrecurrent condition; and making improvements in merge, diverge, and weaving segment modeling, and so forth.

As stated in Chapter 2, a large number of performance measures have been proposed for use in assessing reliability. These measures may not necessarily produce consistent assessments of reliability among themselves (Cambridge Systematics 2013d; Alvarez and Hadi 2012). FREEVAL-RL outputs several widely used reliability performance measures in addition to the cumulative distribution plot of the TTI for the evaluated freeway facility. As discussed in Chapter 2, the L08 project recommends using various performance measures, including the primary reliability rating (Sajjadi et al. 2013b).

5.2.2 Utilized Data

The implementation of the L08 proposed HCM procedure for estimating travel time reliability requires data to produce the inputs to the seed file and to the scenario generator. Some of the input parameters required are link volumes, geometry, and free-flow speeds. Other input parameters are provided as optional defaults.

One of the objectives of this study was to examine the sensitivity of the HCM-based reliability assessment procedure to using local parameters derived from collected data instead of default values. The assessment was made for the PM peak period of the I-95 NB facility segment and the AM peak of the I-95 SB facility segment.

5.2.3 Calibration of Traffic Flow Parameters

FREEVAL can be considered a macroscopic traffic simulation model that uses traffic flow model parameters in its assessment of traffic conditions. FREEVAL incorporates the HCM procedures for basic freeway segments, weaving segments, and merge and diverge segments. It also has a cell-transmission model to support the analysis of oversaturated freeway facilities. The model is able to assess queue accumulation and dissipation over multiple segments and multiple time periods. The traffic flow model parameters of FREEVAL are not required to be specified by the user because it uses the HCM procedures to calculate these parameters, including estimating capacity and free-flow speed values. Default values are also provided for other parameters, such as jam density and the queue discharge rate during traffic breakdown conditions. Like other traffic simulation models, however, it is recommended that the above traffic flow parameters are calibrated using local data (if available) to improve the ability of the model to reflect observed conditions, particularly when there are indications that the operation of the facility under consideration is considerably different than the national averages and that the capacity and free-flow adjustment factors provided in the HCM are not sufficient to account for these differences. There were indications that the selected I-95 segment operated differently from an average facility because it passed through a dense urban environment with frequent interchanges, had vertical and horizontal alignment that may have affected capacity, and included parallel ELs that were separated from the GPLs by soft barriers. The importance of calibrating microscopic traffic simulation models is well documented (Dowling et al. 2004), but the calibration of macroscopic simulation models like FREEVAL is also needed to improve analysis quality and credibility.

The first step in the analysis was to create a seed input file in FREEVAL to be used by the model when assessing the travel times under different scenarios in the reliability estimation process. This seed file was basically the same input file required for the usual freeway facility analysis (Rouphail et al. 2011). The inputs included required geometric and operational characteristics such as defining freeway segments, ramp locations, number of lanes, length of acceleration and deceleration lanes, segment demands, and heavy and recreational vehicle percentages. In addition to the above inputs, FREEVAL has traffic flow model parameters with default values that can be modified by using adjustment factors to reflect local measurements.

As stated earlier, this project investigated the benefits of modifying the default modeling parameters based on real-world measurements. The considered parameters were free-flow speeds, capacity adjustment factors, jam density, and the percentage drop in throughput during traffic breakdown conditions. The benefits of these modifications are assessed based on how close the resulting speeds were to real-world measurements of these parameters.

The free-flow speed can be calculated using the HCM procedure based on geometric attributes, including the number of lanes, lane width, right-shoulder lateral clearance, and interchange density. The free-flow speed estimated for the study facility was 66.9 mph based on HCM 2010. The estimation of free-flow speed based on field measurements was conducted by averaging the speeds for time periods with volumes less than 1,000 passenger cars per hour per lane (pcphpl) and detector occupancy below 10%. The results indicated that the free-flow speed ranged between 57 to 62 mph, with the low free-flow speed estimated at two complex freeway-to-freeway interchange locations. Thus, it appeared that HCM 2010 overestimated the free-flow speed for this facility.

FREEVAL uses HCM procedures to estimate capacity based on traffic and link attributes. However, the user can specify a capacity adjustment factor for each link. The latest version of FREEVAL also considers the drop in the maximum throughput when operating in the queue discharge mode during traffic breakdown conditions. The program used a default value of 5% for this drop. The first step in this study to measure capacity in the field was to identify the bottleneck locations during normal recurrent conditions (no incident and no rain). Detector data for these normal days were extracted by excluding incident days, bad weather days, and abnormal detector data. Visualization techniques in combination with examining the relationships between upstream and downstream measurements were used to identify recurrent bottleneck locations and their impacts. The speed contours shown in Figure 5.1 indicate that Mileposts 7.6 and 9.1 were the bottleneck locations in the period between 3:30 and 5:00 p.m. These two bottlenecks were located at on-ramp merging areas.

Even when using the lower free-flow speed estimates based on field measurements, as mentioned above, the HCM capacity estimate for the bottleneck locations was around 2,200 pcphpl, considerably higher than the value estimated based on field measurements, as discussed next.

Two methods were used to measure capacity based on field data. The first estimated the 15-minute average traffic volumes before breakdown occurrence at the two bottlenecks averaged over the measurement days, as suggested by Zhang and Levinson (2004) and Eleftriadou and Lertworawanich (2003). The second method estimated capacity by fitting a fundamental traffic flow model to the volume and speed measurements based on the Van Aerde and Rakha model formulation (1995). Before the field data were used in the capacity estimation, the data were preprocessed to isolate any time steps with backup from downstream bottlenecks to ensure that the considered data only accounted for the capacity constraint at the subject bottleneck and not the downstream locations. The capacity estimation based on the two methods indicated that the capacity ranged between 1,820 and 1,850 pcphpl at the two bottlenecks, significantly lower than HCM estimates, again demonstrating the difference between the capacity characteristics of this facility and the national averages.

The drop in the maximum throughput during the queue discharge at breakdown conditions was estimated to be 7% at the two bottleneck locations based on detector data. As mentioned earlier, the default value for this variable was 5% (allowed to vary between 0% and 10%) in FREEVAL. The default jam density in FREEVAL was 190 passenger cars per mile per lane. In this study, the jam density was estimated based on counting the number of vehicles in standing queues on I-95 by using recorded videos. It was found that the jam density was 185 passenger cars per mile per lane, which was very close to the default value.

Figures 5.1, 5.2, and 5.3 show the speed contour maps of I-95 NB based on field measurement and analysis results from the uncalibrated and calibrated FREEVAL model, respectively. Note that the analysis time period for I-95 NB was between 2:00 and 7:00 p.m. to allow the analysis to start and end with uncongested traffic conditions, but the calculation of measures of effectiveness for calibration focused on the time period between 3:15 and 5:00 p.m. as the congestion due to the two bottlenecks, identified as described above, occurred in this time period. After 5:00 p.m., the congestion on the facility was affected by a backup on an off-ramp to another freeway. It is clear, from Figures 5.1 to 5.3, that for the I-95 NB facility, the calibration of the model was necessary to replicate the facility bottlenecks and their impacts.

Figures 5.4, 5.5, and 5.6 show the speed contour maps of I-95 SB based on field measurement and analysis results from the uncalibrated and calibrated FREEVAL model, respectively. The analysis time period for I-95 SB was between 6:00 and 10:00 a.m. Figures 5.4 to 5.6 show that the I-95 SB facility, like the I-95 NB facility, required the model to be calibrated. The measures of performance used in assessing the traffic flow model performance were the root mean square deviation (RMSD), absolute average speed error (AASE), and speed error bias (SEB). These measures are calculated as given by Equations 5.1 to 5.3:

$$RMSD = \sqrt{\frac{1}{N}\sum_{i,t}(S_{i,t,e} - S_{i,t,a})^2} \tag{5.1}$$

$$AASE = \frac{1}{N}\sum_{i,j}\left|S_{i,t,e} - S_{i,t,a}\right| \tag{5.2}$$

$$SEB = \frac{1}{N}\sum_{i,j}(S_{i,t,e} - S_{i,t,a}) \tag{5.3}$$

where $S_{i,t,e}$ represents the resulted speed from the FREEVAL model at segment i and time interval t, and $S_{i,t,a}$ is the speed measurement from real-world data. All three measures of effectiveness were greatly improved with the calibration of the model. For I-95 NB, the root mean square deviation in speed decreased from 17.6 to 10 mph, the absolute average speed error dropped from 14.684 to 8.414 mph, and the speed error bias was reduced from 14.624 to –1.526 mph. For I-95 SB, the root mean square deviation in speed decreased from 8.4 to 5.8 mph, the absolute average speed error dropped from 6.336 to 4.519 mph, and the speed error bias was reduced from 3.082 to –0.835 mph.

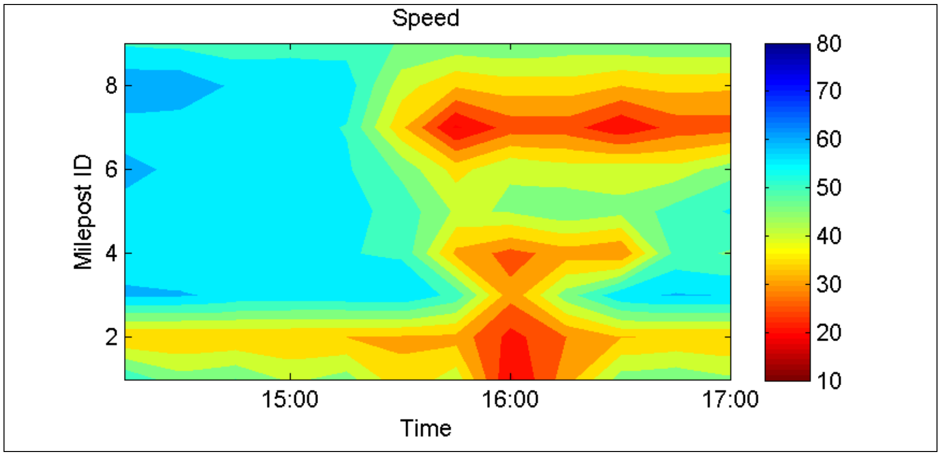


Figure 5.1. Speed contour map based on real-world data for I-95 NB.

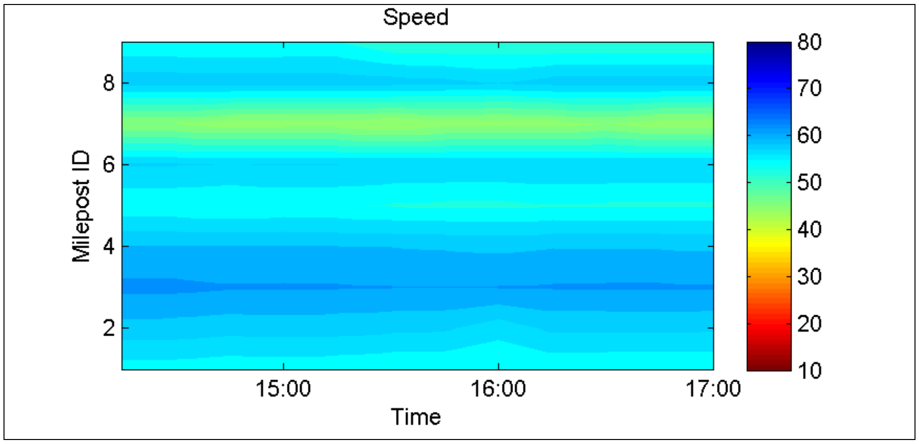


Figure 5.2. Speed contour map based on uncalibrated FREEVAL model for I-95 NB.

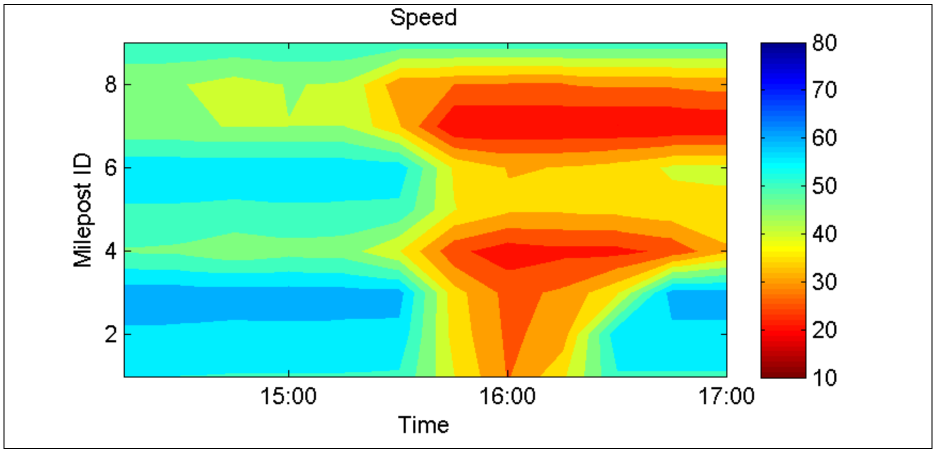


Figure 5.3. Speed contour map based on calibrated FREEVAL model with a capacity adjustment factor of 0.81 for I-95 NB.

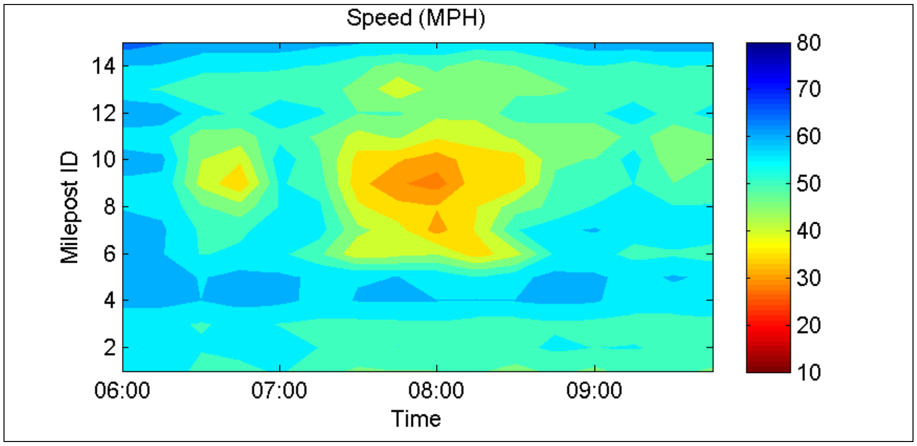


Figure 5.4. Speed contour map based on real-world data for I-95 SB.

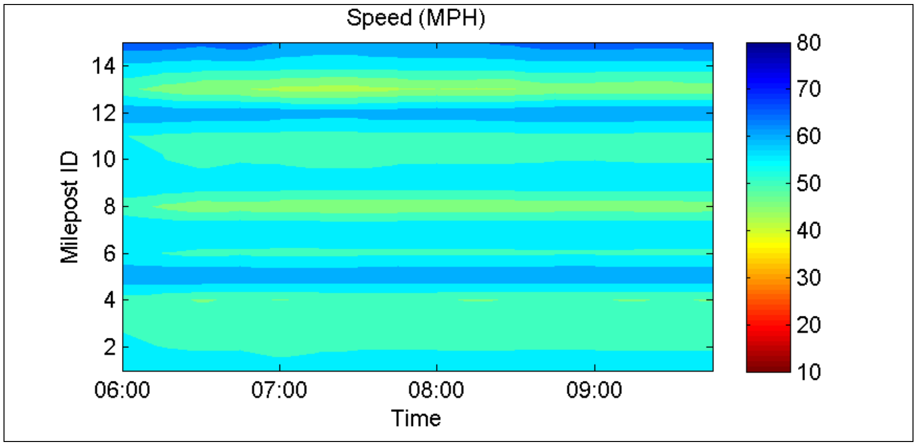


Figure 5.5. Speed contour map based on uncalibrated FREEVAL model for I-95 SB.

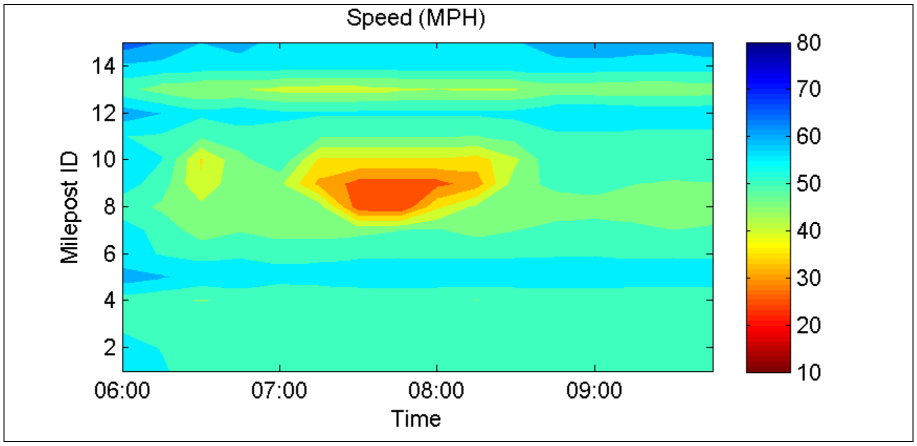


Figure 5.6. Speed contour map based on calibrated FREEVAL model with capacity adjustment factors of 0.95 and 0.85 for I-95 SB.

5.2.4 Updating Scenario Generator Parameters

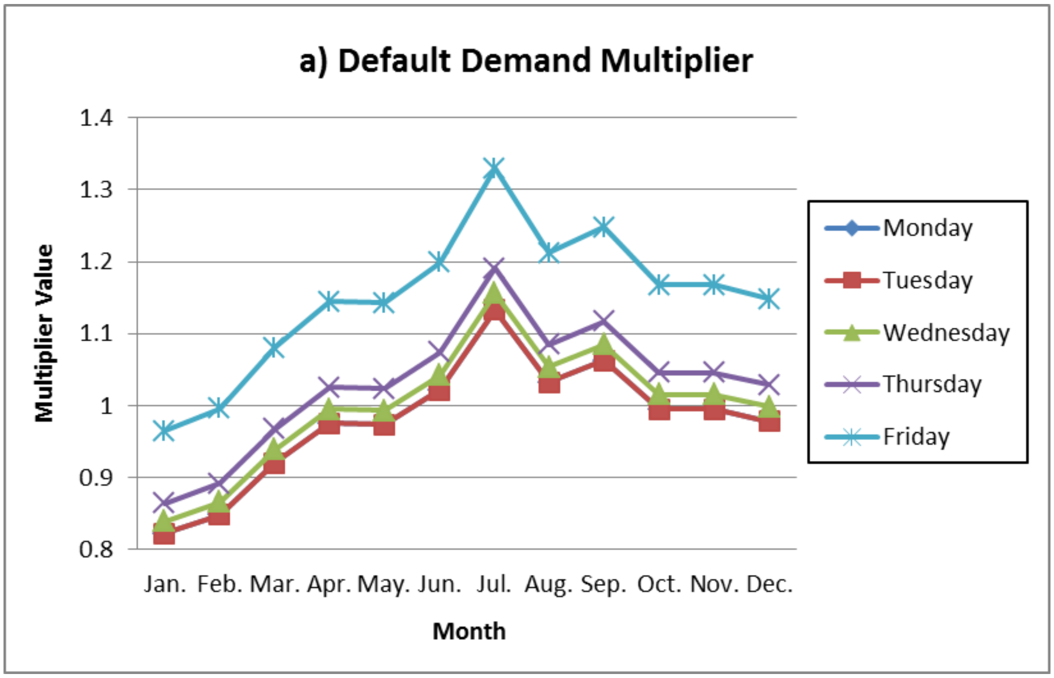
The scenario generator is a component of FREEVAL-RL that produces scenarios of variations in traffic conditions to be evaluated by the traffic flow model. The scenarios represent variations in capacities and/or demands due to changing operational conditions in the reliability estimation period. The reliability estimation period is usually one or more years. Each scenario is then evaluated by the traffic flow model to estimate the resulting variations in travel times, allowing the estimation of travel time reliability.

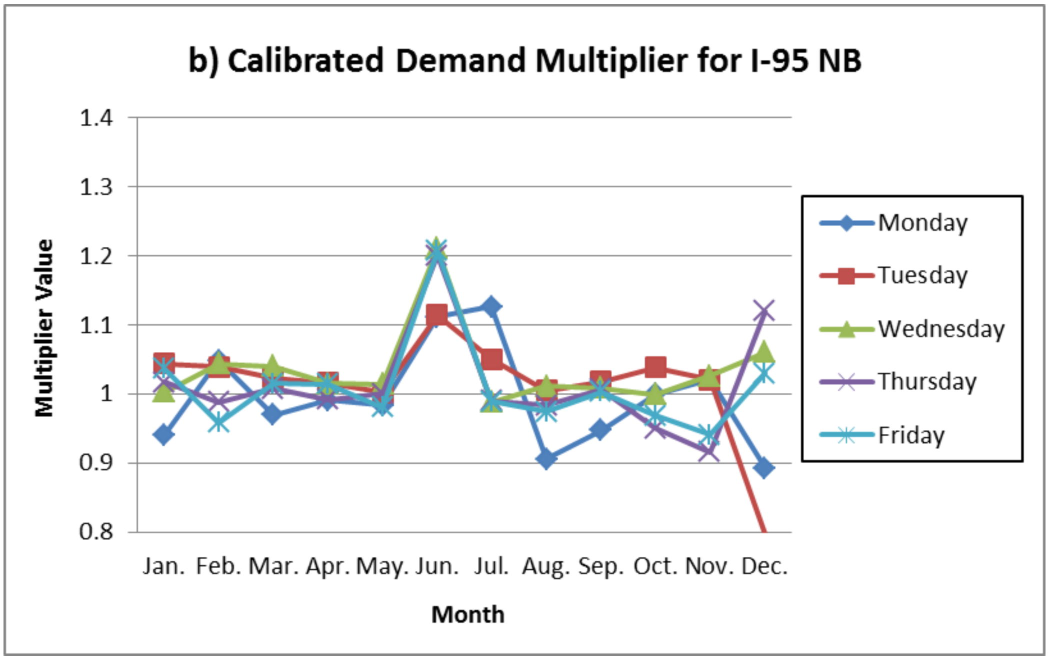
The variations in demand through the year are estimated based on user inputs of the distribution of demands by month of the year and day of the week. National urban and rural default distributions are provided in the model, but obviously these distributions vary significantly by location. In this study, the distributions were based on ITS point detector data. Figure 5.7 shows the difference in demand multipliers between the national defaults and the locally derived values for the I-95 facility. This figure shows that the default monthly and daily variations were higher than the variations based on the locally derived values.

For incident modeling, incident scenarios can be generated by the scenario generator based on local data using different methods depending on the level of information available in a region. For data-poor environments, the user can provide the average crash rate for the entire facility per 100 million vehicle miles (Option A). The model then estimates the incident rates by using default multipliers that relate the incident rate to the crash rate. If more detailed data are available and the incident rate can be estimated directly, this rate should be used as an input to the model (Option B). For data-rich environments, it is recommended that the user conduct more detailed processing of incident data to estimate the proportion of time with incidents by lane blockage severity (Option C). In this study, the results from using the three approaches were compared to assess the importance of inputting more detailed data. The results are shown in Table 5.1 and Table 5.2. For the I-95 NB facility, the crash rate was 101.2 per 100 million VMT, and the conversion factor from crash rate to incident rate was assumed to be the same as the national average, which is 4.9, when the crash rate was used as the main input. Using these values resulted in an estimated incident rate of 496 incidents per 100 million VMT. The incident rate estimated based on actual incident data was about 349.4 per 100 million VMT for this facility. For the I-95 SB facility, the crash rate was 246.2 per 100 million VMT, and the conversion factor from crash rate to incident rate was assumed to be the same as the national average, which is 4.9, when the crash rate was used as the main input. Using these values resulted in an estimated incident rate of 1,206.3 incidents per 100 million VMT. The incident rate estimated based on actual incident data was about 1,133.1 per 100 million VMT for this facility.

The results in the first two far-left columns of Table 5.1 and Table 5.2 show that when incident duration was updated to reflect local conditions, the 50th and 80th percentile TTIs did not change, but the mean TTI, 95th percentile TTI, and misery index increased. The average travel time and speed changed only slightly with inputting the local incident duration information. The misery index was the average of the highest 5% of travel times divided by the free-flow travel time. The above discussion indicates that the main difference between the results obtained using the default and local incident durations was the congestion level of the 5% worst travel conditions, which was affected by the incidents that cause higher levels of delays.

It can also be seen in Table 5.1 and Table 5.2 that the travel time reliability and mobility measures resulting from using the measured crash rate (Option A) and incident rate (Option B) were close. However, when the proportion of time with incidents by lane blockage severity was used (Option C), the results showed significantly higher TTI and misery index values. Compared to the other cases, this scenario (with Option C) also had the highest average travel time and lowest speed. Option C appeared to be the best approach because it better reflected the impact of incidents and produced higher reliability indexes, reflecting the unreliability of the I-95 facility.





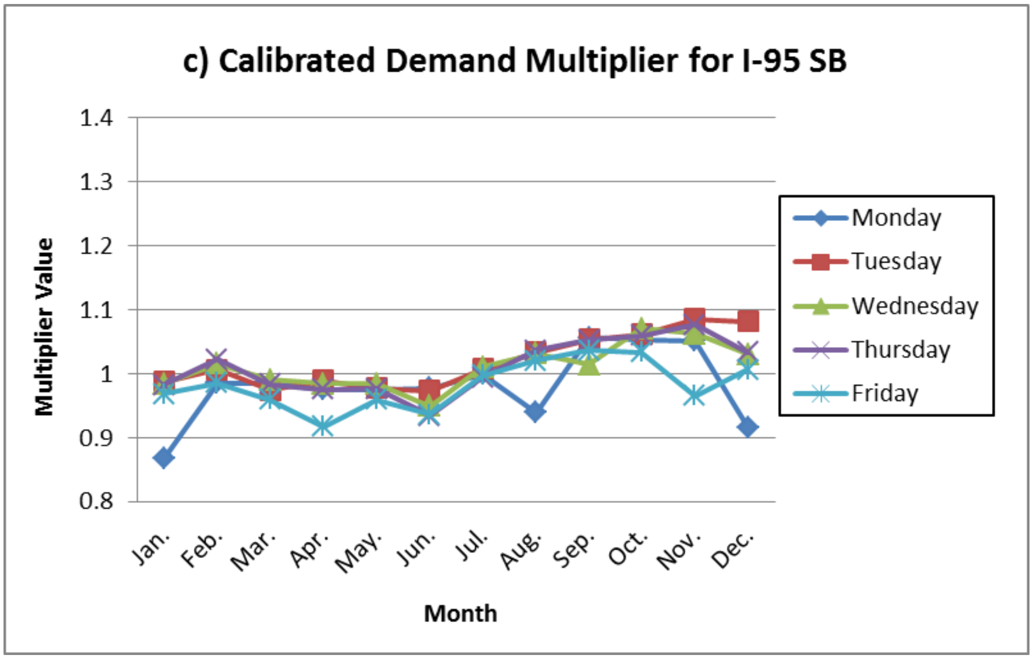


Figure 5.7. Demand multipliers: (a) default and calibrated for (b) I-95 NB and (c) I-95 SB.

Table 5.1. Impacts of Updating Incident Information on I-95 NB Travel Time Reliability Analysis Results

Measure	I-95 Crash Rate and National Default Duration Data	I-95 Crash Rate and I-95 Duration Data	I-95 Incident Rate and National Default Duration Data	Option C Coding
Mean TTI	1.16	1.20	1.15	1.33
50th Percentile TTI	1.13	1.13	1.13	1.14
80th Percentile TTI	1.15	1.15	1.15	1.28
95th Percentile TTI	1.19	1.37	1.18	2.12
Misery Index	1.74	2.32	1.44	3.84
Average Travel Time per Vehicle (min)	6.72	7.04	6.59	7.76
Space Mean Speed (mph)	52.33	51.65	52.67	50.46

Table 5.2. Impacts of Updating Incident Information on I-95 SB Travel Time Reliability Analysis Results

Measure	I-95 Crash Rate and National Default Duration Data	I-95 Crash Rate and I-95 Duration Data	I-95 Incident Rate and National Default Duration Data	Option C Coding
Mean TTI	1.29	1.40	1.28	1.68
50th Percentile TTI	1.12	1.12	1.12	1.13
80th Percentile TTI	1.14	1.16	1.14	1.87
95th Percentile TTI	2.00	2.80	1.91	3.86
Misery Index	4.02	5.09	3.89	6.75
Average Travel Time per Vehicle (min)	7.96	8.78	7.85	10.95
Space Mean Speed (mph)	51.44	49.81	51.61	45.73

The default values of capacity drops due to incidents, which were adopted in FREEVAL from the HCM 2010, were used in the analysis. The analysis of real-world data conducted in this study for a limited number of incidents indicated that capacity drop was also a stochastic variable that depended on a number of factors, and that, in some cases, the values of the capacity drops provided in the HCM can be lower than real-world measurements. However, the drop in the capacity parameter was not changed in the analysis due to the small sample size used in the capacity drop observations in this study.

In all the above analyses, the variation in weather conditions (e.g., percentage of time in the estimation period that the facility experienced heavy rainfall) was estimated based on data obtained from the National Climatic Data Center (2013). The default impact of these conditions on capacity in the model was used in the analysis.

5.2.5 Comparison with Real-World Estimates

Figure 5.8 presents a comparison between the estimation of reliability metrics using real-world data and those obtained using FREEVAL-RL. As seen in this figure, for I-95 NB, FREEVAL-RL underestimated the values of some metrics (e.g., the 80th percentile TTI). For the 95th percentile TTI, when the scenario exclusion threshold (the threshold that controls which scenarios to include in the analysis) was set to a small value, such as 0.01%, FREEVAL-RL overestimated the 95th percentile TTI by 35%. Increasing the threshold to 0.05% or more resulted in the underestimation of the 95th percentile TTI.

However, the FREEVAL model used for the I-95 NB facility did not account for the backup from the Florida Turnpike off-ramp, which was a major reason for the unreliability of the facility between 5:00 and 7:00 p.m. Other reasons for the underestimation may have included potential impacts of external factors not accounted for the analysis, such as backups from other off-ramps and downstream incidents, events on the ELs or opposing traffic, or diversion from other routes.

For the I-95 SB direction (results not shown), the 80th percentile TTI from FREEVAL was very close to that estimated from the real-world data (around 1.9). However, the estimated 95th percentile TTI by FREEVAL was higher for the SB direction (2.8 based on the real-world versus 3.9 based on FREEVAL), probably due to the value used for the exclusion threshold.

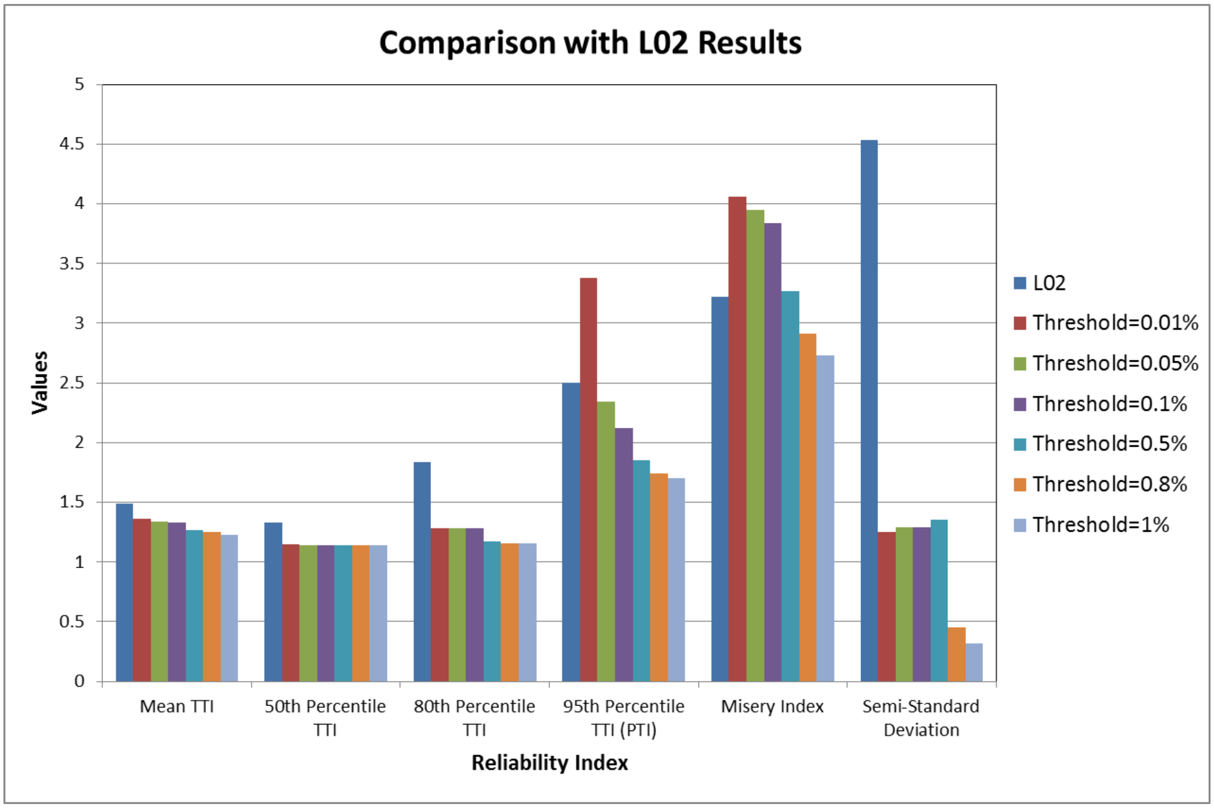


Figure 5.8. Comparison of real-world and FREEVAL-RL reliability estimates for I-95 NB.

5.3 Urban Street Facilities

5.3.1 Reliability Estimation Methodology

As described above, the L08 project proposed methods for incorporating travel time reliability analysis into HCM procedures and developed two computational engines: FREEVAL-RL, which focuses on the reliability of freeway facilities, and STREETVAL-RL, which is designed for the reliability evaluation of urban streets. Both of these are Microsoft Excel spreadsheet-based tools with codes written in the Visual-Basic-for-Application programming language.

STREETVAL-RL can be used to evaluate the impacts of weather, incidents, demand variations, traffic control, work zones, and special events on urban street travel time reliability (Kittelson & Associates et al. 2012). In STREETVAL-RL, different scenarios are generated based on the input of a base STREETVAL model and input of other information, such as incidents, demands, weather, and so on. The weather events in STREETVAL are divided into two categories, rain and snow. The probability of these two types of weather events is predicted based on an assumption of binomial distribution of daily weather events and a Monte Carlo simulation method. Additional assumptions of normal distribution for precipitation type (rain or snow), gamma distribution for rain intensity and total precipitation duration, and an empirical relationship for wet pavement duration lead to a complete determination of weather event occurrences and intensities. The impacts of weather events on traffic are reflected by the use of an adjustment factor for saturation flow rate at signalized intersections and free-flow speed adjustment factors along urban street segments. Weather events also result in additional impacts on the time headways of critical left-turn movements. The variations of demand are implemented in STREETVAL-RL by using the demand adjustment factors by month of year, day of week, and hour of day.

Twelve incident types are considered in STREETVAL-RL depending on the combinations of crash or noncrash, severity level (fatal, injury, and property damage only), and number of lanes blocked (shoulder, one lane blocked, and two or more lanes blocked). All types of incidents are converted to equivalent incident frequency with a given weather condition for every day. The occurrence of each type of incident is determined by a Poisson distribution, and the corresponding duration is calculated using a gamma distribution that was developed in previous studies. For incidents that occur at signalized intersections, approach is determined by comparing a variable value generated based on a random number with the proportion of cumulative volume for each approach. Similarly, the direction of an incident along a segment is determined based on the proportions of each directional volume. To account for the impacts of incidents at intersections, an empirical expression that relates the saturation flow rate adjustment factor to the number of lanes blocked and incident severity is applied. The effect of segment incidents on the segment speed is determined by using empirical coefficients in the expression that estimates the additional segment delays and also reduction in the available lanes on the segment and associated driveways.

By aggregating the travel time for each modeled scenario, STREETVAL-RL outputs various reliability performance measures for each segment, as well as the whole facility, including average travel time; 5th, 10th, 50th, 80th, 85th, and 95th percentile travel time; standard deviation; and skewness of travel time distribution.

In this study, the STREETVAL-RL tool was applied to model the selected urban street facility, SR-7/US-441. This section provides a detailed description of this modeling effort.

5.3.2 STREETVAL Base Model

Due to the limitation of STREETVAL in total number of segments that can be modeled (eight-segment maximum), only a part of the SR-7 facility was modeled in this study. The segment started at NW 79th Street and ended at NW 125th Street, as shown in Figure 5.9. This roadway section had three through lanes in each direction with a total length of 2.9 miles. It was divided into seven segments, and each segment was bounded by a signalized intersection at both ends. This study focused on the AM peak period from 6:00 to 9:00 a.m. and the PM peak between 4:00 and 7:00 p.m.

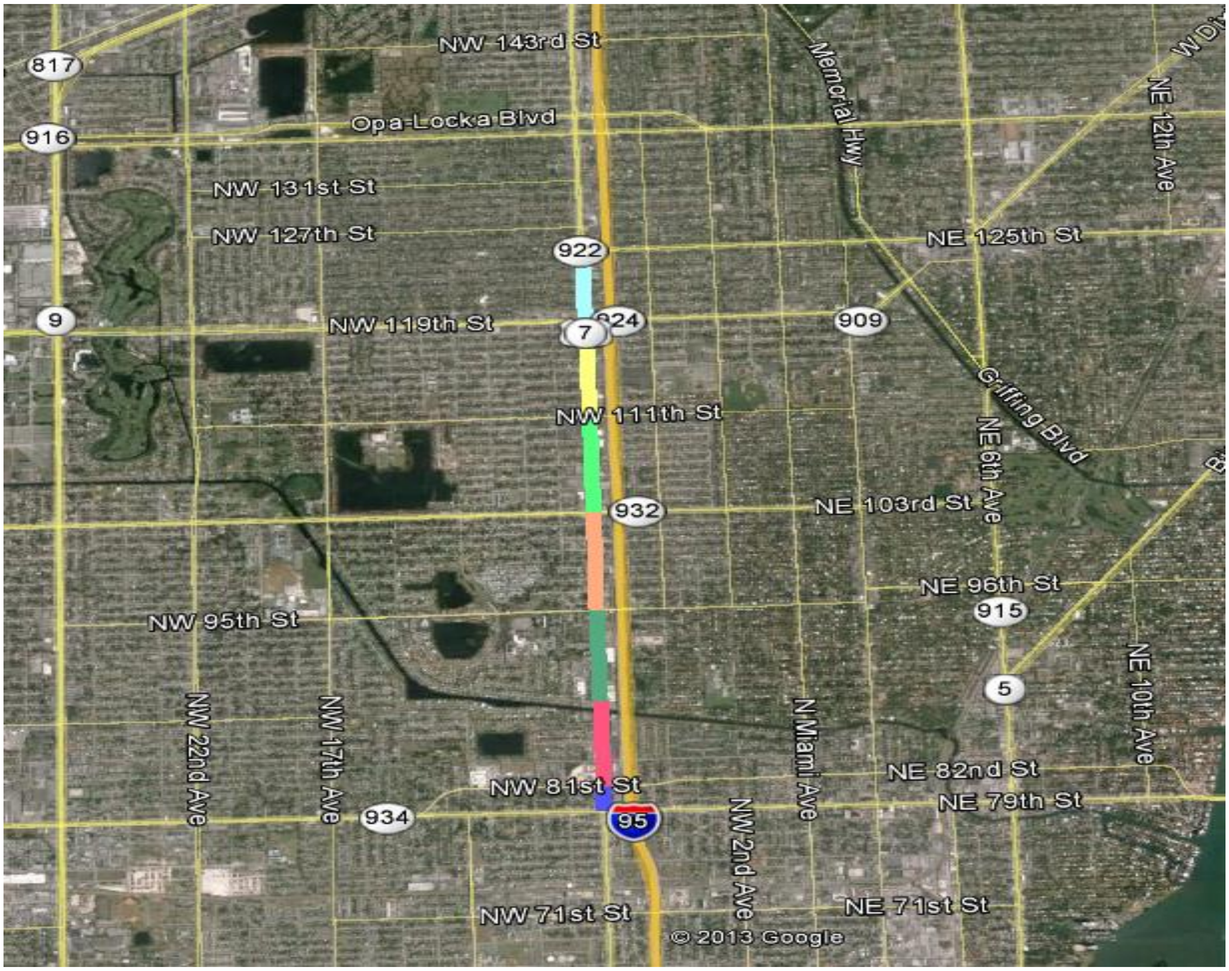
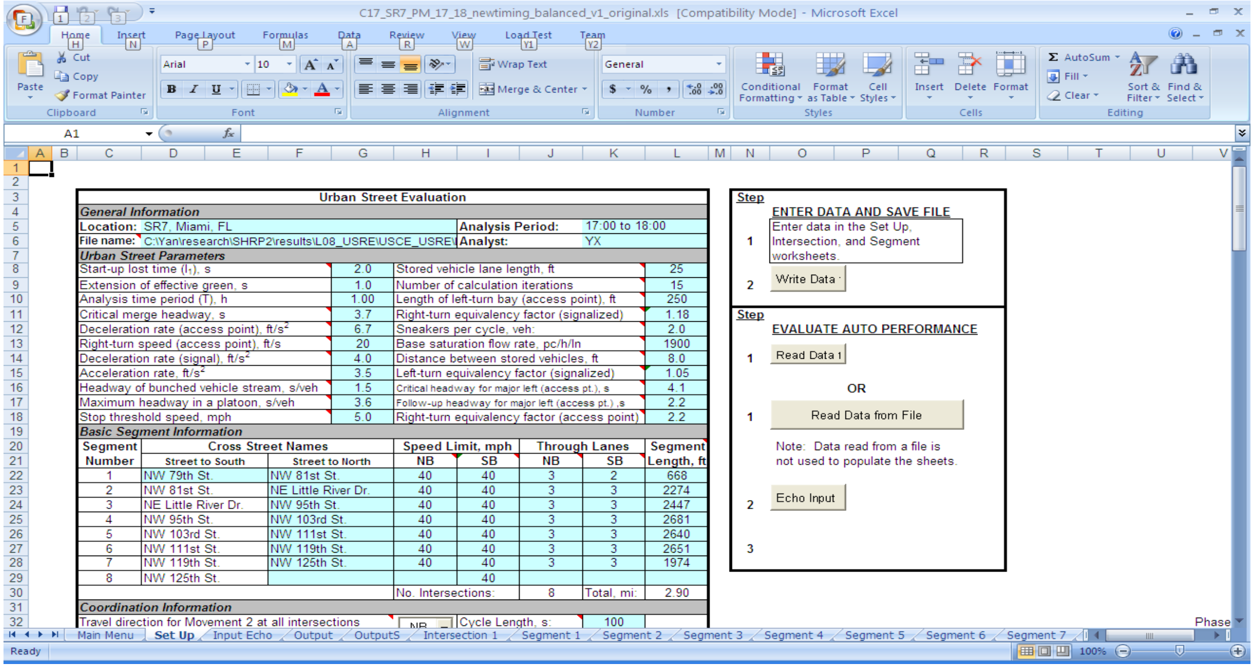


Figure 5.9. Locations of study segments along SR-7.

A base STREETVAL model was needed as an input for STREETVAL-RL analysis. It required three categories of input: roadway configurations, demand volumes, and signal timing plans. Even though STREETVAL is a macroscopic model, it still required some detailed roadway information, as listed below:

- Segment lengths,
- Intersection widths,
- Lane widths,
- Number of lanes including through and left- and right-turn lanes,
- Lengths of restrictive and nonrestrictive medians,
- Lengths of right-hand-side curbs,
- Numbers of access points, and
- Turn-bay lengths.

For this study, this set of roadway geometry information was retrieved from the Google satellite image and documents produced by the SR-7 reversible-lane study conducted by Miami-Dade County Public Works (F.R. Aleman & Associates, Inc. 2008). The traffic data used in this study were collected between October 16, 2013, and November 16, 2013, as part of the ongoing SR-7 corridor study project conducted for the Florida DOT (Jacobs 2014). The data obtained from this data source consisted of turning movement counts, truck volumes, and pedestrian counts at an aggregation level of 15 minutes, as well as field measurements of travel time, speed, and number of stops based on a floating car study. These measurements provided important inputs needed for the STREETVAL model. For signalized intersections, STREETVAL required the input of phase sequence, left-turn mode, and phase settings. The signal timing and operational plan for the modeled intersections were obtained from the Miami-Dade County Public Works signal operation office. Figure 5.10 shows a snapshot of the coded STREETVAL model for the SR-7 study segments.



Urban Street Evaluation

General Information

Location: SR7, Miami, FL
Analysis Period: 17:00 to 18:00
File name: C:\Yan\research\SHRP2\results\L08_USRE\USCE_USRE\
Analyst: YX

Urban Street Parameters

Start-up lost time (l_1), s	2.0	Stored vehicle lane length, ft	25
Extension of effective green, s	1.0	Number of calculation iterations	15
Analysis time period (T), h	1.00	Length of left-turn bay (access point), ft	250
Critical merge headway, s	3.7	Right-turn equivalency factor (signalized)	1.18
Deceleration rate (access point), ft/s^2	6.7	Sneakers per cycle, veh:	2.0
Right-turn speed (access point), ft/s	20	Base saturation flow rate, pc/h/ln	1900
Deceleration rate (signal), ft/s^2	4.0	Distance between stored vehicles, ft	8.0
Acceleration rate, ft/s^2	3.5	Left-turn equivalency factor (signalized)	1.05
Headway of bunched vehicle stream, s/veh	1.5	Critical headway for major left (access pt.), s	4.1
Maximum headway in a platoon, s/veh	3.6	Follow-up headway for major left (access pt.) ,s	2.2
Stop threshold speed, mph	5.0	Right-turn equivalency factor (access point)	2.2

Basic Segment Information

Segment Number	Cross Street Names		Speed Limit, mph		Through Lanes		Segment Length, ft
	Street to South	Street to North	NB	SB	NB	SB	
1	NW 79th St.	NW 81st St.	40	40	3	2	668
2	NW 81st St.	NE Little River Dr.	40	40	3	3	2274
3	NE Little River Dr.	NW 95th St.	40	40	3	3	2447
4	NW 95th St.	NW 103rd St.	40	40	3	3	2681
5	NW 103rd St.	NW 111st St.	40	40	3	3	2640
6	NW 111st St.	NW 119th St.	40	40	3	3	2651
7	NW 119th St.	NW 125th St.	40	40	3	3	1974
8	NW 125th St.			40			
			No. Intersections:		8	Total, mi:	2.90

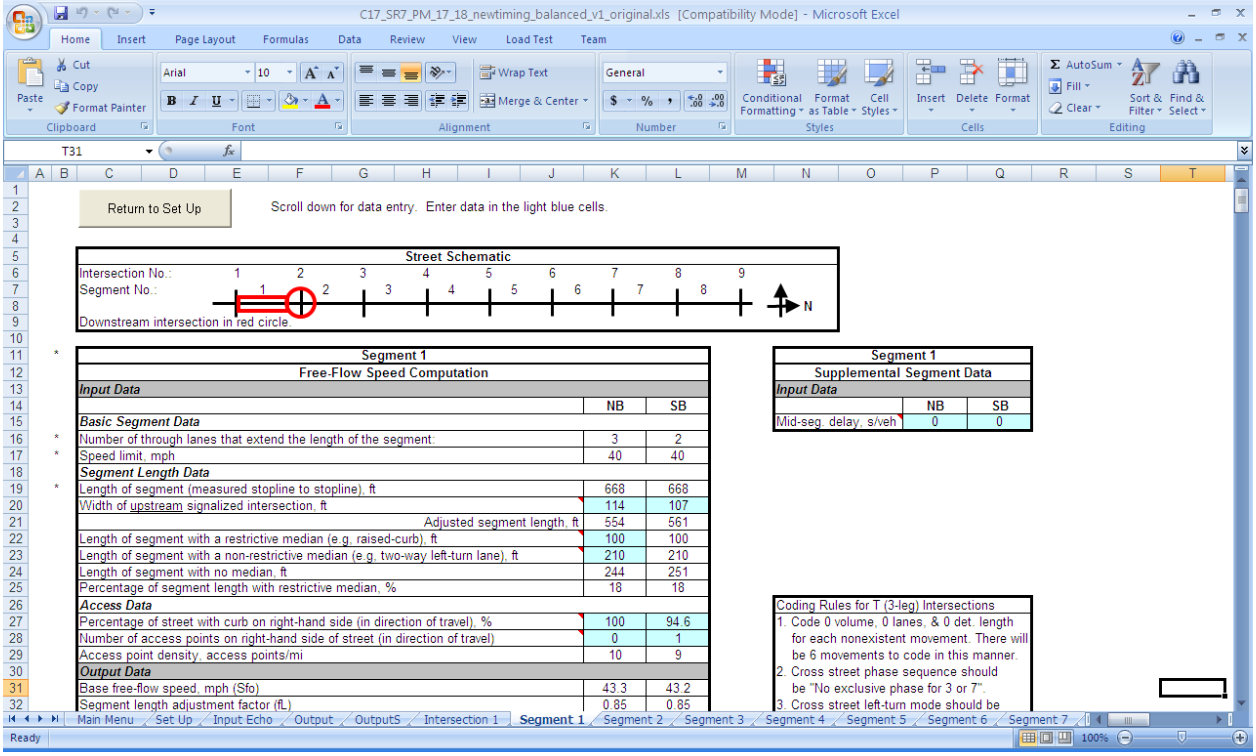
Coordination Information

Travel direction for Movement 2 at all intersections: NB
Cycle Length, s: 100

Step
1 Enter data in the Set Up, Intersection, and Segment worksheets.
2 Write Data

Step
1 Read Data
OR
1 Read Data from File
Note: Data read from a file is not used to populate the sheets.
2 Echo Input
3

(a)



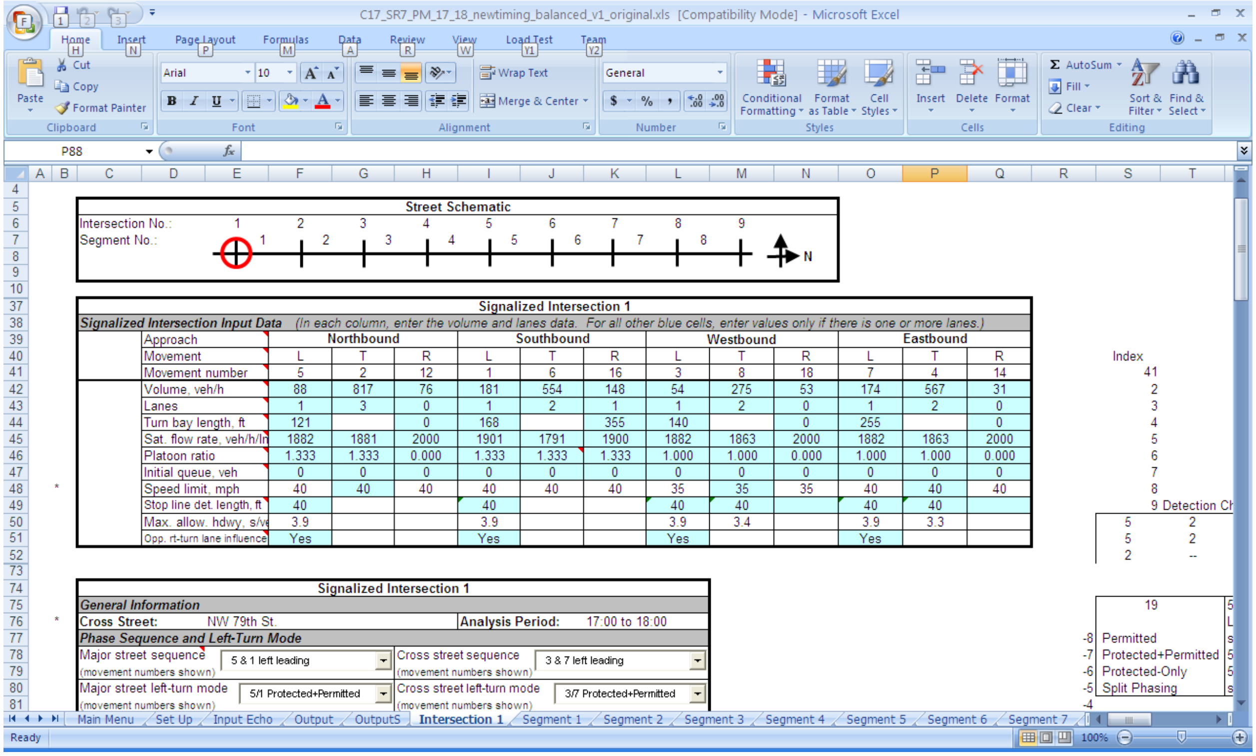
Scroll down for data entry. Enter data in the light blue cells.

Segment 1 Free-Flow Speed Computation		
Input Data		
	NB	**SB**
Basic Segment Data		
Number of through lanes that extend the length of the segment:	3	2
Speed limit, mph	40	40
Segment Length Data		
Length of segment (measured stopline to stopline), ft	668	668
Width of upstream signalized intersection, ft	114	107
Adjusted segment length, ft	554	561
Length of segment with a restrictive median (e.g. raised-curb), ft	100	100
Length of segment with a non-restrictive median (e.g. two-way left-turn lane), ft	210	210
Length of segment with no median, ft	244	251
Percentage of segment length with restrictive median, %	18	18
Access Data		
Percentage of street with curb on right-hand side (in direction of travel), %	100	94.6
Number of access points on right-hand side of street (in direction of travel)	0	1
Access point density, access points/mi	10	9
Output Data		
Base free-flow speed, mph (Sfo)	43.3	43.2
Segment length adjustment factor (fL)	0.85	0.85

Segment 1 Supplemental Segment Data		
Input Data		
	NB	**SB**
Mid-seg. delay, s/veh	0	0

Coding Rules for T (3-leg) Intersections
1. Code 0 volume, 0 lanes, & 0 det. length for each nonexistent movement. There will be 6 movements to code in this manner.
2. Cross street phase sequence should be "No exclusive phase for 3 or 7".
3. Cross street left-turn mode should be

(b)



Signalized Intersection 1

Signalized Intersection Input Data *(In each column, enter the volume and lanes data. For all other blue cells, enter values only if there is one or more lanes.)*

Approach	Northbound			Southbound			Westbound			Eastbound		
Movement	L	T	R	L	T	R	L	T	R	L	T	R
Movement number	5	2	12	1	6	16	3	8	18	7	4	14
Volume, veh/h	88	817	76	181	554	148	54	275	53	174	567	31
Lanes	1	3	0	1	2	1	1	2	0	1	2	0
Turn bay length, ft	121		0	168		355	140		0	255		0
Sat. flow rate, veh/h/ln	1882	1881	2000	1901	1791	1900	1882	1863	2000	1882	1863	2000
Platoon ratio	1.333	1.333	0.000	1.333	1.333	1.333	1.000	1.000	0.000	1.000	1.000	0.000
Initial queue, veh	0	0	0	0	0	0	0	0	0	0	0	0
Speed limit, mph	40	40	40	40	40	40	35	35	35	40	40	40
Stop line det. length, ft	40			40			40	40		40	40	
Max. allow. hdwy, s/ve	3.9			3.9			3.9	3.4		3.9	3.3	
Opp. rt-turn lane influence	Yes			Yes			Yes			Yes		

Index	
41	
2	
3	
4	
5	
6	
7	
8	
9 Detection Ch	
5	2
5	2
2	--

Signalized Intersection 1			
General Information			
Cross Street: NW 79th St.		**Analysis Period:** 17:00 to 18:00	
Phase Sequence and Left-Turn Mode			
Major street sequence (movement numbers shown)	5 & 1 left leading	Cross street sequence (movement numbers shown)	3 & 7 left leading
Major street left-turn mode (movement numbers shown)	5/1 Protected+Permitted	Cross street left-turn mode (movement numbers shown)	3/7 Protected+Permitted

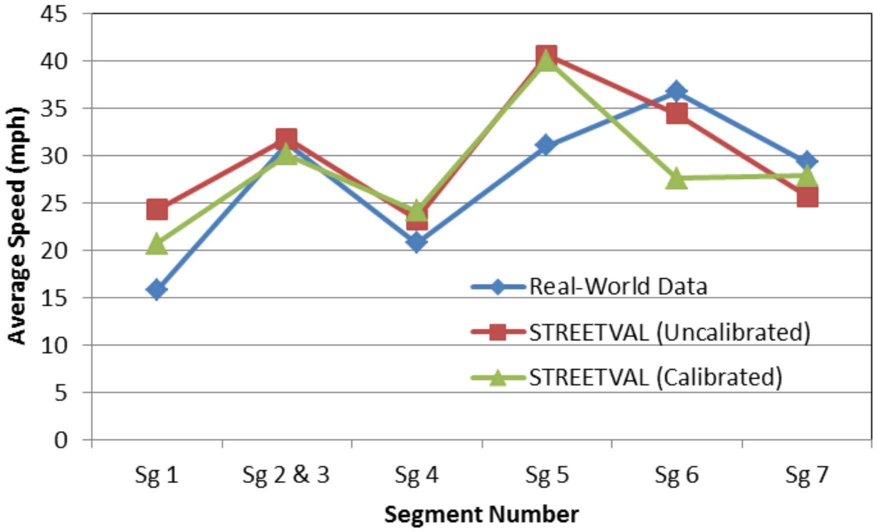
	19
-8	Permitted
-7	Protected+Permitted
-6	Protected-Only
-5	Split Phasing
-4	

(c)

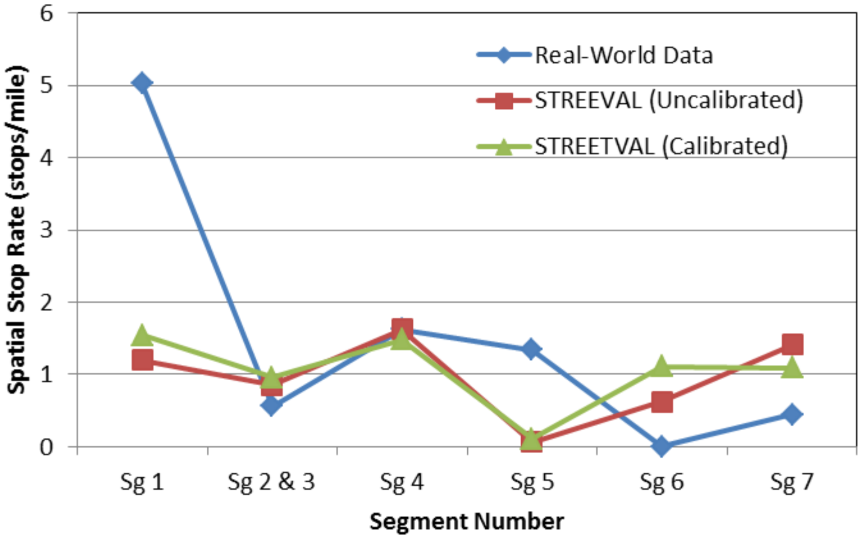
Figure 5.10. Snapshot of STREETVAL model for the SR-7 study segments showing (a) setup, (b) segment, and (c) intersection interfaces.

In addition to the above inputs, the saturation flow rates for each movement at signalized intersections had to be adjusted to account for the impacts of lane width, presence of heavy vehicles, and pedestrians, as there is no input option for those parameters in STREETVAL. It is important for the user to understand that the inputs to STREETVAL are adjusted saturated flow rates that need to be adjusted external to the model. To obtain the adjusted saturation flow rates, the eight signalized intersections studied were coded in the Highway Capacity software (HCS 2010). As suggested by the *Urban Street Reliability Engine User Guide* (Bonneson 2013), the saturation flow rates entered for turning movements should not be adjusted for permitted and protected operations, and therefore the left- and right-turn adjustment factors were set at 1.0. The resulting saturation flow rates from the Highway Capacity software were then manually adjusted to remove the impacts of turn movements.

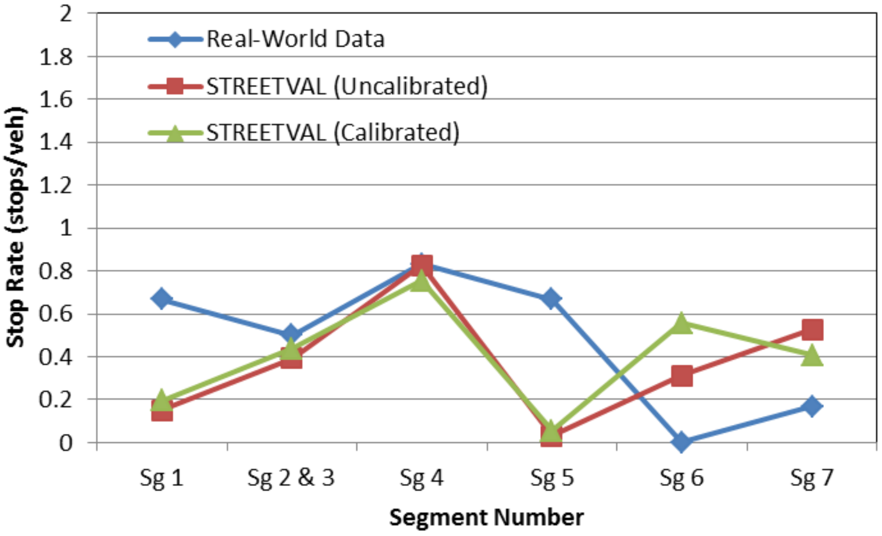
The STREETVAL model was further calibrated to replicate the real-world travel times and speeds and stop rate data collected through the floating car study. During the calibrations, it was found that varying the input values of saturation flow rate (within the range considered) did not have significant impacts on the model results in better producing the observed travel times. There were also indications that the main street green times estimated by STREETVAL for actuated signal control were overestimated by comparison with the maximum limits set for the real-world signal controls. However, there was no input option for maximum green limits in STREETVAL. Figures 5.11 to 5.14 show the calibration results for both SR-7 NB and SB STREETVAL models during the AM and PM peak periods. The results for Segments 2 and 3 were combined as only the data of the speeds and stop rates between NW 81st Street and NW 95th Street (i.e., Segments 2 and 3) were available from the data collected by the SR-7 corridor study project. As shown in these figures, the uncalibrated STREETVAL model produced closer results to the real-world data for uncongested compared to congested traffic conditions. Figures 5.11 and 5.12 further indicate that with calibration, the simulated results better replicated the real-world traffic conditions. For example, the absolute percentage error for speed was 19% for SR-7 NB traffic and 41% for SR-7 SB traffic during the AM peak period with uncalibrated models; these two values dropped to 18% and 14%, respectively, with the calibrated models. Figures 5.13 and 5.14 present the comparison for the PM peak period. The results in these two figures again indicate that STREETVAL better modeled the uncongested conditions. The figures show that in general, the calibration process improved the estimation performance. However, it can also be noted that, as shown in Figure 5.13, the average speed for Segment 5 along SR-7 NB during the PM peak period was overestimated. A closer examination of the signal timing plan at the downstream intersection of Segment 5 revealed that NB traffic was supposed to have more than enough green time for the traffic demand to pass through this intersection. However, the real-world speed for this segment was relatively low compared to others, which indicated spillback from downstream intersections. These spillback effects may not have been adequately modeled in the STREETVAL tool. Note that an enhanced queue spillback modeling method was developed for the STREETVAL-RL tool as documented in the L08 final report (Kittelson & Associates et al. 2012). This issue may need further examination.


Average Speed (mph)
45
40
35
30
25
20
15
10
5
0
Real-World Data
STREETVAL (Uncalibrated)
STREETVAL (Calibrated)
Sg 1
Sg 2 & 3
Sg 4
Sg 5
Sg 6
Sg 7
Segment Number

(a)

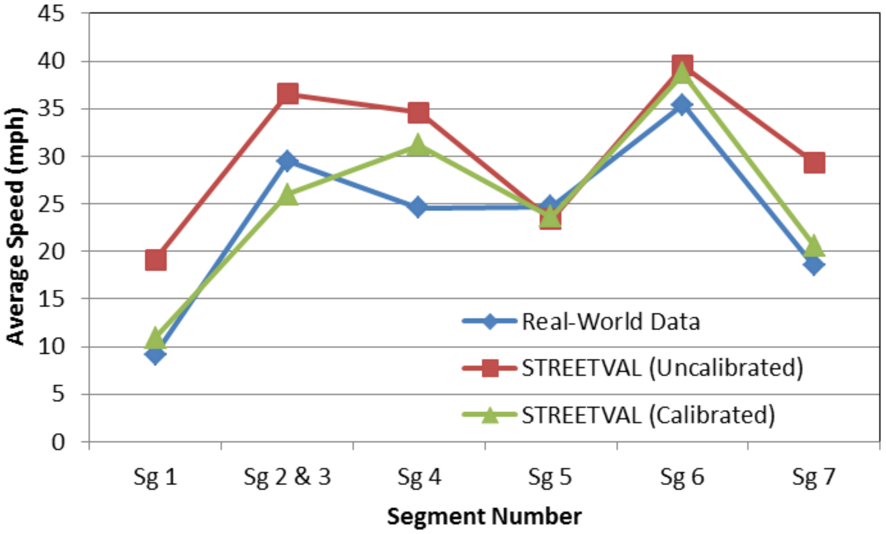

Spatial Stop Rate (stops/mile)
6
5
4
3
2
1
0
Real-World Data
STREEVAL (Uncalibrated)
STREETVAL (Calibrated)
Sg 1
Sg 2 & 3
Sg 4
Sg 5
Sg 6
Sg 7
Segment Number

(b)

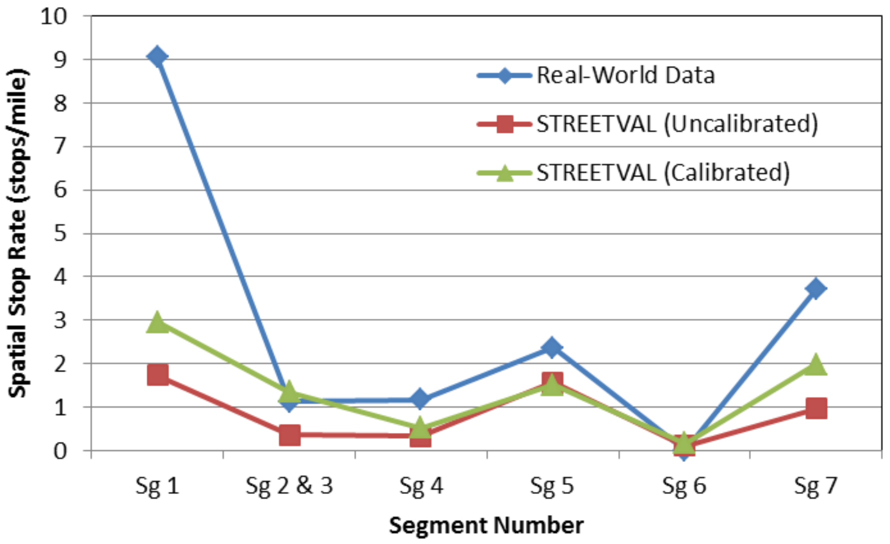


(c)

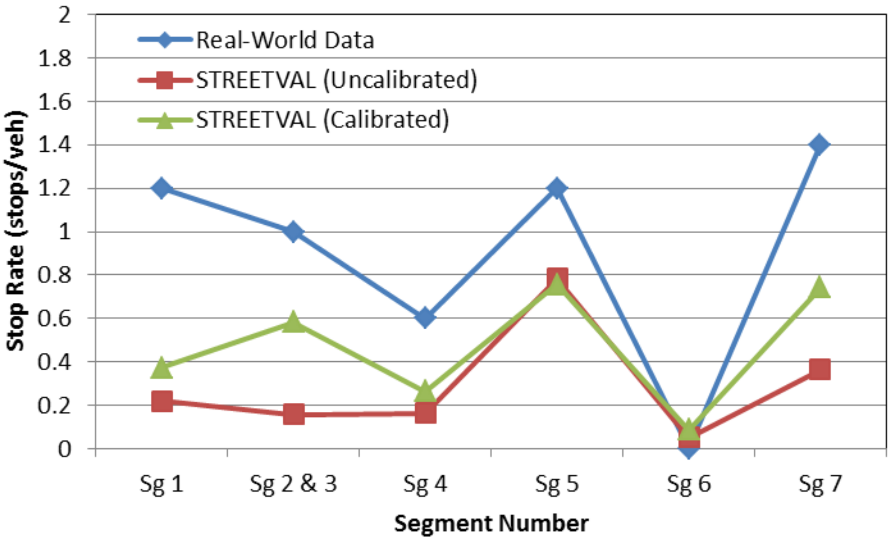
Figure 5.11. Comparison of simulated (a) average speed and (b) spatial stop rate and (c) stop rate with real-world data on SR-7 NB during AM peak period.



(a)

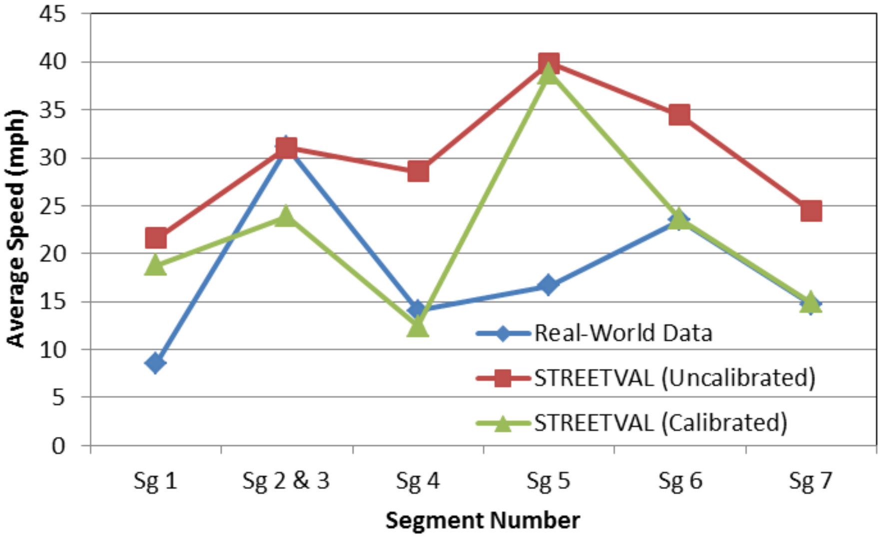


(b)

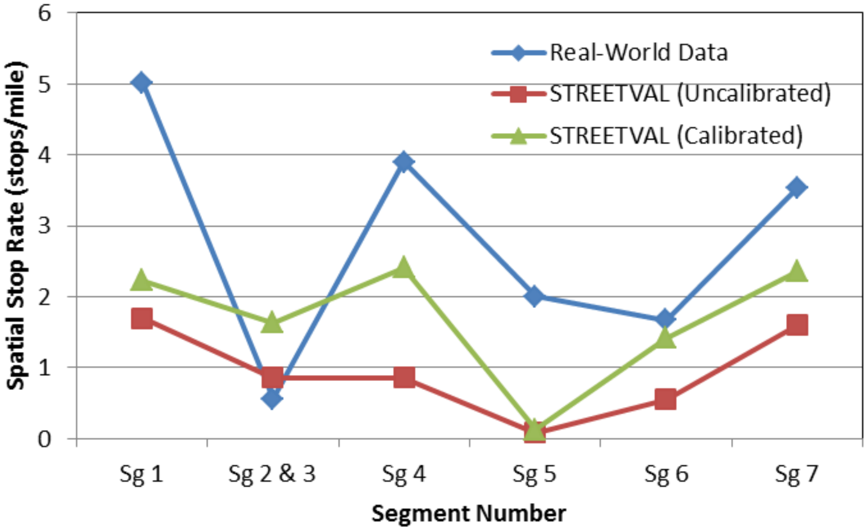


(c)

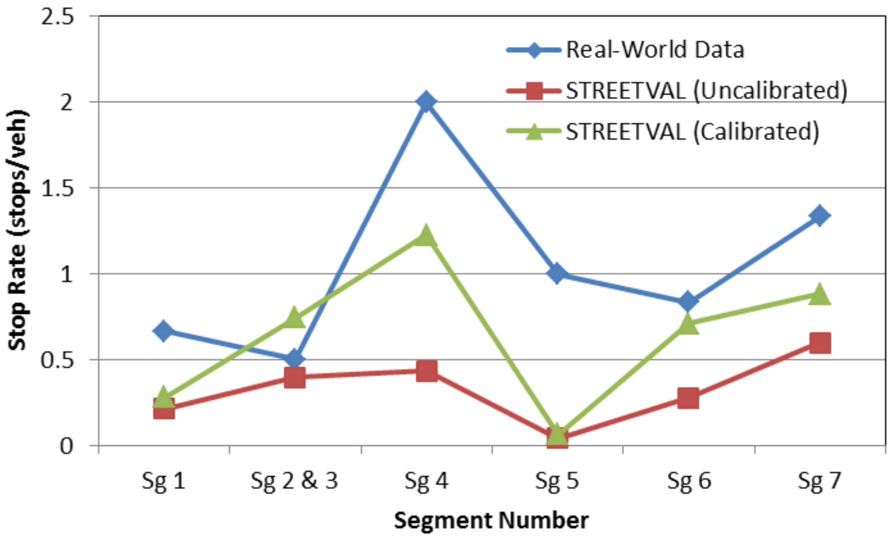
Figure 5.12. Comparison of simulated (a) average speed and (b) spatial stop rate and (c) stop rate with real-world data on SR-7 SB during AM peak period.


Average Speed (mph)
45
40
35
30
25
20
15
10
5
0
Sg 1
Sg 2 & 3
Sg 4
Sg 5
Sg 6
Sg 7
Segment Number
Real-World Data
STREETVAL (Uncalibrated)
STREETVAL (Calibrated)

(a)

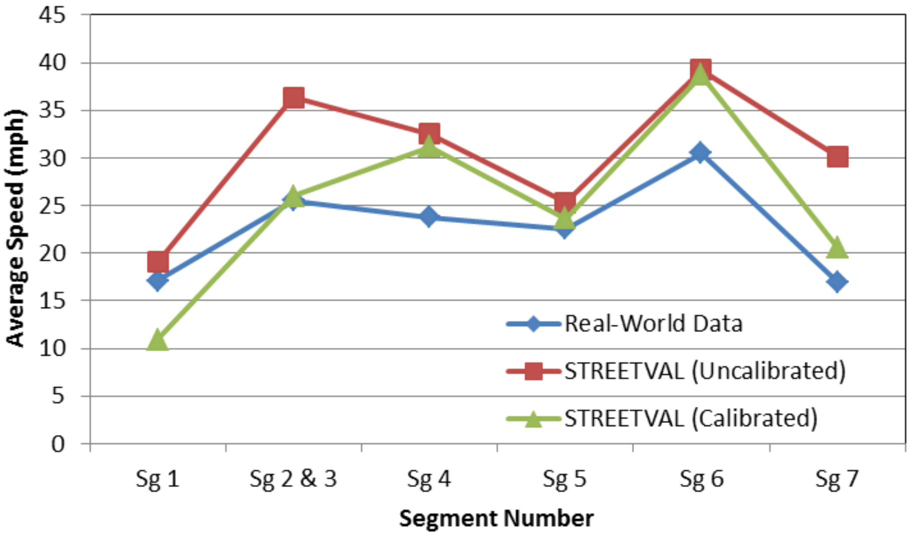

Spatial Stop Rate (stops/mile)
6
5
4
3
2
1
0
Sg 1
Sg 2 & 3
Sg 4
Sg 5
Sg 6
Sg 7
Segment Number
Real-World Data
STREETVAL (Uncalibrated)
STREETVAL (Calibrated)

(b)

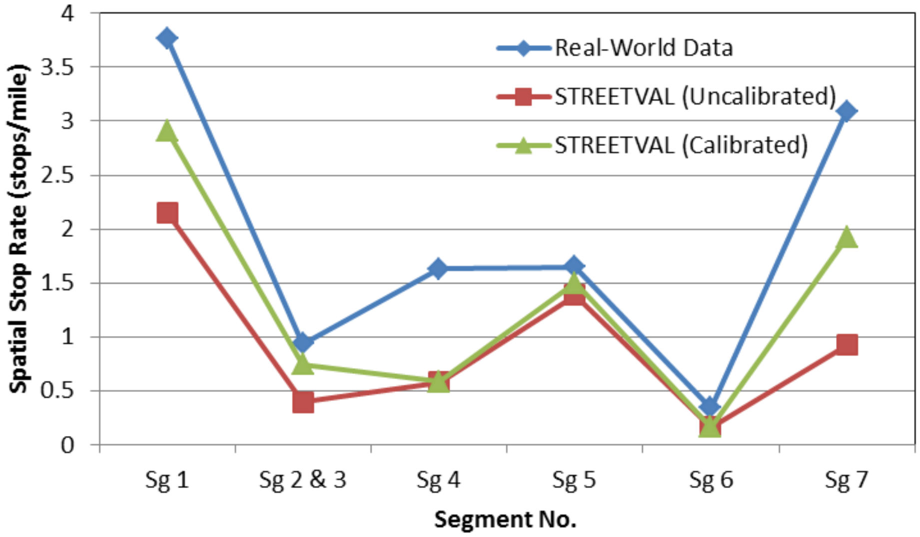


(c)

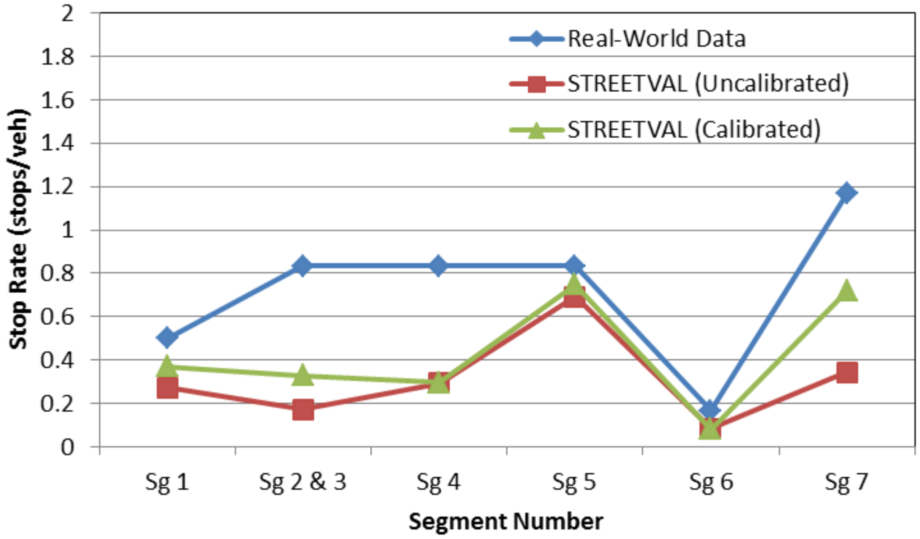
Figure 5.13. Comparison of simulated (a) average speed and (b) spatial stop rate and (c) stop rate with real-world data on SR-7 NB during PM peak period.



(a)



(b)



(c)

Figure 5.14. Comparison of simulated (a) average speed and (b) spatial stop rate and (c) stop rate with real-world data on SR-7 SB during PM peak period.

5.3.3 Updating STREETVAL-RL Scenario Parameters

In STREETVAL-RL, scenarios are generated for each analysis period based on basic inputs, including crash frequency, percentages of different types of incidents, weather conditions, and demand variation factors. In this study, depending on data availability, some of these parameters were updated to reflect local conditions.

Crash data used in this study were retrieved from Florida Signal Four Analytics, a web-based crash-mapping and analysis system. Three-year crash data along the study facility were obtained from this system. According to the description of crash streets and intersection types, as well as the latitude and longitude of crash locations, these crash data were mapped to each study segment and intersection modeled in STREETVAL-RL. Figure 5.15 shows the resulting crash frequency for the study segments and intersections. Two series of crash frequency are presented in this figure. The first is based on one-year crash data for the study time period (weekdays between August 6, 2012, and August 5, 2013). The second series is based on the crash data of the past three years (weekdays between August 6, 2010, and August 5, 2013). As shown in this figure, at least based on the analyzed data, crashes occurred more frequently along the study segments than at signalized intersections. Segment 7 between NW 119th Street and NW 125th Street had the highest three-year average crash frequency, followed by Segment 5, Segment 3, and Segment 4. (These segments are located between NW 95th Street and 119th Street.) Compared to those segments, the crash frequencies at the beginning segments of the study facility were relatively low. Segment 5 between NW 103rd Street and NW 111th Street had a very high crash frequency within the study time period.

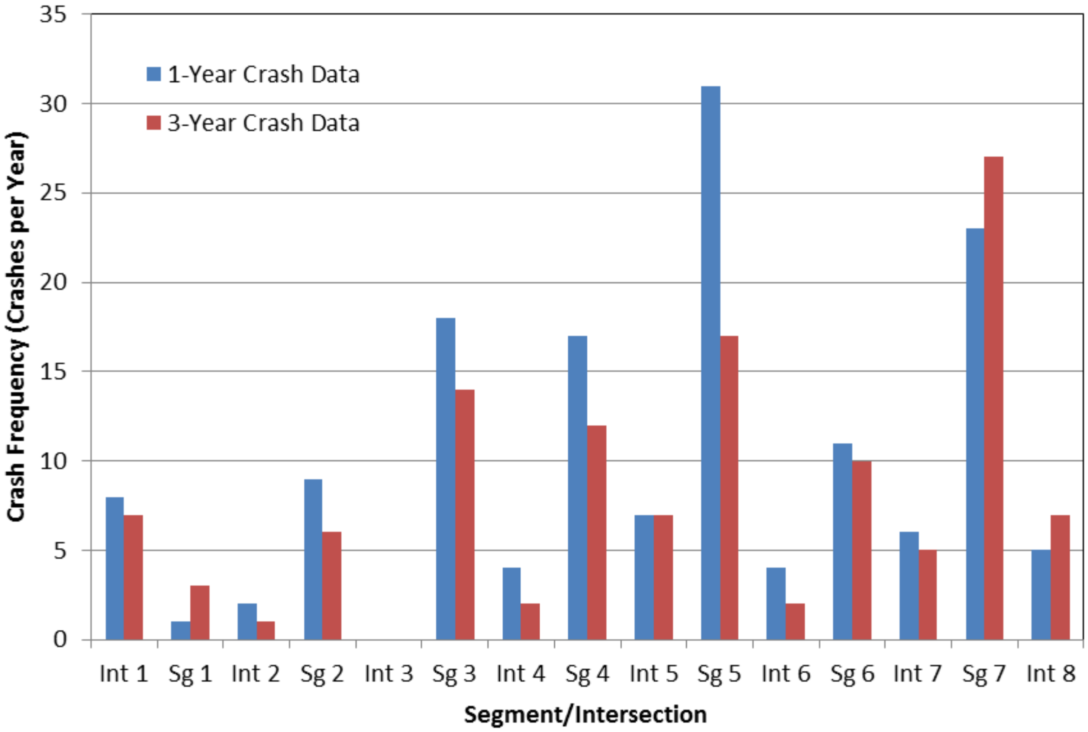


Figure 5.15. Crash frequency for study segments and intersections.

As mentioned in the previous section, STREETVAL-RL requires detailed incident information. It classifies the incidents into different types based on their locations (segment or intersection), incident type (crash or noncrash), lane blockage, severity, and weather conditions at occurrence (no precipitation or rain and dry or wet pavement). The methodology in STREETVAL-RL requires inputting of proportions of each type of incident and the associated incident response time and clearance time. It also needs crash frequency adjustment factors that convert crashes during the weather event to equivalent crash frequency under clear and dry pavement conditions. However, these types of detailed data are normally not available for arterial streets as incident management activities have focused on freeways in most parts of the United States. For SR-7, only crash data from police reports were available, and noncrash incident data were unavailable. Moreover, the available crash data did not include crash duration and lane blockage information. Therefore, other than crash data, the default incident parameters provided in STREETVAL-RL were used in this study due to lack of data.

STREETVAL-RL includes the following weather-related parameters:

- Run-time calibration factor,
- Time after rain stops falling that water is running off the pavement,
- Time after snow stops falling that snow pack (or ice) remains on the pavement,
- Inches of snow for one inch of precipitation,
- Standard deviation of hourly rain rate divided by average rain rate,
- Standard deviation of daily mean temperature in a month,
- Normal precipitation for each month,
- Snowfall in each month,
- Number of days with precipitation 0.01 inches or more,
- Normal daily mean temperature in each month, and
- Monthly precipitation rate.

Default values are provided in the STREETVAL-RL tool based on historical averages. In this study, one-year quality-controlled local climatological data for the Miami Opa Locka Airport station between August 6, 2012, and August 5, 2013, were downloaded from the National Climatic Data Center. These data included detailed hourly temperature and precipitation measurements that were used to extract the required STREETVAL-RL calibration parameters.

Table 5.3 lists the default and updated first six weather-related calibration parameters listed above. Figures 5.16 to 5.19 present the remaining weather-related calibration parameters. As shown in Table 5.3, the first three parameters were not updated due to lack of data. Miami does not have snow events, so the snowfall parameter was set to zero. The last two items in Table 5.3, which are the standard deviation of the hourly rain rate divided by the average rain rate and the standard deviation of the daily mean temperature in a month, were calculated from local weather data. The default values of these two parameters were 1 and 5, respectively, and the local values were 2.57 and 3.72, respectively. It is seen from Figure 5.16 that the normal precipitation for the months between July and October during the study time period was much higher than the default values based on historical averages. The number of days with precipitation of 0.01 inches or more was also higher compared to the historical average values. However, the daily mean temperature based on the default values and updated local values appeared to be close. The comparison of the monthly precipitation rate in Figure 5.19 shows a significant difference between the default values and updated local data. It can be seen that the rate in the study time period was almost half the default values.

Table 5.3. Comparison of Default and Calibrated Weather Parameters

Calibration Parameter	Default Value	Updated Value
Computer run-time calibration factor	1	—
Time after rain stops falling that water is running off pavement (min)	5	—
Time after snow stops falling that snow pack (or ice) remains on pavement	30	—
Inches of snow for one inch of precipitation	10	0
Standard deviation of hourly rain rate divided by average rain rate	1	2.57
Standard deviation of daily mean temperature in a month	5	3.72

Note: — = not updated due to lack of data.

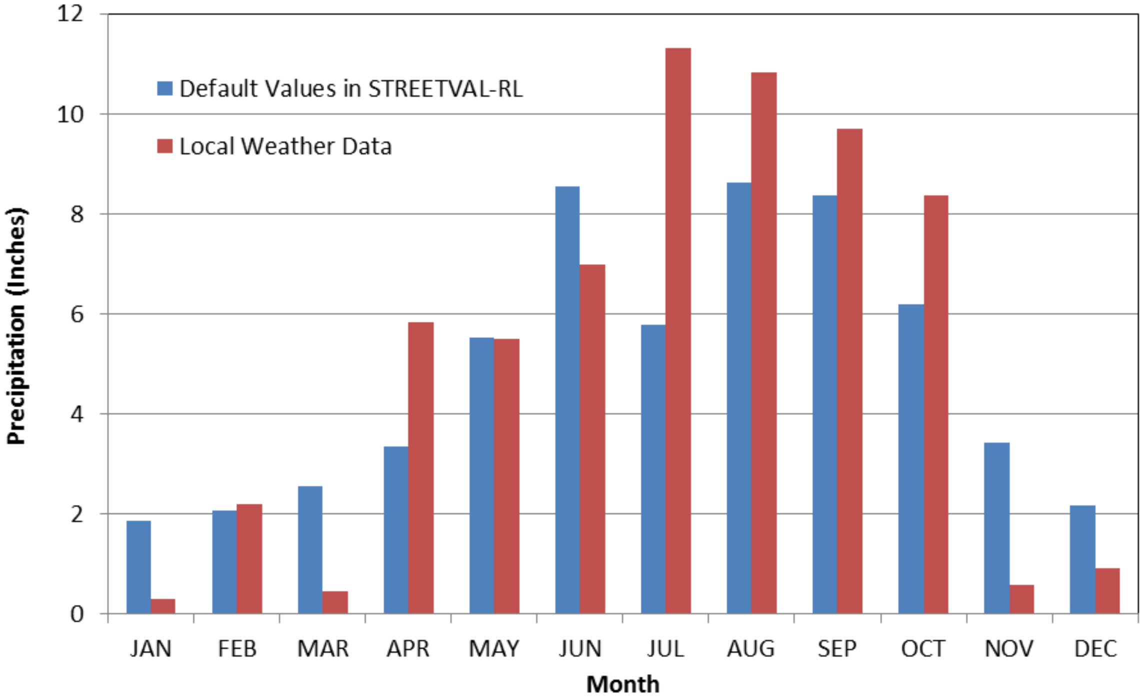


Figure 5.16. Normal precipitation.

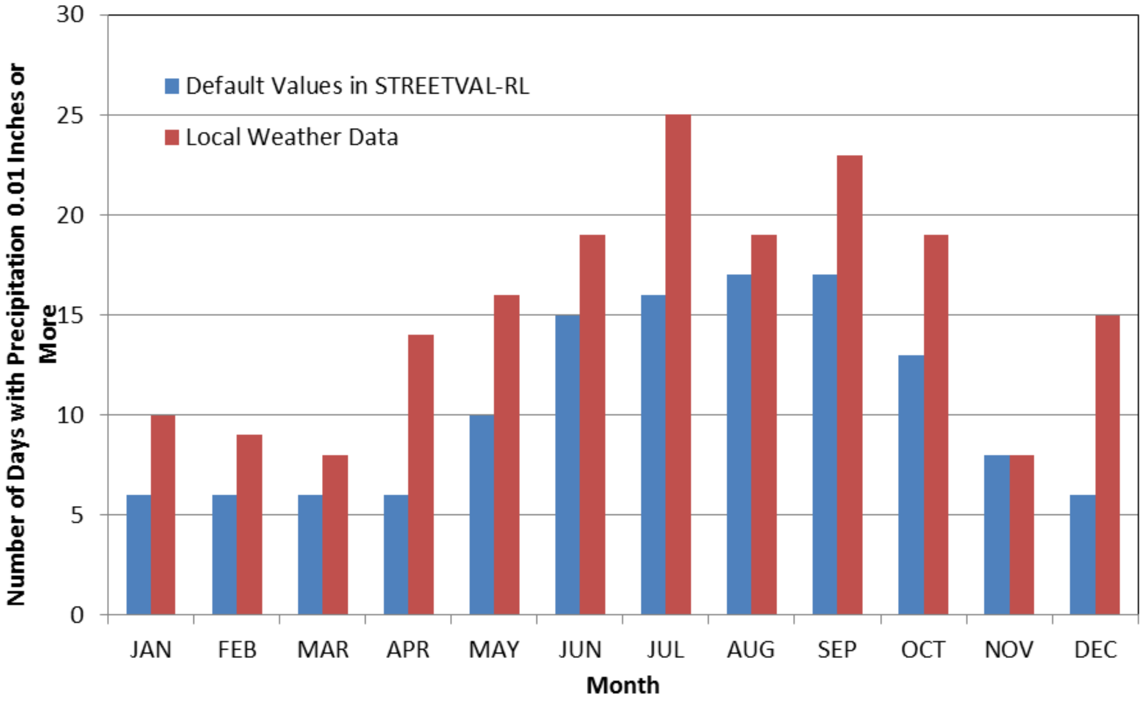


Figure 5.17. Number of days with precipitation 0.01 inches or more.

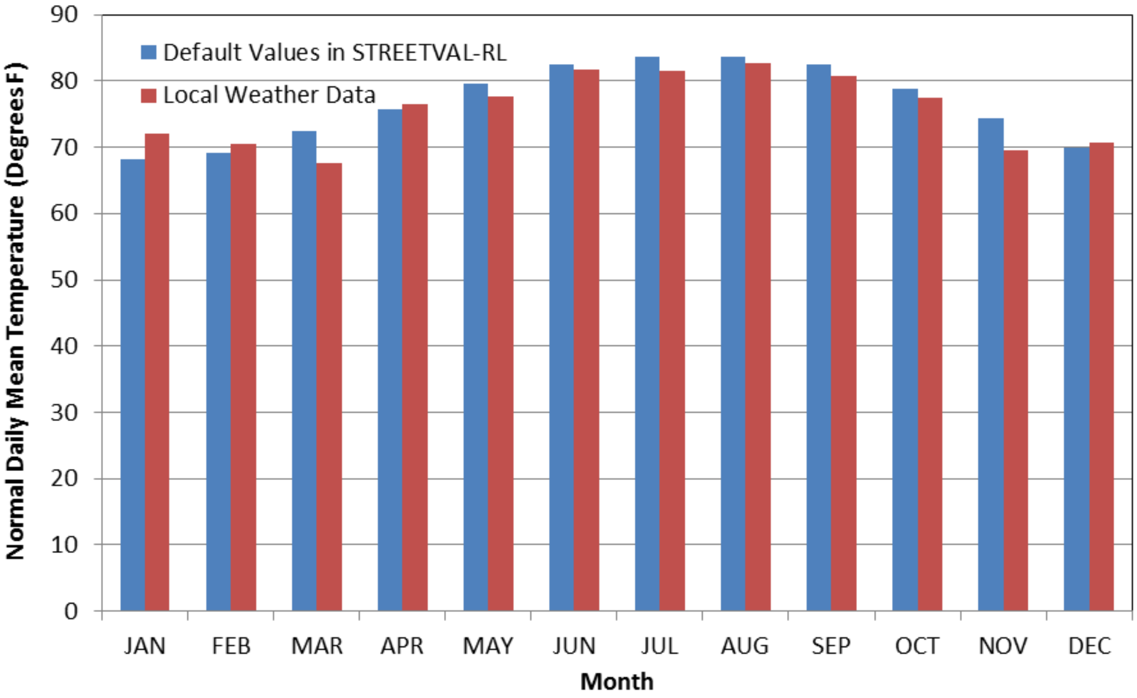


Figure 5.18. Normal daily mean temperature.

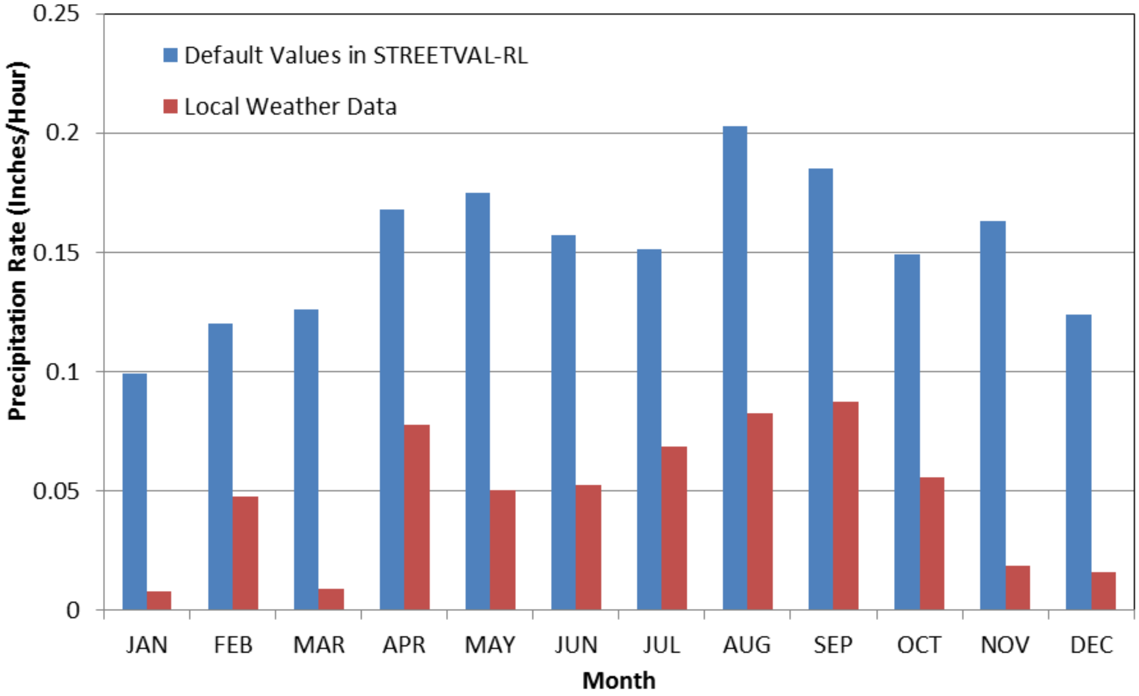


Figure 5.19. Precipitation rate.

In order to account for the variations in demand in each hour, multiple factors were applied to the traffic volumes coded in the base STREETVAL model, including factors to account for the variation by month of year, day of week, and hour of day. Because only peak period traffic counts were available in this study, only the hour of day factors were modified to reflect the relative variation of volume in the AM and PM peak periods, as shown in Table 5.4.

Table 5.4. Comparison of Default and Calibrated Demand Factor

Time Period	Hour	Default Value	Updated Value
AM	6	0.054	0.040
	7	0.071	0.071
	8	0.058	0.075
PM	16	0.073	0.071
	17	0.073	0.073
	18	0.063	0.068

In addition to the above parameters, the peak hour factor for each intersection was updated based on local traffic data to better capture the demand variation within each hour. Table 5.5 presents the locally calculated peak hour factor values.

Table 5.5. Comparison of Default and Calibrated Peak Hour Factor

Intersection Number	Default Value	Updated Value for AM Peak	Updated Value for PM Peak
1	0.99	0.95	0.96
2	0.92	0.94	0.96
3	0.93	0.95	0.95
4	0.94	0.96	0.95
5	0.95	0.97	0.92
6	0.96	0.94	0.91
7	0.97	0.94	0.94
8	0.99	0.90	0.92

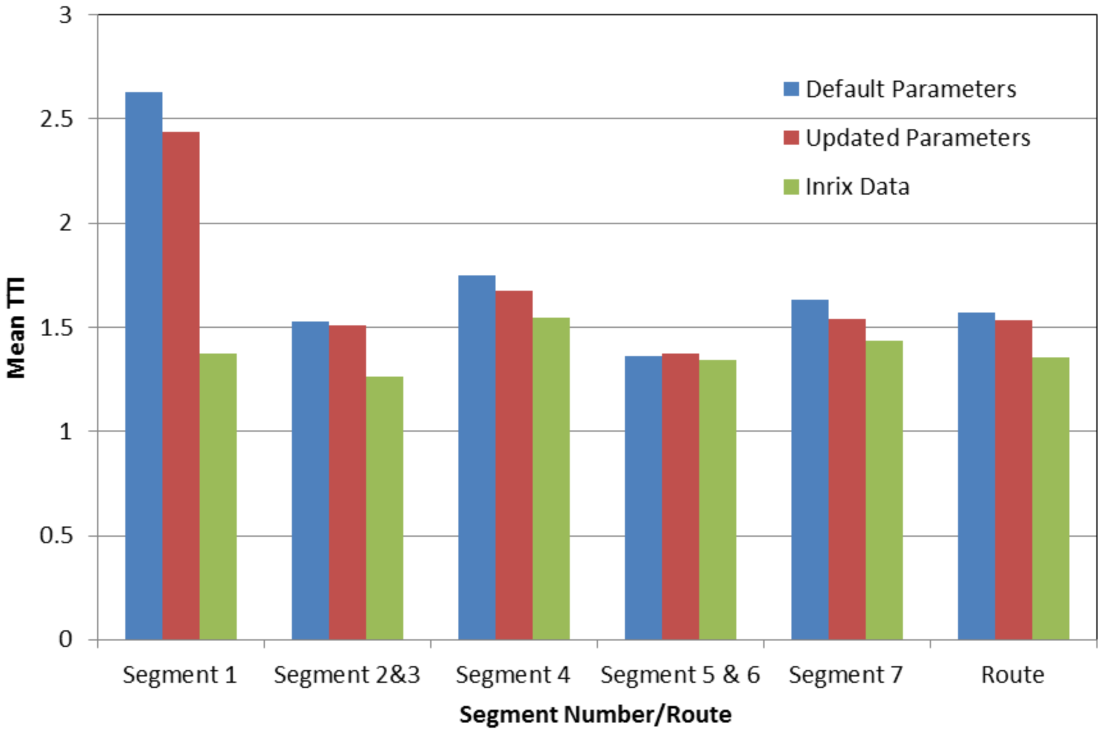
5.3.4 STREETVAL-RL Results Analysis

Running the STREETVAL-RL analysis included three steps: generating scenarios, evaluating scenarios, and performance summary. In this study, various reliability case studies were conducted using the developed STREETVAL-RL model for SR-7. Figures 5.11 to 5.14 present the reliability analysis results for SR-7 in both directions during the AM and PM peak periods.

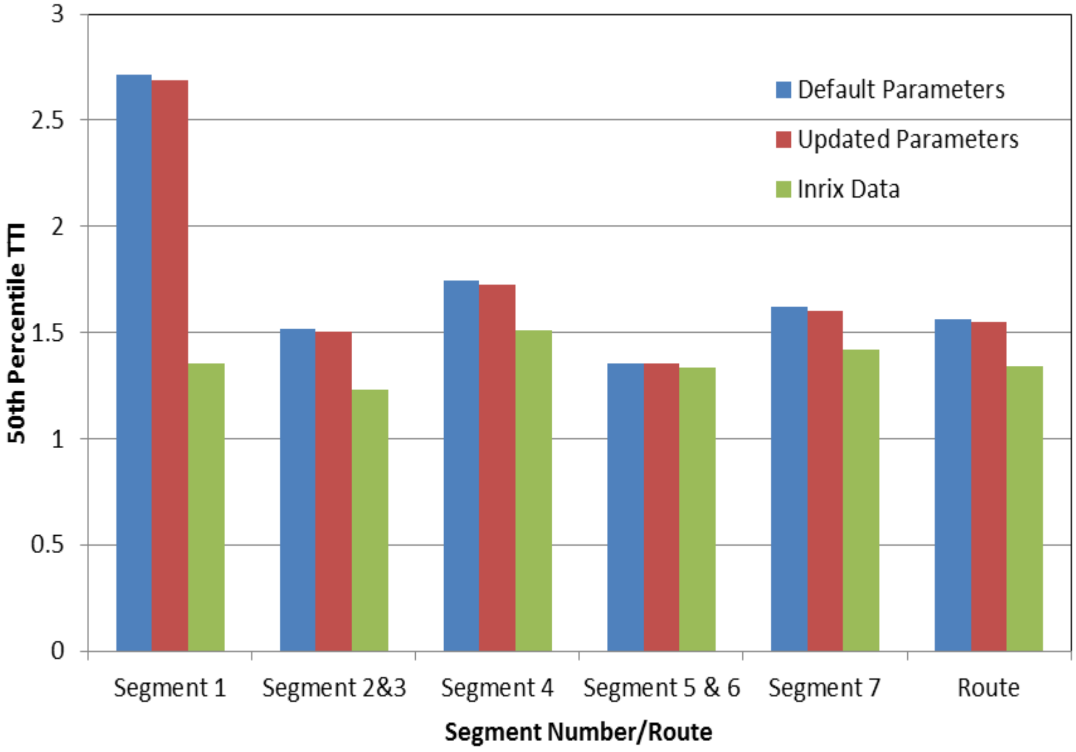
As shown in Figure 5.20, the estimated travel time reliability indexes by STREETVAL-RL for SR-7 NB during the morning peak were close to those values obtained from INRIX data for the whole route and also for most of segments, except the first segment between NW 79th Street and NW 81st Street. It was found that updating the scenario input parameters produced slightly better results. Note that the SR-7 NB traffic was not congested in the morning peak hours for most segments except the first segment. However, the comparison in Figure 5.21 for the more congested SR-7 SB traffic during the AM peak period shows a significant difference between the modeling results and estimation from INRIX data. The modeled reliability measures were more than double or triple the values estimated from INRIX data. It is seen from this figure that the difference became larger with the increase in the percentile TTI. The estimated TTI for the whole route was about two times higher than TTIs based on INRIX data for the mean and 50th percentile TTIs and about three times for the 80th and 95th percentile TTIs. This figure also shows that updating reliability input parameters greatly improved the estimation performance.

Figure 5.22 presents the comparison for the SR-7 NB traffic during the PM peak period. This is the direction for the afternoon peak hours. Similar to the results for the congested SB morning peak, significant differences can be observed between the modeling results and INRIX results, especially at Segment 4 and Segment 7, that is, from NW 95th Street to NW 103rd Street and from NW 119th Street to NW 125th Street. Again, better correspondence between modeling results and INRIX results was found for the SR-7 SB traffic in the PM peak period, as shown in Figure 5.23, as the traffic along this direction was not as congested as NB traffic in the PM peak.

Based on the discussion above, it can be concluded that the urban street reliability model corresponded better to models based on INRIX data under uncongested conditions than congested conditions. Updating input parameters based on local conditions was shown to produce better results. The differences between the modeling results and INRIX results may be explained by several reasons. The first possibility is that INRIX data may have underestimated travel time during the congested conditions. If this were the case, the actual difference between the modeling and real-world estimates should be much smaller. The second possibility is that STREETVAL-RL generated some extreme scenarios (e.g., severe lane-blocking crashes), and under those scenarios, travelers may divert to alternative routes, which was not modeled in STREETVAL-RL. A threshold similar to the one used in FREEVAL-RL can be applied in STREETVAL-RL to cut off the extreme scenarios and reduce the overestimation of reliability. Third, the delay equation of the HCM procedure was possibly generating very high delays under extremely congested conditions due to the occurrence of extreme events. Finally, due to the lower amount of incident data on arterial streets, the real-world frequencies, locations, and durations of incidents may not have been sufficiently accurate for the analysis.

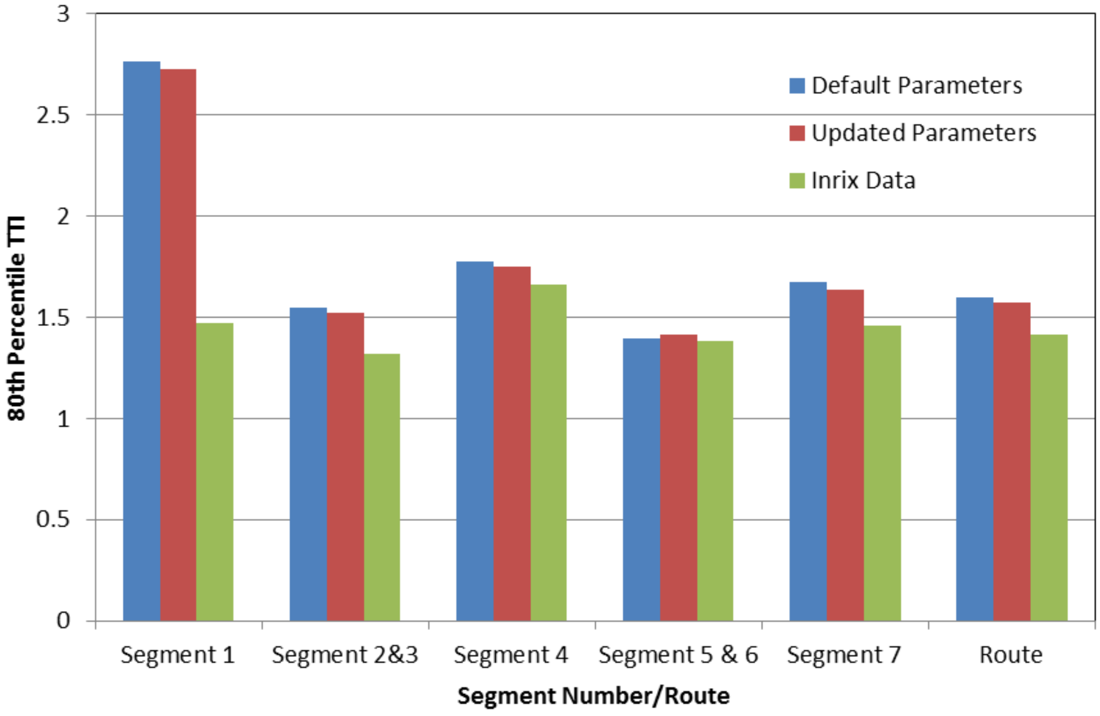


(a)



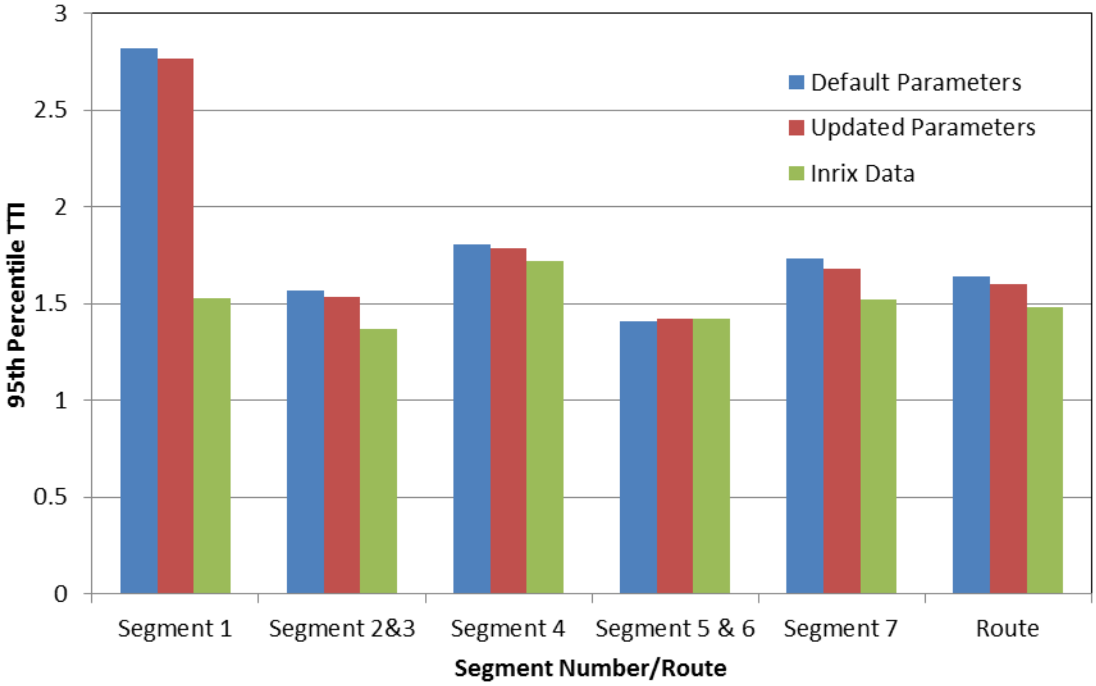
3
2.5
2
1.5
1
0.5
0
50th Percentile TTI
Default Parameters
Updated Parameters
Inrix Data
Segment 1
Segment 2&3
Segment 4
Segment 5 & 6
Segment 7
Route
Segment Number/Route

(b)



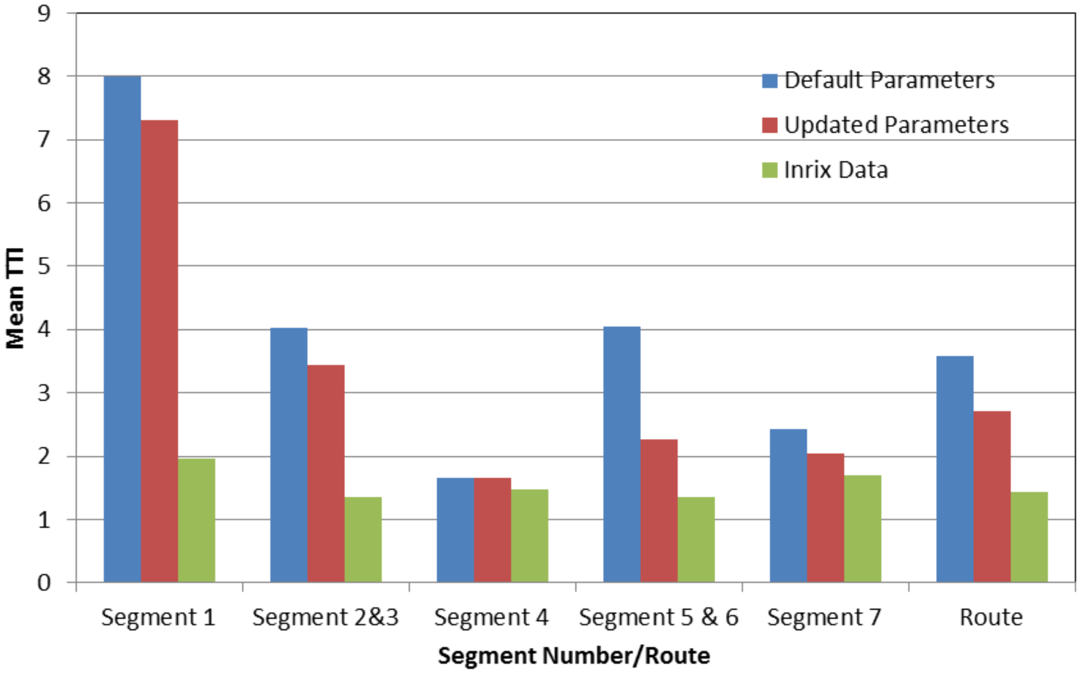
3
2.5
2
1.5
1
0.5
0
80th Percentile TTI
Default Parameters
Updated Parameters
Inrix Data
Segment 1
Segment 2&3
Segment 4
Segment 5 & 6
Segment 7
Route
Segment Number/Route

(c)

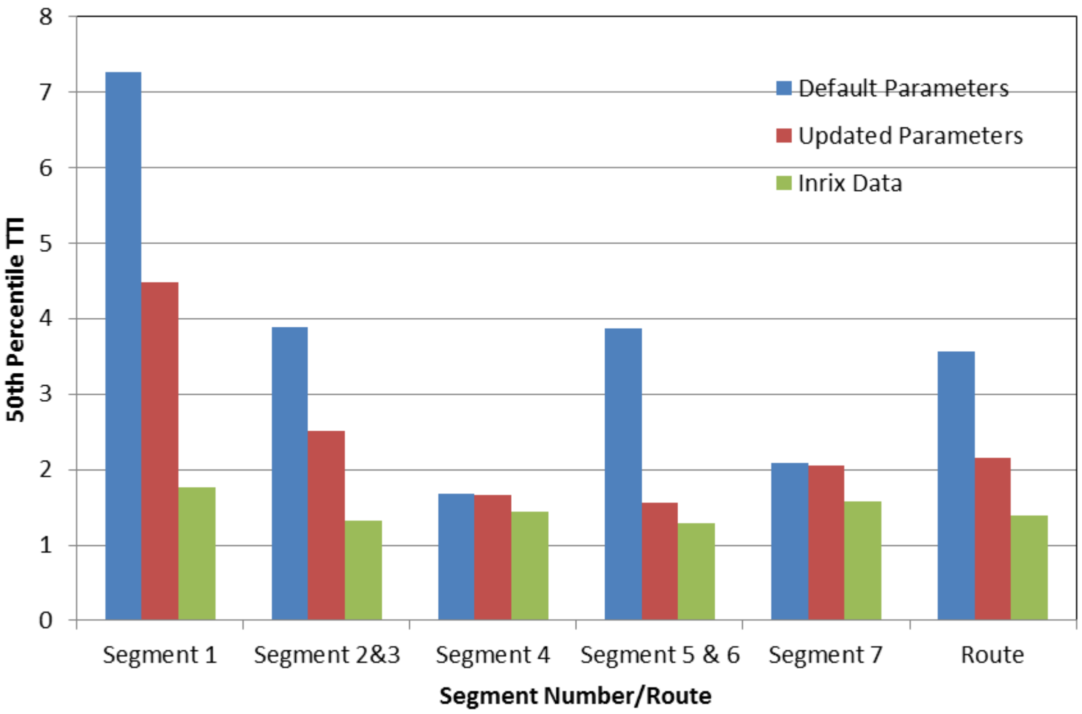


(d)

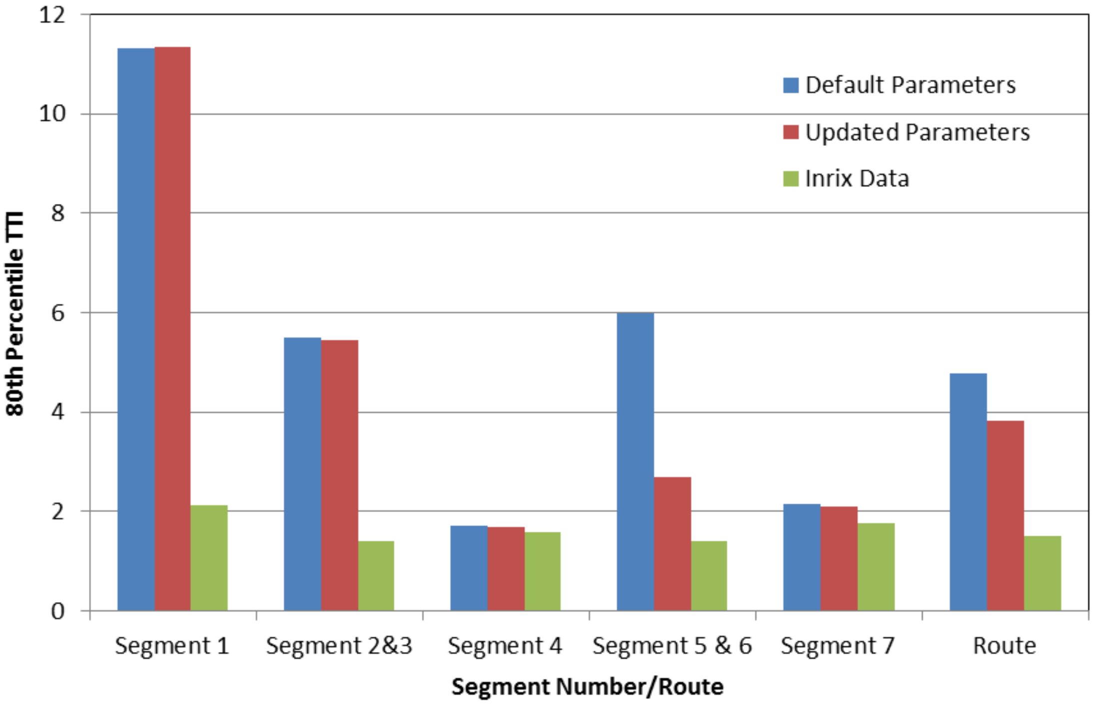
Figure 5.20. Reliability analysis results for SR-7 NB during AM peak period for (a) mean and (b) 50th, (c) 80th, and (d) 95th percentile TTIs.



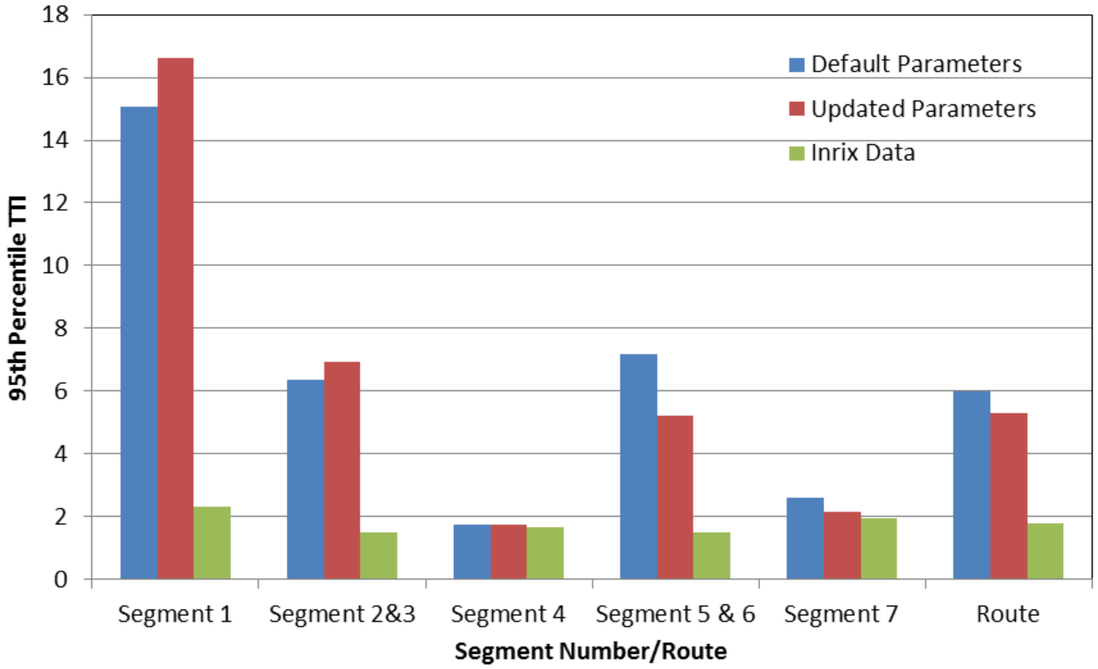
(a)


8
7
6
5
4
3
2
1
0
50th Percentile TTI
Default Parameters
Updated Parameters
Inrix Data
Segment 1
Segment 2&3
Segment 4
Segment 5 & 6
Segment 7
Route
Segment Number/Route

(b)

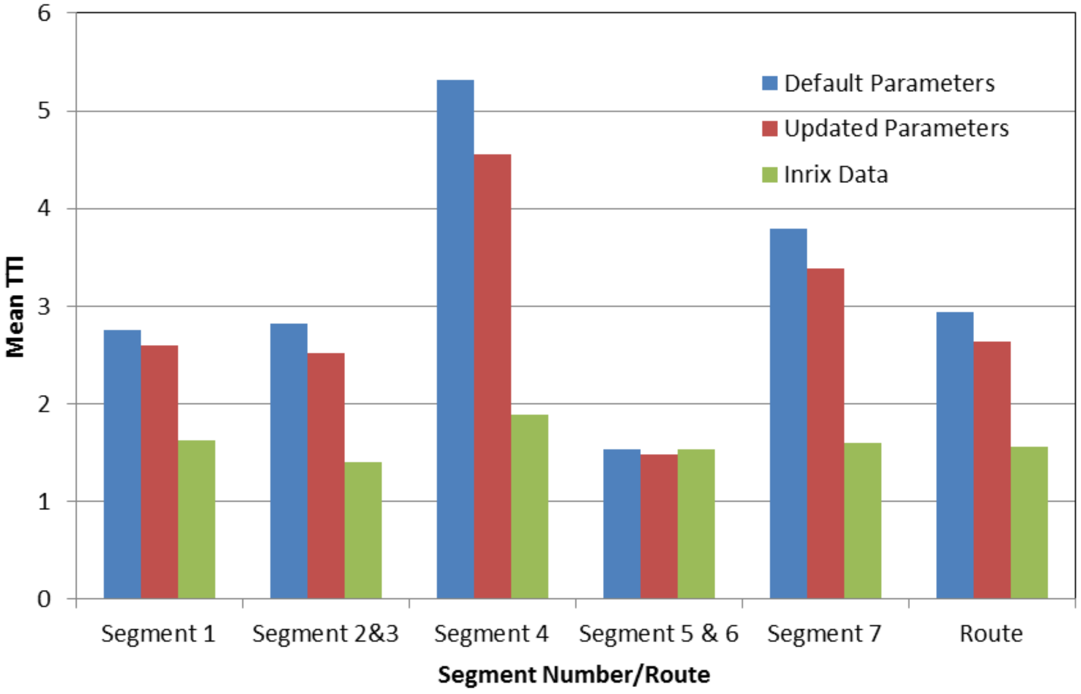

12
10
8
6
4
2
0
80th Percentile TTI
Default Parameters
Updated Parameters
Inrix Data
Segment 1
Segment 2&3
Segment 4
Segment 5 & 6
Segment 7
Route
Segment Number/Route

(c)

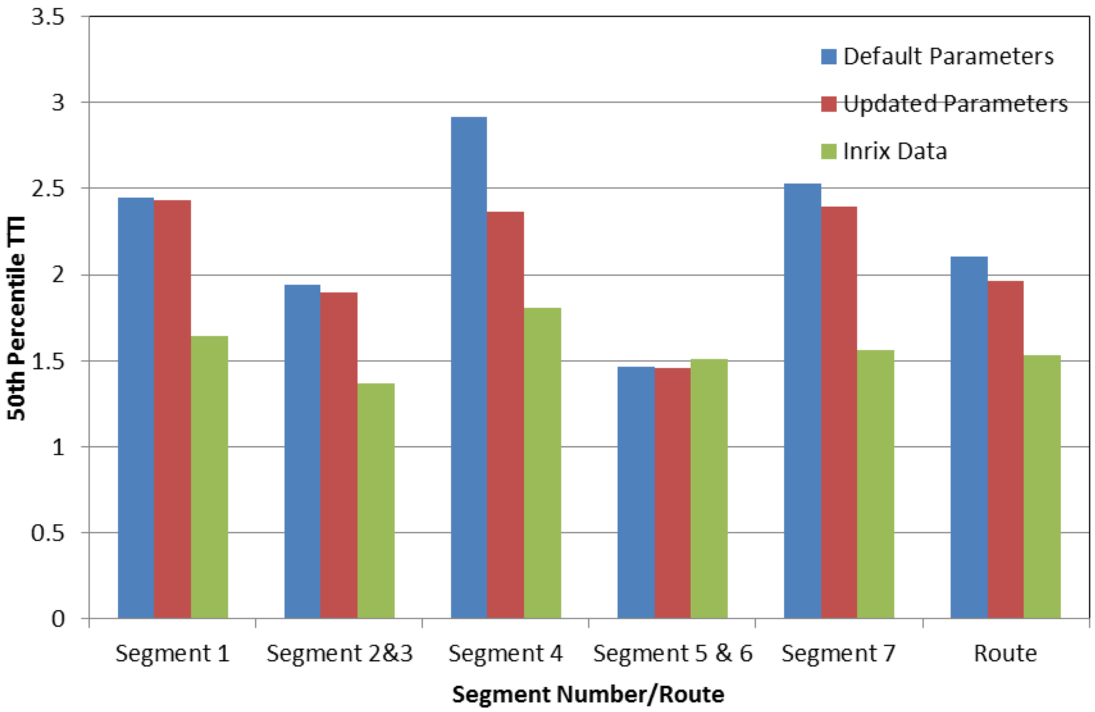


(d)

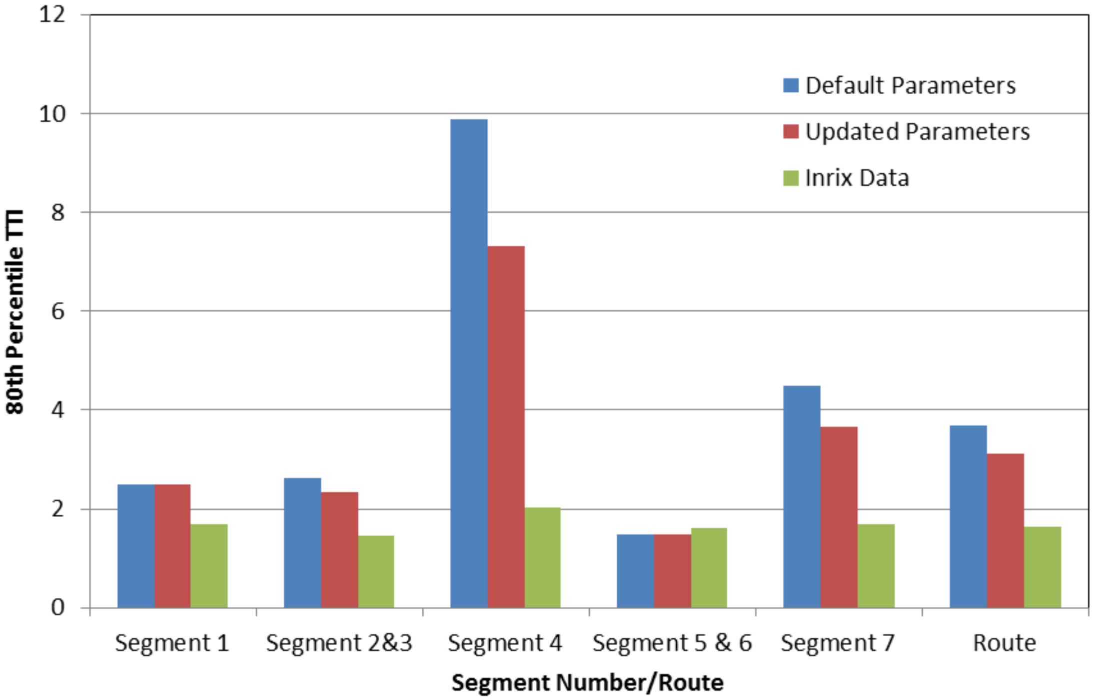
Figure 5.21. Reliability analysis results for SR-7 SB during AM peak period for (a) mean and (b) 50th, (c) 80th, and (d) 95th percentile TTIs.



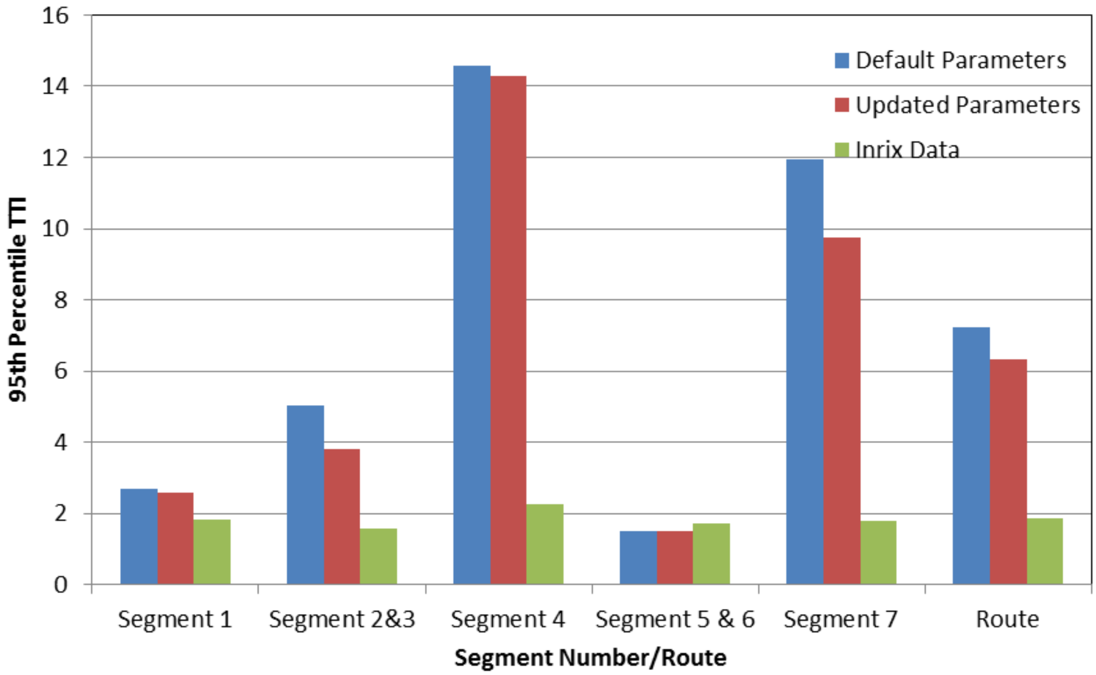
(a)


3.5
3
2.5
2
1.5
1
0.5
0
50th Percentile TTI
Default Parameters
Updated Parameters
Inrix Data
Segment 1
Segment 2&3
Segment 4
Segment 5 & 6
Segment 7
Route
Segment Number/Route

(b)

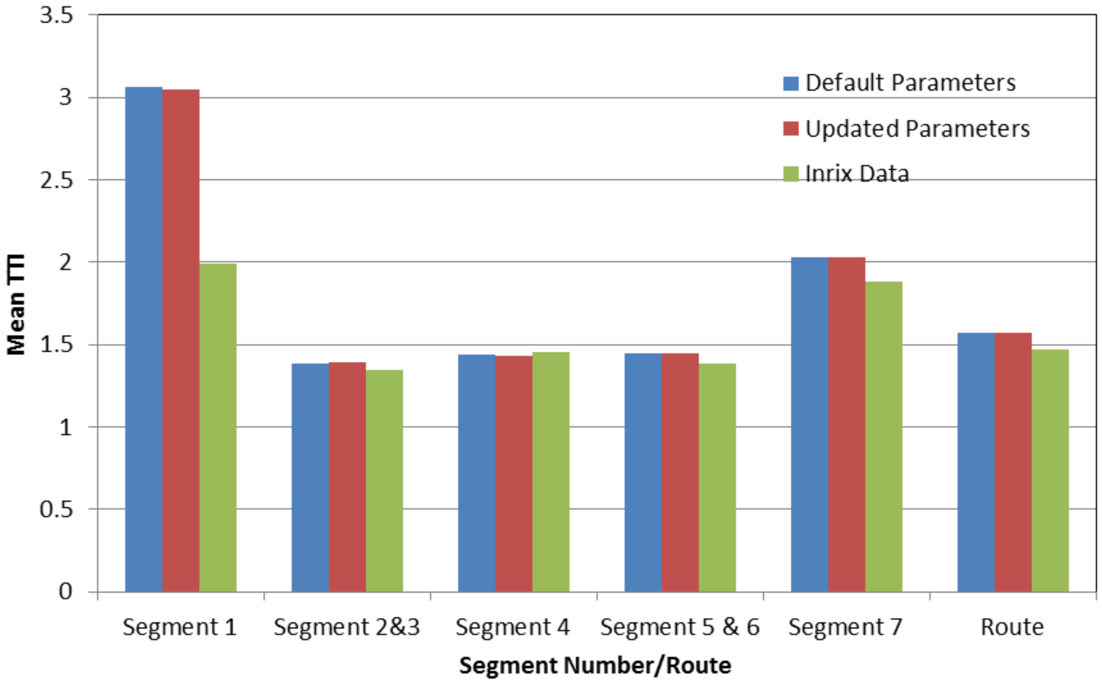

12
10
8
6
4
2
0
80th Percentile TTI
Default Parameters
Updated Parameters
Inrix Data
Segment 1
Segment 2&3
Segment 4
Segment 5 & 6
Segment 7
Route
Segment Number/Route

(c)

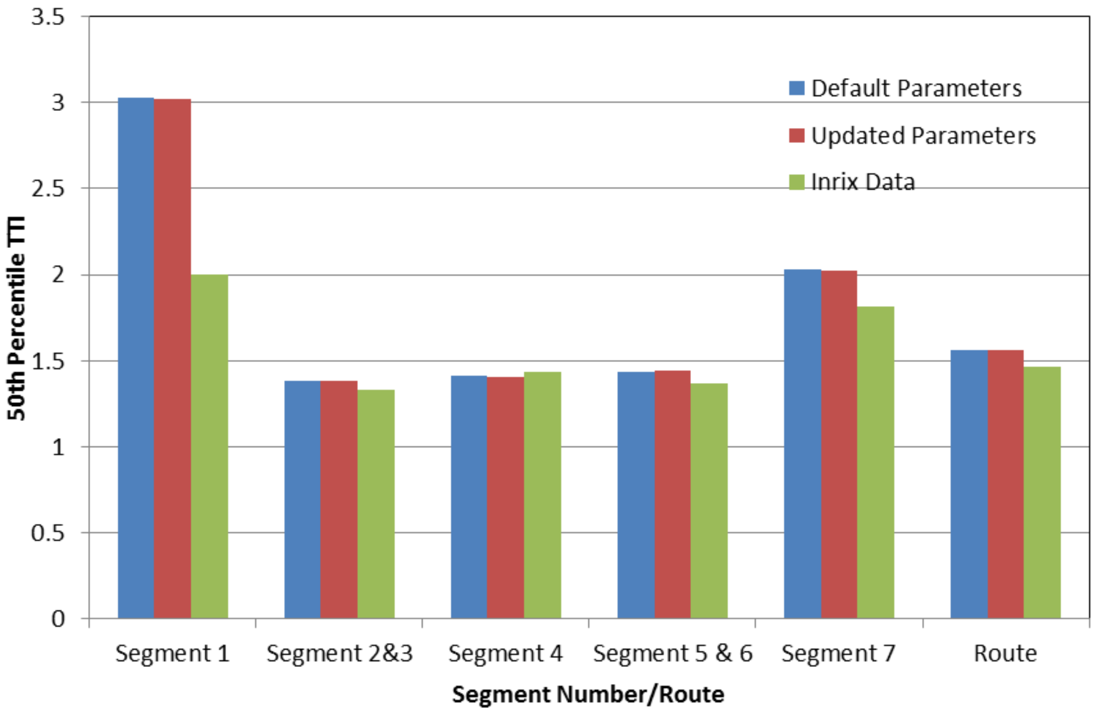


(d)

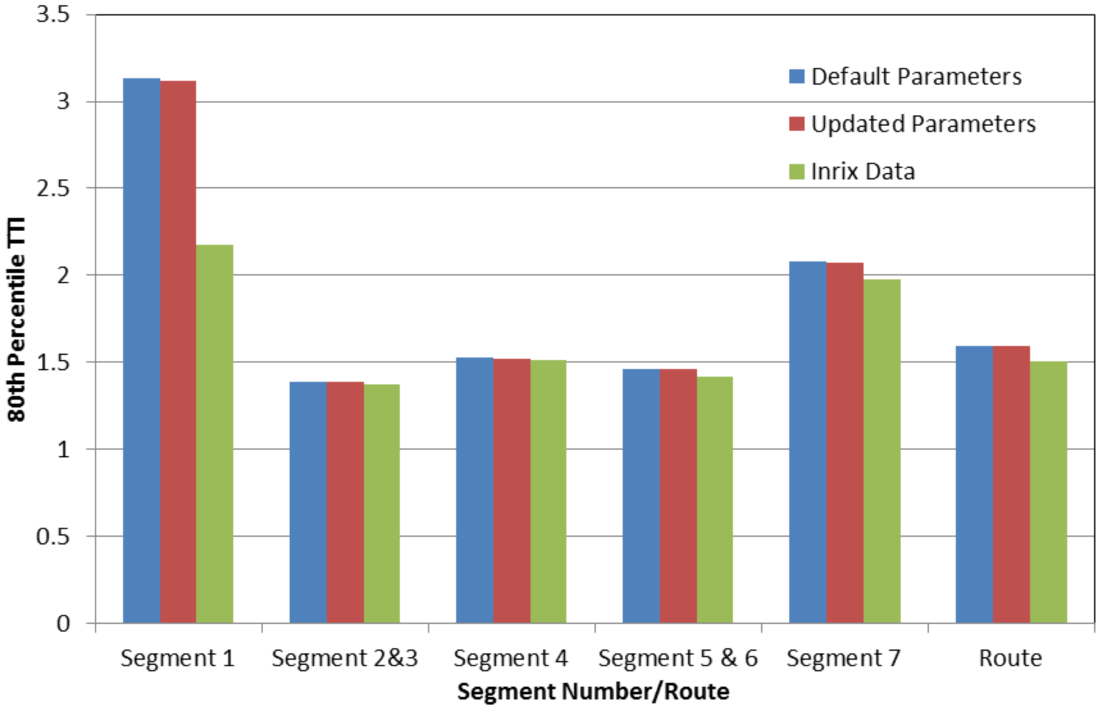
Figure 5.22. Reliability analysis results for SR-7 NB during PM peak period for (a) mean and (b) 50th, (c) 80th, and (d) 95th percentile TTIs.



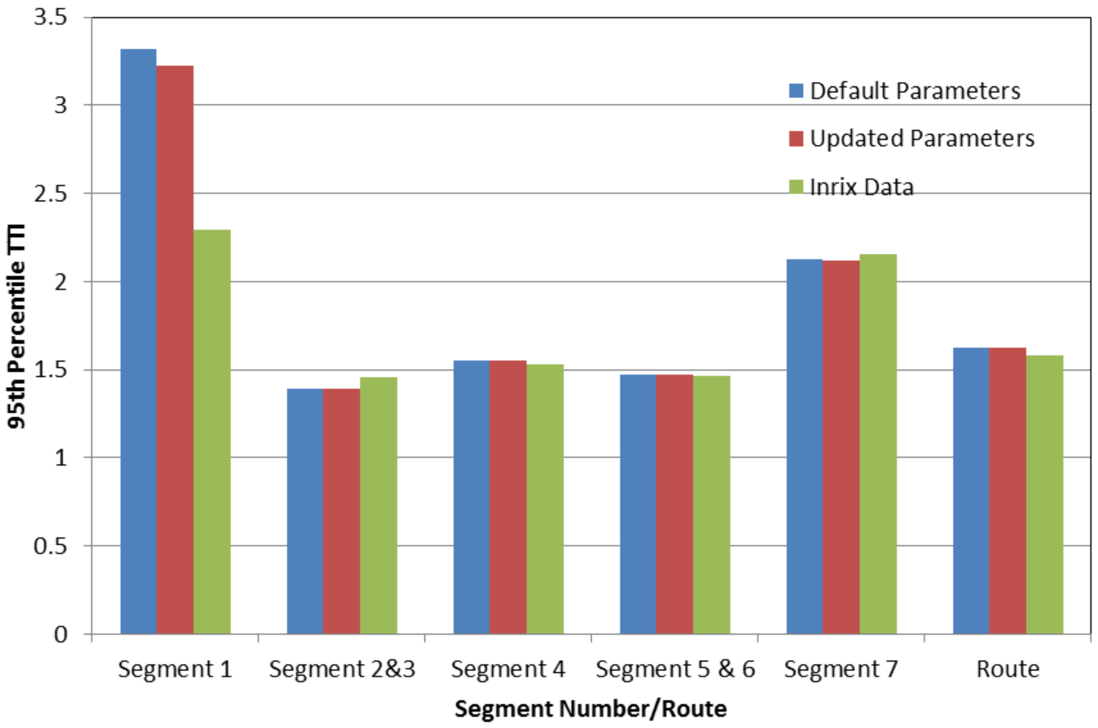
(a)


3.5
3
2.5
2
1.5
1
0.5
0
50th Percentile TTI
Default Parameters
Updated Parameters
Inrix Data
Segment 1
Segment 2&3
Segment 4
Segment 5 & 6
Segment 7
Route
Segment Number/Route

(b)


3.5
3
2.5
2
1.5
1
0.5
0
80th Percentile TTI
Default Parameters
Updated Parameters
Inrix Data
Segment 1
Segment 2&3
Segment 4
Segment 5 & 6
Segment 7
Route
Segment Number/Route

(c)



(d)

Figure 5.23. Reliability analysis results for SR-7 SB during PM peak period for (a) mean and (b) 50th, (c) 80th, and (d) 95th percentile TTIs.

5.4 Summary

This chapter presents an investigation of the use of the HCM-based reliability estimation procedure to assess the existing travel time reliability of study facilities. For the freeway facilities, the results from the calibration of the traffic flow model indicated that adjusting the capacity values to the values measured based on traffic detector data improved the system ability to replicate real-world queues and travel times. Using different methods to identify incident attributes to input to the model was found to affect, in particular, the 95th percentile TTI and the misery index, which were indicators of the worst five percentile conditions on the facility. Fewer impacts were found on the 80th percentile TTI values. The modeling results for urban streets indicated that the current procedures can produce better reliability estimation under the uncongested conditions, and the estimation for congested conditions may need further examination. Similar to using traffic detector data for freeway facilities, updating input parameters for urban streets based on local conditions was necessary for improving estimation performance.

CHAPTER 6

Strategies to Address Unreliability

6.1 Introduction

This chapter presents potential strategies for addressing the reliability issues identified for the study facilities. Example assessments of these strategies were conducted in this study using the L07 and L08 tools, considering the limited ability of these tools to evaluate such strategies. The results of these assessments are also presented in this chapter.

6.2 Transportation Management Center Operations

TMCs provide monitoring, dispatching, command, and control functions for addressing incident, traffic, transit, and emergency management. Within southeast Florida, there are 11 TMCs:

- Florida DOT District 6 regional TMC (includes Miami-Dade Expressway Authority and FHP),
- Florida DOT District 4 regional TMC (includes Broward County traffic signals and I-595 concessionaire),
- Florida Turnpike TMC (Pompano Beach, serving the southern 100 miles of the turnpike),
- Miami-Dade County Traffic Signal Control Center,
- Miami-Dade Transit Bus Control Center,
- Miami-Dade Transit Train Control Center,
- South Florida Regional Transit Authority (Tri-Rail) Control Center,
- Broward County Transit Control Center (buses),
- Palm Beach County Traffic Signal Control Center,
- Boca Raton Traffic Signal Control Center, and
- Palm Tran Transit Control Center (buses).

During the next few years, it is anticipated that these TMCs will be better integrated through center-to-center communications and software systems that will improve connectivity and enable more effective operations of the multimodal transportation system. It is expected that this integration will be realized through predictive models and decision support systems, as well as performance management systems, including travel time reliability as an important metric.

Project L38C focused on I-95 and SR-7. The potential planning for operations and operations applications for including travel time reliability in TMC operations can be classified in the following areas:

- Trend analyses,
- Predictive analyses,
- Transportation management strategies,

- Decision support systems, and
- Integrated corridor management.

It is suggested that these functional areas begin to include travel time reliability in their day-to-day processes, standard operating guidelines, and performance reporting systems. TMC operations should be audited to determine gaps in the existing services versus what is needed, and reliability tools should be applied to address these gaps. It is anticipated that this procedure will be conducted offline initially, then transitioned to real-time, online processes as the TMC operations staff begins to be more comfortable with the accuracy, timeliness, and usefulness of such information. The following sections discuss these functional areas in more detail.

6.2.1 Trend Analyses

It is recommended that TMCs dedicate time to analyzing trends of reliability data, as well as other related information, to determine how operations may be improved. These analyses will lead to the identification of specific problem areas such as substandard sections of merging, weaving, geometrics, pavement condition, and other safety and operational deficiencies. In addition, they will lead to identifying time of day and segments where additional and/or improved traffic, demand, and incident management strategies could be implemented. A traffic engineer (or analyst) at the TMC could then monitor the identified problem areas, including ELs and GPLs, by using CCTV cameras, detectors, and other ITS tools during periods when travel time is most unreliable. As stated above, unreliability may be attributed to incidents, inclement weather, work zones, fluctuation in traffic demand, special events, bottlenecks, traffic control devices, or combinations of these factors. The detailed reliability analysis presented in Chapter 3 clearly demonstrates the unreliability magnitude, location, time, duration, and causes for the I-95 GPLs and ELs.

The analyses should consider the relationship of reliability to percentage occurrence, severity, and unreliability contribution for non-lane-blocking incidents as well as lane-blocking (1, 2, 3+ lanes blocked) events by location for different time periods throughout the day. The analyses of capacity problems may be simplified by identifying the location of bottleneck impacts by using contour (heat) maps. Based on this preliminary analysis, the problem areas could be summarized and then submitted to District 6 traffic operations for more detailed traffic safety and operations studies. TMC staff should be available to support traffic operations during the development of these studies, and then conduct before and after analyses using the ITS tools and data afforded by the TMC.

6.2.2 Predictive Analyses

It is recommended that TMCs begin to use the ITSDCAP tool, with the enhanced reliability model based on SHRP 2 products, as a predictive tool to complement the trend analyses. ITSDCAP captures data from a number of sources; filters, imputes, and fuses the data; calculates various mobility, reliability, safety, and environmental impacts; and contains modules that support data mining, traffic modeling, and ITS benefit–cost analysis. These features will enable TMC operations staff to be more proactive in addressing problems before they occur.

Specifically, ITSDCAP could be applied to measure travel time reliability for the study facility (i.e., I-95 and SR-7), ELs, and GPLs, as well as interconnecting links within the regional network. As with trend analyses, predictive analyses should consider the impact on reliability from lane-blocking (1, 2, 3+ lanes blocked) events by location for different time periods throughout the day.

The results of this analysis may be posted on the TMC video walls and/or operator workstations with clear and simple indications illustrating which system links and nodes are expected to experience the most unreliable travel times. A system map with green, yellow, and red indications illustrating the severity of travel time reliability based on 95th percentile TTIs could be used. For example, green may be used for 95th percentile TTIs ≤ 1.25 (good); yellow within the 1.25 to 2.00 range (fair); and red when the 95th percentile TTI is expected to exceed 2.00 (poor). TMC staff may then focus on the most severe system links and nodes in applying the most appropriate transportation management strategies.

6.2.3 Transportation Management Strategies

It is recommended that a comprehensive menu of transportation management strategies be developed and stored in an evolving library to be deployed when certain system links and nodes exceed a certain threshold (e.g., 95th percentile TTI > 2.00). These strategies should consider a broad range of measures as presented below. The strategy activation decision can be a planning for operations (offline) decision or operations (online) decision.

6.2.3.1 Active Lane Management

Based on the merging, ramp backup, and incident lane blockage issues identified in the previous chapter, it is recommended that additional active lane management strategies, including lane control, variable speed display, and dynamic lane assignment systems, be considered. Hard-shoulder running was considered for the I-95 GPLs, but based on discussions with TMC staff it was considered unfeasible for the studied I-95 segment due to the unavailability of a left shoulder and the interference of the right shoulder with ramp operations.

Lane control systems are often installed with variable speed displays to provide advance notice that a lane or lanes are closed ahead and to start the merge process into the available lanes well in advance of the actual closure. Variable speed displays may be advisory or regulatory; if they are regulatory, they require enforcement to be effective. The intent of these systems is to advise motorists of downstream conditions, incidents, and/or congestion. These systems also provide advance warning to motorists of the need to reduce speeds before an incident or congestion and the ability to merge out of lanes that are closed downstream in an orderly manner. In addition, by stabilizing traffic speeds, variable speed displays and lane control systems work to reduce flow breakdown and the onset of stop-and-go driving behavior. This stabilization results in more uniform traffic flow and safer driving conditions and reduces both primary and secondary incidents and their severity. Traffic sensors along the roadway collect vehicle speeds, congestion information, and traffic flow rates. This information is continuously monitored by TMC operations staff. When circumstances (e.g., congestion) are identified that would benefit from a lowered speed limit, an algorithm automatically reduces the approaching traffic flow to the congested area.

Lane control systems also provide the benefit of clearly identifying the operational status of each lane, which is particularly important along I-95, where ELs may be closed due to construction, maintenance, or incidents while GPLs are open. A lane control system would address the current situation along I-95, where DMS messages are sometimes confusing. For example, motorists may not know if the message “two left lanes closed” means the GPLs or ELs are closed.

Dynamic lane assignment systems manage lanes primarily upstream of an interchange to change access based on traffic demands in the lane or at the interchange. These strategies are intended to improve traffic flow by expanding or restricting capacity at existing access points based on traffic conditions. Deployments can take the form of creating a new lane out of a shoulder during peak periods, or, in the case of dynamic merge control, expanding the entrance or exit capacity of a ramp from a single lane to dual lanes. Typically, the concept is applied at entrance ramps or merge points where there are fewer downstream lanes than upstream lanes. The typical application to this geometric condition would be a lane drop for one of the outside lanes or a forced merge of two lanes, both of which are static treatments. This application may be appropriate at critical locations (such as the NW 79th Street and NW 103rd Street interchanges on I-95 NB) to provide temporary relief at unreliable system connections.

Variable speed limit, dynamic lane assignment, and dynamic merge control are best modeled using microscopic simulation analyses; however, L08 tools can be used to assess some aspects such as hard-shoulder running and possibly dynamic merge lanes. Current research by a team from North Carolina State University and FIU is working on modifying FREEVAL to model variable speed limits at the macroscopic level.

6.2.3.2 Express Lanes Operations

EL operations have been operational along I-95 NB in Miami since December 2008 and are being expanded north along I-95 to Broward Boulevard in Broward County. Within the next few years, ELs will also be constructed along SR-826 and I-75 in forming a regional EL network. Travel time reliability is an important performance measure for ELs with the FHWA policy of maintaining average peak period travel speeds at 45 mph or higher in these lanes. As the EL network grows, optimizing systemwide reliable VMT on the ELs and GPLs may be used as a performance metric.

As the EL network expands, travel time reliability should be monitored on a link-by-link basis, as should the interfacing nodes providing system connectivity. Monitoring would enable TMC operators to detect unreliable links and segments along the network to take appropriate actions. The same concept could also be applied to access and egress points of the ELs. Such actions may include, for example, adjusting dynamic pricing to reduce the flow of traffic into congested links and nodes; using lane control systems to open up needed capacity in the access–egress lane within critical weaving segments; assessing changed policies (e.g., HOV 3+ only) during critical periods; and justifying flyover improvements at critical access–egress points. In these cases, it would be useful to have flexibility in applying reliability in a predictive, real-time (i.e., five-minute increments), and forecasting mode to address all mitigation strategies.

The I-95 EL analysis presented in the previous section indicated that the ELs are unreliable in the SB direction in the AM peak and in the NB direction in the PM peak, although for a shorter period compared to the unreliability period of the GPLs. Part of this unreliability is due to the high demand during the no-event periods. Therefore, more aggressive and potentially a more advanced predictive pricing strategy should be implemented to predict unreliability conditions and implement higher prices to reduce demands on the EL. However, a large proportion of unreliability is due to the severe impacts of individual incidents due to the geometry constraints of the EL. This issue will be discussed in more detail in the incident management section below.

Managed lane strategies can be tested using the managed lane version of FREEVAL (FREEVAL-ML). However, advanced pricing strategy impacts on driver behavior can best be tested using dynamic traffic assignment combined with mesoscopic or microscopic simulation models.

6.2.3.3 Ramp Signaling Operations

District 6 began operating ramp signaling along I-95 in early 2009. Ramp signals operate at 22 on-ramps during the AM and PM peak periods by using an adaptive ramp-metering system based on a fuzzy logic algorithm updated every 20 seconds. Ramp signaling will be extended along I-95 north to Broward and Palm Beach Counties and along SR-826 within the next few years.

As the ramp signaling system expands, travel time reliability should be monitored to detect unreliable links to address traffic congestion during off-peak periods, as well as traditional AM and PM peak periods. This additional monitoring may be necessary to accommodate recurring congestion that has extended to the shoulders of peak periods; to be used as an operational tool as part of incident, special event, or emergency management strategies; or to better integrate with arterial operations, particularly with traffic signals adjacent to ramp termini.

In addition, unreliable segments of the system network may be analyzed to determine special ramp signal timing plans that would override the existing real-time traffic condition–based algorithm. These special ramp signal timing plans are based on historic and predictive information for various operational scenarios (e.g., heavy rains, queuing, incidents).

The analysis of the I-95 facility indicated the need for more restrictive ramp metering. In addition, ramp metering may need to start earlier than the current starting time at 3:30 p.m. in the peak period to prevent traffic breakdown. Ramp metering should also be activated when reliability is affected by lane-blocking incidents, incident plus rain conditions, and moderate-to-heavy rains, as identified in Chapter 3. After confirming with the TMC staff, it was found that the current I-95 ramp signals are activated during incidents and special events when necessary.

Ramp metering is best assessed using microscopic simulation, although macroscopic modeling such as FREEVAL can also be used for a high level of analysis. The research being conducted by North Carolina State University and FIU is exploring extending FREEVAL to better model ramp metering.

6.2.3.4 Incident Management

As stated in Chapter 2, advanced traffic management strategies have already been implemented for the limited-access facilities in Miami. Travel time reliability analysis results should be considered as part of incident management strategies to assess and implement actions to speed up the recovery of delays and queuing due to lane blockages. The analysis in Chapter 3 indicated the need for even more strategies, including staging additional incident management assets (e.g., Road Rangers, incident response vehicles, tow trucks) at strategic locations exhibiting unreliability during certain time frames (e.g., heavy rains during PM peak periods); modifying Road Ranger patrol beats to focus on unreliable segments of the roadway network; applying portable visual screens and incident investigation sites; and using lane control systems, managed lanes, variable speed displays, and ramp signaling to manage incidents more efficiently. Certain periods of times and locations with high incident frequencies, incident severities, and incident impact levels should be analyzed to determine and address the causes. For example, the analysis on I-95 indicated that the number of crashes was higher during the after-PM peak; the SB direction had more crashes than the NB direction, particularly in the AM and midday periods; and the impact of a single incident event on an EL was much higher than a single event on a GPL in the peak periods. In addition, rain combined with incidents more than doubled the incident impacts.

Incident management strategies could be assessed in measuring travel time reliability based on software tools that estimate the impacts of queue accumulation and dissipation for lane-blocking events with various durations. L08 and L07 products could be used for assessing the benefits of incident management strategies if the impacts of these strategies on incident and/or lane blockage durations, capacity drops, and incident frequency can be estimated.

6.2.3.5 Work Zone Management

Travel time reliability is particularly important during construction and maintenance operations. In certain cases, contractors are eligible for performance incentives based on maintaining open lanes and 45 mph minimum operating speeds through construction work zones. Contractors should be encouraged to develop and implement their maintenance of traffic (MOT) plans by using fixed and portable ITS assets to maintain reliability upstream, through, and downstream of work zones. These =MOT plans should assess the reliability of the affected areas by using appropriate microsimulation and predictive tools. Several work zone management strategies can be assessed using L07 and L08 tools. Others require more advanced dynamic traffic assignment tools and/or microscopic simulation.

6.2.3.6 Traveler Information

Travel time reliability may begin to be applied as part of a suite of traveler information tools. An objective in providing reliability information to travelers is to provide them sufficient information to encourage change in their travel behavior. It is critical for reliability information to be simple and easy to understand and to provide added value to the traveler as compared to traditional travel time and congestion data. Possible strategies to consider include adding travel time (or buffer) indexes to 511, highway advisory radio, websites, and smart phone apps;

providing color-coded travel times on DMSs that correlate to different reliability levels (this strategy would require a *Manual on Uniform Traffic Control Devices* amendment and FHWA approval); or providing comparative reliability indexes for alternative routes, modes, and travel times.

TMCs currently provide CCTV video images to local television news stations. Travel time reliability could be provided, as well. Most local news stations have a traffic reporter who provides updates on current traffic conditions and locations of accidents. Travel time reliability could be used similar to a weather forecast. Current reliability conditions could be provided, eventually leading to reliability forecasts.

6.2.3.7 Traffic Engineering

Travel time reliability is an important performance measure in identifying operational problem locations, time frames, and causes and also in analyzing the impacts of alternative traffic operations and safety improvements. If the traffic engineer were situated at the TMC, the CCTV camera images and detection and reliability information would be available for conducting a more comprehensive traffic analysis, as well as before and after studies. Such improvements may address a wide range of deficiencies, including the interaction of capacity and safety, substandard weaving and merging areas, signal system problems, queuing, sight distance restrictions, railroad grade crossing issues, substandard lighting, unsafe curve speeds, and so on.

6.2.3.8 Arterial Operations

Travel time reliability may be a useful performance measure for improving arterial operations. This performance measure would help traffic engineers better identify and prioritize signal timing, as well as equipment and communications repairs based on abnormalities in system performance. Travel time reliability data could be generated by traditional detector data, as well as other sources. Travel time reliability for each roadway segment can be provided by any interval (e.g., five minutes, 15 minutes) traffic engineers desire. In addition, Miami-Dade County has plans to install approximately 200 CCTV cameras to monitor traffic conditions along the arterials, which will enable operations staff to be more proactive in addressing recurring and nonrecurring congestion. Offline or online signal timing strategies that are responsive to unreliability conditions could provide significant benefits.

STREETVAL can be used to assess several arterial improvement strategies, including incident management strategies; however, traffic-responsive and advanced traffic management strategies cannot be evaluated using this tool.

6.2.3.9 Summary

Travel time reliability provides another performance measure for improving situational awareness for operations staff at TMCs. TMC staff may monitor the system network to identify where and when certain segments are operating unreliably and apply appropriate traffic management strategies. Geographic information system–based maps may be posted on the video walls and/or operator workstations as a tool for monitoring the system network, including travel time reliability. Other strategies were considered, such as hard-shoulder running; however, this practice was not considered feasible due to the lack of adequate shoulders within restricted rights-of-way and the frequency of on-ramp conflict points along the facility.

6.3 SR-7 Corridor Improvement Alternatives

As stated in Chapter 2, the SR-7 corridor study is an ongoing effort. The study has identified improvement alternatives to address various performance issues related to different objectives. These objectives are sometime in conflict with each other. The alternatives may have positive or negative impacts on reliability. The research team is currently working with the Florida DOT and project consultant to finalize the improvement alternatives. Once these alternatives are finalized, they will be evaluated using STREETVAL by the research team to complement the VISSIM analysis conducted by the study consultant.

6.4 I-95 Implementation Plan

As mentioned in Chapter 2, the I-95 implementation plan is expected to start shortly to identify capacity and TSM&O-type improvements of the corridor. The research team is coordinating with the Florida DOT and their consultants to communicate the L38C study results and determine how they can be used as part of the project.

6.5 Integrated Corridor Management

It is recommended that the advanced strategies applied to different modes and facility types begin to be combined in developing an integrated corridor management (ICM) system within the I-95/SR-7/SR-826 facilities in Miami-Dade County. These strategies should then be expanded to cover the tricounty region (i.e., Miami-Dade, Broward, and Palm Beach Counties). The ICM system should include travel time reliability as a performance metric in achieving the following functionality (FHWA 2008) as an extension of ITSDCAP and IRISDS:

1. *Establish and manage a data warehouse.* A configuration data warehouse would maintain information on various parameters within the ICM corridor.
2. *Collect and process data.* This core service supports most of the system functionality. Data are collected from a variety of existing and planned systems according to interface control documents, some of which need to be developed as new systems come online. Once data are collected, certain processing algorithms are invoked that provide a higher level of information aggregation (e.g., volumes, occupancies, and speeds at multiple locations converted to travel time reliability).
3. *Collect ICM historical information.* A historical database should be created and populated with real-time information on corridor performance. Having consistent export formats for data from these historical databases would simplify corridorwide analysis. Ad hoc reporting based on this historical data would allow system users to create a variety of reports that characterize corridor operations and performance. These reports could then be stored in the historical database.

4. *Publish information to system managers.* ICM data from all sources should be disseminated to agencies that manage one or more modes in the integrated corridor network.
5. *Interactively conference with multiple agencies.* System managers would directly collaborate in real time before, during, or after a major event in the ICM corridor. A variety of voice, video, and data formats would be supported for multisite collaboration.
6. *Display information.* Information produced by the ICM and its subsystems would be displayed in a variety of data formats that agency decision makers could use to visualize corridor operations, make decisions, and take actions to implement the various decision components.
7. *Coordinate transportation and public safety operations.* Public safety users should be provided the multidimensional data inherent in transportation management systems, while at the same time seeking technical solutions to extracting useful incident information from public safety CAD systems.
8. *Share control of devices.* Shared control would allow agencies to remotely control selected functions of field devices regardless of location or agency ownership. Interagency agreements are required to allow such sharing under carefully defined conditions.
9. *Manage video imagery.* The southeast Florida region has a variety of video sources that provide a critical view of emerging and ongoing events. These video sources can produce aerial, snapshot, archived clips, and real-time imagery to a wide variety of system users via high-bandwidth links.
10. *Respond to corridor planned and unplanned events.* Response capability would allow ICM stakeholders to use some form of decision tool (e.g., expert system or table driven) that fuses real-time data and manually entered data derived from field communications at the event site (e.g., FHP officers talking to dispatchers using the FHP radio system). The response plan would be manually or automatically generated based on the fused data input. Once a response plan was generated, the system operator could review the plan's components and make changes as deemed necessary before transmitting plan components to the affected systems. The status of affected systems would then be returned to the TMC operator and logged in the historical database.
11. *Assess impact of corridor management strategies.* Impact assessment would allow stakeholders to model various traffic and service management strategies for the corridor to gauge the impact of these strategies on corridor performance. The intent is to model strategies and to return results within a time frame suitable to affect decision making during a major event in the corridor. Strategic modeling would also be invoked for longer-term assessments.
12. *Publish information to system users.* Corridor information should be provided to the regional 511 system, where it will be further disseminated to various classes of system users across a variety of media. A standard XML data stream and video imagery to other entities for dissemination to system users would be available.

13. *Measure corridor performance.* Multimodal corridor data from both a short-term and long-term perspective would be viewed. Existing historical databases would provide mode-specific data. Based on these data sources, corridor demand would be analyzed using actual data or by demand modeling techniques. By using stored corridor configuration data, excess corridor capacity could be measured for any desired time period. This ability would be most valuable for long-term corridor management.
14. *Manage corridor demand and capacity to optimize long-term performance.* Users would be able to collaboratively develop longer-term corridor management strategies, including both capacity and demand management strategies (e.g., ELs, ramp metering). The goal is to increase total corridor performance in the long term by optimally balancing capacity and demand.
15. *Measure system performance.* Constant monitoring of field devices, server systems, and communications networks would be conducted to support the various ICM functions. Based on monitored data, metrics for system components such as reliability and availability would be measured and stored in the ICM historical database.
16. *Manage the ICM system.* The administrative function of ICM would include data management for ICM configuration data, user account management incorporating systemwide security functions, and IT-centric functions such as data backup and archival.
17. *Document system and train system users and maintainers.* Documentation and training would provide logistical support to the ICM.

6.6 Example Assessments of Alternatives Using FREEVAL-RL

6.6.1 Incident Management

As mentioned in Chapter 2, TMCs in Florida maintain detailed incident management archives in Oracle database files. The incident archives include incident time stamps (detection, notification, responses, arrivals, and departures), incident ID, responding agencies, event details, chronicle of the event, and environmental information for all incidents on the managed corridors. In addition to the incident archives, a statewide data archive has been developed for the collection and use of ITS data in Florida. The data archive contains summaries of traffic volumes, speeds, and occupancies collected from point traffic detectors in five-minute, 15-minute, and one-hour aggregation intervals as requested by the user.

The FREEVAL model with the calibrated traffic flow model was used to assess the impacts of incidents. Table 6.1 and Table 6.2 show the variation in mobility and reliability of the selected facility based on the model runs, with existing incident statistics and when no incident was assumed to have occurred in the facility. As can be seen in these tables, incidents contributed significantly to the reliability of the facility, especially when measured in terms of the misery index and the 95th percentile TTI. For example, the 95th percentile TTI was 1.17 without incidents and 2.12 with incidents. These findings indicate that with incidents, motorists have to budget 2.12 times the free-flow travel time to ensure that they reach their destination on or before time 95% of the time. If no incidents happened on the facility, then motorists would have to budget only 1.17 of the free-flow travel time to reach their destinations on time 95% of the time.

Table 6.1. Impacts of Incidents on I-95 NB Facility Reliability

Performance Measure	I-95 with No Incident	I-95 with Incident (Option C Coding)
Mean TTI	1.13	1.33
50th Percentile TTI	1.13	1.14
80th Percentile TTI	1.14	1.28
95th Percentile TTI	1.17	2.12
Misery Index	1.26	3.84
Average Travel Time per Vehicle (min)	6.50	7.76
Space Mean Speed (mph)	52.98	50.46

Table 6.2. Impacts of Incidents on I-95 SB Facility Reliability

Performance Measure	I-95 with No Incident	I-95 with Incident (Option C Coding)
Mean TTI	1.11	1.68
50th Percentile TTI	1.11	1.13
80th Percentile TTI	1.13	1.87
95th Percentile TTI	1.15	3.86
Misery Index	1.20	6.75
Average Travel Time per Vehicle (min)	6.23	10.95
Space Mean Speed (mph)	54.26	45.73

An advanced incident managed program has been applied for the facility. The reliability with existing incident statistics accounts for the benefits of this incident management system in reducing incident duration. Previous studies have shown that the implementation of an incident management program can reduce incident duration by 27% for non-lane-blocking incidents and 22% for lane-blocking incidents (Hadi et al. 2010). To assess the benefits of incident management on reliability, the coded incident durations for the I-95 facility were increased by 27% and 22% for non-lane-blocking and lane-blocking incidents, respectively, to allow the estimation of reliability without incident management. Table 6.3 and Table 6.4 show the results of analysis. It is seen from these two tables that the main effect of incident management was on the 95th percentile TTI and the misery index. The results in Table 6.3 and Table 6.4 are provided for instances when (1) the incident information was input as an incident rate (Option B) and (2) the input was the proportion of time with an incident (Option C).

Table 6.3. Impacts of Incident Management on I-95 NB Facility Reliability

Performance Measure	Local Incident Rate and Existing Duration (Option B)	Local Incident Rate and Increased Duration (Option B)	Existing Incident Time (Option C)	Increased Incident Duration (Option C)
Mean TTI	1.17	1.19	1.33	1.36
50th Percentile TTI	1.13	1.13	1.14	1.14
80th Percentile TTI	1.15	1.15	1.28	1.28
95th Percentile TTI	1.21	1.31	2.12	2.85
Misery Index	1.83	2.22	3.84	4.22
Average Travel Time per Vehicle (min)	6.77	6.83	7.76	8.65
Space Mean Speed (mph)	52.21	50.86	50.46	48.16

Table 6.4. Impacts of Incident Management on I-95 SB Facility Reliability

Performance Measure	Local Incident Rate and Existing Duration (Option B)	Local Incident Rate and Increased Duration (Option B)	Existing Incident Time (Option C)	Increased Incident Duration (Option C)
Mean TTI	1.37	1.44	1.68	1.77
50th Percentile TTI	1.12	1.12	1.13	1.13
80th Percentile TTI	1.15	1.17	1.87	2.03
95th Percentile TTI	2.67	2.96	3.86	4.24
Misery Index	4.87	5.56	6.75	7.73
Average Travel Time per Vehicle (min)	8.52	9.32	10.95	11.98
Space Mean Speed (mph)	50.14	49.26	45.73	44.88

The impacts of incident management presented in Tables 6.3 and 6.4 are for the existing incident management systems. Additional assessment was made of two geometric design features that were among those included in the L07 project list of features that can address nonrecurrent congestion. These two features, incident screens and crash investigation sites, were considered as potential I-95 improvements based on discussion with TMC staff. Two methods were used in assessing the benefits: (1) the two features were assumed to reduce the incident duration by a certain percentage, which is a similar approach to that of the L07 evaluation of these improvements; and (2) the drop in capacity due to incidents was reduced by a certain percentage, which is possibly a better approach as the main impacts of the incident screen and incident investigation site improvements are to reduce the rubbernecking that results in additional incident-related capacity drops. Table 6.5 shows the results of using these two analysis approaches. The results in Table 6.5 indicate that in general, travel time reliability for the I-95 NB study facility was slightly improved with the implementation of these two strategies. However, the average travel time increased when the incident duration was decreased. This issue is being investigated.

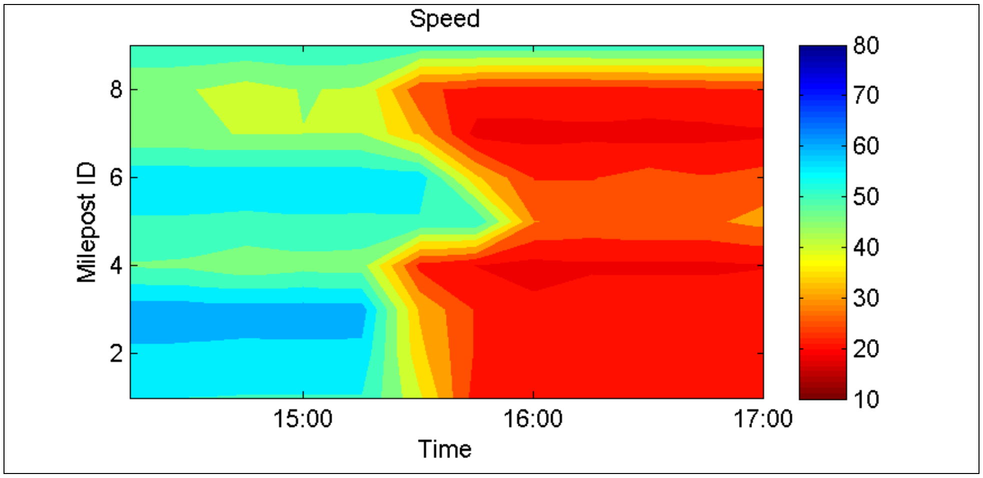
Table 6.5. Impacts of Incident Screen and Crash Investigation Site on I-95 NB Facility Reliability

Performance Measure	Option C but Implementing Both Improvements (Lane Block Duration Decreased by 20%)	Option C but Implementing One Improvement (Capacity Drop Decreased by 5%)	Existing Incident Time (Option C)
Mean TTI	1.32	1.27	1.33
50th Percentile TTI	1.14	1.14	1.14
80th Percentile TTI	1.28	1.28	1.28
95th Percentile TTI	2.10	1.68	2.12
Misery Index	3.78	2.96	3.84
Average Travel Time per Vehicle (min)	8.45	7.63	7.76
Space Mean Speed (mph)	49.01	49.70	50.46

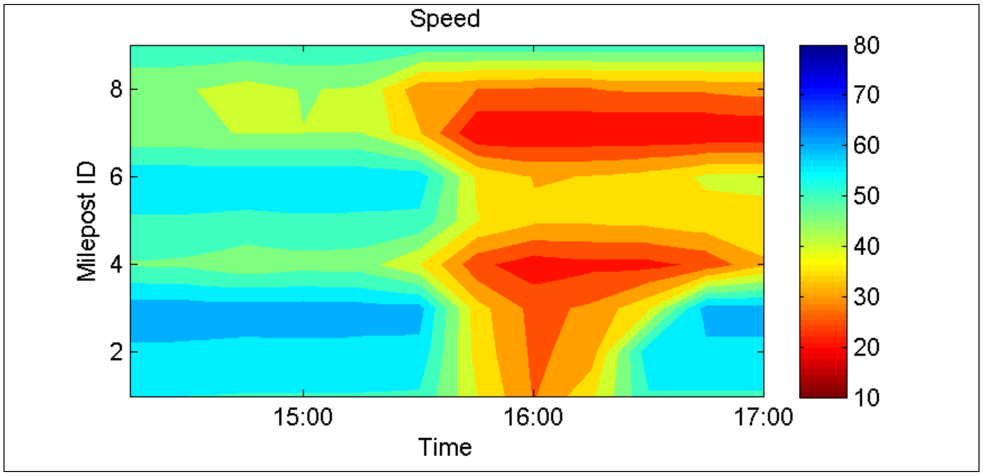
6.6.2 Ramp Metering

An adaptive ramp-metering system based on a fuzzy logic ramp-metering algorithm was implemented for the tested facility segment. In order to calibrate the model correctly based on existing conditions, it was necessary to replicate the ramp-metering operations as closely as possible. FREEVAL does not allow the modeling of adaptive ramp-metering control. However, it allows the modeling of time-of-day ramp metering based on metering rates specified for each time interval. In this study, the rates produced by the fuzzy logic adaptive control were estimated based on real-world data. The results presented in this section were based on runs assuming these average rates.

In order to determine the impact of this type of ramp metering on the analysis results, the coded ramp metering was removed from the analysis. Figure 6.1 and Figure 6.2 show the speed contour maps with and without ramp metering. It is noted that without ramp metering, the congestion became more severe. Table 6.6 and Table 6.7 show the average travel time and reliability statistics with and without ramp metering. The results indicated that with the implementation of ramp metering, travel time reliability improved only slightly. For example, the 95th percentile TTI decreased from 3.38 to 3.30, which is only a slight improvement. However, although the metering rates used were based on real-world average values, as described above, the modeled ramp metering was fixed by time of day for each 15-minute interval and did not adapt to traffic as in the real world because FREEVAL does not allow the modeling of adaptive ramp metering. The benefits of a real-world adaptive metering rate are expected to be higher than time-of-day ramp metering. Another important consideration is that based on discussion with the FREEVAL tool developer, the current version is too restrictive in allowing on-ramp traffic to enter the freeway in capacity-constrained conditions. This restriction may affect the impact of on-ramp traffic and thus reduce the assessed benefits of ramp metering. The tool developer is currently addressing this issue.

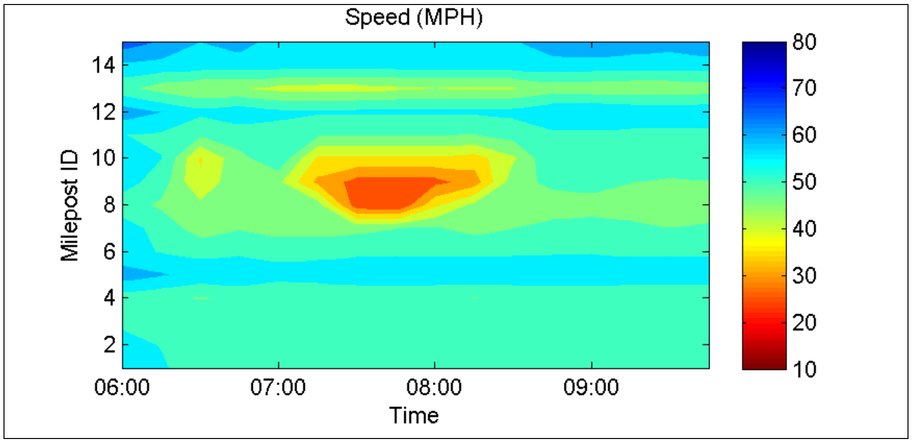


(a)

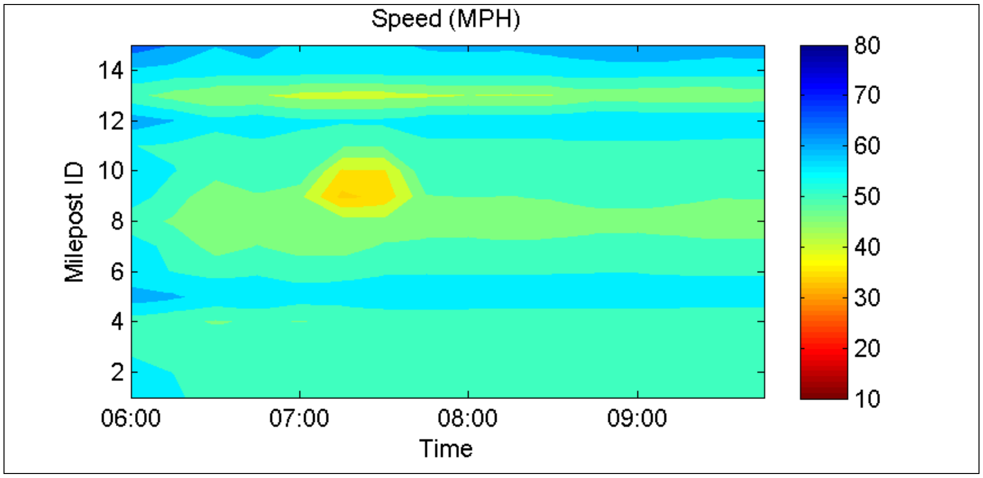


(b)

Figure 6.1. Speed contour map (a) without and (b) with ramp-metering cases in FREEVAL for I-95 NB.



(a)



(b)

Figure 6.2. Speed contour map (a) without and (b) with ramp-metering cases in FREEVAL for I-95 SB.

Table 6.6. Impacts of Ramp Metering on I-95 NB Facility Reliability

Measures	I-95 with Ramp Metering	I-95 without Ramp Metering
Mean TTI	1.34	1.37
50th Percentile TTI	1.15	1.15
80th Percentile TTI	1.18	1.20
95th Percentile TTI	3.30	3.38
Misery Index	3.84	3.87
Average Travel Time Per Vehicle (Min)	7.46	7.52
Space Mean Speed (mph)	53.78	53.01

Table 6.7. Impacts of Ramp Metering on I-95 SB Facility Reliability

Performance Measure	I-95 With Ramp Metering	I-95 Without Ramp Metering
Mean TTI	1.58	1.68
50th Percentile TTI	1.13	1.13
80th Percentile TTI	1.41	1.87
95th Percentile TTI	3.54	3.86
Misery Index	6.37	6.75
Average Travel Time per Vehicle (min)	10.33	10.95
Space Mean Speed (mph)	47.22	45.73

6.6.3 Drivable Shoulder

Attempts have been made to determine the impacts of hard-shoulder running on system performance. However, difficulty has been found with the model. Even when the capacity adjustment factor was adjusted using the edit function in FREEVAL-RL, the program produced exactly the same results as it did without the capacity adjustment factor. This issue is being discussed with the FREEVAL developer.

6.7 Example Assessments of Alternatives Using the L07 Spreadsheet

The L07 spreadsheet tool was applied to assess selected strategies. Due to the limitation of types of treatments that can be evaluated by the L07 tool, only the following strategies were assessed in this study:

- *Portable incident screens*, which are portable screening devices placed around an incident to restrict motorists' view of the incident and reduce congestion caused by rubbernecking.
- *Crash investigation sites*, which are provided near highways to allow moving vehicles from the crash site to a safer area where crash investigations can be conducted.
- *Emergency crossover*, which is a median opening for crossing by emergency, law enforcement, maintenance, and traffic service vehicles.
- *Drivable shoulders*, which allow vehicles to use the shoulder as a travel lane during certain conditions.

Before conducting the benefit–cost analysis of L07, the default values for incident duration and proportions of each incident type provided by the L07 tool were compared with the local incident data, as these inputs significantly affect the analysis results. Table 6.8 and Table 6.9 show the default values and local values related to incident inputs. Table 6.8 shows that the local incident durations for all incident types and all three studied segments were significantly higher than the default values in the L07 tool. It is interesting to note from Table 6.9 that the average proportion of different incident types for the three segments was close among the different segments.

Table 6.8. Comparison of Default and Local Incident Duration

Duration (min)	Property Damage Only	Minor	Major	Non-Lane-Blocking	Lane-Blocking	Other
Segment 1	58	72	52	64	46	51
Segment 2	58	87	46	64	42	60
Segment 3	52	66	75	56	36	118
Default	28	40	45	26	20	23

Table 6.9. Comparison of Default and Local Proportion of Incidents

Proportion (%)	Crash Incident	Non-Lane-Blocking	Lane-Blocking	Other
Segment 1	19	64	13	4
Segment 2	24	53	9	14
Segment 3	22	37	11	30
Default	22	55	13	10

The benefit–cost analysis was conducted only for the three segments and not for the whole route, as the initial trial showed that the evaluation tool was very sensitive to the number and duration of incidents. If the whole study segment were considered, an extremely high benefit–cost ratio would be obtained due to the large number of incidents, which may bias the assessments. Guidelines should be provided to the analyst regarding the segment length that should be included in the analysis for each improvement type.

Table 6.10 presents the benefit–cost analysis results from the L07 tool. As shown in this table, the benefit–cost ratio was higher when using local average incident duration compared to the default incident duration because the local duration was higher. Segment 3 had the highest benefit–cost ratio value because this segment had the largest number of incidents. It is also seen from this table that only Segment 3 could benefit from the incident screen and drivable shoulder strategies. Incident investigation site and emergency crossover can produce significant benefits based on the L07 analysis results for all segments. When local incident duration and incident proportions were applied, the benefit–cost ratios for Segment 3 produced by the L07 tool were extremely high.

Table 6.10. Benefit–Cost Ratio for Different Treatments

Segment	Scenario	Incident Screen	Incident Investigation Site	Emergency Pull-Off	Emergency Crossover	Drivable Shoulder
Segment 1	Default Duration and Default Proportion	0.57	1.15	5.35	5.27	0.15
	Local Duration and Default Proportion	0.74	17.90	61.52	5.45	0.16
	Default Duration and Local Proportion	0.57	1.10	5.14	5.27	0.15
	Local Duration and Local Proportion	0.48	18.58	61.25	5.44	0.16
Segment 2	Default Duration and Default Proportion	1.06	1.60	7.45	12.58	0.41
	Local Duration and Default Proportion	1.34	25.76	90.76	13.10	0.45
	Default Duration and Local Proportion	1.05	1.63	7.60	12.55	0.41
	Local Duration and Local Proportion	1.15	71.18	274.45	20.23	0.44
Segment 3	Default Duration and Default Proportion	5.9	30.66	142.7	163.25	3.45
	Local Duration and Default Proportion	15.73	707.57	2,667.86	241.07	5.02
	Default Duration and Local Proportion	6.66	41.68	193.96	185.37	3.66
	Local Duration and Local Proportion	24.58	1,467.36	6,023.80	378.14	7.42

CHAPTER 7
Usability and Acceptability of the Products

7.1 Introduction

This chapter presents observations concerning the usefulness of the products tested in the L38C project, a look at the issues identified by the research team related to those products, and a review of the level of understanding and acceptance by the stakeholders involved in the project.

7.2 Research Team Observations

7.2.1 L02 Products

The new procedures, measures, and visualization techniques identified in the L02 project can be used as a powerful component of performance assessment and management. A number of issues identified by the research team have the capacity to improve the usefulness of the L02 product, as described below:

- The L02 project focused on specific performance measures, including travel time rates and semivariance. L05 and L08 recommended using combinations of performance measures to assess reliability. The Florida DOT central planning office identified specific preferred performance measures. In the L38C project implementation, multiple performance measures were estimated and visualized to determine the issues on the facility. Additional visualization techniques were also used in the L38C project to support the implementation.
- It was found that the analysis by time-of-day period was preferred to that based on congestion levels to allow separating different congestion patterns and associated causes as much as possible.
- For operations and planning for operations purposes, analysis based on five-minute intervals was necessary to identify the exact times during which the system became unreliable to recommend the activation of advanced strategies.
- The analysis was time consuming and requires knowledge and experience in transportation system analysis and advanced strategies. It is recommended that a data extraction and fusion tool be used to support the analysis. In addition, automation of the analysis is recommended as much as possible.
- Overlapping conditions such as incident plus rain, incident plus construction, and construction plus rain should be considered. Incident plus rain conditions were analyzed in the L38C project.
- For operational purposes, the analysis of reliability impacts by incident severity and rain intensity as done in this study is desirable.
- As in the L38C implementations, the analysis should report both the total contribution of a certain event type to unreliability and the contribution of a single event to unreliability.

Both are important to planning and operations agencies. For example, incident plus rain events may have less frequency, and their contributions to overall reliability are small. However, a single incident plus rain condition has the highest impact on traffic.

- Additional guidelines are needed regarding the aggregation of time intervals and the segmentation of highway facility based on the analysis scope. These guidelines may be location and scope specific.
- A planning tool is needed to support agency decisions on the locations for additional data collection technologies to support reliability analysis, particularly for arterial streets, where installing such equipment on a large scale can be expensive.
- The lingering effects of incident and weather events after the end of the events were not considered in this guide. These effects can be included in the analysis; however, some guidance is necessary.
- The effects of downstream incidents were not considered in the guide or analysis.
- The production of a high-level user guide may be useful to support agencies in their analysis.

7.2.2 L08 Freeway Facility Products

L08 freeway products and the FREEVAL-RL tool can provide a strong platform for assessing the benefits of capacity improvements and incident management benefits for freeway facilities. The following issues related to these products were identified by the research team:

- Traffic modeling using L08 tools should be calibrated to reflect observed operations. The calibration of the model required much less effort than that provided by calibration microscopic simulation models; however, the calibration required detailed data from multiple systems.
- Updating scenario generator parameters based on local data produced reliability measurement values that were closer to real-world values.
- FREEVAL-RL has a limited ability to assess active traffic and demand management strategies, such as variable speed limit, lane control, managed lanes, and ramp metering. Ongoing and previous related research and development results should be incorporated in the model.
- Diversion during incidents was not modeled in FREEVAL-RL.
- The scenario exclusion threshold affected the TTI values significantly. Better guidance is necessary regarding these values.
- The calculation of reliability measures should be by time interval (e.g., 15 minutes) and by highway segment (or a subset of highway segments).
- When evaluating alternative strategies by modifying certain parameters, such as incident duration and capacity adjustment factor, unexpected results were obtained in some cases. This issue is being discussed with the developer.
- Based on discussion with the FREEVAL developers, the tool is being revised to allow more realistic release of ramp demands during congested conditions. This revision should

improve the modeling of the impacts of ramp metering; the current version seems to underestimate these benefits.

- The tool should output additional TTIs, such as the 90th and 85th percentile TTIs.
- It is recommended that the tool should allow the user to specify different incident rates and attributes for different time intervals.
- Additional minor issues regarding the tool were found. For example, the ramp-metering button could not be edited after the seed file was created, and when using small percentiles to exclude scenarios, unrealistic results occurred (e.g., average travel time = 65535).

7.2.3 L08 Urban Street Facility Products

In general, L08 STREETVAL-RL has good documentation and can reasonably model urban street reliability. Below is a list of findings and recommendations for L08 STREETVAL and STREETVAL-RL:

- STREETVAL and STREETVAL-RL can simulate at most only eight segments.
- Some input options had restrictive values or ranges in STREETVAL and STREETVAL-RL. For example, intersection width was limited to a range of 25 to 150 feet in STREETVAL, but one intersection in the study area had a width of 162 feet. The length of the stop line detector was limited to 1, 20, 40, 60, and 80 feet; however, the stop line detector had a length of 30 feet in this study. The input of saturation flow rate in STREETVAL was limited to 1,600 to 2,000 vehicles per lane, but for certain turning movements, even after the adjustment of left- and right-turn factors, the adjusted saturation flow rate was still less than 1,600 vehicles per lane. In STREETVAL-RL, the parameter inches of snow for one inch of precipitation required a value greater than zero; however, in states such as Florida, it has a value of zero.
- There were no input options in STREETVAL for lane width, truck percentage, pedestrian counts, and so forth. To obtain the adjusted saturation flow rate, signalized intersections had to be coded in other software such as Highway Capacity software, which took almost the same time and effort as coding a STREETVAL model. Therefore, the suggestion is made to include those influential factors as input in the STREETVAL model so that the model has the ability to directly calculate the adjusted saturation flow rate.
- Data from only one analysis period at a time could be input in the STREETVAL data set. An input of multiple time periods may better take into account the demand variation and also signal timing plan change among different time periods, for example, input at 15-minute intervals.
- Even when two equal nonintegers were input for phase split, due to computer accuracy, a very small difference may have existed between these two numbers. For example, for a number of 10^{-15}, STREETVAL would report an advisory error message indicating that these two phases had an unequal phase split.

- The button size in STREETVAL-RL was not fixed, and the buttons may be enlarged after one or two runs.
- The input of segment crash and work zone data was not differentiated between directions. Directional input of NB–SB and EB–WB information may better capture the impacts of incident and construction on travel time reliability.
- Although the L08 project developed an elegant methodology to take into account incident type, lane blockage, and corresponding weather conditions, for most of applications, it is extremely difficult to get such detailed crash and incident information on arterials.
- A threshold similar to the one used in FREEVAL-RL could be applied in STREETVAL-RL to cut off the extreme scenarios.
- Better guidance and documentation are needed for handling the error code reported during the run time of STREETVAL-RL.
- It took several hours to run one STREETVAL-RL case study. When there was any error with one of scenarios, all the scenarios had to be rerun, which took another several hours. If the program could resume the calculation starting from the scenario with the error, it would save a lot of time.
- Performance output of STREETVAL-RL only reported the various travel time values, not the travel time reliability index. Instead of outputting performance for each segment separately, it is suggested to output all the segments' performance at the same time for the purpose of comparison.

7.2.4 L07 Products

The L07 spreadsheet can be adapted for use in analyzing improvement alternatives. The research team made the following observations:

- The output from the tool should be saved to tables in addition to being displayed in graphs.
- The tool should allow more flexibility in the input parameters, such as allowing the user to input adjustment factors for capacity.
- There is a need for future work on creating a similar sketch-planning tool for arterial streets.
- Guidance is needed for setting spatial limits for evaluating the impacts of improvement alternatives, because these limits will significantly influence the estimated benefits. These recommendations should take into consideration the areas of influence of the specific improvement alternatives under evaluation. There is a need to extend the tool to include additional strategies normally considered by agencies and a need to provide guidance or allow the user to assess time-dependent management strategies.
- It was found that the default reliability models may not be applicable for all segment lengths and that they produced different accuracies depending on segment lengths. This issue needs to be investigated further.

- Additional issues with the user interface included the following: the geometry inputs could not be saved, the subtotal for noncrash incidents did not change when input changed, incident data could not be saved, and the interface did not fit on all computers.

7.2.5 L05 Products

The L05 products were helpful in setting the evaluation and implementation plan for the project and in stakeholder involvement during the project. A useful aspect of the L05 project was the guidance provided regarding how to identify tools, performance measures, thresholds and deficiencies, and the visualization of performance. The general guidelines regarding identifying the agency business processes were also helpful.

7.3 Understandability and Acceptability by Stakeholders

Stakeholder workshops were conducted at the beginning (June 20, 2013) and end (May 21, 2014) of the project. The purpose of these workshops was to share the objectives and results of *Pilot Testing of SHRP 2 Reliability Data and Analytical Products* with project stakeholders. A summary of the interactive discussions with the stakeholders at the May 21, 2014, workshop is presented below.

SHRP 2 products can be used for a diverse range of planning and operations applications. The planning applications include development of TIPs, LRTPs, TSM&O plans, corridor studies, and PD&E studies. The operations applications include arterial operations, freeway and toll road operations, transit operations, and freight operations. Reliability reporting should be coordinated with statewide efforts for planning and operations.

Automated tools such as the ITSDCAP reliability module will be useful to help implement reliability as additional input to agency business processes. The reliability estimation requires a good understanding of data as it uses an extensive amount of data for reliability calculations. Thus, automated tools are necessary to help in this effort

Although CDF and PDF curves are valuable analytical tools, they may be too difficult to apply for nontechnical users and audiences. Animated or video tools may be useful, as well as other methods to convey the same message to nontechnical audiences (e.g., policy makers). The challenges in conveying the meaning and importance of travel time reliability to nontechnical audiences will be in presenting the information in simple visual graphics or video animations. It was suggested that a common definition be selected from the many possible definitions of travel time reliability (e.g., TTI, buffer index, misery index) and used consistently in presentations to nontechnical audiences.

It will be useful to incorporate travel time reliability into the planning process to better assess capacity improvements versus operations improvements. For planning applications, it was suggested that the reliability tools begin to be applied to corridor studies, then evolve into regional planning applications.

Travel time reliability can be used in qualitatively developing TIP and LRTP goals and objectives, as well as quantitatively as a measure of effectiveness in evaluating improvement projects. The MPO will need to assess this in developing plans. For LRTPs, the CDF and PDF graphs are too detailed and too technical. Simple graphics indicating reliability performance levels are preferred. The more technical outputs of the reliability tools may be more applicable to corridor planning studies than to LRTPs. High-level tools (such as those developed in Projects C11 and L07) can be used to evaluate reliability in long-range plans, as these tools are easy to use.

Reliability can be incorporated into corridor study scope of services and for alternatives analysis and should be used in the ongoing I-95 implementation plan and SR-7 in Miami-Dade County. As part of PD&E studies and alternatives analyses, travel time reliability should be considered as a possible measure of effectiveness in comparing project alternatives in addition to other measures of effectiveness (e.g., costs, right-of-way impacts, delay savings, crash reduction, emission savings, benefit–cost ratio) that are traditionally used.

Travel time reliability performance reports are already being generated by Florida DOT District 6 TMC for all Interstate facilities within Miami-Dade County by direction and by hourly time frames. These monthly reliability reports are archived on their website. District 4 generates monthly reports for the arterial and freeway system, but it does not yet include travel time reliability reports. However, these reports are not used adequately for operations and planning for operations tasks. District 6 is interested in applying travel time reliability as input to developing predictive models and decision support systems to be more proactive in addressing both recurring and nonrecurring congestion. The challenges will be applying travel time reliability to develop accurate predictive models that can provide input to decision support systems. This change may begin with selected applications, such as applying this information to make decisions concerning activating ramp signals earlier than peak periods or adjusting ramp signal release rates.

The Miami-Dade County Traffic Signal agency recognizes that the reliability products can help develop and implement better signal timing plans; however, their constrained staff resources are a concern in applying travel time reliability in their operations. Therefore, automated tools would be needed to make them more useful without creating a burden on their staff.

Reliability is helpful in comparing multimodal alternatives. Miami-Dade Transit is applying travel time reliability as a performance measure for transit signal priority along Kendall Drive. Travel time reliability should also be considered for freight traffic. Freight carriers can use reliability as part of the dynamic routing and dispatching of their truck fleets.

Travel time reliability may be used by the media as part of traffic reports to supplement the real-time camera images they use and the travel time information they report along selected links within the regional highway network. This information may also be used by the private sector in developing smartphone apps to report real-time travel time reliability to supplement the congestion-level information currently being displayed. It may be useful to provide reliability information, as well as speed and travel time information, to travelers.

Although visualization tools (e.g., heat maps) are useful to technical staff, relating reliability data to geography is more important for the public. A time variation of data using video would be useful. Reliability data need to be marketed to help the public understand the concept (e.g., simple color-coded maps indicating the level of travel time reliability as opposed to PDFs). The public may have a different understanding of reliability (e.g., leave early or arrive on time) than traffic analysts and will find PDFs difficult to understand.

It is important to further demonstrate the applicability of reliability in the real world. Its importance needs to be emphasized. More funding is needed to support the integration of reliability as part of the planning and operations processes.

A survey was conducted at the beginning and end of the May 21, 2014, workshop to gauge the level of understanding that the stakeholders had regarding the research. Although the survey was not conducted to provide statistically accurate conclusions, the following inferences may be drawn:

- Most participants were familiar with the concept of travel time reliability.
- Most participants believed, particularly after the completion of the workshop, that travel time reliability can be quantified.
- The participants had not seen travel time reliability used frequently as part of project evaluations.
- The participants had not seen their agencies frequently use travel time reliability in a program or planning application.
- All participants believed that the evaluation of travel time reliability will likely or very likely be used in the future.
- The participants believed that the following planning and study applications of travel time reliability (in order of importance) are the most promising: corridor and multimodal studies; followed by PD&E studies; followed by interchange modification reports and MPO LRTP, TIP, and CMP studies.
- The participants believed that the following operations applications of travel time reliability are equally promising: freeway real-time TMC operations, signal agency center operations, TSM&O applications, planning for operations, and transit and freight operations.
- The participants believed that the following barriers (in order of importance) are most likely to impede an agency’s ability to evaluate travel time reliability: staff and time resources, followed by data availability, resistance to change, staff expertise, and believing that existing methods are adequate.

In summary, the workshops were successful in presenting the objectives and results of the research, providing high-level training, and introducing how the reliability data and analytical products may begin to be integrated within transportation planning and operations business processes. Positive feedback was provided by the stakeholders.

7.4 Next Steps

Pilot Testing of SHRP 2 Reliability Data and Analytical Products: Florida Pilot Site provides a foundation for beginning to integrate travel time reliability into the planning and operations business processes. Rolling out of the implementation should consider the following steps:

- *High-level training.* High-level training should be conducted among the various agency stakeholders to bring everyone up to the same level of understanding regarding the reliability tools. In essence, such training would be an extension of the preliminary training provided at the stakeholder workshops.
- *Guidelines.* The L05 guidelines and possibly additional guidelines should be communicated to stakeholders for each planning and operations process. The communicated guidelines would address using reliability in the development of short- and long-range transportation plans, transportation systems management and operations planning, and corridor and PD&E studies. For operations, reliability should be addressed in developing performance management systems and amending standard operating guidelines for active arterial management, freeway and toll road operations, transit operations, and freight management.
- *Pilot projects.* Specific pilot projects should be identified for each planning and operations process to demonstrate how reliability may be integrated into and used to enhance the process. Pilot projects pertaining to planning may include incorporating reliability qualitatively, as part of goals and objectives for TIPs and LRTP updates, or quantitatively, as a measure of effectiveness in comparing alternatives as part of a corridor or PD&E study. Pilot projects pertaining to operations may include establishing performance measures for reliability on arterial, freeway, toll road, transit, and freight systems, then measuring them in a real-time or predictive manner.
- *Refinement of guidelines.* The L05 and other guidelines developed for each planning and operations process should be refined based on the findings of the pilot projects. This refinement should be part of a continuous improvement process for planning guidelines and standard operating guideline updates.
- *Detailed training.* Detailed training materials should be developed for each planning and operations process based on the refined guidelines. These training materials should be used to conduct training for stakeholder agency staff along with certification testing to ensure that staff comprehend the reliability concepts and analytical tools.
- *Performance management.* Performance management systems, in measuring reliability, should be developed using automated processes to provide timely, useful, and accurate reports while not placing additional burden on technical staff in developing these reports using manual processes. These performance management systems should be integrated as part of updates on websites to transparently share this information with agency stakeholders and the public.
- *Implementation.* Reliability should be integrated into each planning and operations process by using appropriate software tools. Planning tools should be used to support

alternatives analyses, project prioritization, and justification. For operations, predictive models and decision support system applications should be considered to facilitate proactive transportation systems management and operations.

- *Public education and outreach.* A simple reliability definition should be selected, among the many definitions available, and used as part of a public education and outreach effort so that executive, management, and technical staff will understand it as well as the public. In addition, third-party traveler information providers should be contacted to determine if there is an interest in developing smartphone apps or incorporating reliability information as part of media traffic reports.

In summary, the SHRP 2 Reliability Program has made significant investments in developing products to support estimating travel time reliability, identifying reliability deficiencies and contributing factors, identifying alternative solutions, and analyzing the impacts of these solutions. The return on these investments will be realized by integrating reliability in planning and operations processes by using the phased approach described above. These actions will support one of MAP-21's goals in integrating performance estimation, measurement, and management in each state.

REFERENCES

Alvarez, P., and M. Hadi. 2012. Time-Variant Travel Time Distributions and Reliability Metrics and Their Utility in Reliability Assessments. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2315*, Transportation Research Board of the National Academies, Washington, D.C., pp. 81–88.

Bonneson, J. A. 2013. *Urban Street Reliability Engine User Guide*. http://shrp2archive.org/wp-content/uploads/USRE_User_Guide-5.pdf.

Cambridge Systematics. 2013a. *Incorporating Reliability Performance Measures into the Transportation Planning and Programming Processes*. Final report. Transportation Research Board of the National Academies, Washington, D.C.

Cambridge Systematics. 2013b. *Guide to Incorporating Reliability Performance Measures into the Transportation Planning and Programming Processes*. Transportation Research Board of the National Academies, Washington, D.C.

Cambridge Systematics. 2013c. *Guide to Incorporating Reliability Performance Measures into the Transportation Planning and Programming Processes: Technical Reference*. Transportation Research Board of the National Academies, Washington, D.C.

Cambridge Systematics. 2013d. *Analytical Procedures for Determining the Impacts of Reliability Mitigation Strategies*. Report S2-L03-RR-1. Transportation Research Board of the National Academies, Washington, D.C.

Dowling, R., A. Skabardonis, and V. Alexiadis. 2004. *Traffic Analysis Toolbox Volume III: Guidelines for Applying Traffic Microsimulation Modeling Software*. Publication No. FHWA-HRT-04-040. Turner–Fairbank Highway Research Center, McLean, Va.

Elefteriadou, L., and P. Lertworawanich. 2003. Defining, Measuring, and Estimating Freeway Capacity. Presented at 82nd Annual Meeting of the Transportation Research Board, Washington, D.C.

FHWA. 2008. *Concept of Operations for the I-15 Corridor in San Diego, California*. FHWA-JPO-08-009, EDL No. 14395.

FHWA. 2012. *Moving Ahead for Progress in the 21st Century Act (MAP-21): A Summary of Highway Provisions*. Office of Policy and Governmental Affairs, FHWA, Washington, D.C.

FHWA. 2013. MAP-21. http://www.fhwa.dot.gov/map21. Accessed January 2013.

Florida Department of Transportation. 2014a. *Project Development and Environment Manual*. http://www.dot.state.fl.us/emo/pubs/pdeman/pdeman1.shtm. Accessed March 5, 2014.

Florida Department of Transportation. 2014b. TEO/About us. http://www.dot.state.fl.us/trafficoperations/Mission_Vision.shtm. Accessed March 5, 2014.

Florida Department of Transportation. 2014c. TMC Reports. District 6 Intelligent Transportation Systems. Miami. http://www.sunguide.info/sunguide/index.php/tmc_reports. Accessed March 5, 2014.

F. R. Aleman & Associates, Inc. 2008. *NW 7th Avenue (SR-7/US 441) Reversible Lane Control System PD&E Study*.

Hadi, M., Y. Xiao, C. Zhan, and A. Gan. 2010. Use of the HCM Freeway Facility Procedures Combined with ITS Data Archives to Assess the Benefits of Incident Management Systems. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2173,* Transportation Research Board of the National Academies, Washington, D.C., pp. 115–122.

Highway Capacity Manual 2010. 2010. Transportation Research Board of the National Academies, Washington, D.C.

Highway Capacity Manual 2010. 2012. Proposed Chapter 36: Travel Time Reliability. Transportation Research Board of the National Academies, Washington, D.C. http://onlinepubs.trb.org/onlinepubs/shrp2/RFPL38/L08Chapter36.pdf. Accessed March 5, 2014.

Highway Capacity Manual 2010. 2012. Proposed Chapter 37: Travel Time Reliability: Supplemental. Transportation Research Board of the National Academies, Washington, D.C. http://onlinepubs.trb.org/onlinepubs/shrp2/RFPL38/L08Chapter37.pdf. Accessed March 5, 2014.

Institute for Transportation Research and Education. 2012. *Guide to Establishing Monitoring Programs for Travel Time Reliability*. Transportation Research Board of the National Academies, Washington, D.C.

Institute for Transportation Research and Education. 2013. *Establishing Monitoring Programs for Travel Time Reliability*. Transportation Research Board of the National Academies, Washington, D.C.

Jacobs. 2014. *SR-7/US 441/NW 7th Avenue Corridor Study: Existing Conditions*. Prepared for Florida Department of Transportation, District 6, Miami.

Kittelson & Associates, Cambridge Systematics, ITRE, and Texas A&M Research Foundation. 2012. *Incorporation of Travel Time Reliability into the HCM*. Unpublished report. Transportation Research Board of the National Academies, Washington, D.C.

McLeod, D. S., L. Elefteriadou, and L. Jin. 2012. Travel Time Reliability As a Performance Measure: Applying Florida's Predictive Model to an Entire Freeway System. *ITE Journal,* Vol. 82, No. 11, pp. 43–47.

Miami-Dade County. 2013a. *2013 Title VI Program Update FTA C4702.1B*.

Miami-Dade County. 2013b. *Transit Development Plan, FY 2014 to FY 2023*.

Miami-Dade County Metropolitan Planning Organization. 2014a. *Miami-Dade 2035 Long-Range Transportation Plan*.

Miami-Dade County Metropolitan Planning Organization. 2014b. *Miami-Dade 2040 Long-Range Transportation Plan*.

MRI Global. 2013a. *Draft Design Guide for Addressing Nonrecurrent Congestion*. Unpublished report. Transportation Research Board of the National Academies, Washington, D.C.

MRI Global. 2013b. *Identification and Evaluation of the Cost-Effectiveness of Highway Design Features to Reduce Nonrecurrent Congestion*. Unpublished report. Transportation Research Board of the National Academies, Washington, D.C.

National Climatic Data Center. 2013. http://www.ncdc.noaa.gov/. Accessed May, 1, 2013.

National Transportation Operations Coalition. 2005. *National Transportation Operations Coalition (NTOC) Performance Measurement Initiative: Final Report*. http://www.ite.org/M&O/ntoc_final_report.pdf.

Rouphail, N., B. Schroeder, and B. Eads. 2011. *Freeway Facilities User's Guide to FREEVAL2010*. http://sites.poli.usp.br/d/ptr2377/HCM2010-FREEVAL%20User%20Guide%20Final_02-27-2011.pdf.

Sajjadi, S., S. Aghdashi, N. Rouphail, A. Hajbabaie, and B. J. Schroeder. 2013. *User Guide for the Freeway Reliability Methodology Computational Engine*. http://shrp2archive.org/wp-content/uploads/FREEVAL-RL-UserGuide_03-17-2013.pdf.

Sajjadi, S., B. Schroeder, and N. Rouphail. 2013. Enhancements to the Freeway Facilities Method in the Highway Capacity Manual to Enable Reliability Analysis. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2395*, Transportation Research Board of the National Academies, Washington, D.C., pp. 21–30.

Wikipedia. Decision Support System. No date. http://en.wikipedia.org/wiki/Decision_support_system. Accessed March 15, 2014.

Van Aerde, M., and H. Rakha. 1995. Multivariate Calibration of Single Regime Speed-Flow-Density Relationships. *Proc., 6th Vehicle Navigation and Information Systems Conference*, pp. 334–341.

Zhang, L., and D. Levinson. 2004. Some Properties of Flows at Freeway Bottlenecks. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1883*, Transportation Research Board of the National Academies, Washington, D.C., pp. 122–131.

APPENDIX A
SHRP 2 Project L38C FIRST Stakeholder Workshop

Time: June 20, 2013, 1:00 to 4:00 p.m.
Location: FIU Engineering Center 2300

Table A.1. Names and Affiliations of Participants

Name	Affiliation
Yan Xiao	FIU
Amauris Ramirez	FIU
Tao Wang	FIU
John Zegeer	Kittelson & Associates, Inc.
Girish Thallapragada	HNTB
Girish Kumar	HNTB
Jorge Gomez	HNTB
Bao Wang	Florida DOT District 6
Daniel Smith	Florida DOT District 4
David Moore	Florida DOT District 4
Melissa Ackert	Florida DOT District 4
Alejandro Motta	Florida DOT District 6
Rory Santana	Florida DOT District 6
Bob Edelstein	AECOM
Alexandra Lopez	Florida DOT District 6
Kim Samson	Turnpike/URS
Anita Vandervalk	Cambridge Systematics
Neil Lyn	Florida DOT District 6
Hiram Hernandez	Miami-Dade County Signals
Martha Oliva	Miami-Dade County
Douglas McLeod	Florida DOT C.O.O.
Reena Mathews	TRB
John Easterling	Florida DOT TPK
Douglas Laird	FHWA
Kris Milster	FHWA

Selected comments from workshop participants include the following:

- Rory Santana from Florida DOT District 6 stated that a five-minute aggregation level for data would be better for real-time applications.
- Douglas McLeod from the Florida DOT central office mentioned that two of the seven topics presented in MAP-21 are related to reliability and freight. Reliability can be reported by roadway or roadway network or by trips.
- Melissa Ackert from Florida DOT District 4 shared that GPS and Bluetooth devices are being considered and/or implemented for arterials and for freight.

- Anita Vandervalk from Cambridge Systematics suggested that INRIX data could be used for freight.
- Daniel Smith from Florida DOT District 4 stated that the default segments for District 4 managed lane projects can be used in reliability reporting.
- Daniel Smith said he preferred to use a tool parallel to the Florida DOT SunGuide system to report travel time reliability.
- Melissa Ackert suggested that travel time reliability might be reported within the ATMS.Now software.
- Daniel Smith said he preferred to have a data warehouse that can report all the performance measures, and both Rory Santana and Martha Oliva from Miami-Dade County agreed. Collaboration is needed.
- Melissa Ackert mentioned that the possible applications of travel time reliability are 511, DMS, freight, and truck-parking locations.
- Reena Mathews from TRB suggested contacting L02 developers to see if they have considered the combination of different factors, such as weather and incident.
- Hiram Hernandez from Miami-Dade County Signals talked about their current situations. He mentioned that it would be helpful to have some tools for prioritizing the deployments. Douglas McLeod suggested that one travel time reliability tool developed by the University of Florida might be used for this purpose. However, this tool uses a predictive model and is not accurate in terms of data.
- Melissa Ackert commented that a performance measurement tool for arterials is needed, and a benefit–cost analysis tool for reliability. Anita Vandervalk responded that their company has developed a Florida-specific benefit–cost analysis tool.
- John Easterling from Florida DOT Turnpike suggested using INRIX data or other private-sector data for arterials such as SR-7.
- Rory Santana preferred less-accurate data but with broad coverage.
- People from MPOs will be met by the research team to discuss how to include travel time reliability in LRP.
- Including travel time reliability into LRP or SRP should be a statewide effort, involving districts and MPOs.
- John Zegeer from Kittelson & Associates, Inc. stated that if there is a tool, it should be a visualization tool in order to help MPOs. It should report travel time reliability not only for freeways but also arterials. He also mentioned that personnel in the Kittelson & Associates Inc. are working on a project related to performance measures.
- Bao Wang from the Florida DOT District 6 PD&E study stated that travel time reliability is important for comparing different alternatives, and there is always a trade-off between alternatives.
- Melissa Ackert from made the following points: (1) travel time reliability and livability should be considered; (2) transit reliability should be considered, especially the impacts of TSP on other vehicles; (3) reliability in work zones during construction is also

important; (4) education is needed through MPOs; and (5) reliability should also be included in congestion management.

- Bao Wang stated that for a PD&E study, the output matrix should include the impacts on reliability and safety. The *PD&E Manual* needs to have travel time reliability.
- Bao Wang suggested pilot studies on how to use reliability in PD&E studies. Douglas McLeod mentioned that how to incorporate reliability in PD&E study needs training. Florida DOT has two projects in which they are testing the inclusion of travel time reliability in PD&E corridor studies.
- Martha Oliva stated that we need to learn how to measure output and perform evaluation.
- Rory Santana stated that design criteria standards are needed to show how reliability will be affected.

APPENDIX B

I-95 Northbound Express Lane

B.1 Overall Express Lane Reliability Performance

The reliability of the I-95 NB EL was analyzed using the same performance measures used for GPLs. Figures B.1 to B.5 present an assessment of the overall system performance for the whole day, as well as for different times of the day. The CDF of the travel time rate shown in Figure B.1 indicates the high unreliability of travel during the PM periods. It can be seen that the 95th percentile travel time rate in the PM peak was close to 151 second/mile (average speed of about 24 mph) compared to about 53 second/mile (68 mph) for free-flow conditions, reflecting a 95th percentile TTI of 2.85. The reliability was good in the remaining periods. The percentage of unreliability contribution illustrated in Figure B.2 shows the unreliability in the PM1 and PM2 peaks as measured by the semivariance contributed to 32% and 47%, respectively, of the overall daily unreliability of the NB EL (a combined contribution of 79%). For comparison purposes, Figures B.3, B.4, and B.5 show the values of the 50th, 80th, and 95th percentile travel times and corresponding travel times, speeds, and TTIs, respectively, for different times of day. Between 5:00 and 7:00 p.m., the 50th, 80th, and 95th TTIs were about 1.1, 1.5, and 2.7. Between 3:00 and 5:00 p.m., the 50th, 80th, and 95th percentile values were 1.1, 1.2, and 2.2. These results indicated that the median travel time of the managed lane was good. However, the 95th percentile TTI was relatively high between 3:00 and 7:00 p.m., and the 80th percentile was somewhat high between 5:00 and 7:00 p.m.

Figures B.6 to B.9 show the variation of different performance measures by five-minute intervals for 24 hours. Figure B.6 indicates that the 80th percentile TTI had a shorter peak period of time on the EL compared to the GPL (4:30 to 6:00 p.m. compared to 3:00 to 7:00 p.m.). The maximum 80th percentile TTI value for the EL during the PM peak was also lower than that for the GPL (peak of 1.75 versus 2.2). Figure B.6 further shows that although the peak 95th percentile TTIs of the EL and GPL were similar in the PM peak (95th percentile TTI value between 2.5 and 3.0), the peak 95th percentile TTI for the EL occurred between 4:15 and 6:15 p.m., but that for the GPL occurred between 3:15 and 7:30 p.m. As shown in Figure B.8, the 1.25 on-time performance of the EL was around 80% in the worst interval within the PM peak period, which is better than the corresponding value of the GPL, which was about 60%. The drop in the on-time performance of the EL is also for a shorter period of time in the PM peak. Similar results were found for the misery index, with a bad performance between 2:15 and 7:15 p.m. on the GPL, but bad performance on the EL only between 4:00 and 5:30 p.m., as shown in Figure B.9.

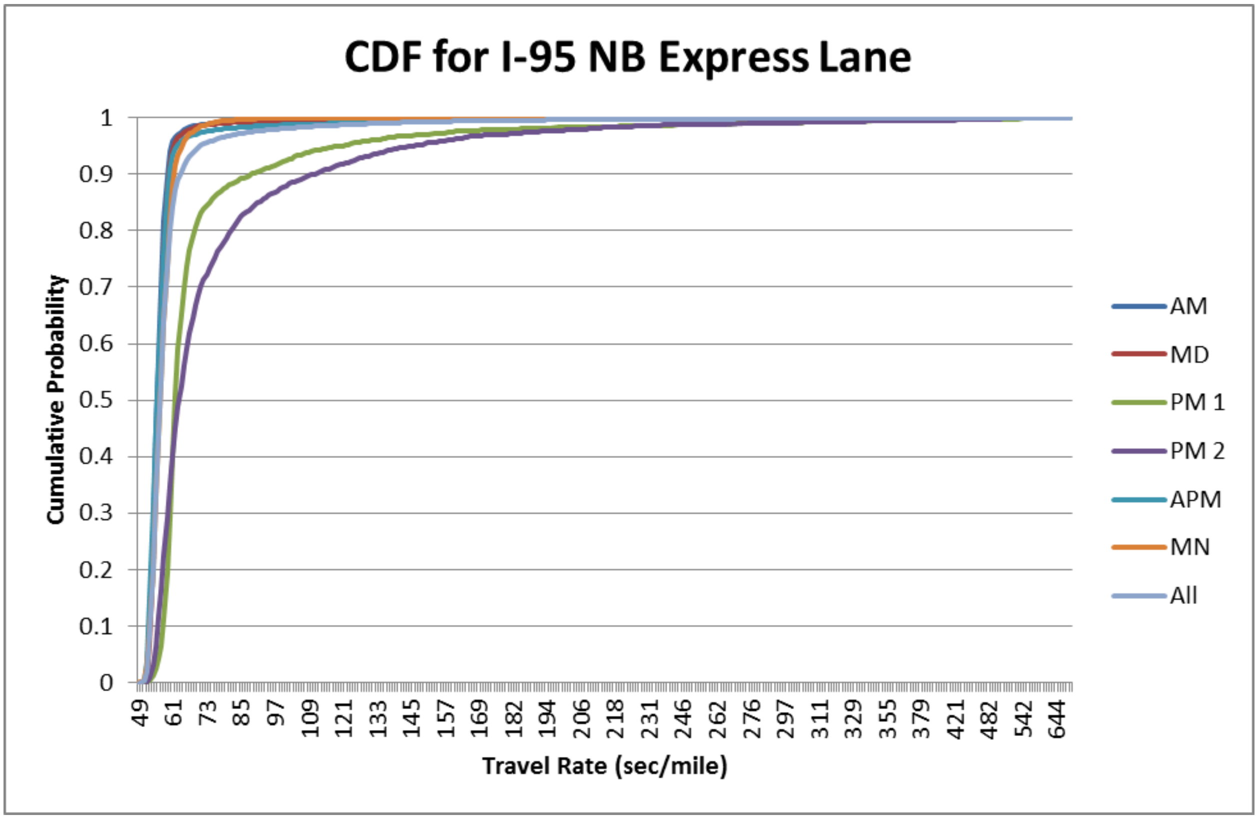


Figure B.1. CDF for I-95 NB EL.

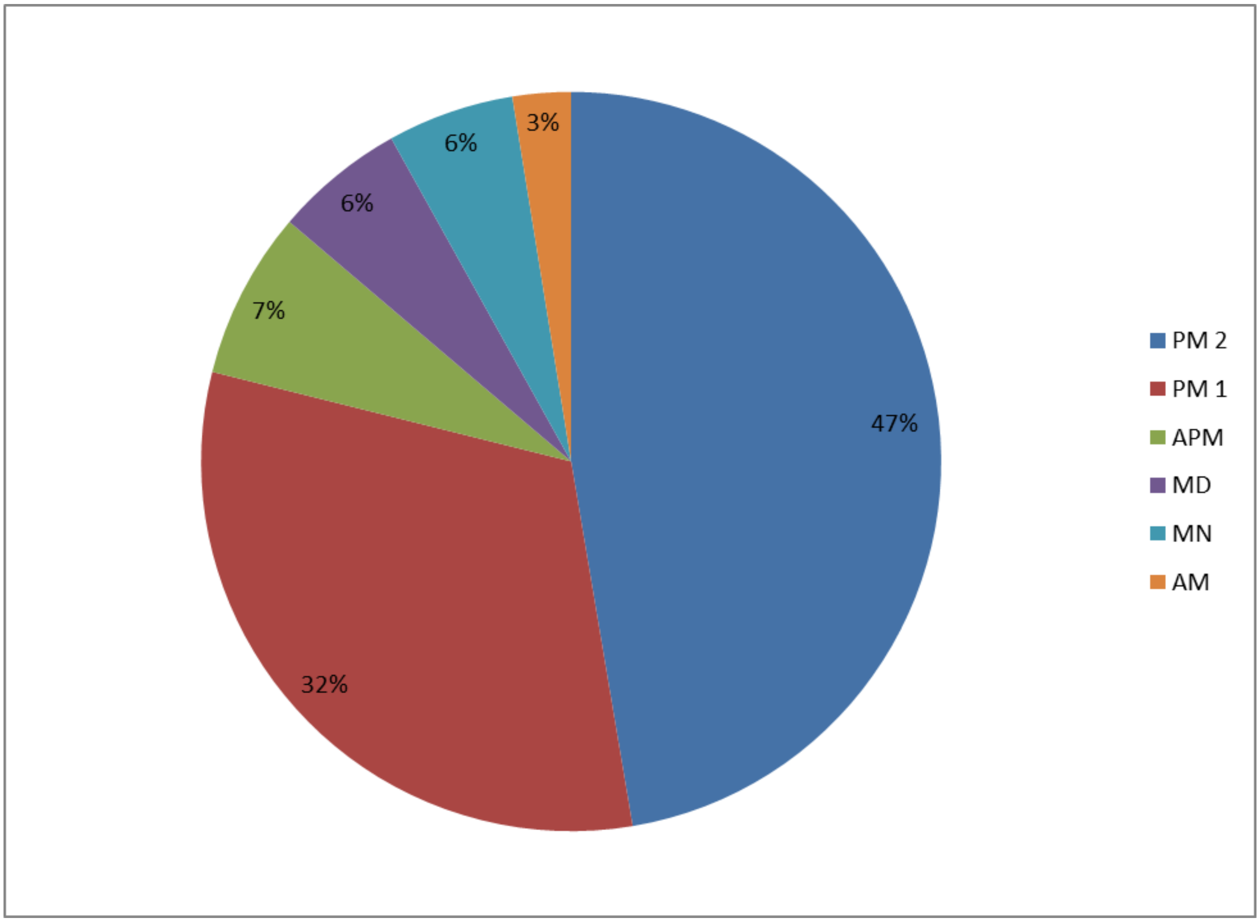


Figure B.2. Percentage of unreliability contribution for I-95 NB EL.

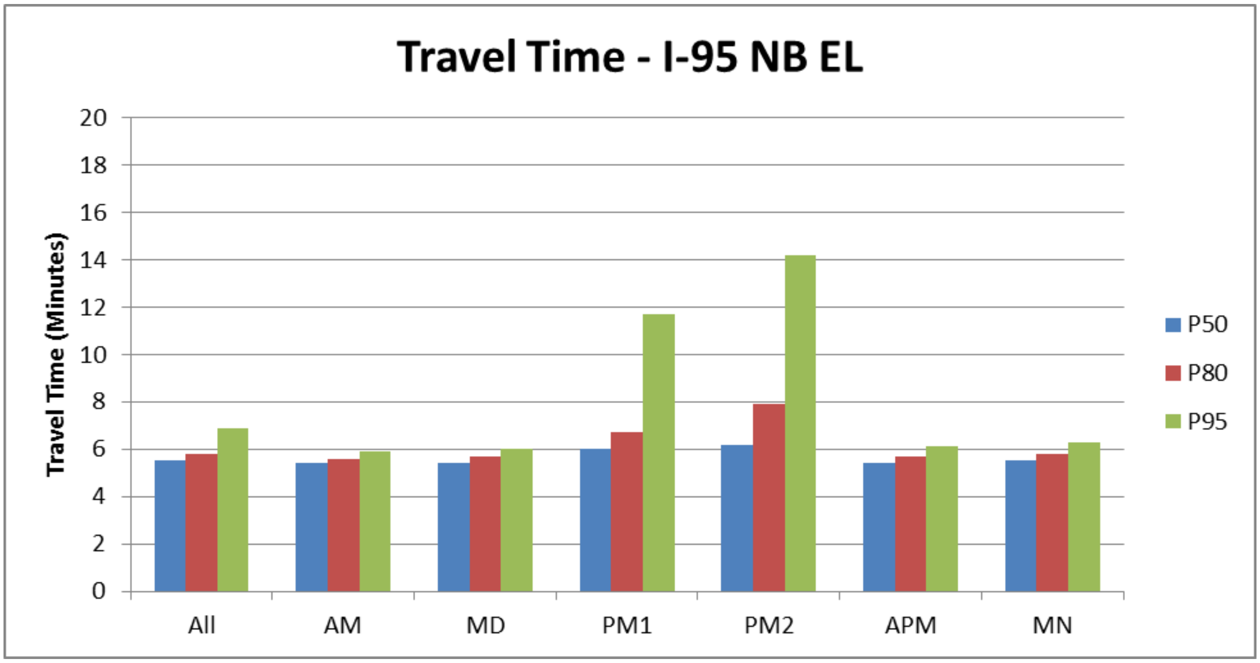


Figure B.3. Travel time for I-95 NB EL.

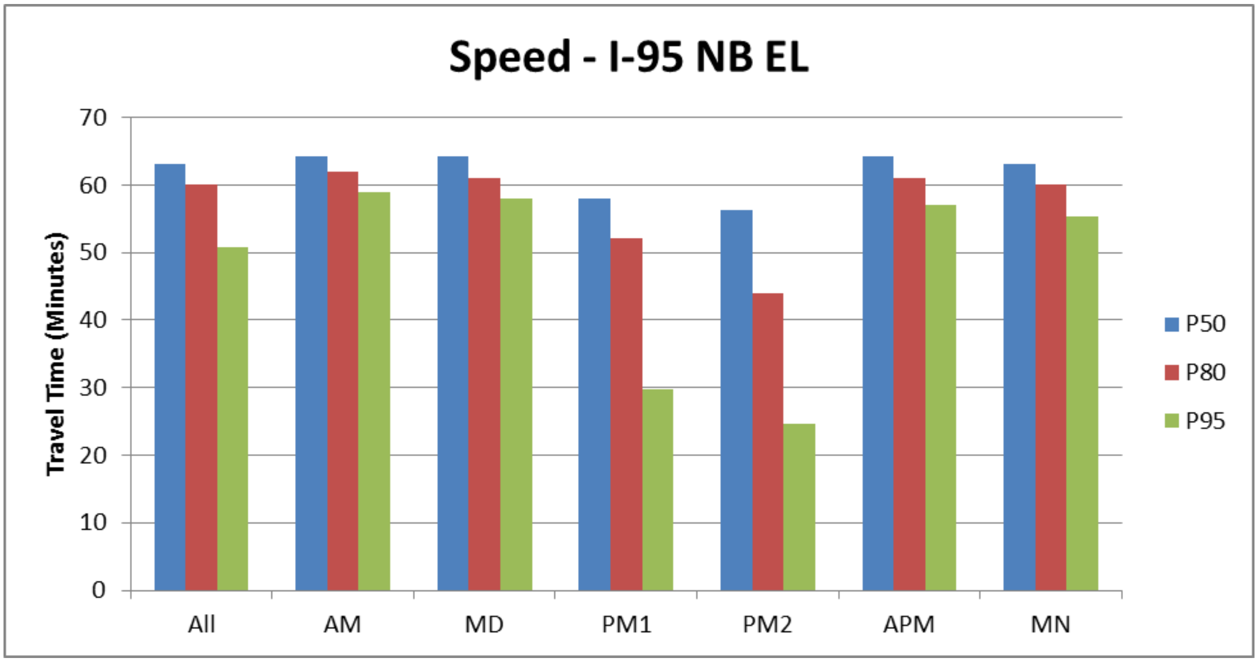


Figure B.4. Speed for I-95 NB EL.

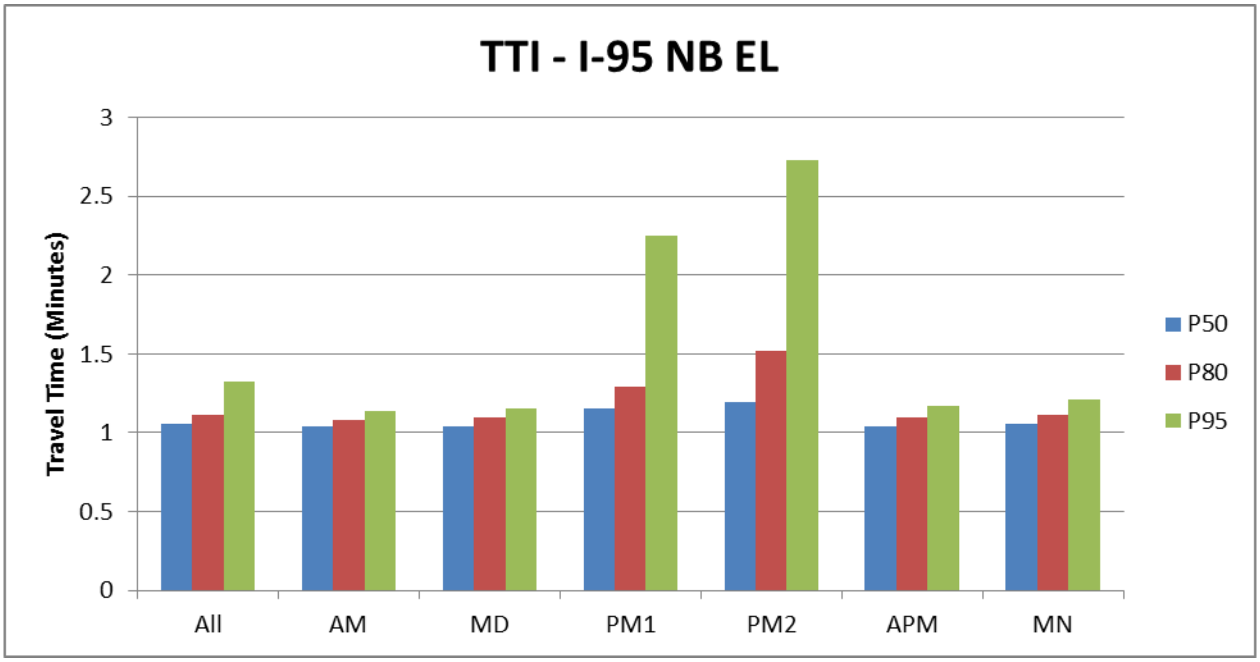


Figure B.5. TTI for I-95 NB EL.

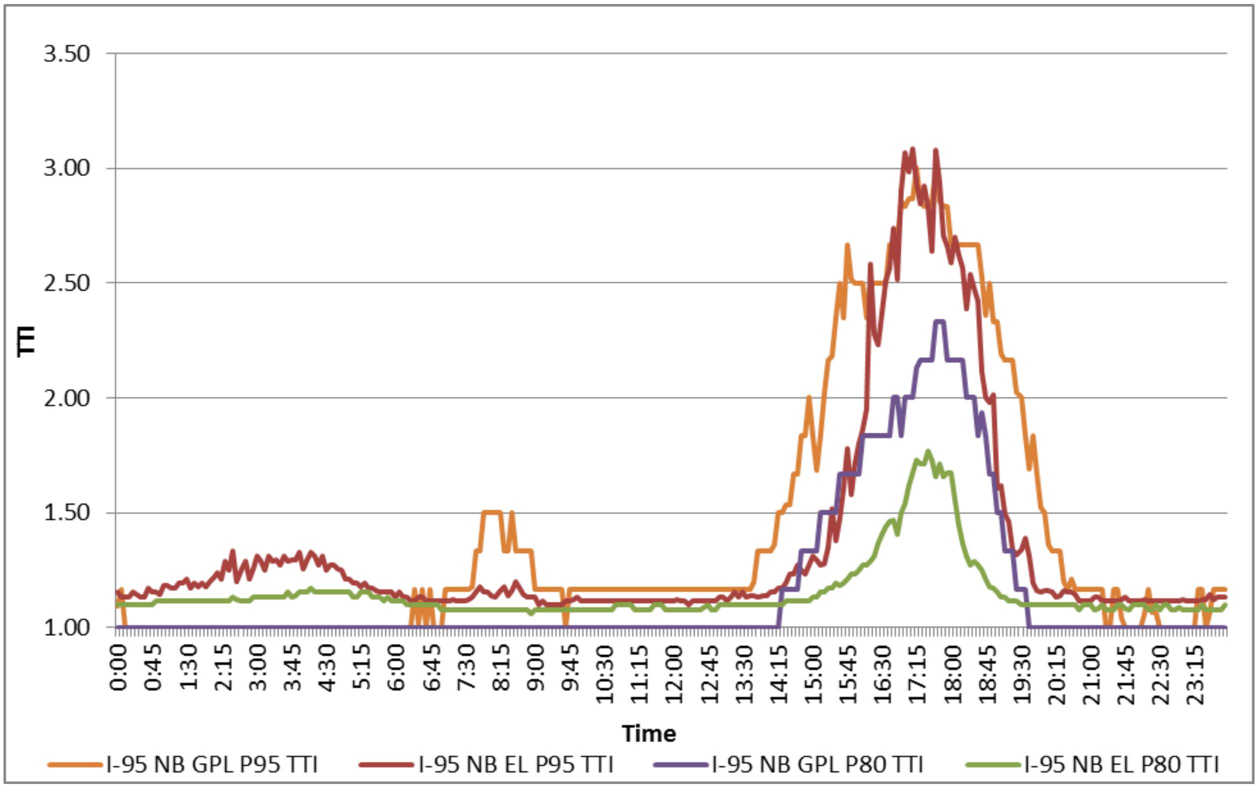


Figure B.6. I-95 NB GPL and EL 80th and 95th percentile TTIs.

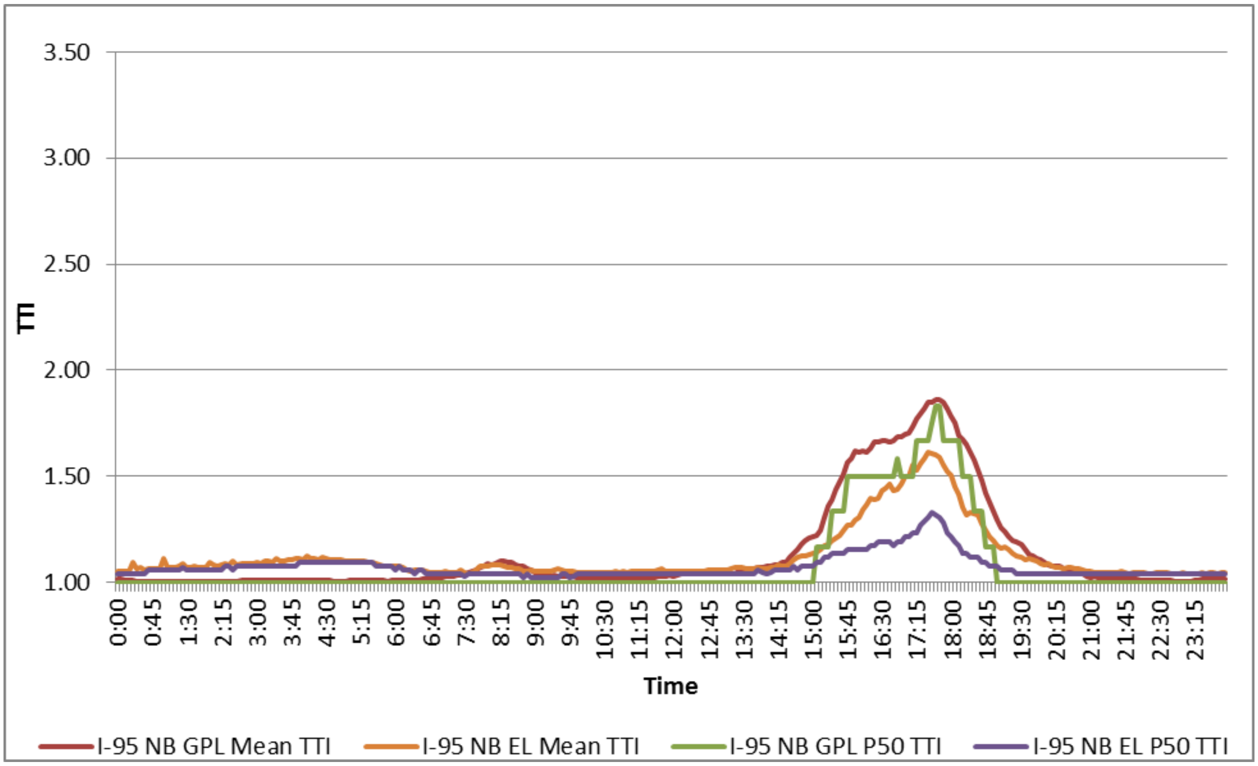


Figure B.7. I-95 NB GPL and EL mean and 50th percentile TTIs.

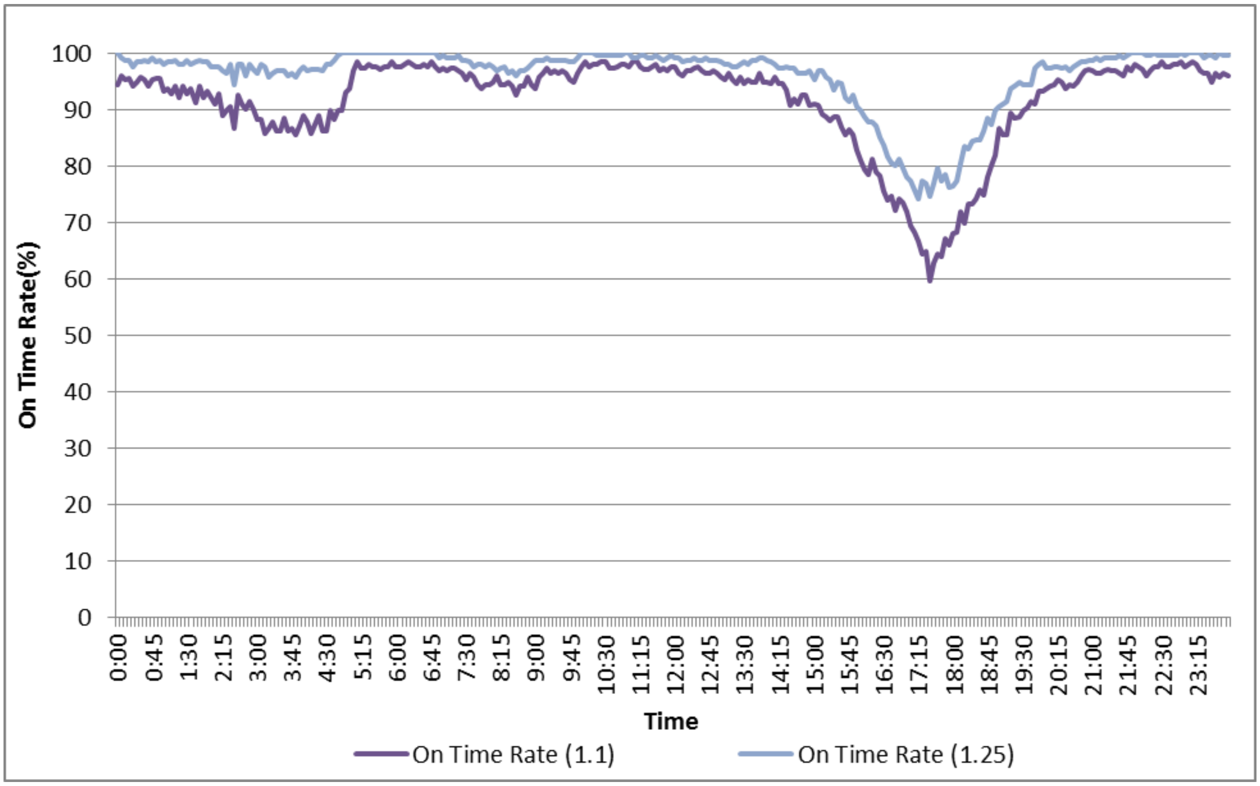


Figure B.8. I-95 NB EL on-time performance.

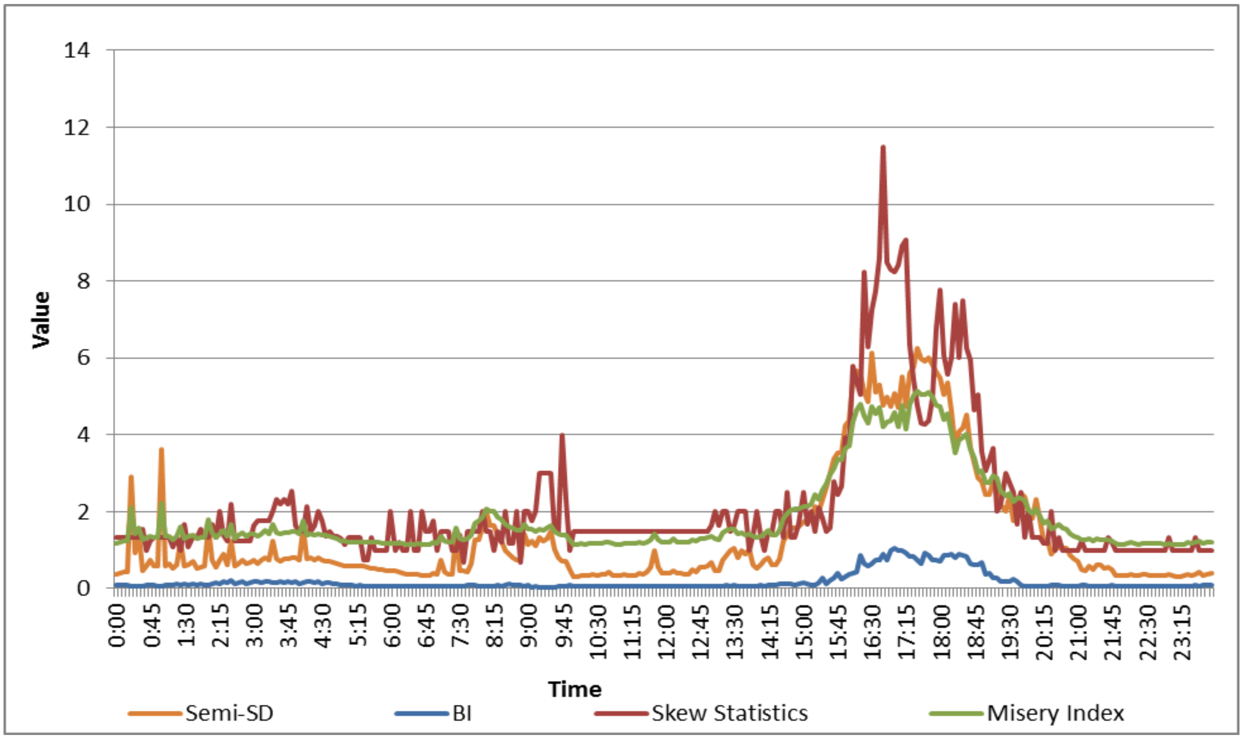


Figure B.9. I-95 NB EL semistandard deviation, buffer index, skew statistics, and misery index.

The temporal and spatial distributions of speed and volume for the EL during the congested PM1 and PM2 peaks were investigated, as shown in Figure B.10 and B.11. Similar bottleneck locations were identified for the I-95 EL as those of the GPL; however, the duration of congestion was much shorter than on the GPL. Figures B.12 and B.13 show the time-dependent variation of VMT and VHT, and Figure B.14 presents the percentage of VMT with a 95th percentile TTI (PTI) less than 1.33, 1.5, and 2.0.

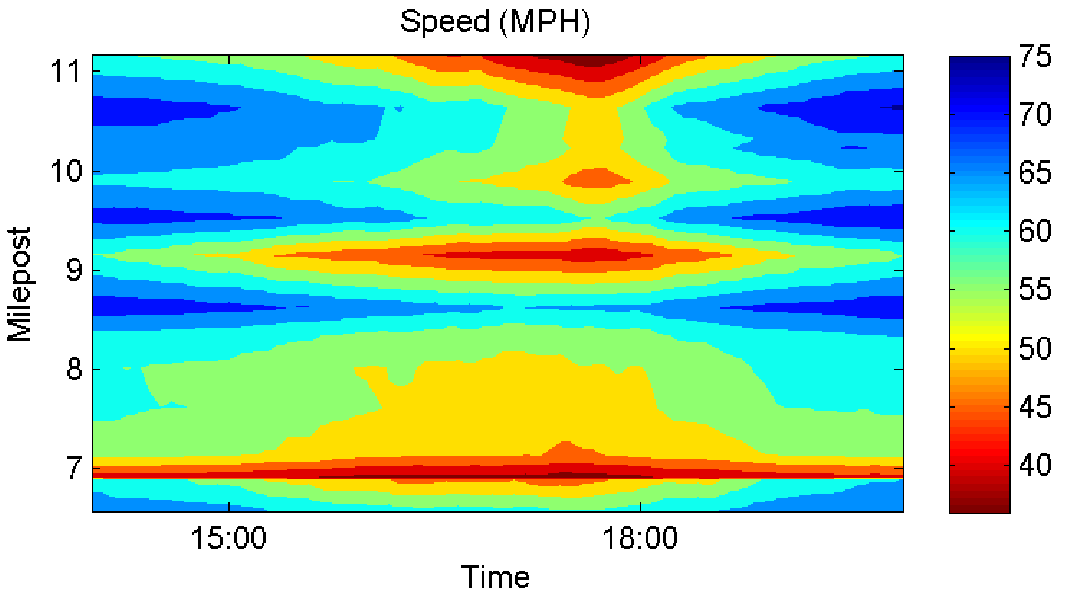


Figure B.10. Temporal and spatial distributions of speed for I-95 NB EL.

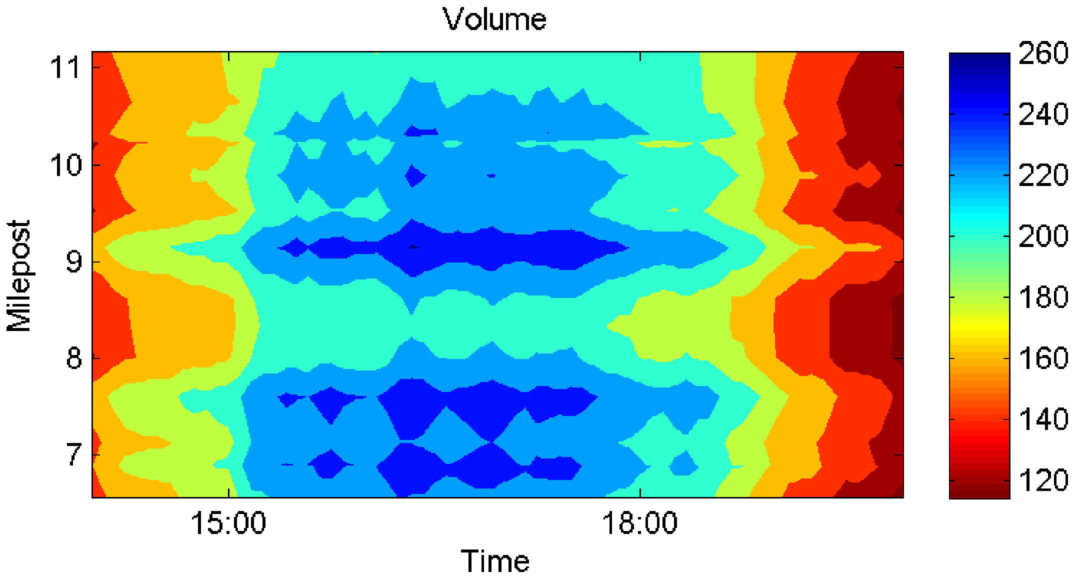


Figure B.11. Temporal and spatial distributions of volume for I-95 NB EL.

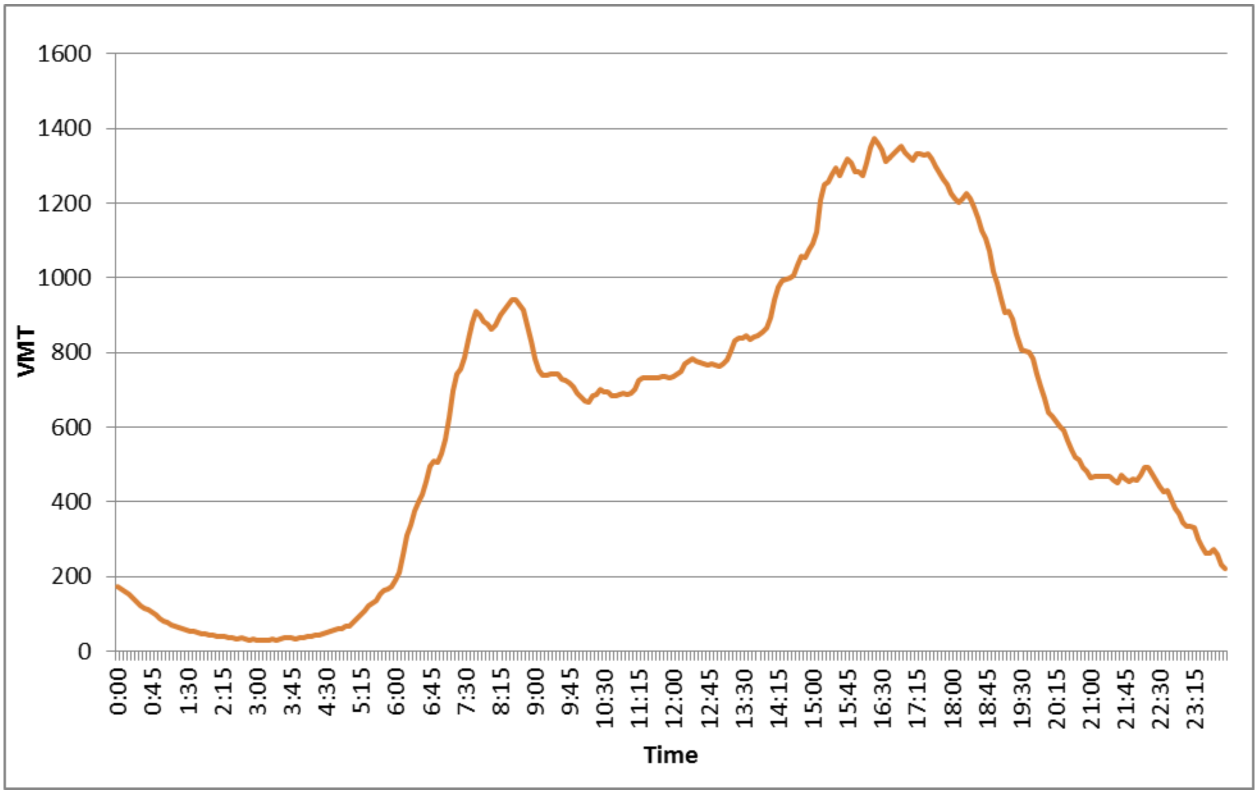


Figure B.12. I-95 NB EL VMT.

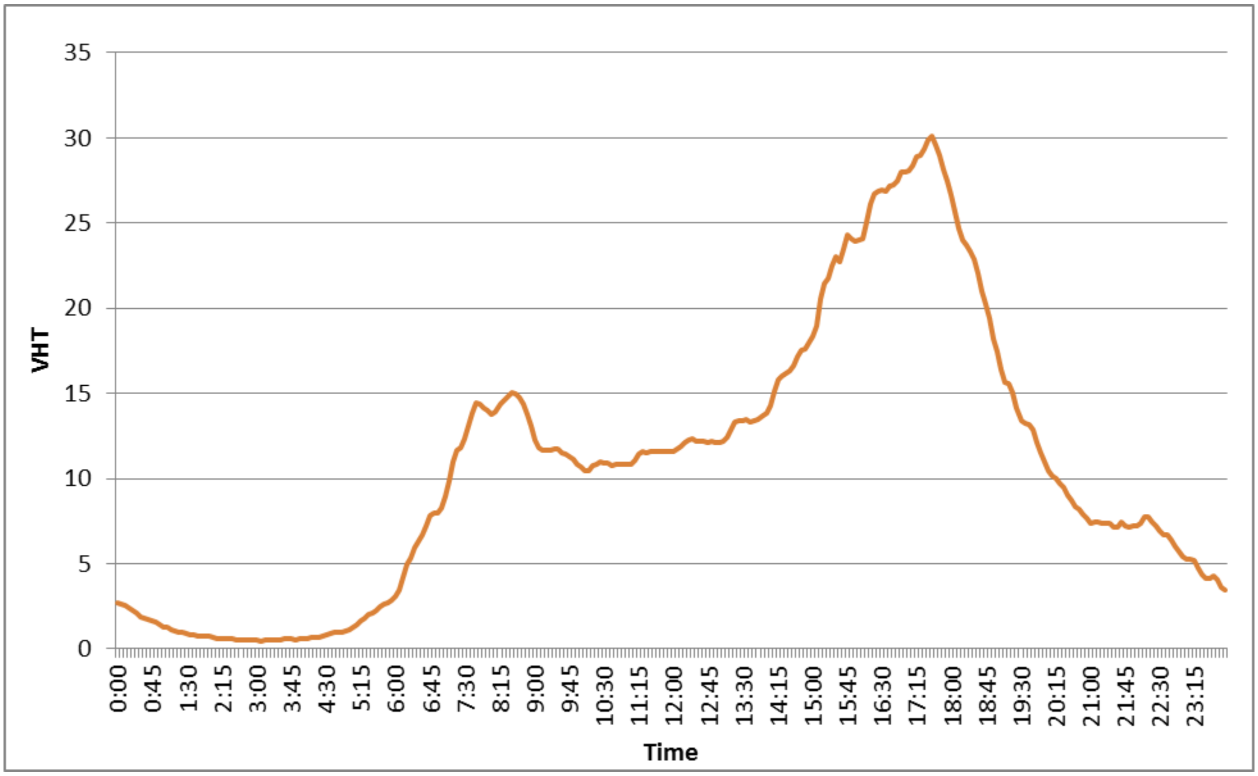


Figure B.13. I-95 NB EL VHT.

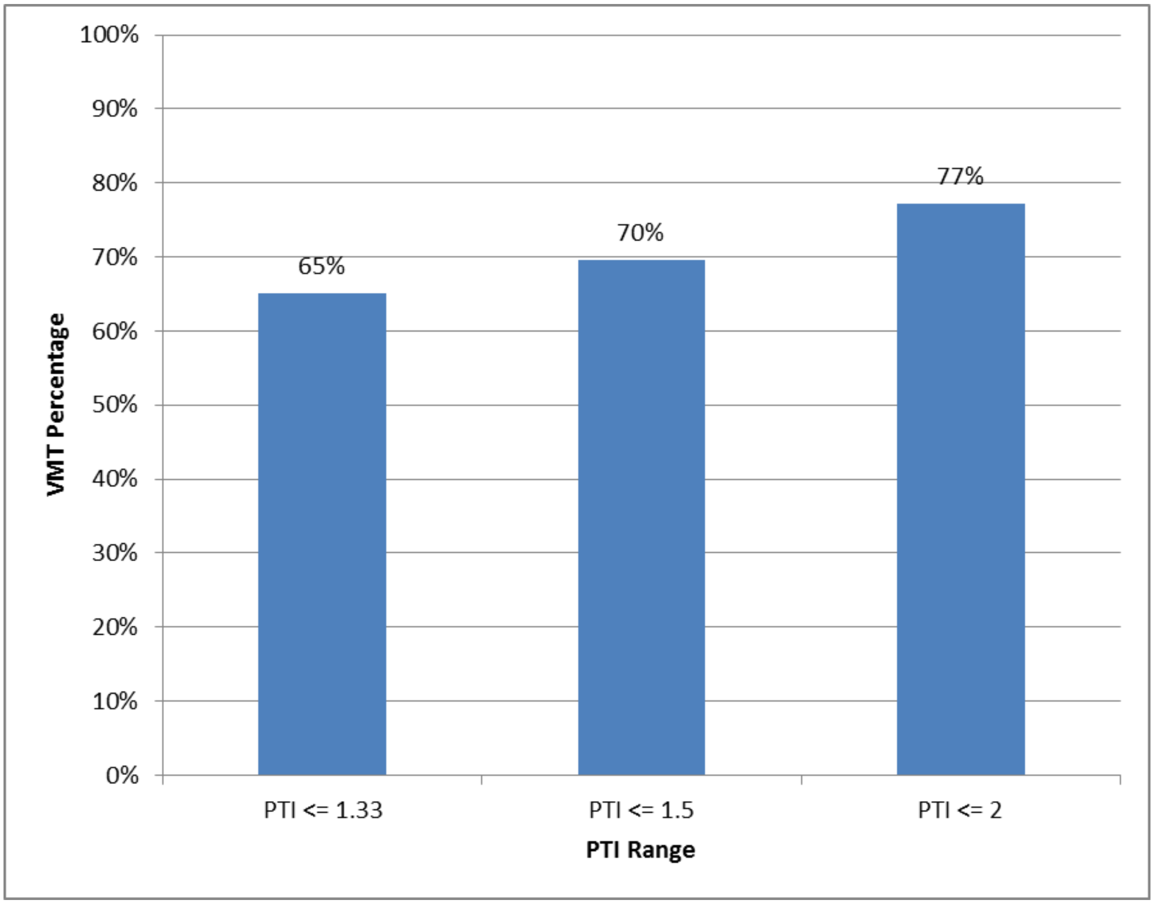


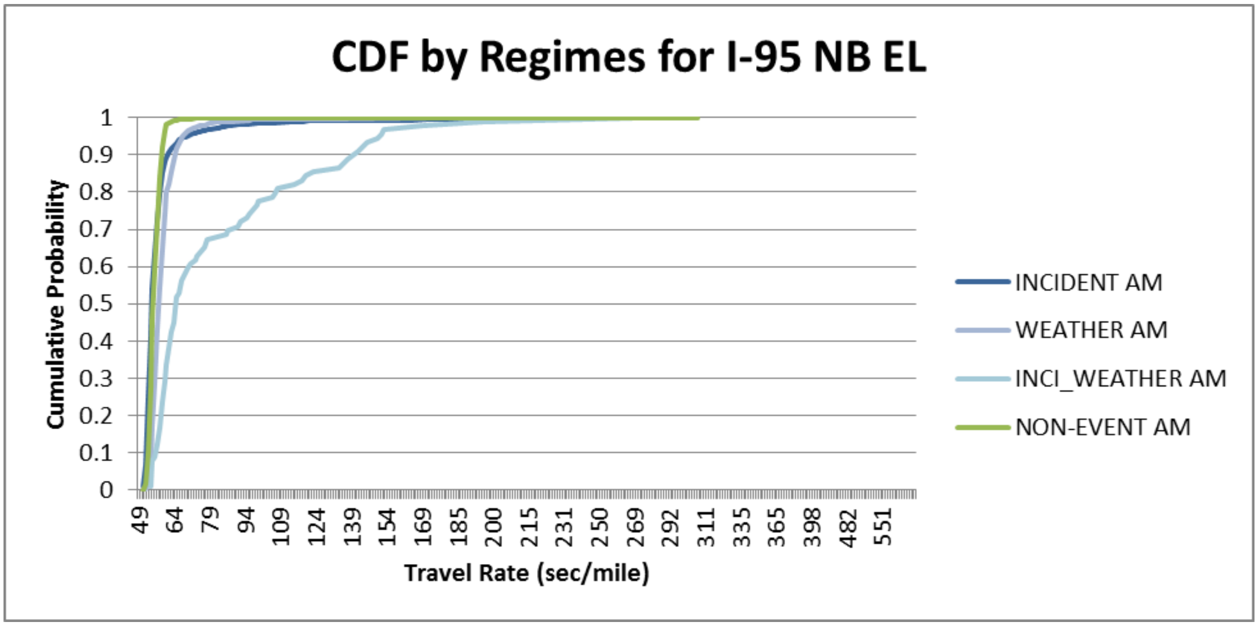
Figure B.14. I-95 NB EL VMT percentage.

B.2 General Assessment of the Contributions of Influential Factors

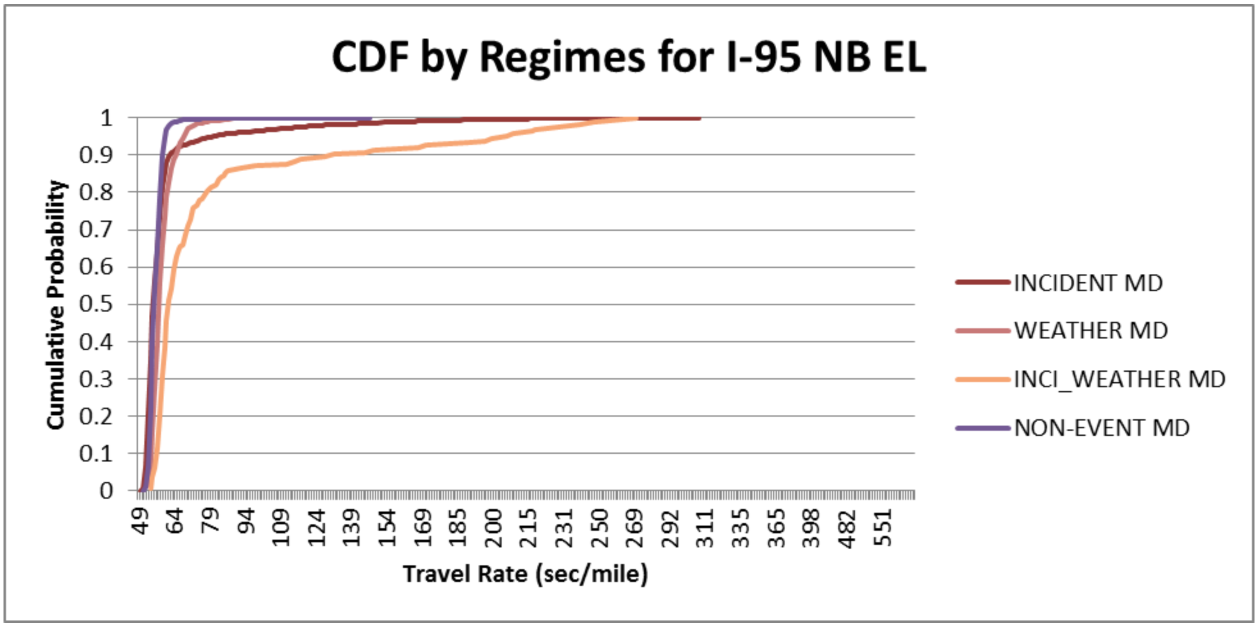
Figure B.15 presents the CDF for travel time rates under different categories of influencing factors, including the no-event period, incident, weather, and combined incident and weather conditions. The percentages of occurrence, severity, and unreliability contribution for these categories are listed in Tables B.1, B.2, and B.3, respectively, and the corresponding pie charts are presented in Figures B.16 to B.18. The results in these figures indicate that incident intervals were the major contributors to unreliability. Although the incident frequency was lower on the EL than on the GPL, the EL contribution to unreliability was very high in the PM peak period due to the high severity per incident when one lane of the two ELs was blocked, and even more when both lanes were blocked. This issue needs to be explored further to determine how these impacts can be reduced considering the geometric constraints of managed lanes that may increase the impacts of incidents. Rainy conditions combined with incidents also increased the impact of a single event. The overall contribution of weather events to reliability was small.

The reliability analysis results of ELs indicated that weather events did not have a major impact on the overall reliability of the EL, as shown in Table B.3 and Figure B.18. However, the incident plus weather event on a single-event basis contributed twice as much as the contribution of incident in good weather to unreliability. The 50th, 80th, and 95th percentiles of travel time, speed, and TTI shown in Figure B.19, B.20, and Figure B.21, respectively, for different regimes on the ELs clearly show that during incident and weather events, the TTIs were worse than those during no-event conditions.

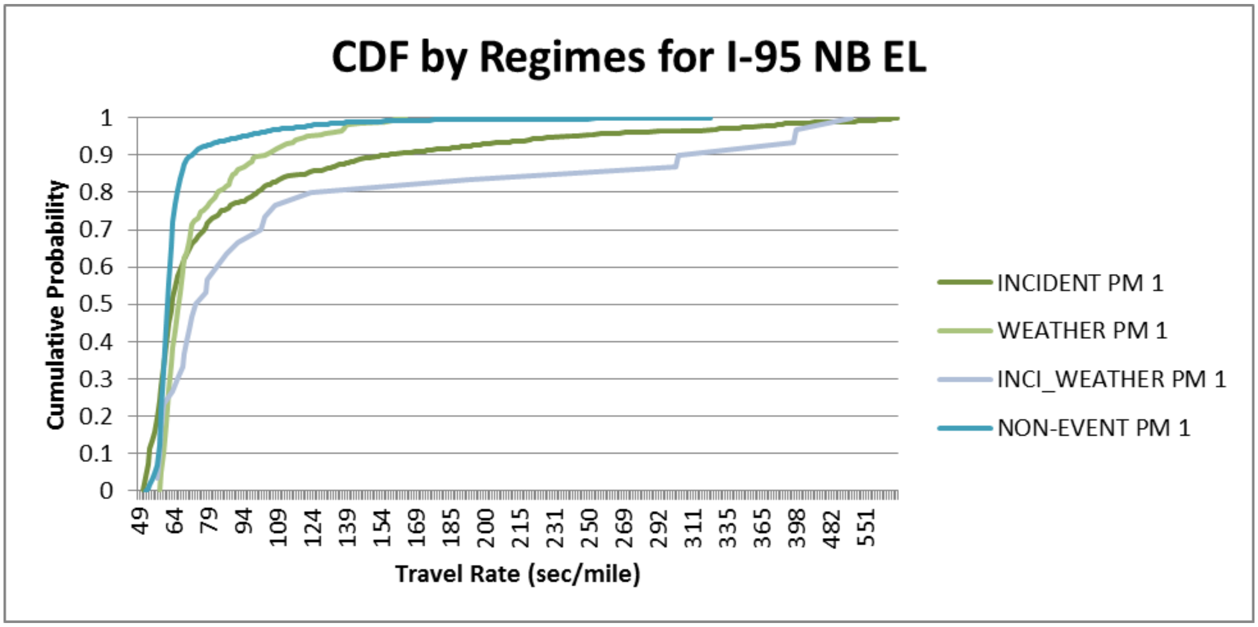
The five-minute variations of TTI values are presented in Figures B.22 to B.25. These figures again show the high impacts of demands and incidents on unreliability.


CDF by Regimes for I-95 NB EL
Cumulative Probability
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
49
64
79
94
109
124
139
154
169
185
200
215
231
250
269
292
311
335
365
398
482
551
Travel Rate (sec/mile)
INCIDENT AM
WEATHER AM
INCI_WEATHER AM
NON-EVENT AM

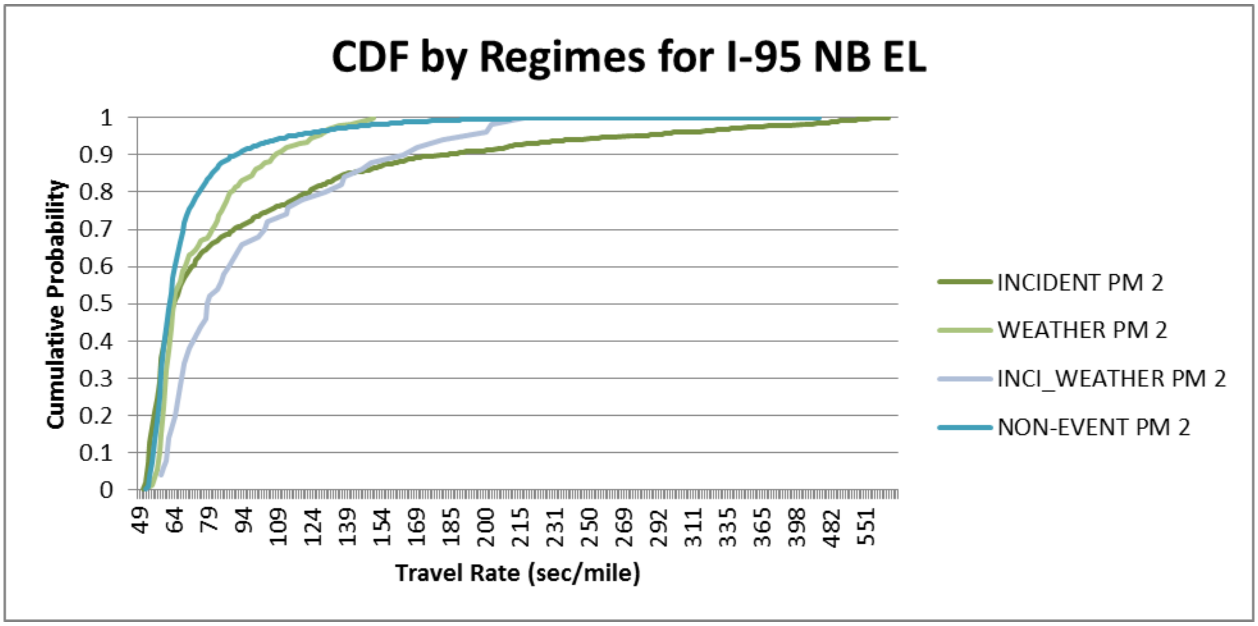
(a)


CDF by Regimes for I-95 NB EL
Cumulative Probability
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
49
64
79
94
109
124
139
154
169
185
200
215
231
250
269
292
311
335
365
398
482
551
Travel Rate (sec/mile)
INCIDENT MD
WEATHER MD
INCI_WEATHER MD
NON-EVENT MD

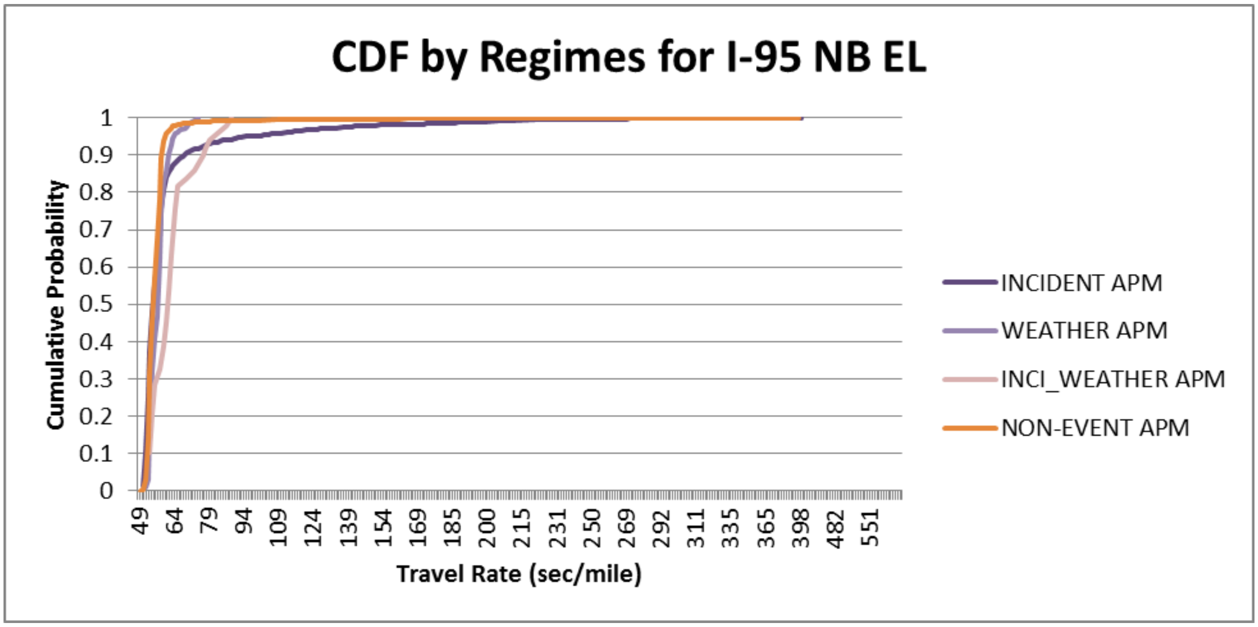
(b)


CDF by Regimes for I-95 NB EL
Cumulative Probability
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Travel Rate (sec/mile)
49
64
79
94
109
124
139
154
169
185
200
215
231
250
269
292
311
335
365
398
482
551
INCIDENT PM 1
WEATHER PM 1
INCI_WEATHER PM 1
NON-EVENT PM 1

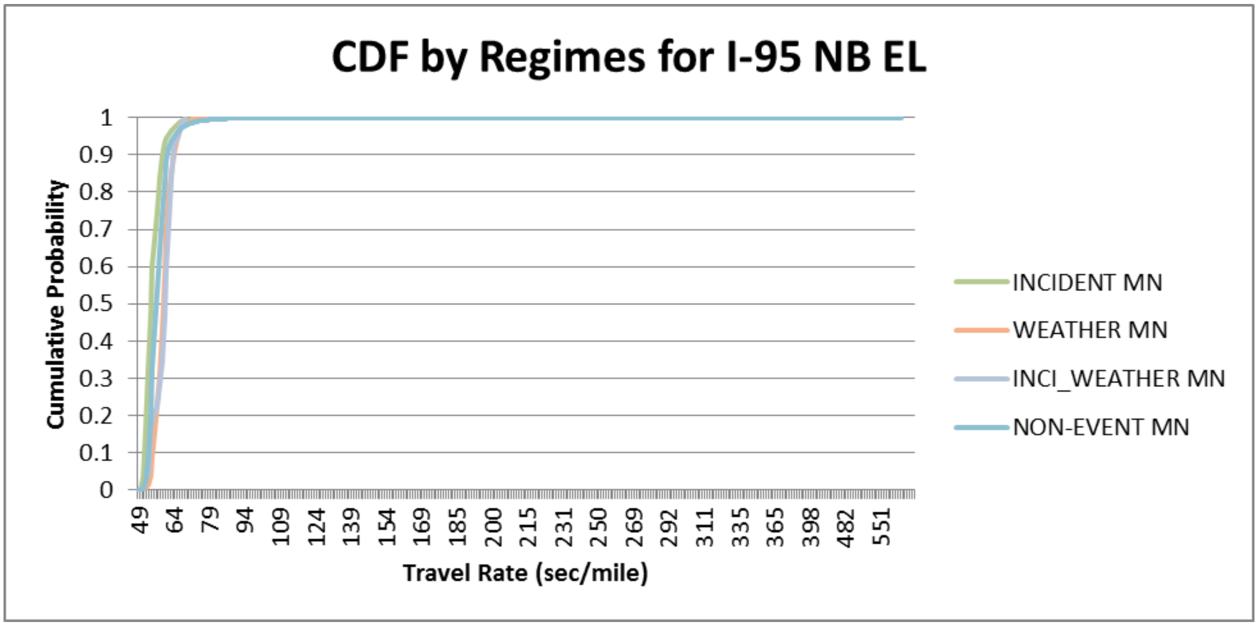
(c)


CDF by Regimes for I-95 NB EL
Cumulative Probability
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Travel Rate (sec/mile)
49
64
79
94
109
124
139
154
169
185
200
215
231
250
269
292
311
335
365
398
482
551
INCIDENT PM 2
WEATHER PM 2
INCI_WEATHER PM 2
NON-EVENT PM 2

(d)



(e)



(f)

Figure B.15. CDF by regimes for I-95 NB EL for (a) AM peak, (b) MD, (c) PM1, (d) PM2, (e) APM, and (f) MN periods.

Table B.1. Percentage of Occurrence

Time Period	Nonevent	Incident	Weather	Incident + Weather	Total
AM	11%	1%	1%	0.12%	12%
MD	22%	3%	1%	0.22%	27%
PM1	5%	1%	0%	0.04%	6%
PM2	7%	1%	0%	0.07%	8%
APM	10%	1%	1%	0.07%	12%
MN	30%	2%	1%	0.07%	33%

Table B.2. Percentage of Severity

Time Period	Nonevent	Incident	Weather	Incident + Weather	Total
AM	0.07%	0.52%	0.23%	4.04%	5%
MD	0.04%	0.76%	0.12%	4.77%	6%
PM1	0.99%	18.45%	1.56%	35.18%	56%
PM2	1.44%	20.44%	1.71%	6.36%	30%
APM	0.29%	1.98%	0.07%	0.32%	3%
MN	0.12%	0.31%	0.11%	0.11%	1%

Table B.3. Percentage of Unreliability Contribution

Time Period	Nonevent	Incident	Weather	Incident + Weather	Total
AM	1%	1%	0.20%	0.61%	3%
MD	1%	3%	0.22%	1.32%	6%
PM1	6%	23%	0.69%	1.80%	32%
PM2	12%	34%	0.62%	0.54%	47%
APM	4%	3%	0.05%	0.03%	7%
MN	5%	1%	0.19%	0.01%	6%

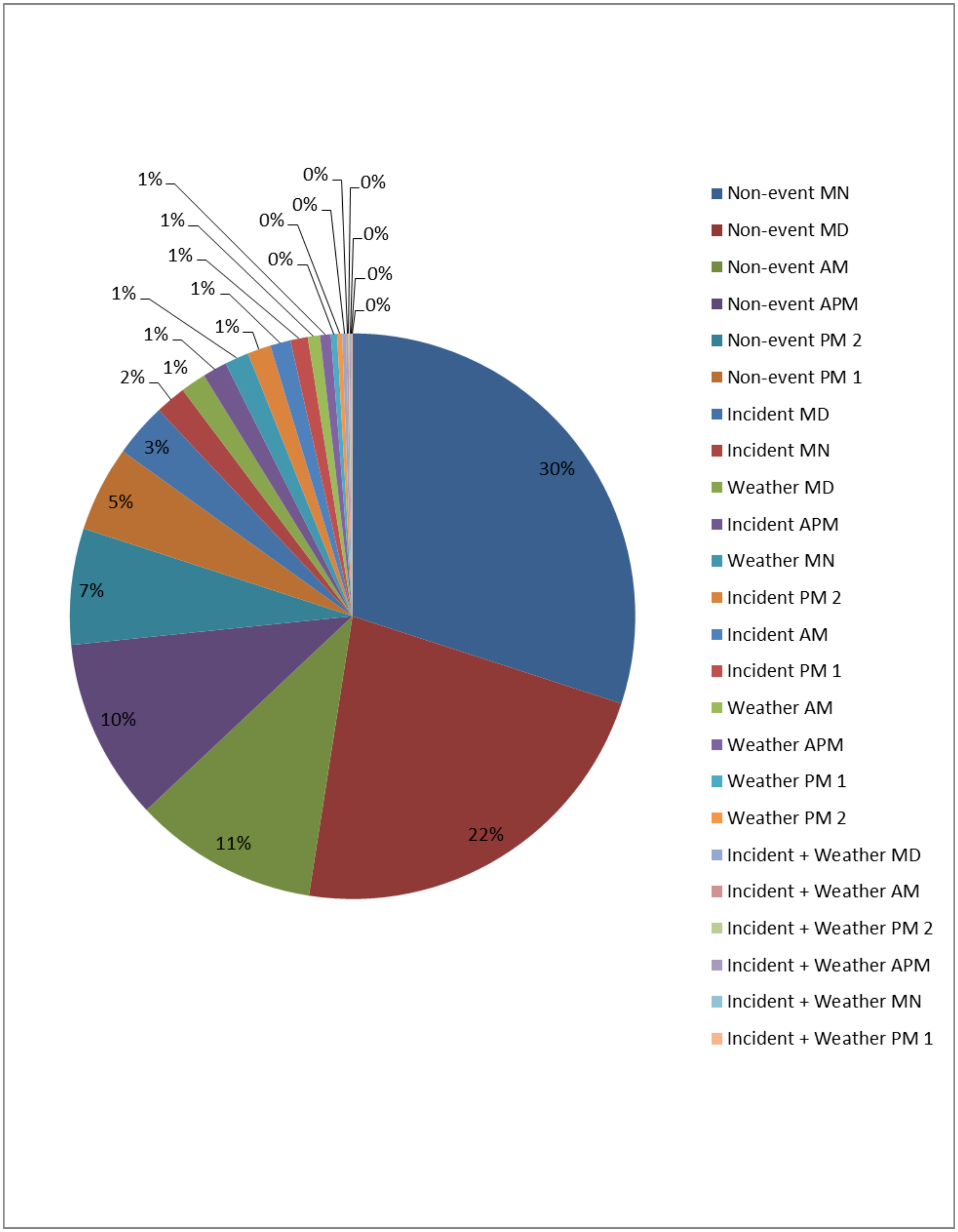


Figure B.16. Percentage of Occurrence for I-95 NB EL.

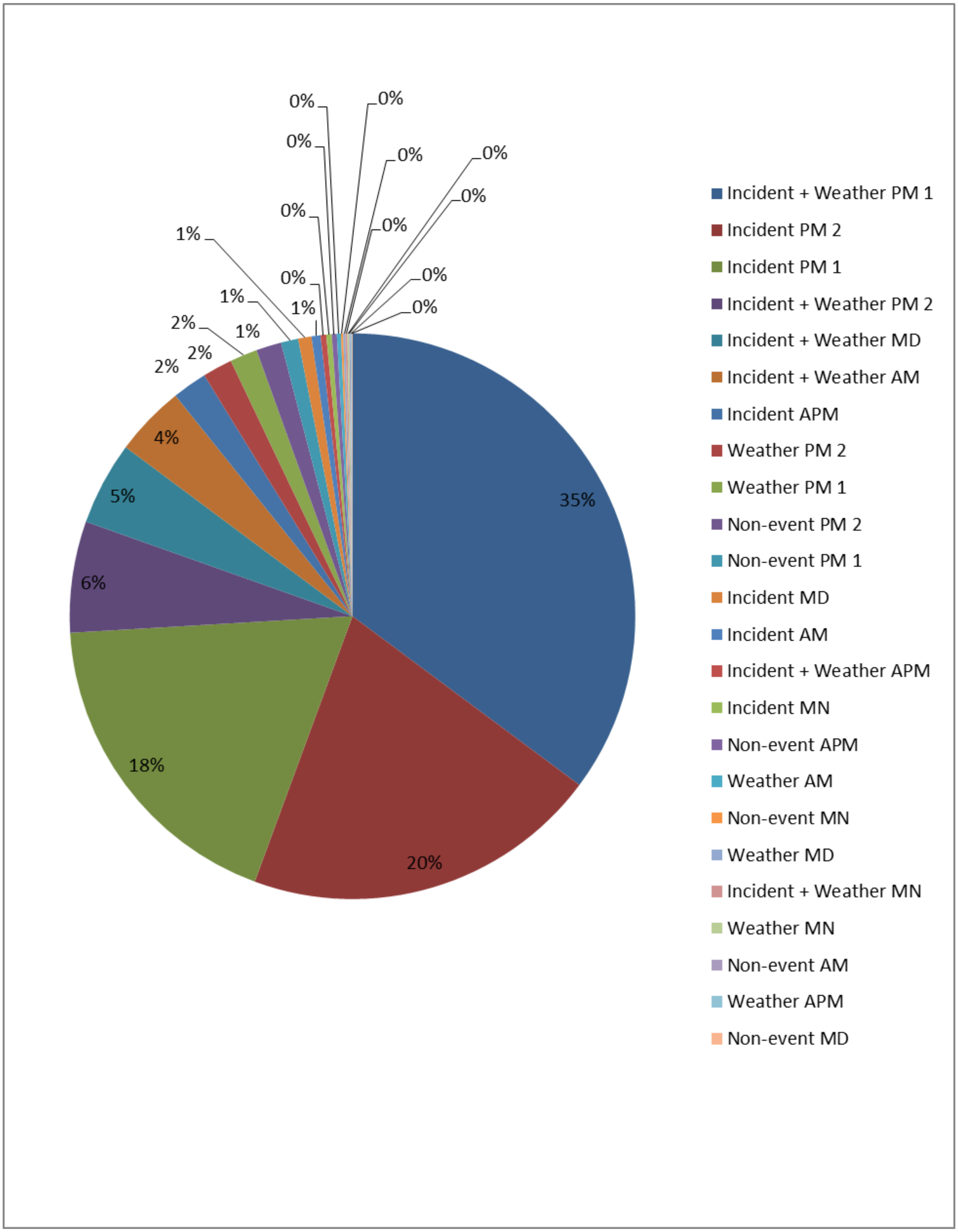


Figure B.17. Percentage of severity for I-95 NB EL.

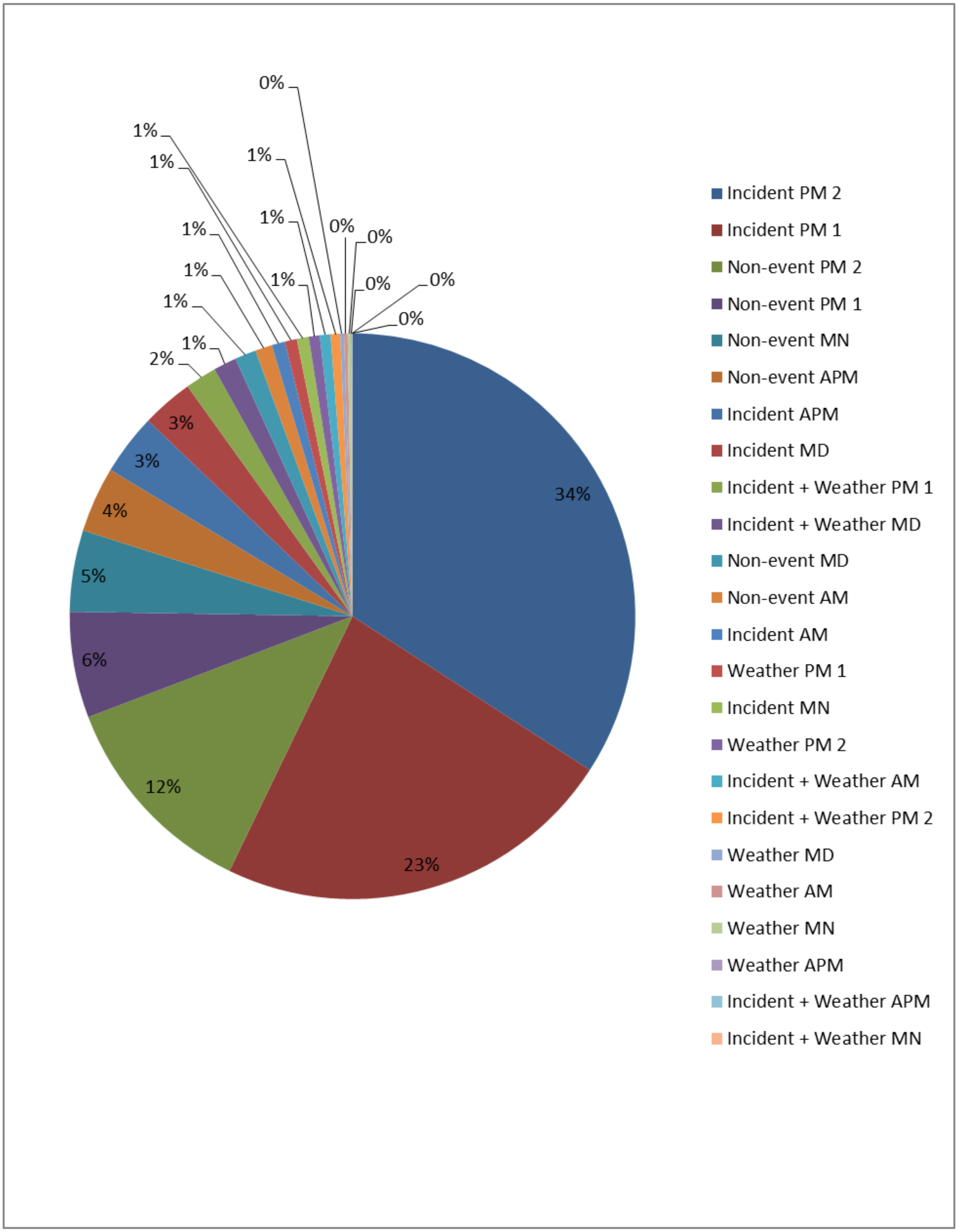
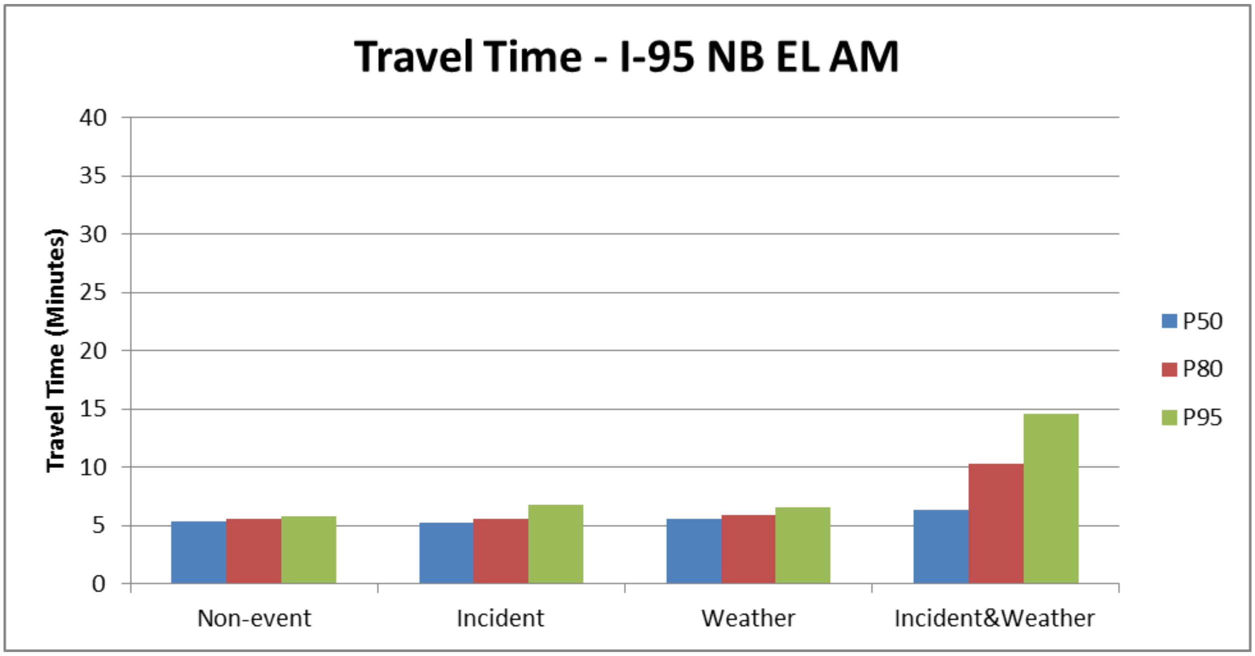
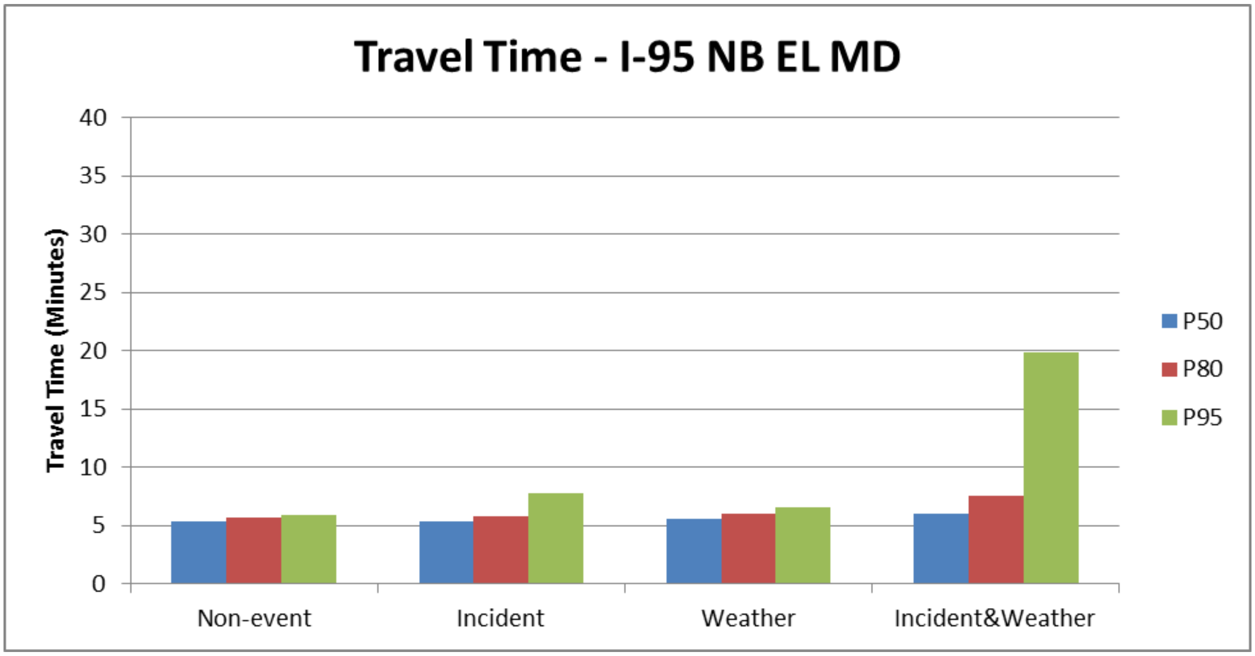


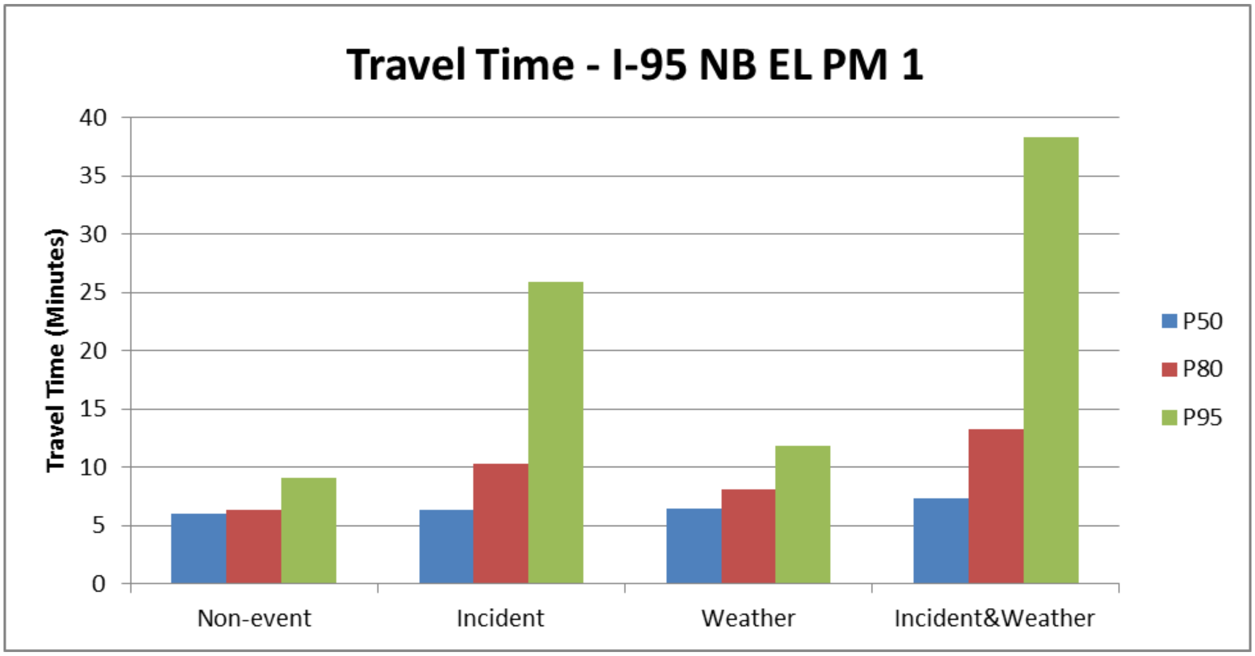
Figure B.18. Percentage of unreliability contribution for I-95 NB EL.


Travel Time - I-95 NB EL AM
Travel Time (Minutes)
0
5
10
15
20
25
30
35
40
Non-event
Incident
Weather
Incident&Weather
P50
P80
P95

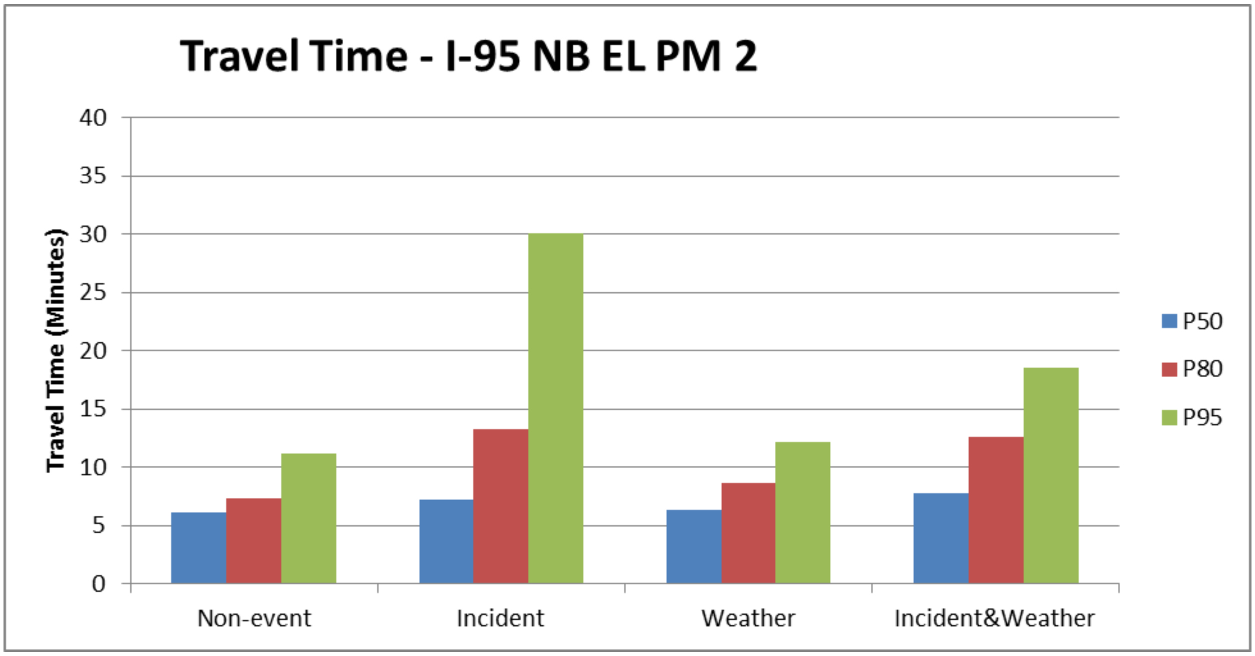
(a)


Travel Time - I-95 NB EL MD
Travel Time (Minutes)
0
5
10
15
20
25
30
35
40
Non-event
Incident
Weather
Incident&Weather
P50
P80
P95

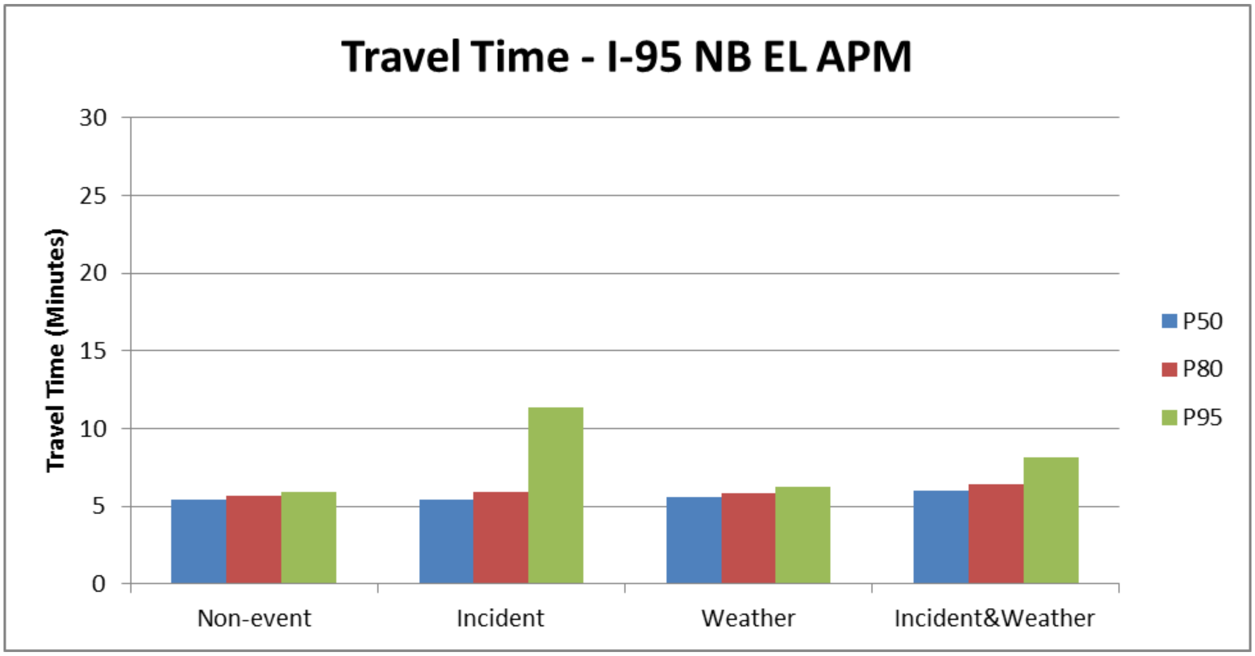
(b)


Travel Time - I-95 NB EL PM 1
Travel Time (Minutes)
0
5
10
15
20
25
30
35
40
Non-event
Incident
Weather
Incident&Weather
P50
P80
P95

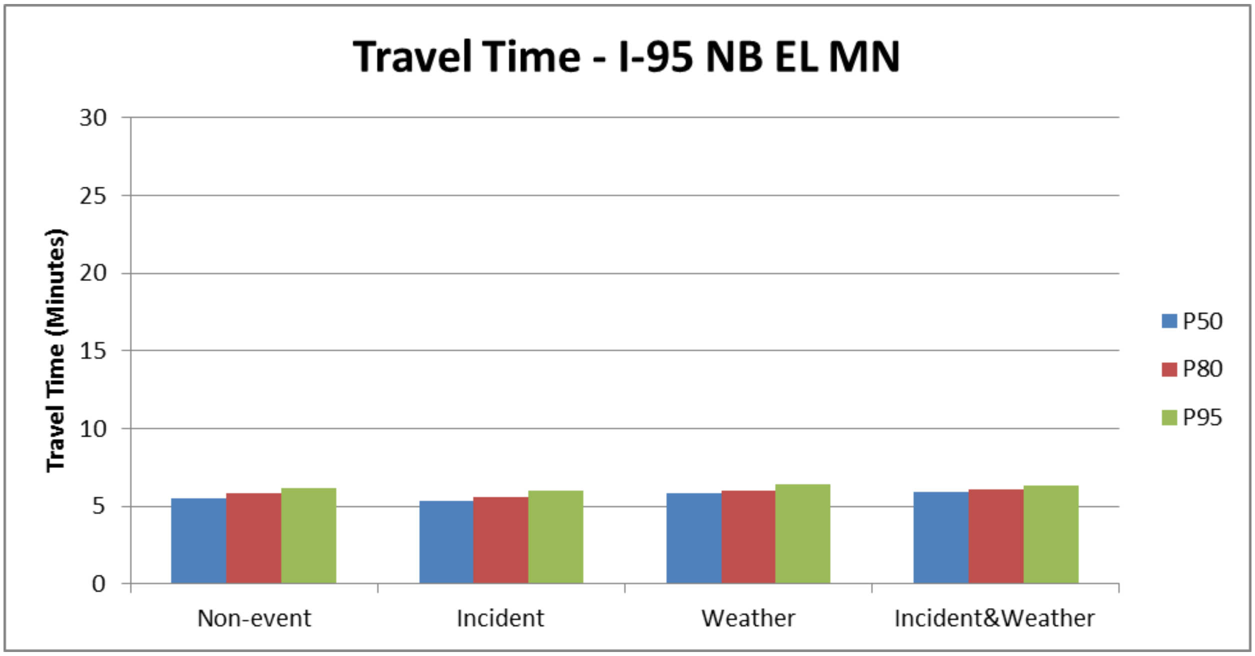
(c)


Travel Time - I-95 NB EL PM 2
Travel Time (Minutes)
0
5
10
15
20
25
30
35
40
Non-event
Incident
Weather
Incident&Weather
P50
P80
P95

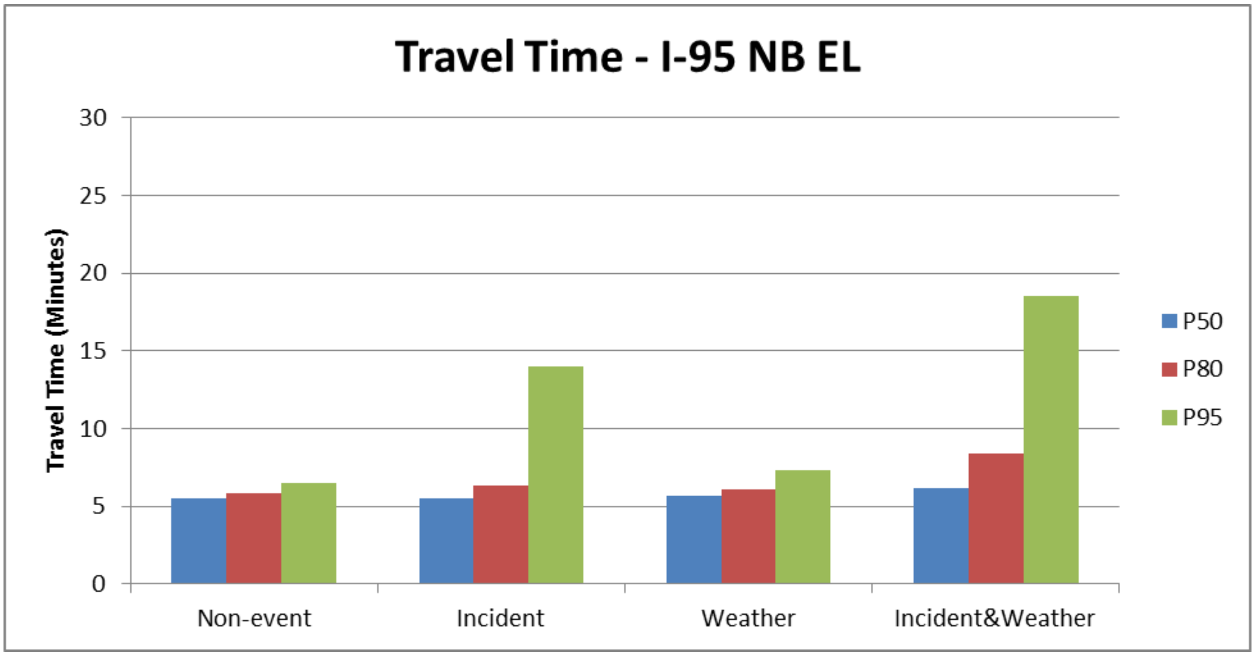
(d)


Travel Time - I-95 NB EL APM
Travel Time (Minutes)
0
5
10
15
20
25
30
Non-event
Incident
Weather
Incident&Weather
P50
P80
P95

(e)

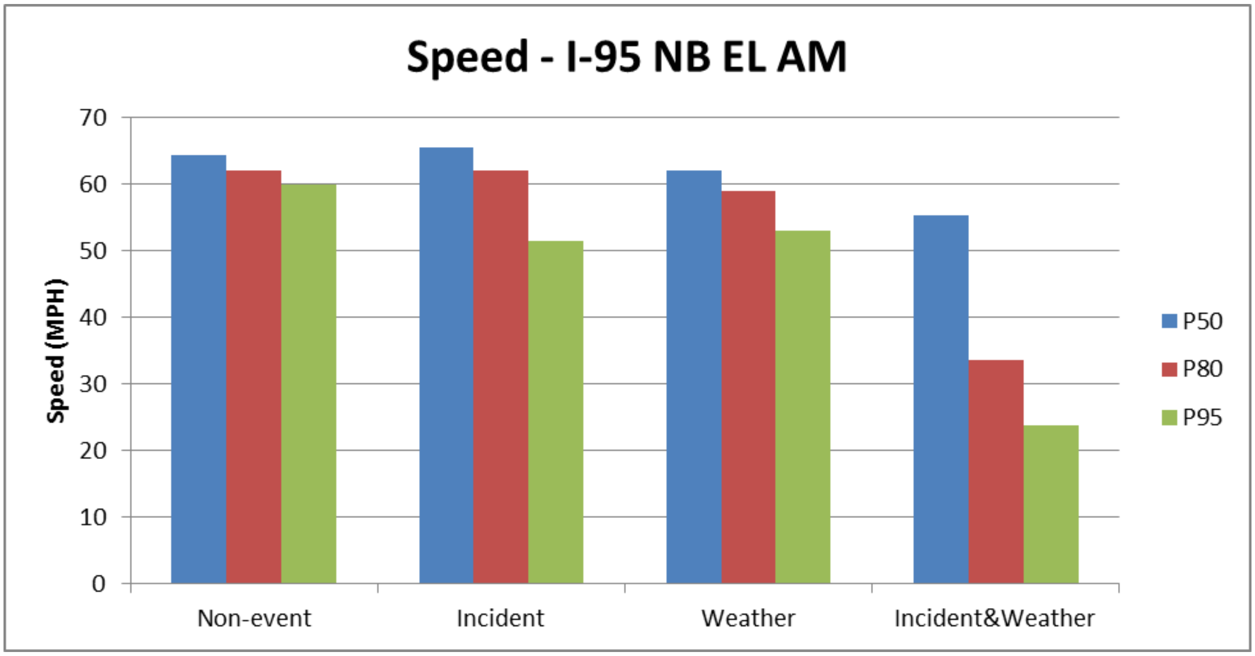

Travel Time - I-95 NB EL MN
Travel Time (Minutes)
0
5
10
15
20
25
30
Non-event
Incident
Weather
Incident&Weather
P50
P80
P95

(f)

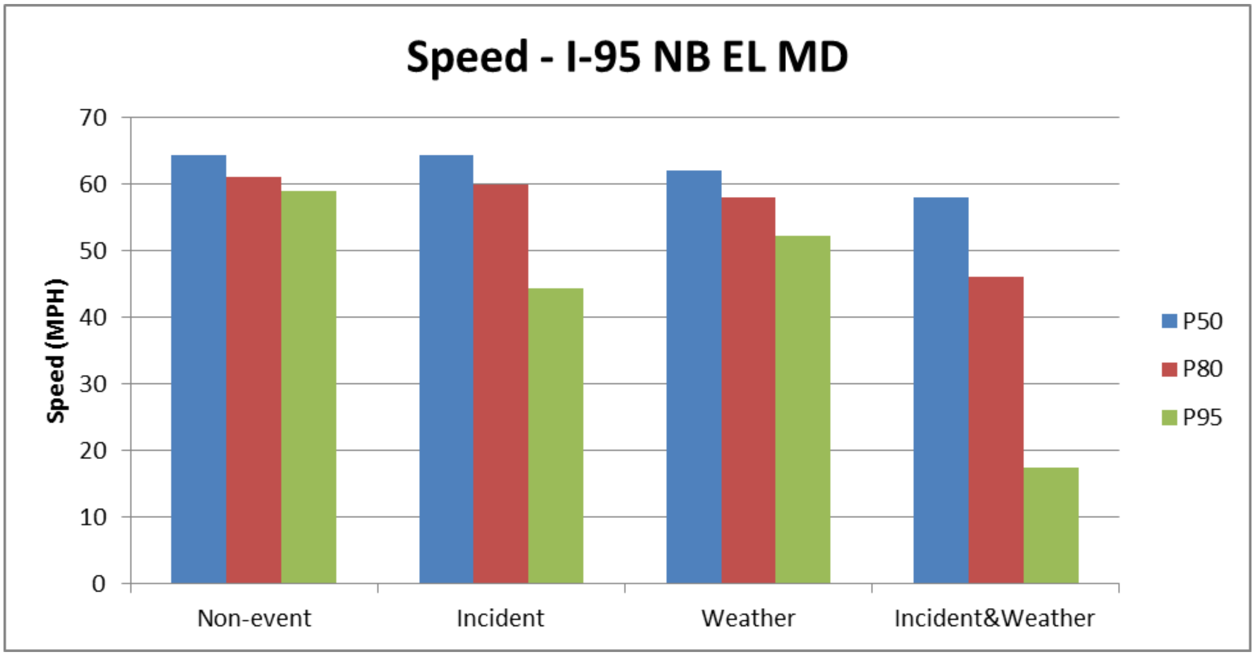


(g)

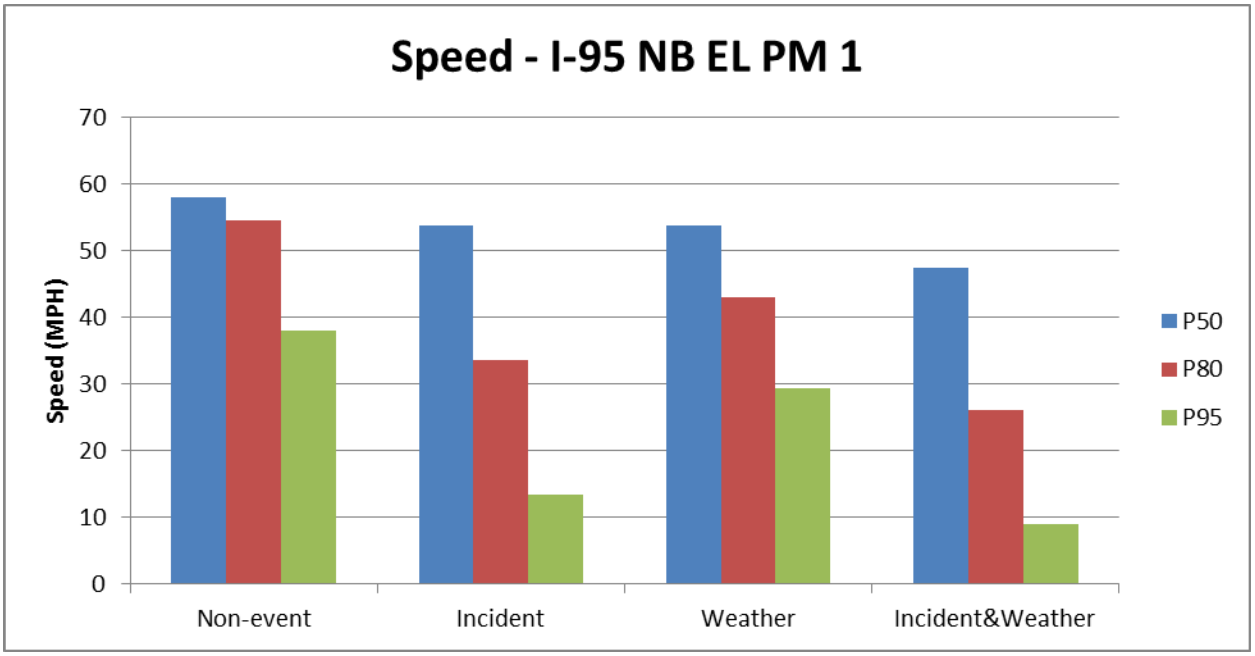
Figure B.19. Travel time for I-95 NB EL for (a) AM peak, (b) MD, (c) PM1, (d) PM2, (e) APM, (f) MN, and (g) all time periods.



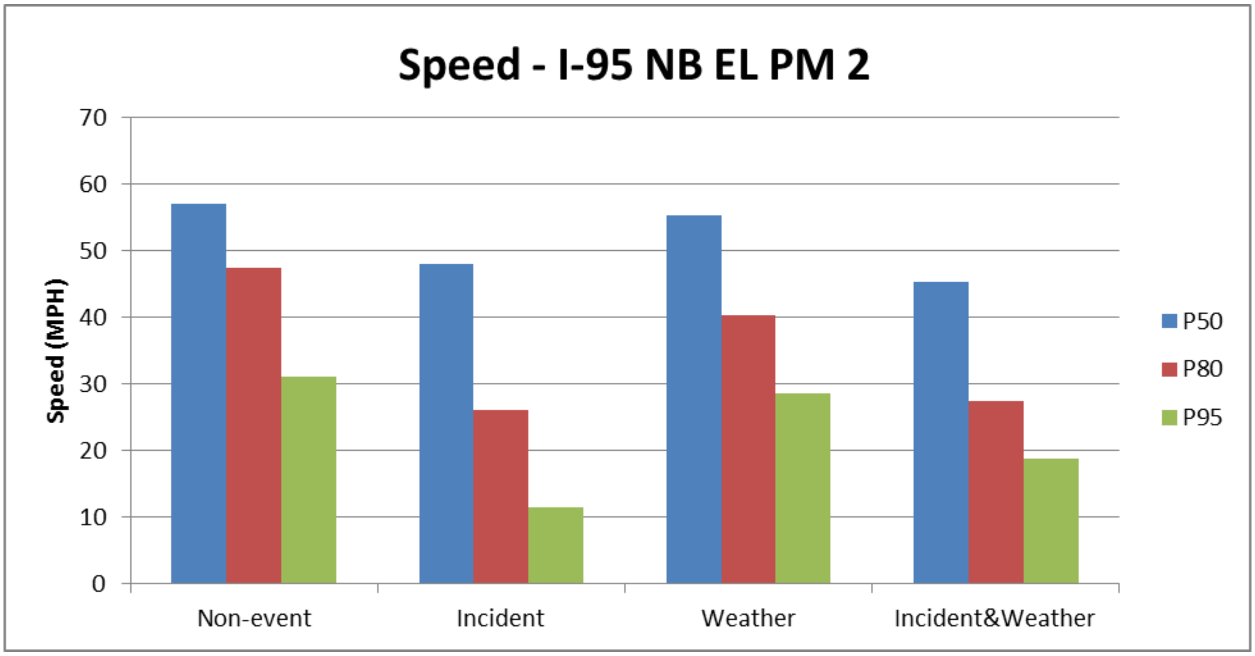
(a)


Speed - I-95 NB EL MD
Speed (MPH)
70
60
50
40
30
20
10
0
Non-event
Incident
Weather
Incident&Weather
P50
P80
P95

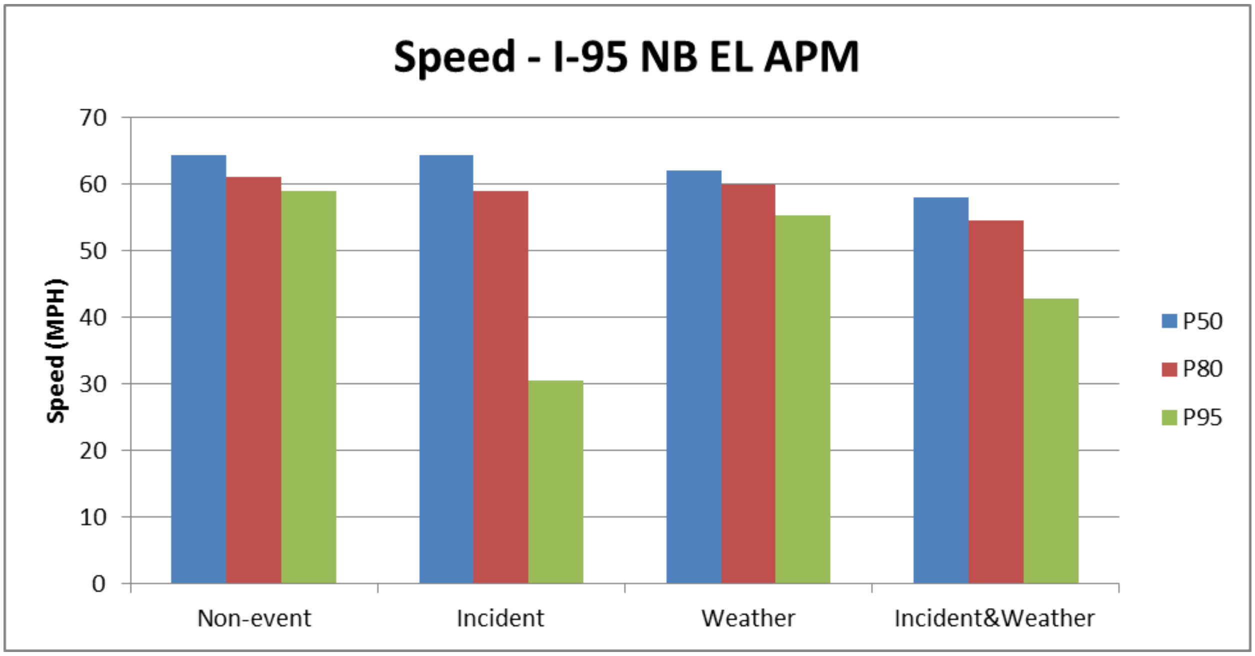
(b)


Speed - I-95 NB EL PM 1
Speed (MPH)
70
60
50
40
30
20
10
0
Non-event
Incident
Weather
Incident&Weather
P50
P80
P95

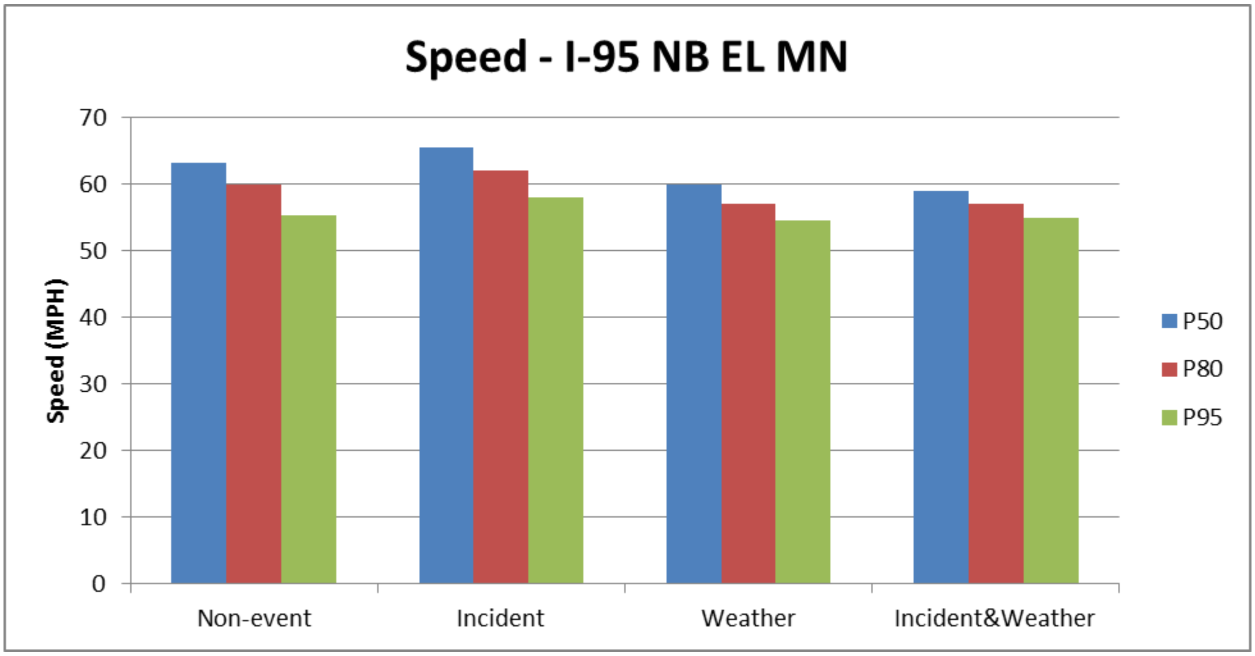
(c)


Speed - I-95 NB EL PM 2
Speed (MPH)
70
60
50
40
30
20
10
0
Non-event
Incident
Weather
Incident&Weather
P50
P80
P95

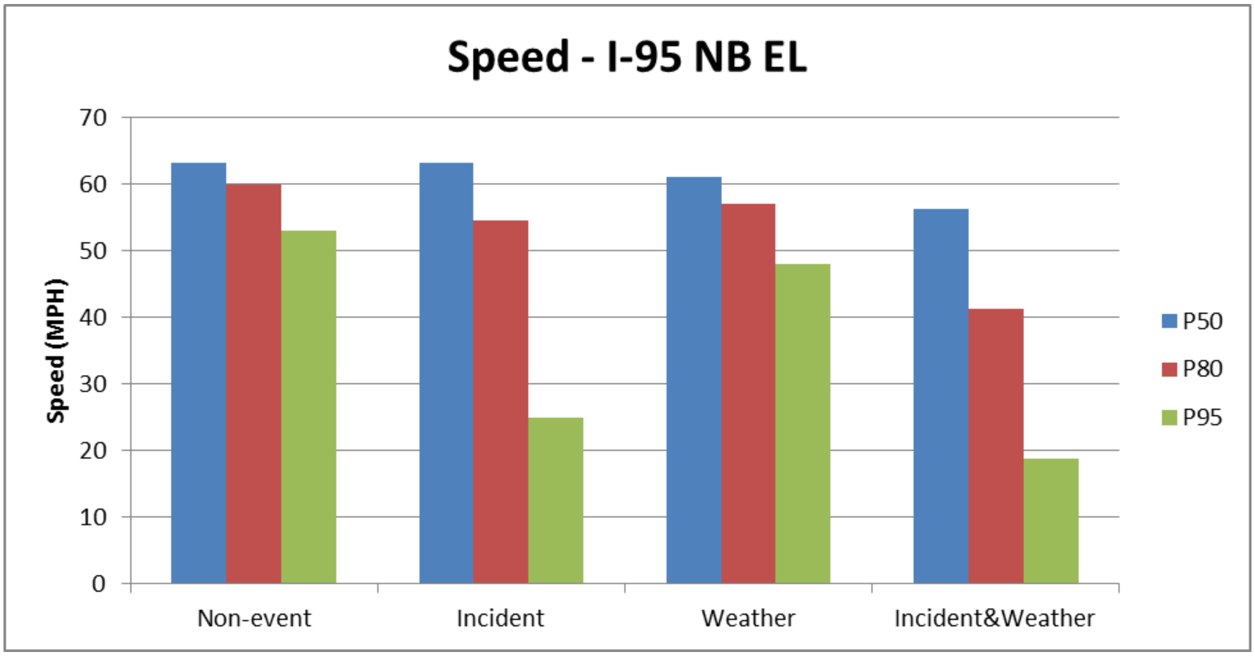
(d)


Speed - I-95 NB EL APM
Speed (MPH)
70
60
50
40
30
20
10
0
Non-event
Incident
Weather
Incident&Weather
P50
P80
P95

(e)

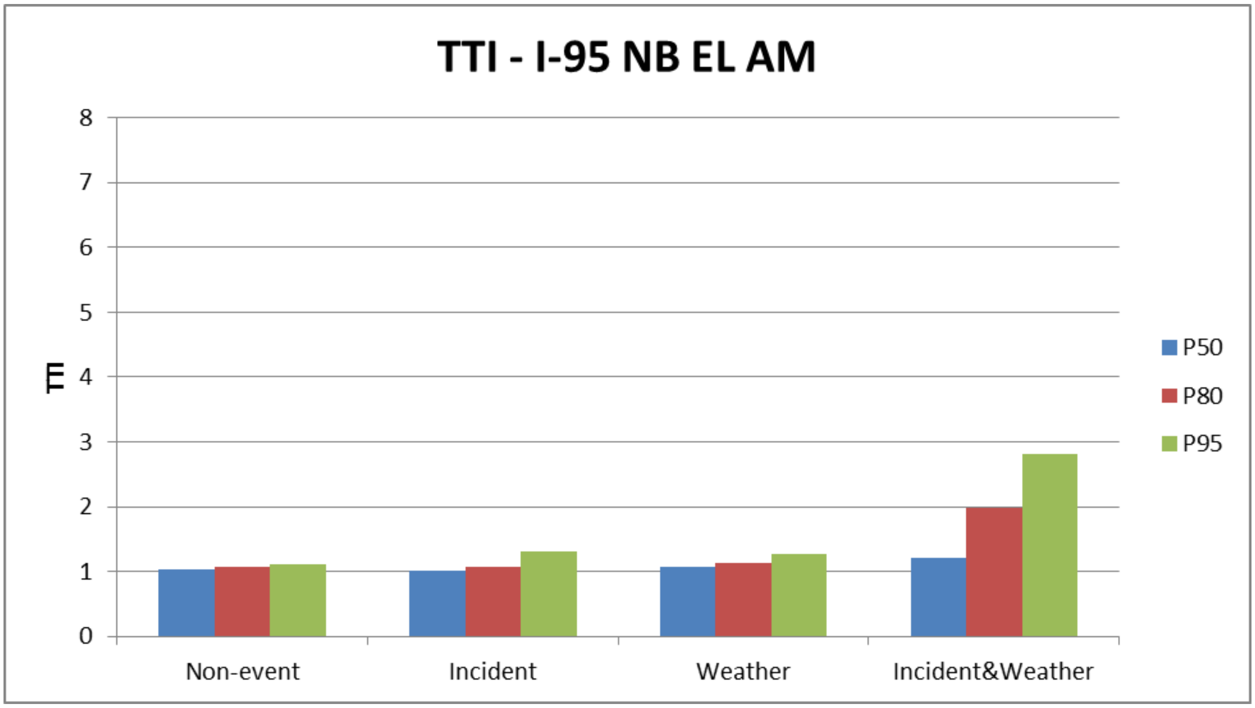


(f)

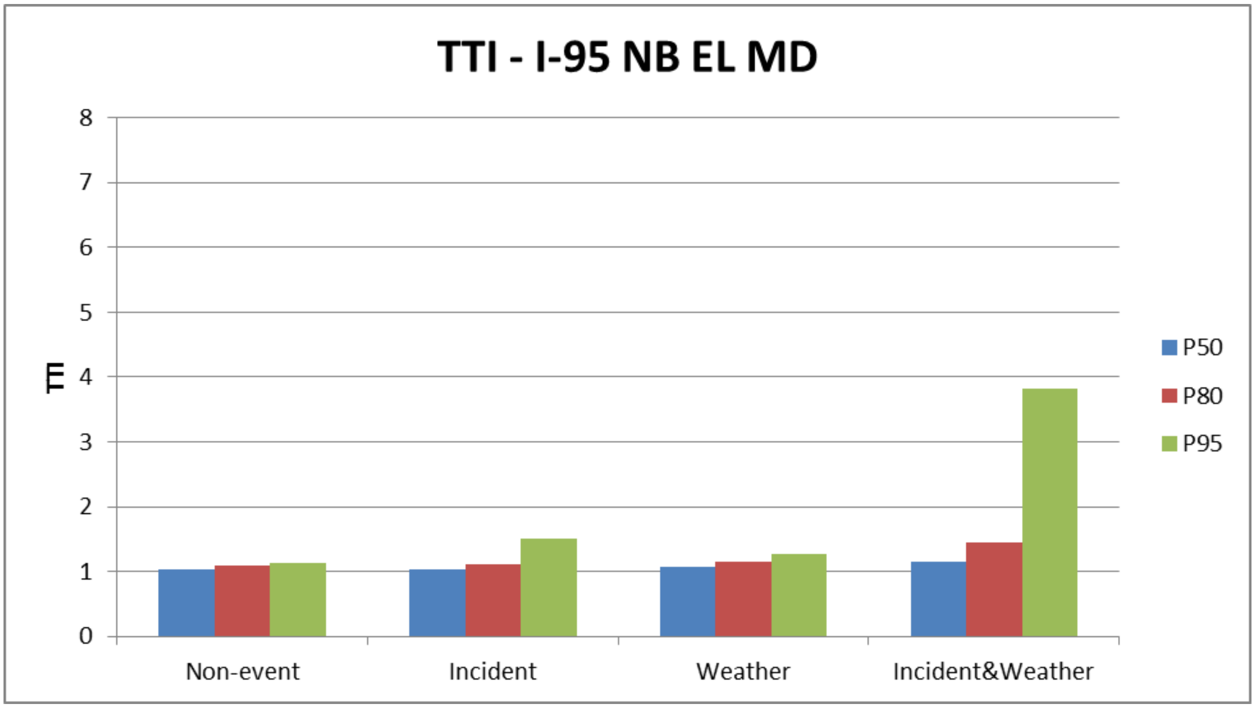


(g)

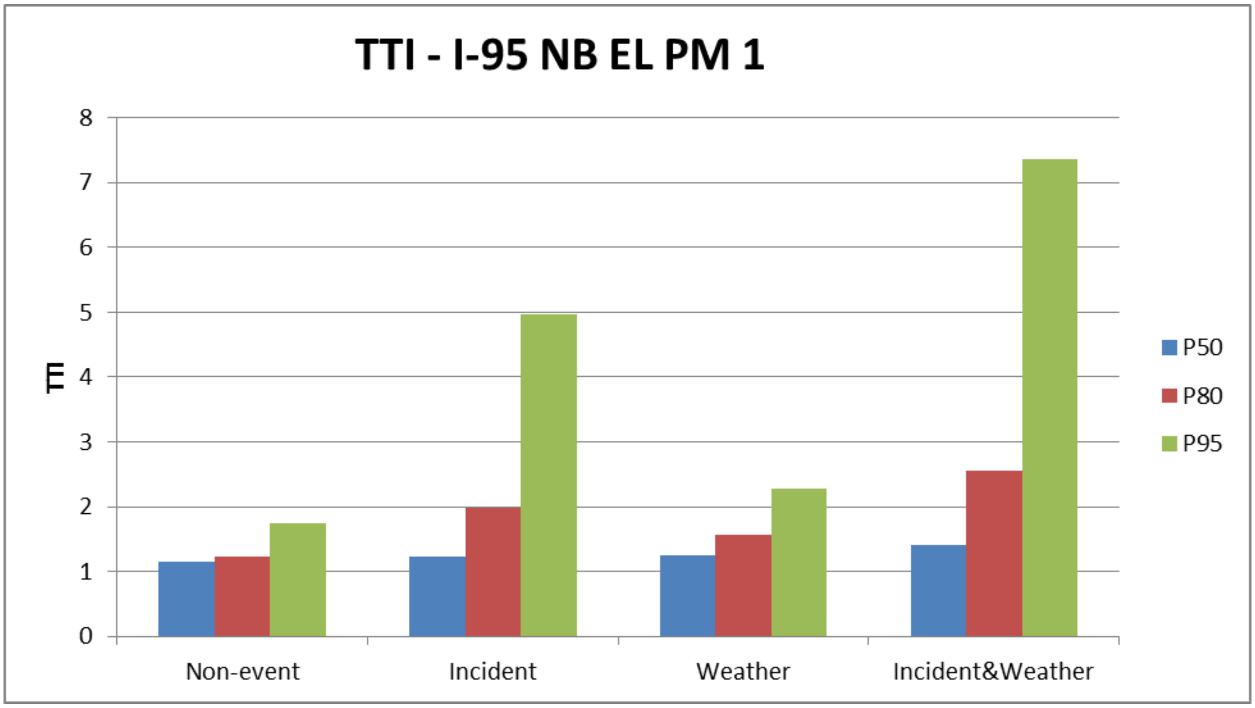
Figure B.20. Speed for I-95 NB EL for (a) AM peak, (b) MD, (c) PM1, (d) PM2, (e) APM, (f) MN, and (g) all time periods.


TTI - I-95 NB EL AM
TTI
8
7
6
5
4
3
2
1
0
Non-event
Incident
Weather
Incident&Weather
P50
P80
P95

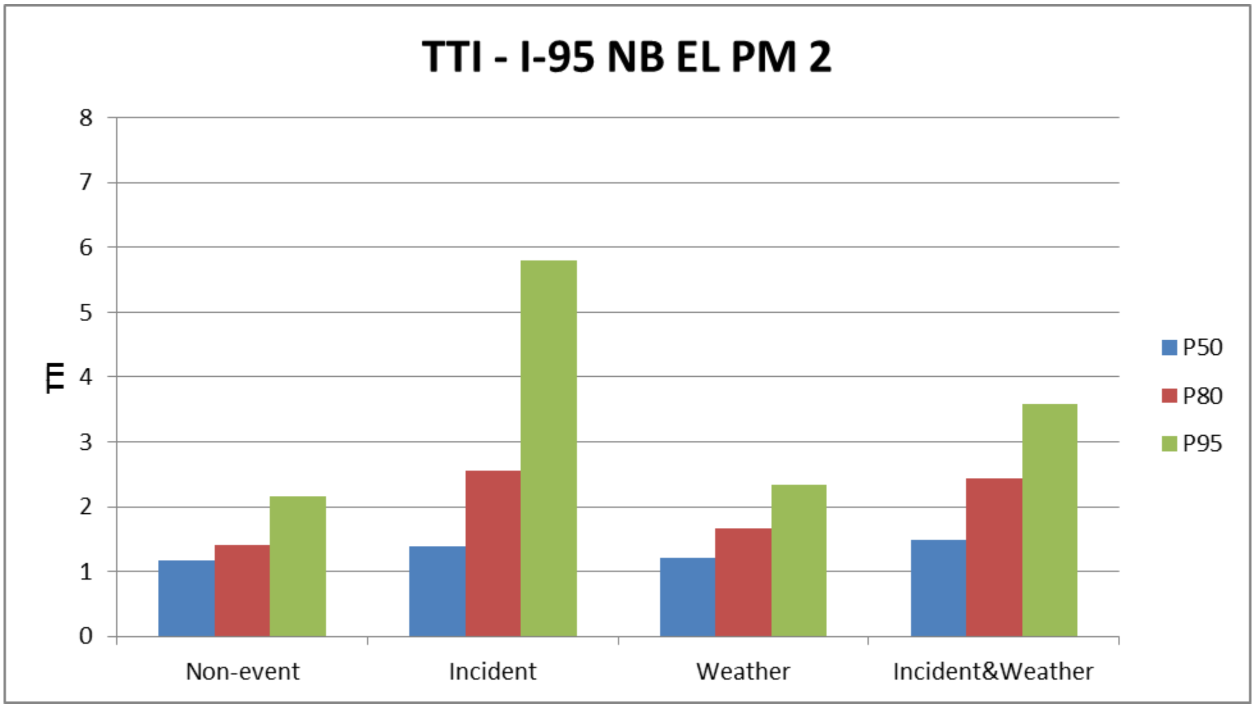
(a)


TTI - I-95 NB EL MD
TTI
8
7
6
5
4
3
2
1
0
Non-event
Incident
Weather
Incident&Weather
P50
P80
P95

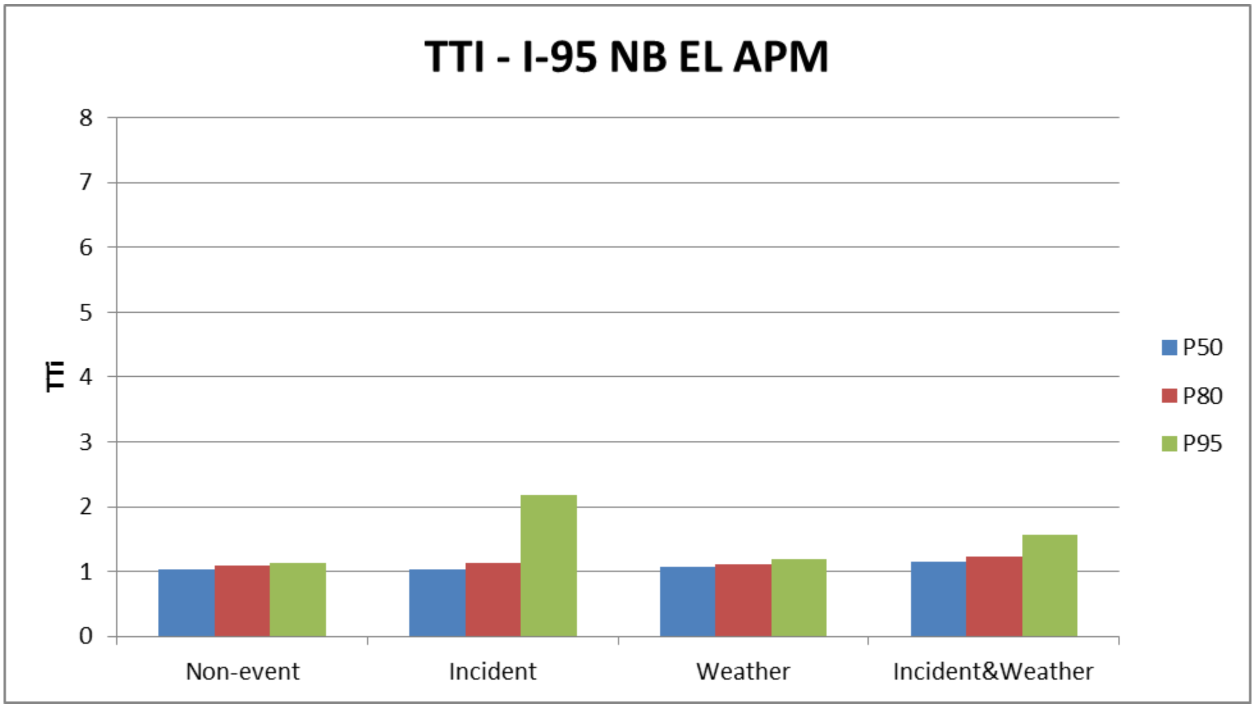
(b)


TTI - I-95 NB EL PM 1
TTI
8
7
6
5
4
3
2
1
0
Non-event
Incident
Weather
Incident&Weather
P50
P80
P95

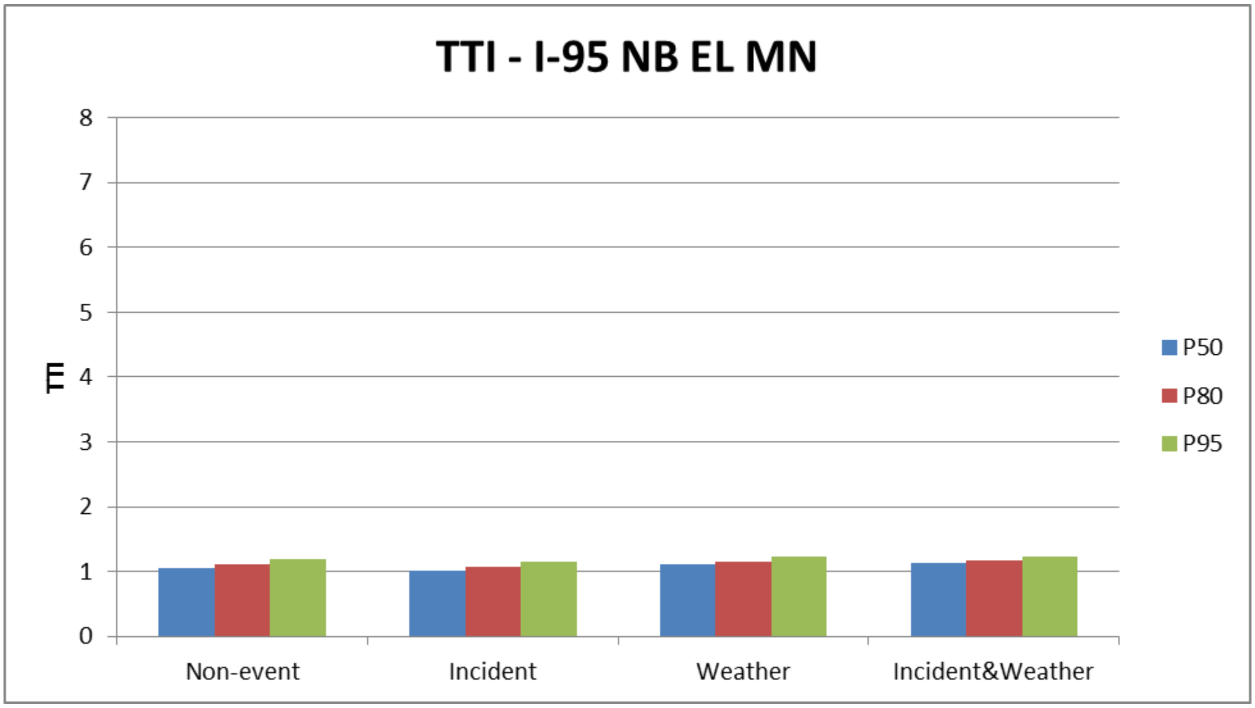
(c)


TTI - I-95 NB EL PM 2
TTI
8
7
6
5
4
3
2
1
0
Non-event
Incident
Weather
Incident&Weather
P50
P80
P95

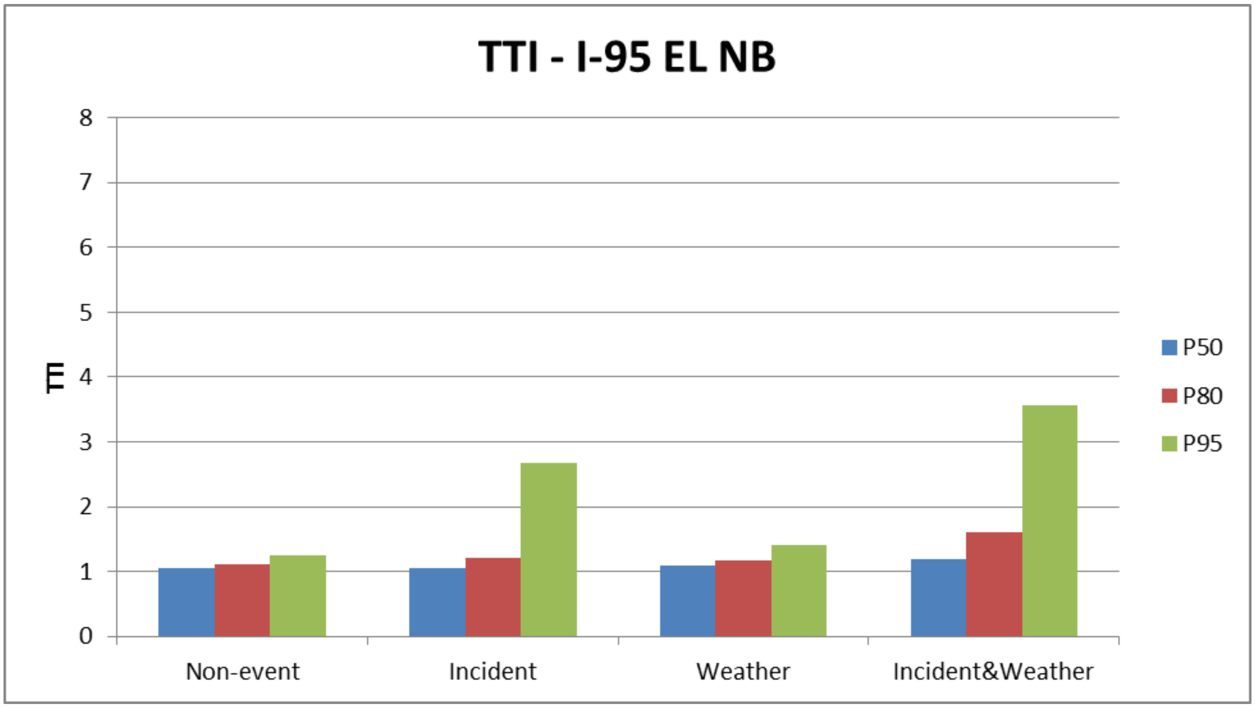
(d)


TTI - I-95 NB EL APM
TTI
0
1
2
3
4
5
6
7
8
Non-event
Incident
Weather
Incident&Weather
P50
P80
P95

(e)


TTI - I-95 NB EL MN
TTI
0
1
2
3
4
5
6
7
8
Non-event
Incident
Weather
Incident&Weather
P50
P80
P95

(f)



(g)

Figure B.21. TTI for I-95 NB EL for (a) AM peak, (b) MD, (c) PM1, (d) PM2, (e) APM, (f) MN, and (g) all time periods.

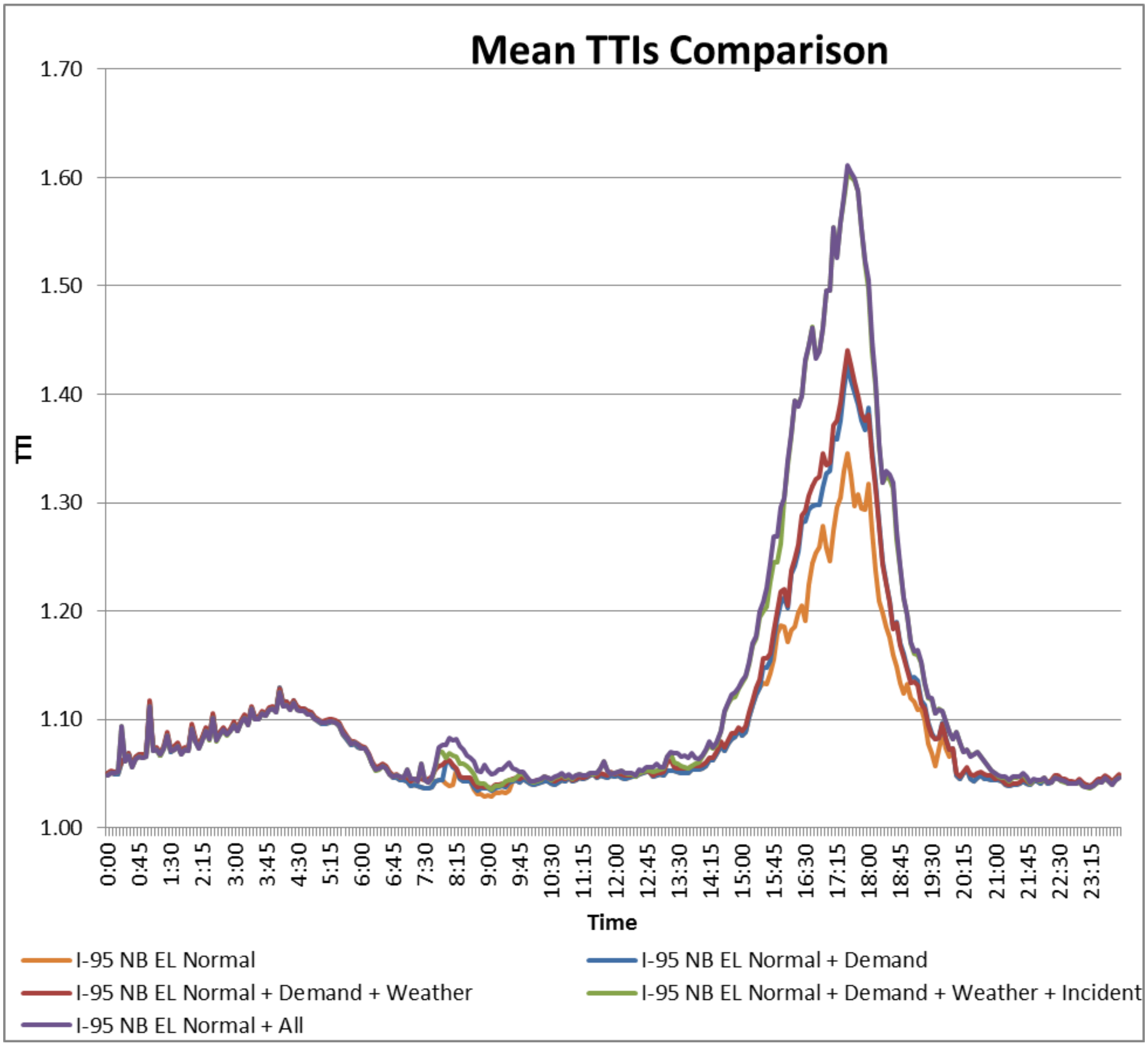


Figure B.22. Mean TTIs comparison for I-95 NB EL.

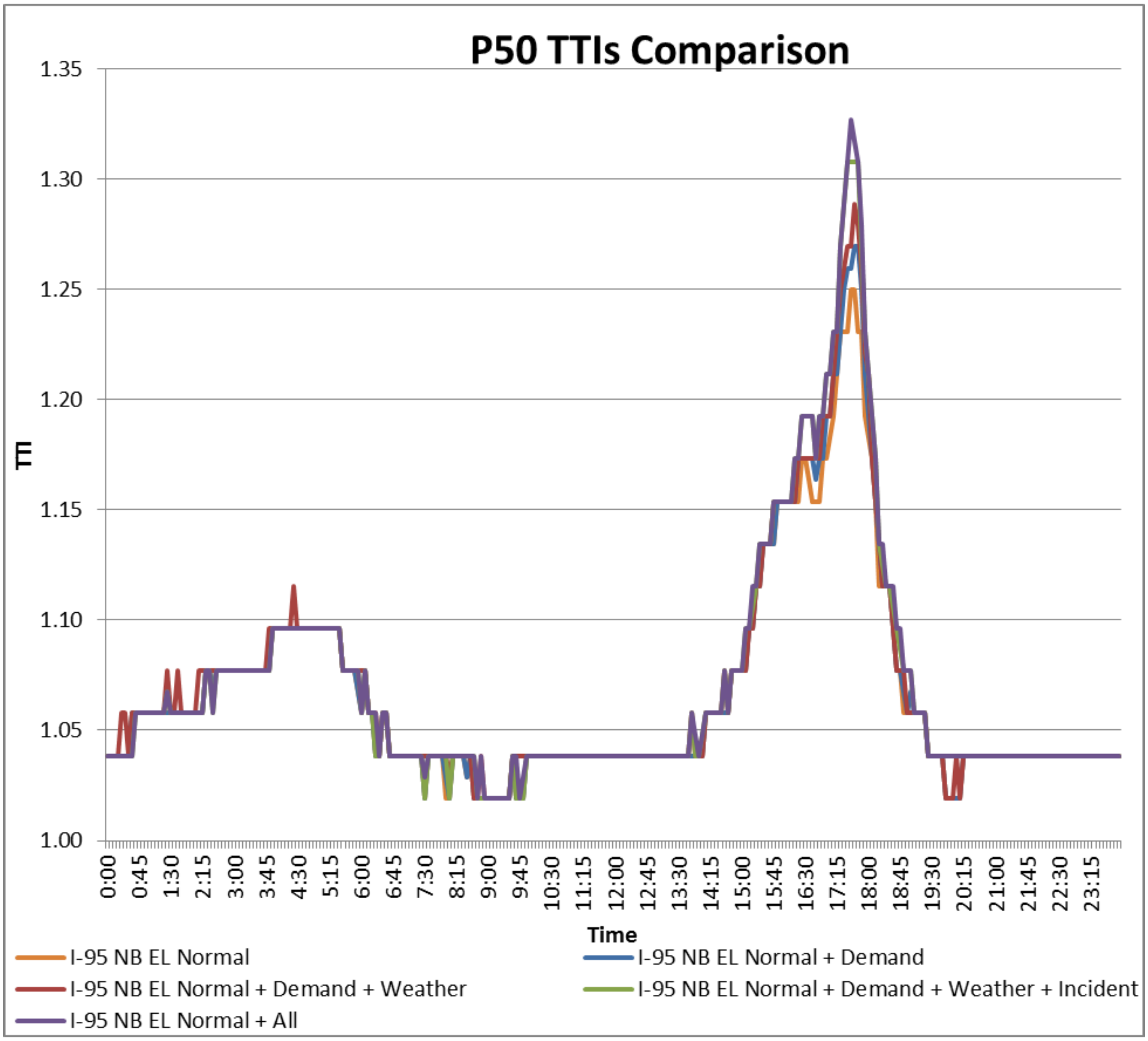


Figure B.23. 50th percentile TTIs comparison for I-95 NB EL.

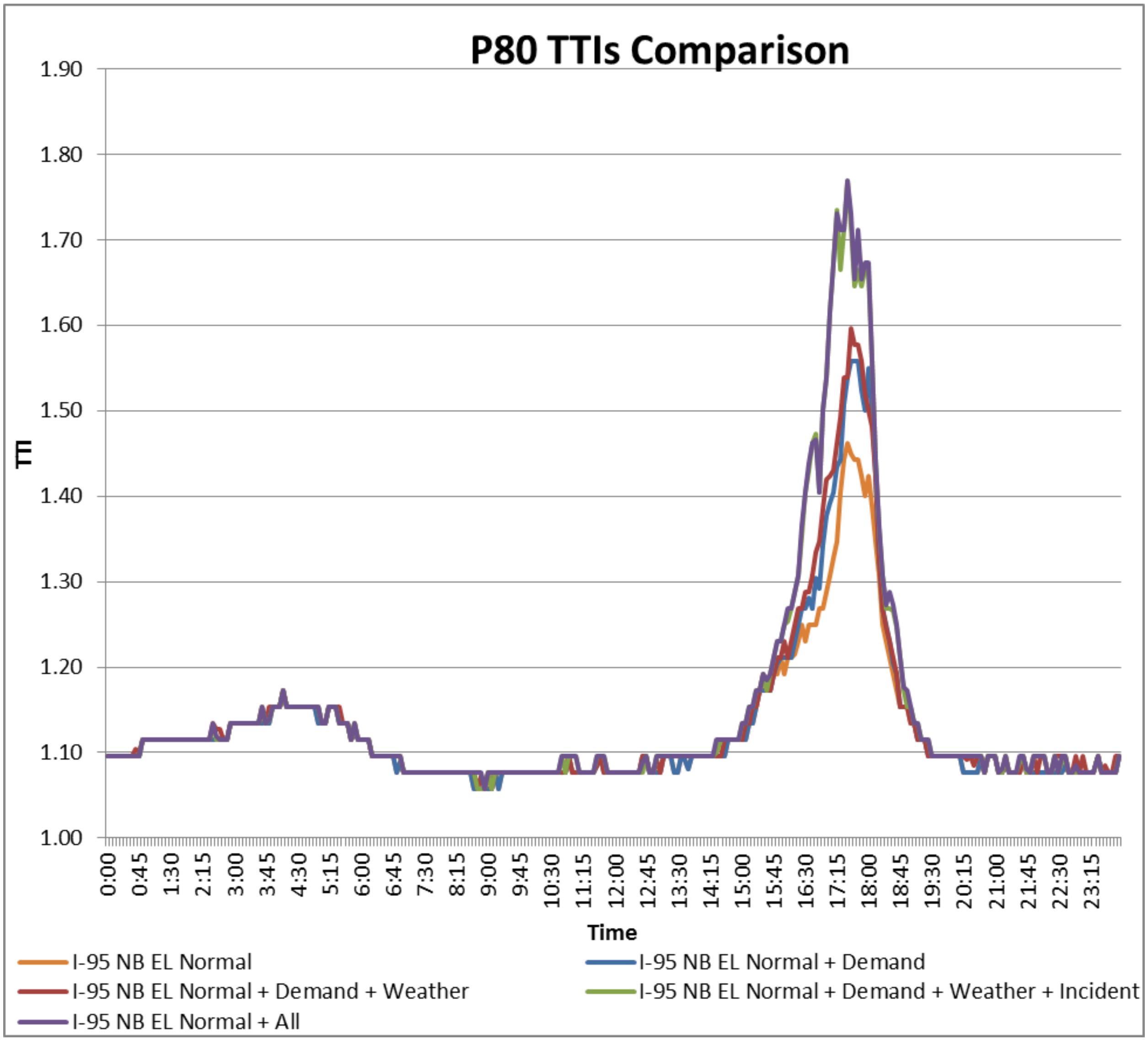


Figure B.24. 80th percentile TTIs comparison for I-95 NB EL.

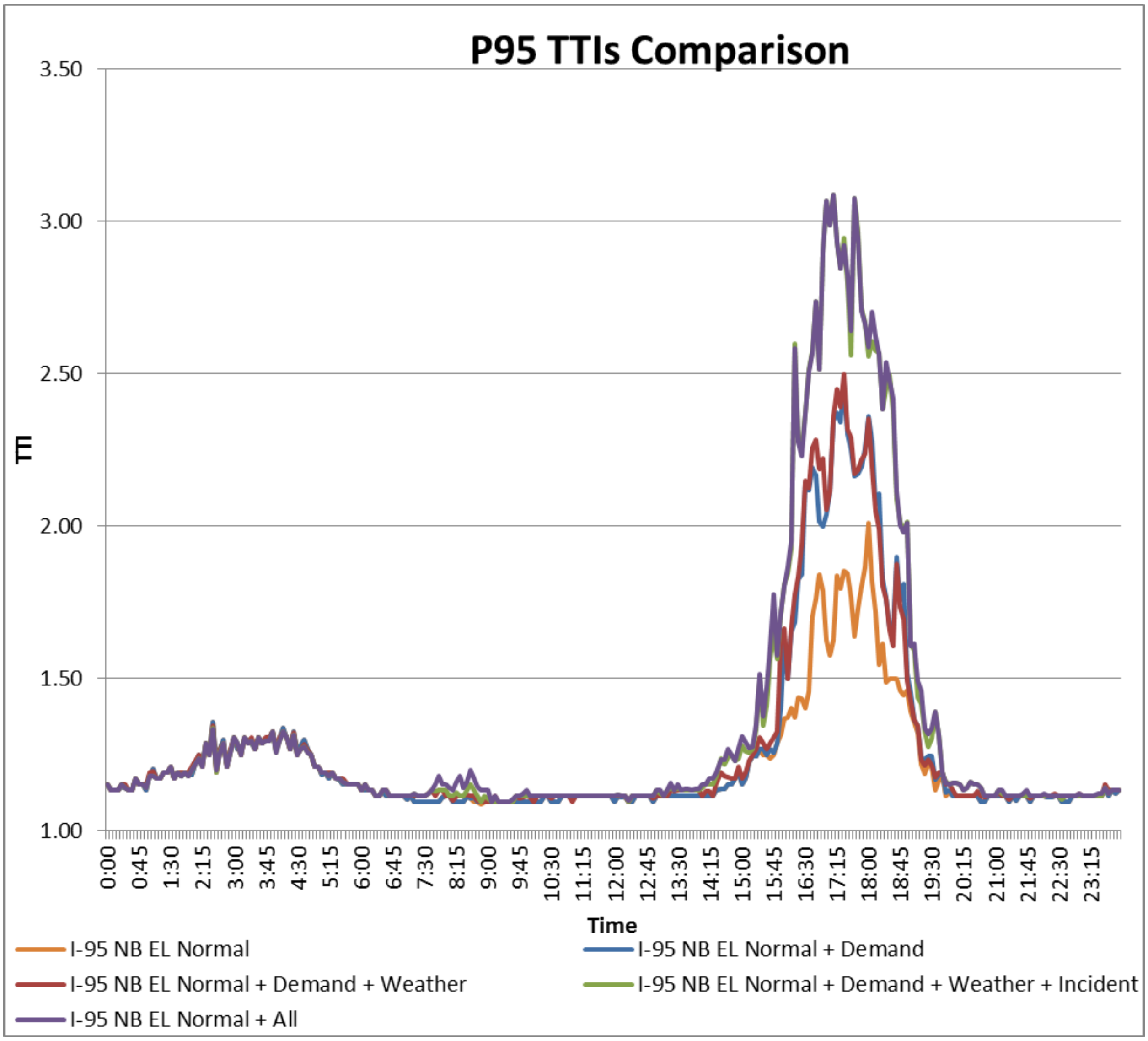
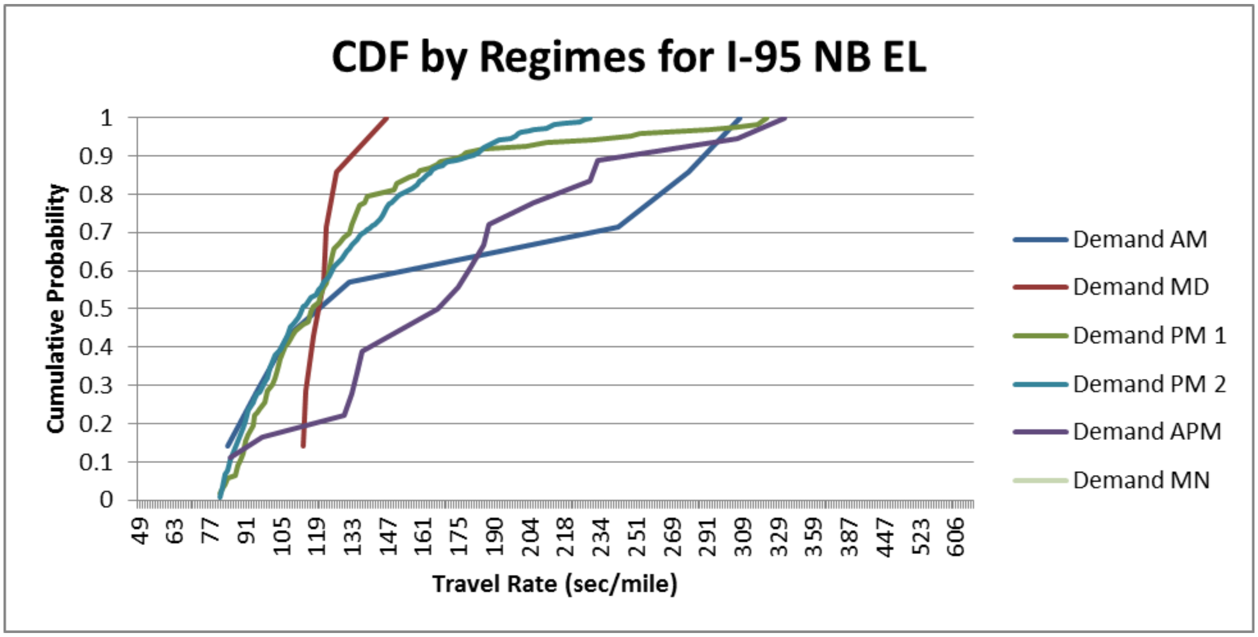


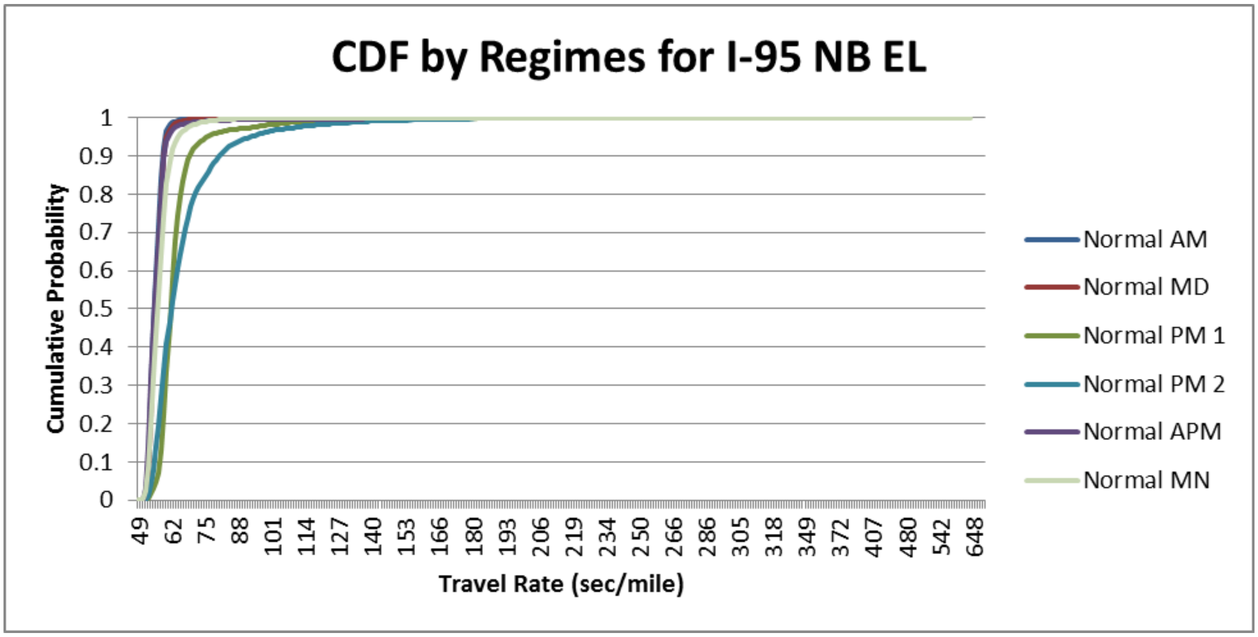
Figure B.25. 95th percentile TTIs comparison for I-95 NB EL.

B.3 Contributions of Normal versus High Demands

Further analysis of the no-event periods, shown in Figure B.26 and Tables B.4 to B.6, indicated that during the PM period, the period with high demand had significantly higher unreliable conditions, as indicated by the CDF curves, and that the overall contribution of high demand to unreliability was comparable to that of normal demand, although the high demand occurred at a much lower frequency than the normal demand. This finding reflects the high contribution of single-demand events, again suggesting the need for more aggressive strategies during these conditions.



(a)



(b)

Figure B.26. CDF by regimes for I-95 NB EL for (a) demand and (b) normal conditions.

Table B.4. Percentage of Occurrence

Time Period	Demand	Normal	Total
AM	0.011%	12%	12%
MD	0.011%	26%	26%
PM1	0.195%	6%	6%
PM2	0.481%	7%	8%
APM	0.029%	12%	12%
MN	0.000%	35%	35%

Table B.5. Percentage of Severity

Time Period	Demand	Normal	Total
AM	37%	0.04%	37%
MD	8%	0.04%	8%
PM1	13%	0.49%	13%
PM2	10%	0.77%	11%
APM	31%	0.19%	31%
MN	N/A	0.11%	0%

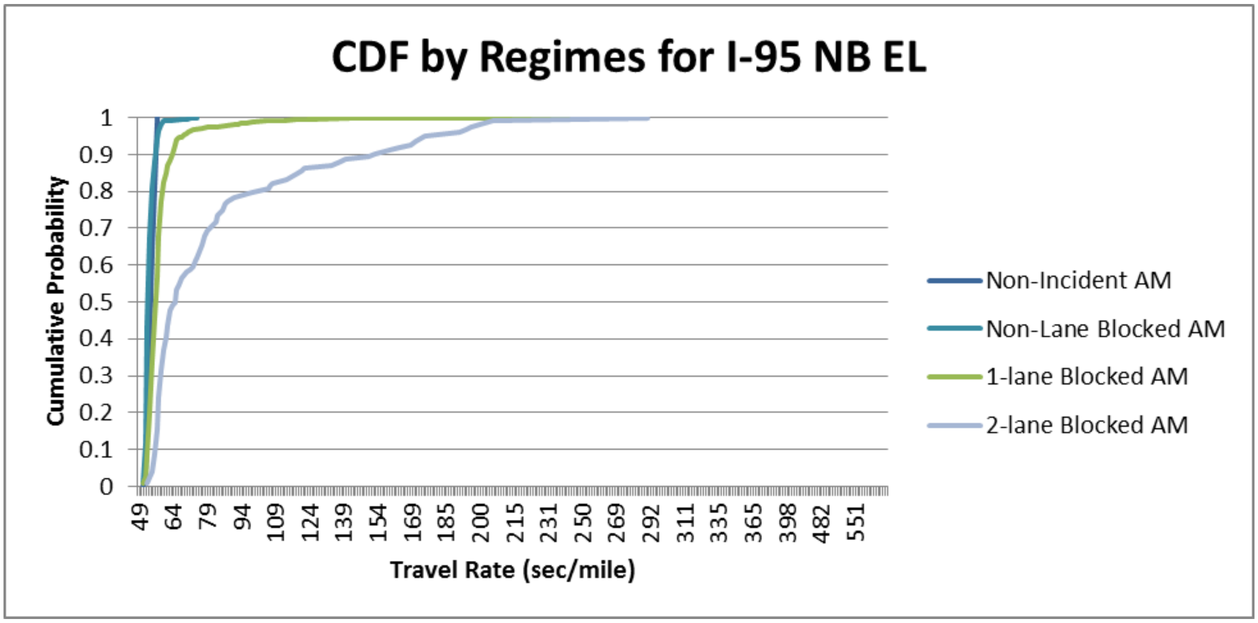
Table B.6. Percentage of Unreliability Contribution

Time Period	Demand	Normal	Total
AM	2%	2%	3%
MD	0.4%	4%	4%
PM1	10%	11%	21%
PM2	19%	23%	42%
APM	4%	10%	13%
MN	N/A	16%	16%

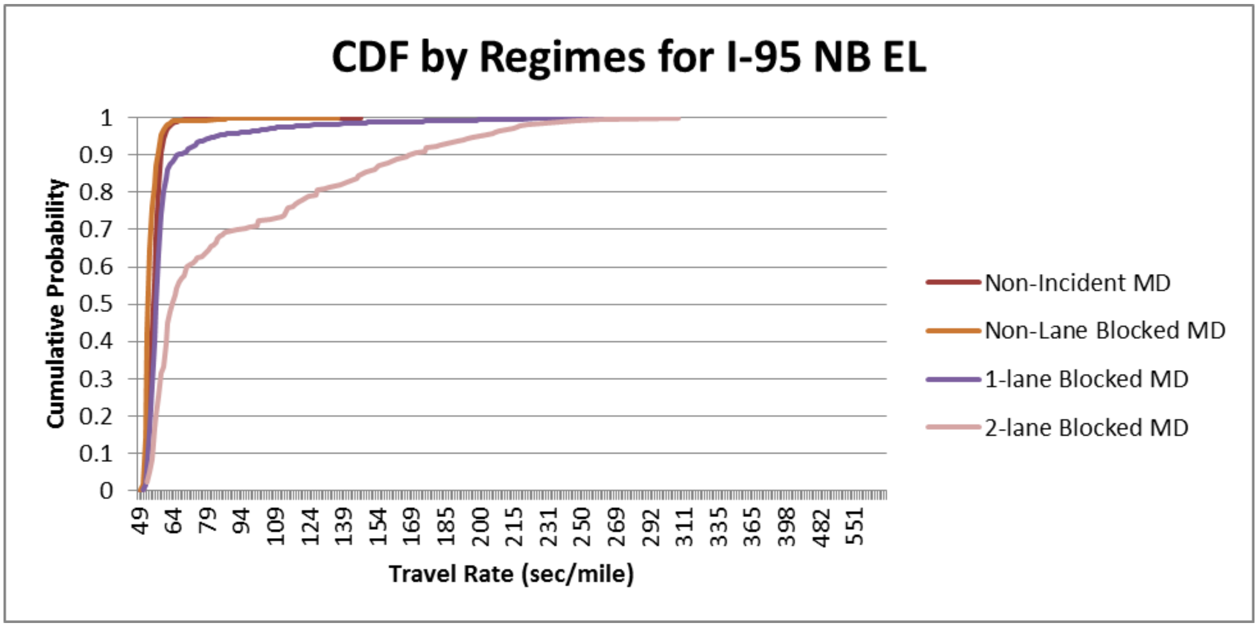
B.4 Impact of Incident Severity

To differentiate the impacts of lane blockages on travel time reliability, the time intervals with incidents were further classified into different regimes depending on the number of lanes blocked. The corresponding results of CDF and unreliability contributions are presented in Figure B.27 and Tables B.7 to B.9, which show that one-lane–blocking incidents had a moderate NSV, but due to a relatively high occurrence, they contributed the most to unreliability. Compared to one-lane–blocking incidents, 2+-lane–blocking incidents had a high NSV but a low occurrence, which resulted in comparable contributions to unreliability as one-lane–blocking incidents in PM2.

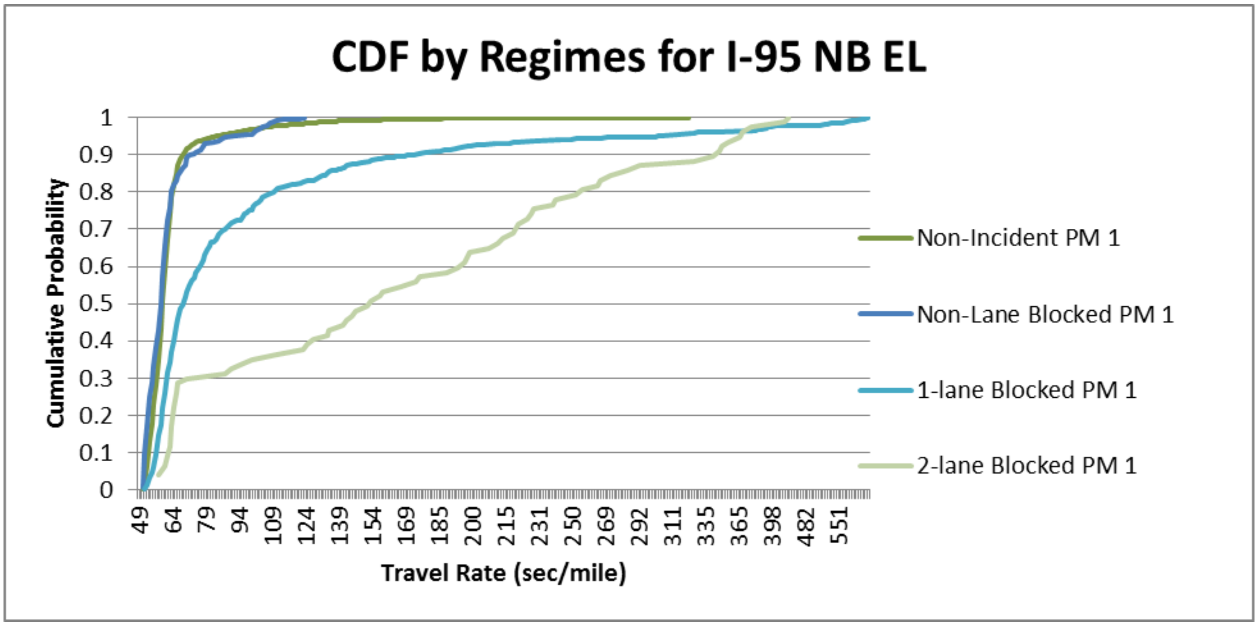
Figure B.28 to Figure B.31 present another way to examine the impacts of lane-blocking incidents. The major impacts within the incident category were found to be the impacts of blocking incidents during the relatively congested AM peak period and heavily congested PM peak period. Figures B.32 to B.35 indicate that among different incident durations, the travel time reliability along the I-95 EL was mainly affected by incidents with duration less than 30 minutes due to the high frequency of these events.



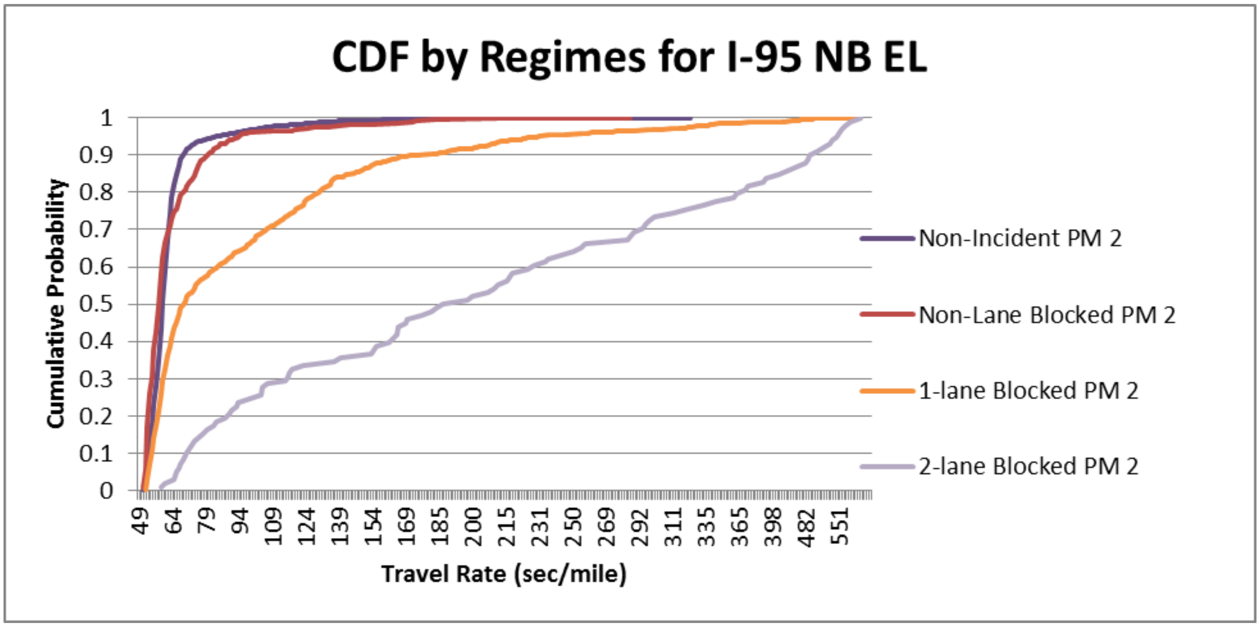
(a)


CDF by Regimes for I-95 NB EL
Cumulative Probability
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
49
64
79
94
109
124
139
154
169
185
200
215
231
250
269
292
311
335
365
398
482
551
Travel Rate (sec/mile)
Non-Incident MD
Non-Lane Blocked MD
1-lane Blocked MD
2-lane Blocked MD

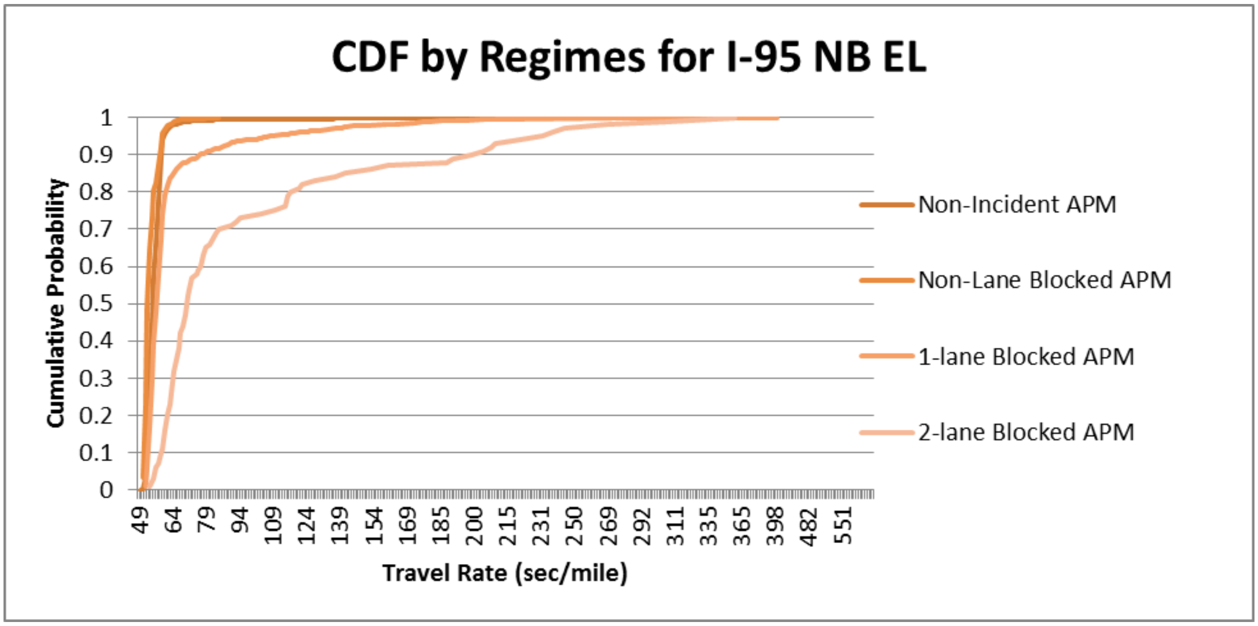
(b)


CDF by Regimes for I-95 NB EL
Cumulative Probability
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
49
64
79
94
109
124
139
154
169
185
200
215
231
250
269
292
311
335
365
398
482
551
Travel Rate (sec/mile)
Non-Incident PM 1
Non-Lane Blocked PM 1
1-lane Blocked PM 1
2-lane Blocked PM 1

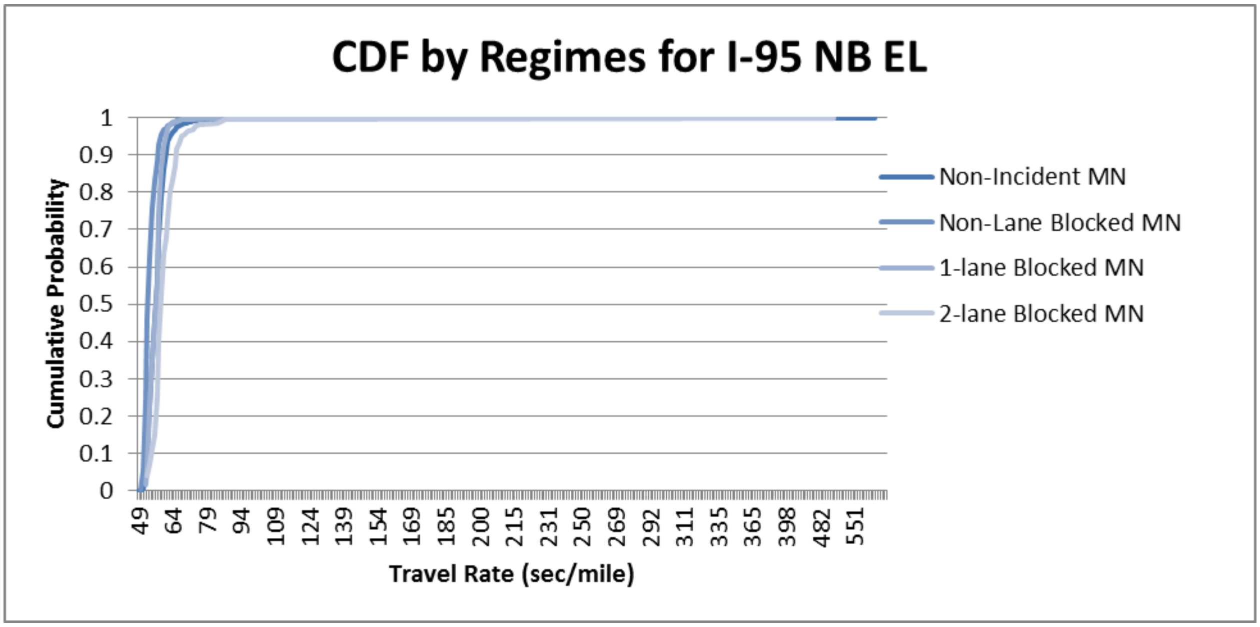
(c)


CDF by Regimes for I-95 NB EL
Cumulative Probability
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
49
64
79
94
109
124
139
154
169
185
200
215
231
250
269
292
311
335
365
398
482
551
Travel Rate (sec/mile)
Non-Incident PM 2
Non-Lane Blocked PM 2
1-lane Blocked PM 2
2-lane Blocked PM 2

(d)


CDF by Regimes for I-95 NB EL
Cumulative Probability
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
49
64
79
94
109
124
139
154
169
185
200
215
231
250
269
292
311
335
365
398
482
551
Travel Rate (sec/mile)
Non-Incident APM
Non-Lane Blocked APM
1-lane Blocked APM
2-lane Blocked APM

(e)



(f)

Figure B.27. CDF by regimes for I-95 NB EL for (a) AM peak, (b) MD, (c) PM1, (d) PM2, (e) APM, and (f) MN periods.

Table B.7. Percentage of Occurrence

Time Period	Nonincident	0 Lanes Blocked	1 Lane Blocked	2 Lanes Blocked	3+ Lanes Blocked
AM	11.2%	0.5%	0.6%	0.1%	0.0%
MD	23.9%	1.2%	1.9%	0.2%	0.0%
PM1	5.2%	0.3%	0.6%	0.1%	0.0%
PM2	6.9%	0.4%	0.9%	0.1%	0.0%
APM	11.0%	0.6%	0.7%	0.1%	0.0%
MN	31.4%	1.3%	0.4%	0.1%	0.0%

Table B.8. Percentage of Severity

Time Period	Nonincident	0 Lanes Blocked	1 Lane Blocked	2 Lanes Blocked	3+ Lanes Blocked
AM	0.1%	0.1%	0.2%	2.5%	0.0%
MD	0.0%	0.1%	0.3%	3.6%	0.0%
PM1	0.4%	0.2%	11.3%	22.0%	0.0%
PM2	0.5%	0.6%	7.0%	44.8%	0.0%
APM	0.1%	0.1%	0.8%	4.9%	0.0%
MN	0.1%	0.1%	0.0%	1.6%	0.0%

Table B.9 Percentage of Unreliability Contribution

Time Period	Nonincident	0 Lanes Blocked	1 Lane Blocked	2 Lanes Blocked	3+ Lanes Blocked
AM	2.5%	0.1%	0.4%	1.2%	0.0%
MD	3.2%	0.3%	2.7%	2.8%	0.0%
PM1	7.6%	0.2%	28.9%	7.2%	0.0%
PM2	14.5%	0.9%	24.8%	24.3%	0.0%
APM	6.1%	0.1%	2.5%	2.2%	0.0%
MN	6.7%	0.3%	0.0%	1.0%	0.0%

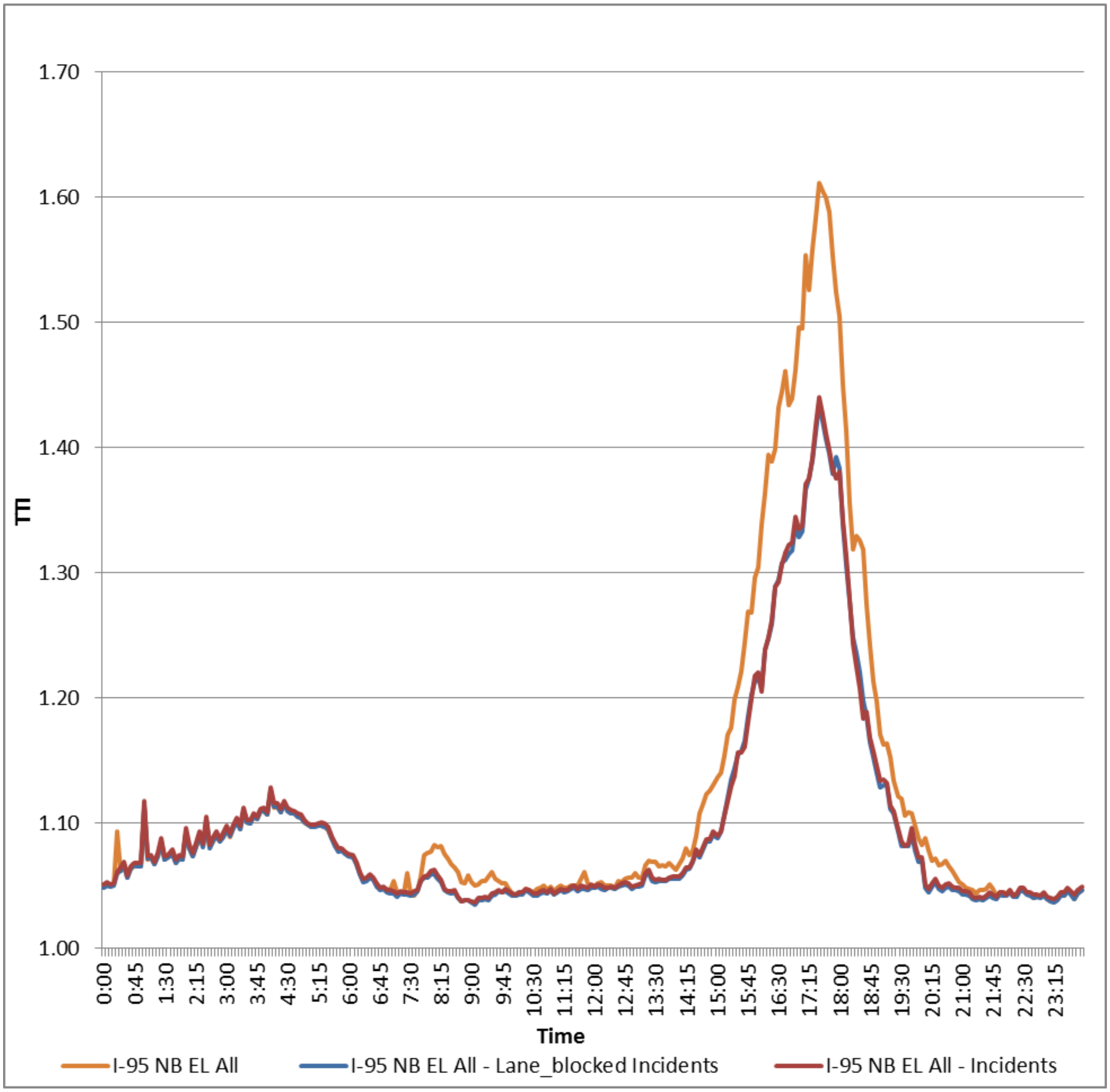


Figure B.28. Mean TTIs comparison for I-95 NB EL.

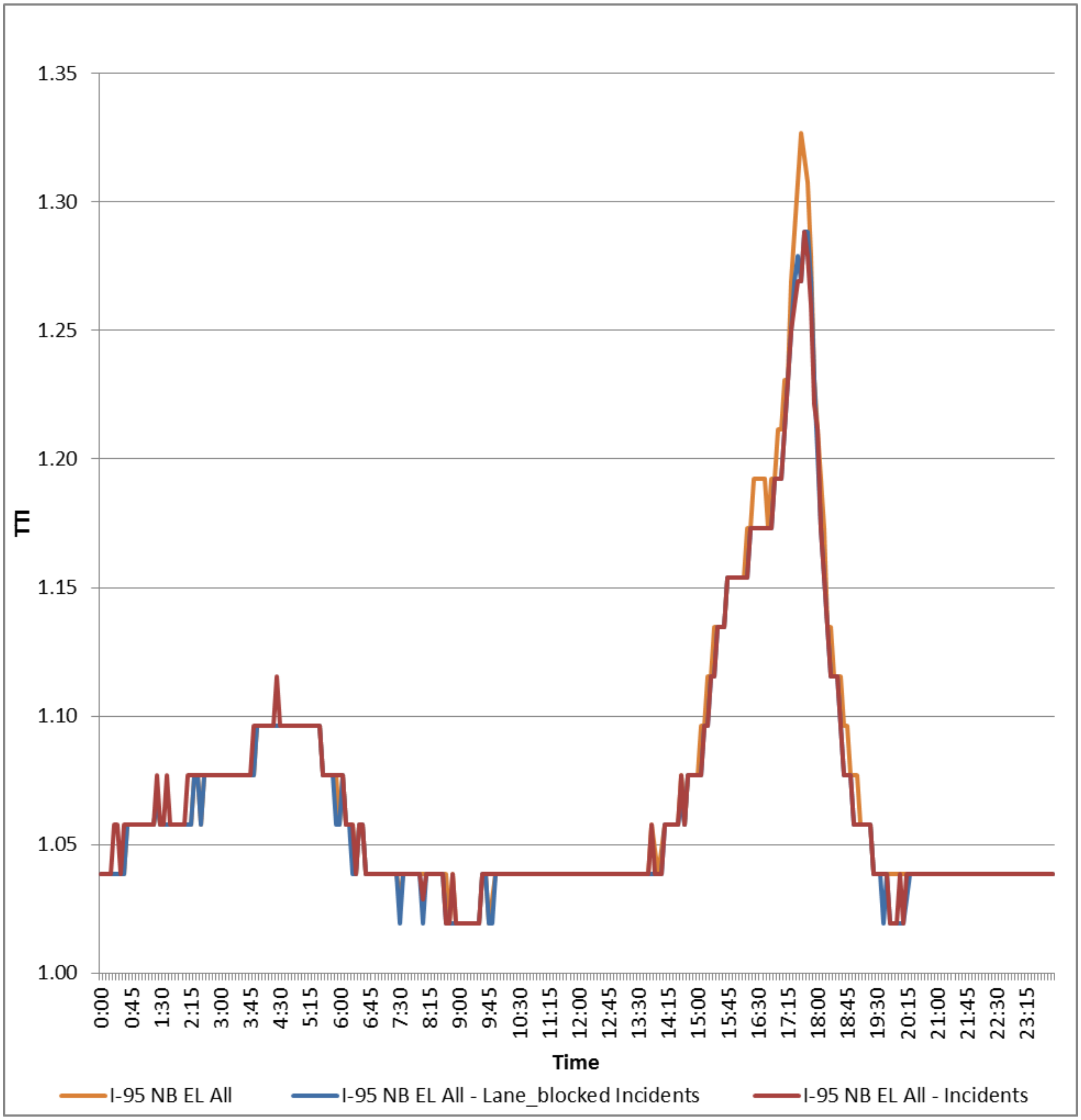


Figure B.29. 50th percentile TTIs comparison for I-95 NB EL.

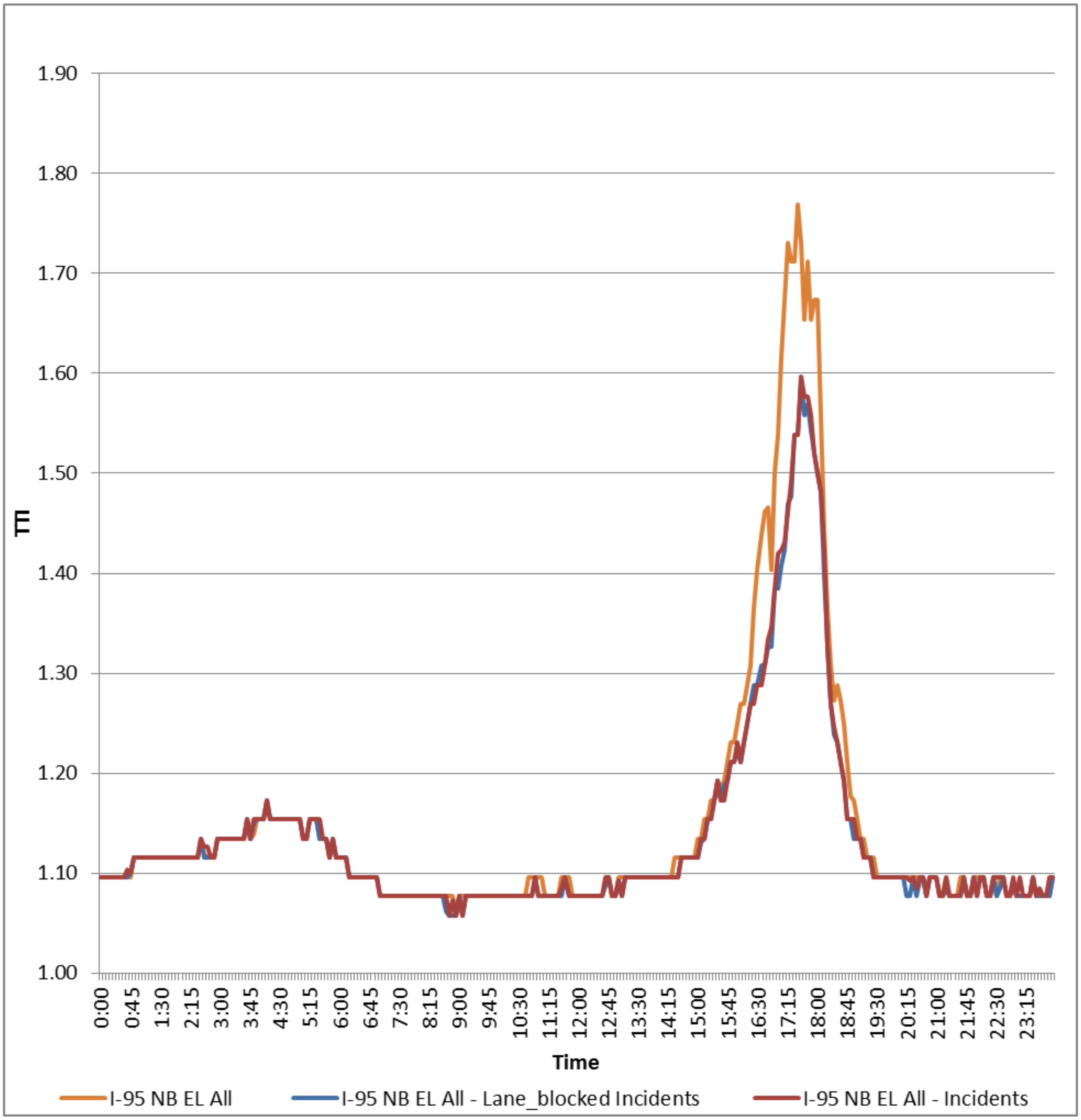


Figure B.30. 80th percentile TTIs comparison for I-95 NB EL.

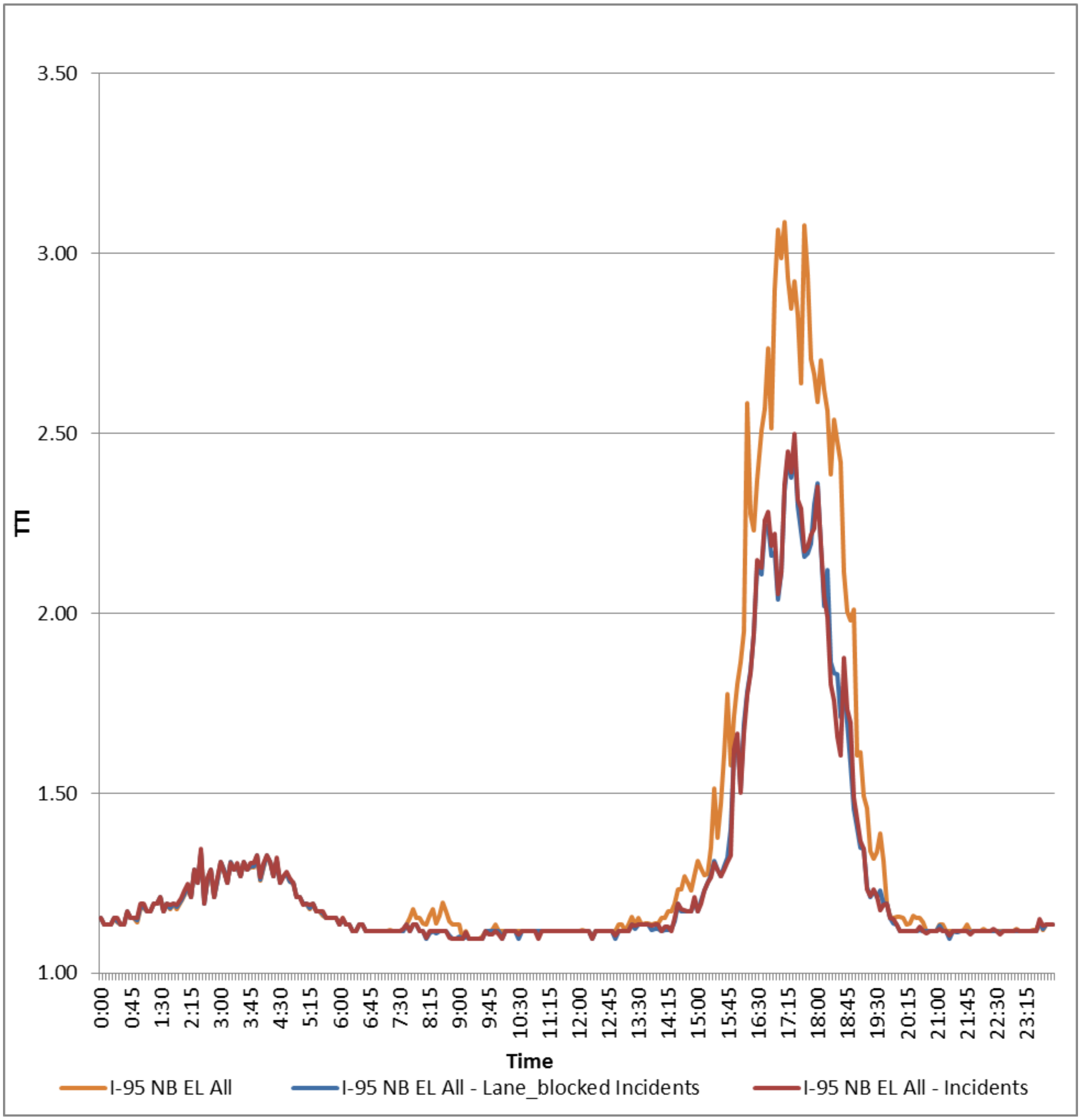


Figure B.31. 95th percentile TTIs comparison for I-95 NB EL.

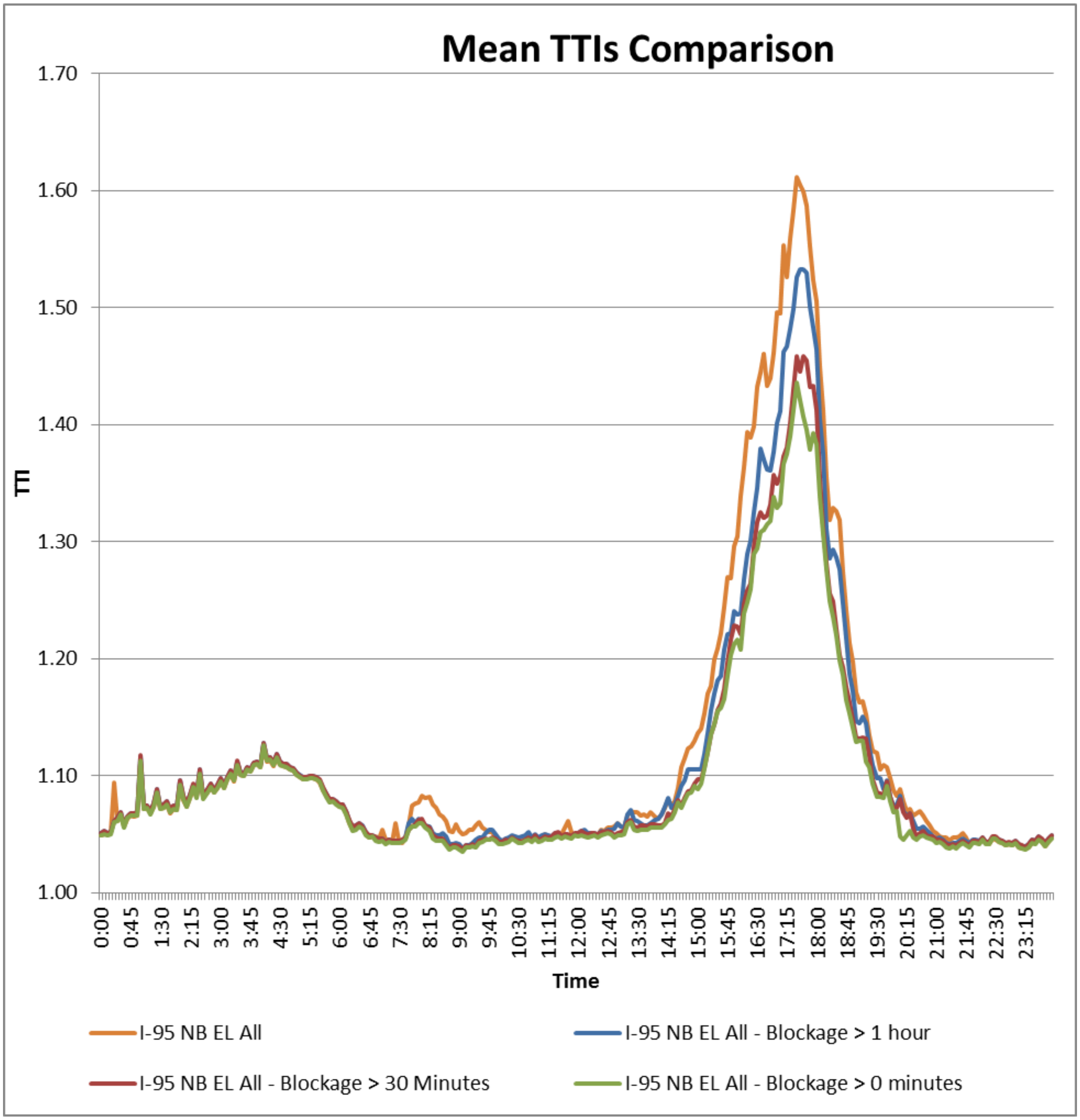


Figure B.32. Impacts of incident duration on mean TTI for I-95 NB EL.

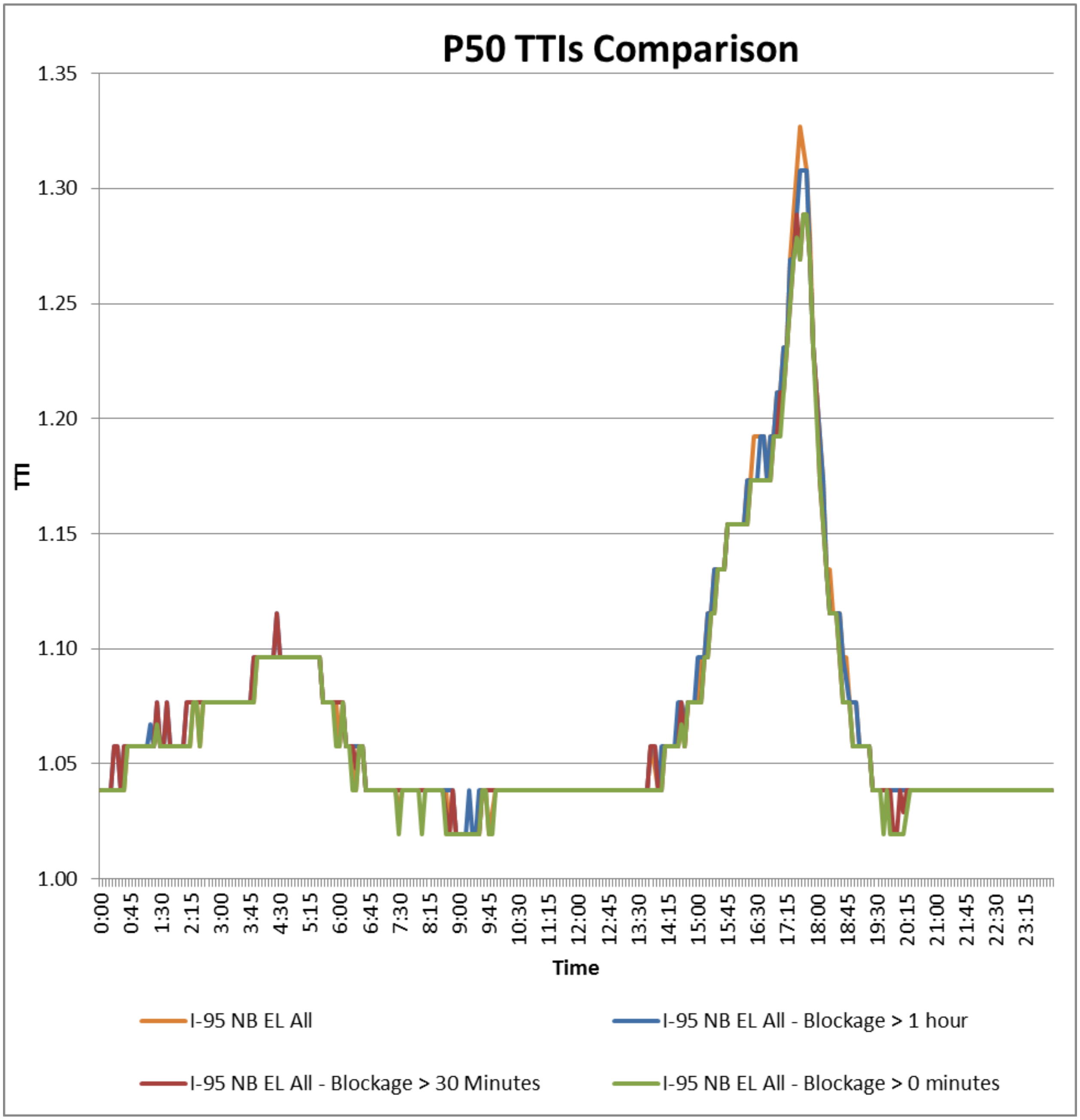


Figure B.33. Impacts of incident duration on 50th percentile TTI for I-95 NB EL.

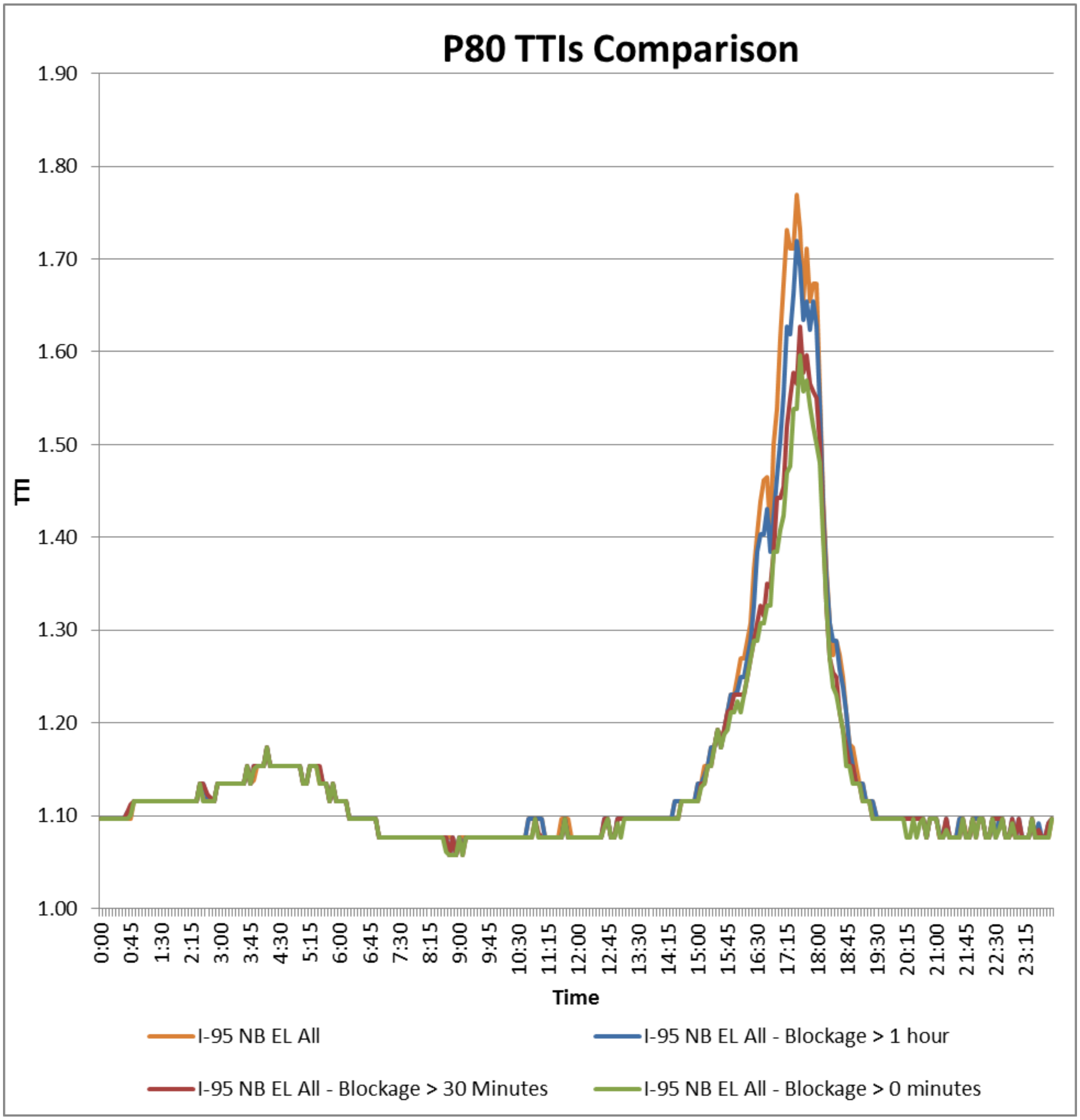


Figure B.34. Impacts of incident duration on 80th percentile TTI for I-95 NB EL.

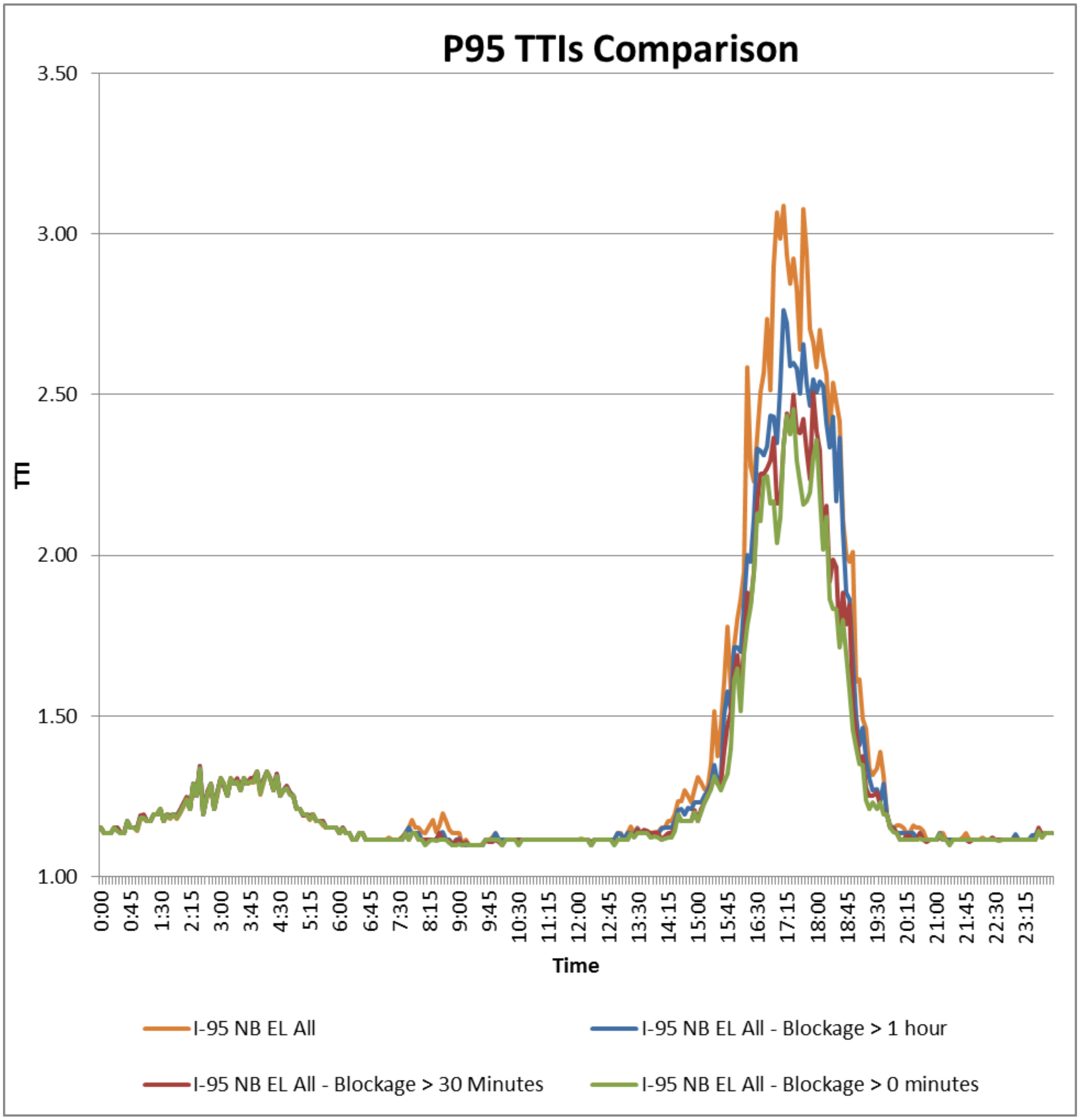
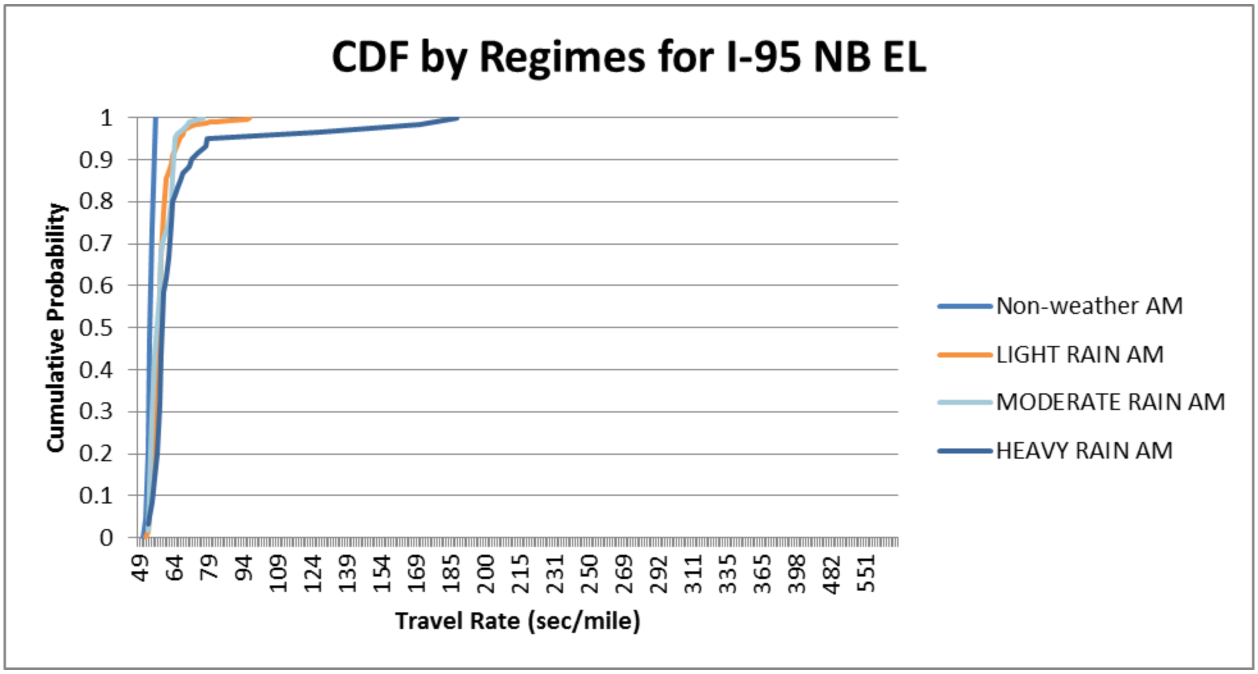


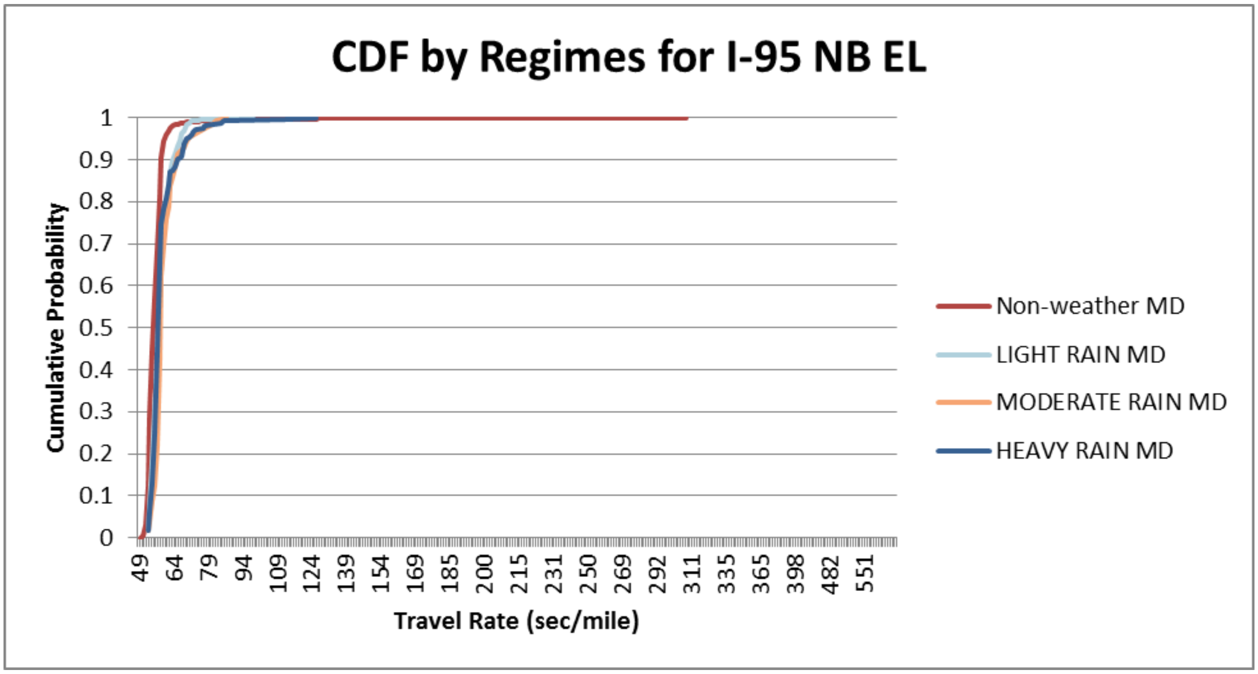
Figure B.35. Impacts of incident duration on 95th percentile TTI for I-95 NB EL.

B.5 Weather Impacts

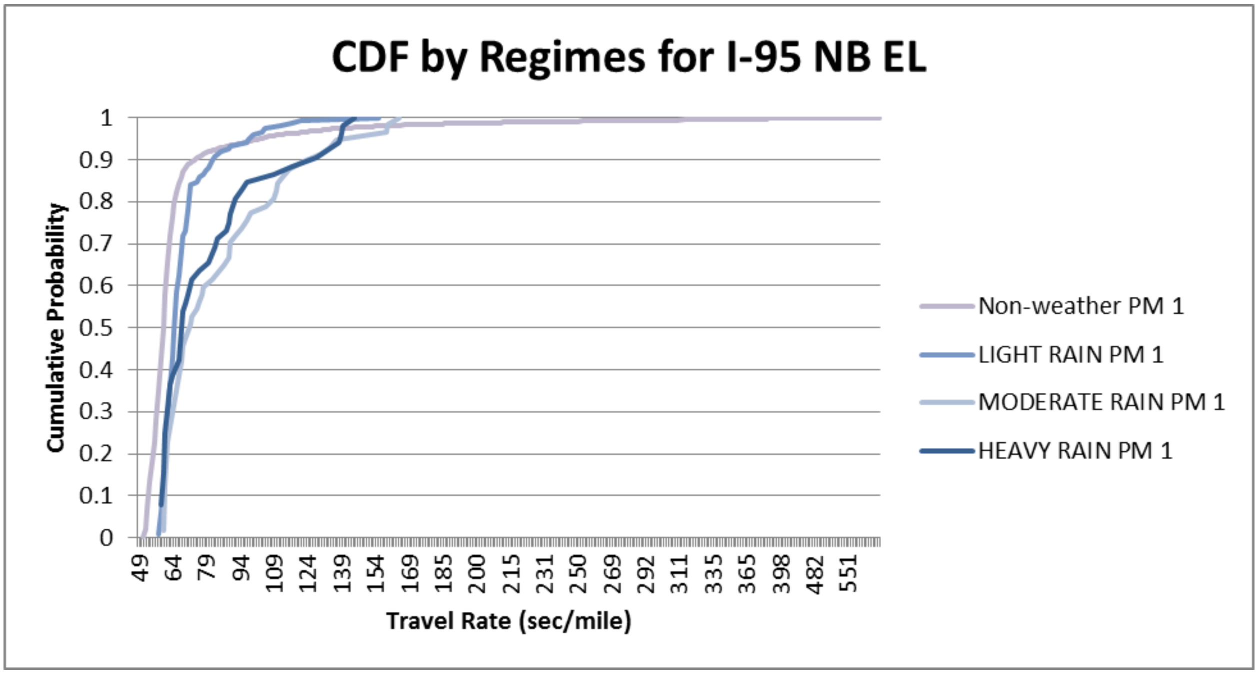
Similar to the GPL, the weather impacts on the EL were further investigated by different precipitation levels. The results in Figure B.36 and Table B.10 to Table B.12 show that rain events had a limited impact on EL performance.



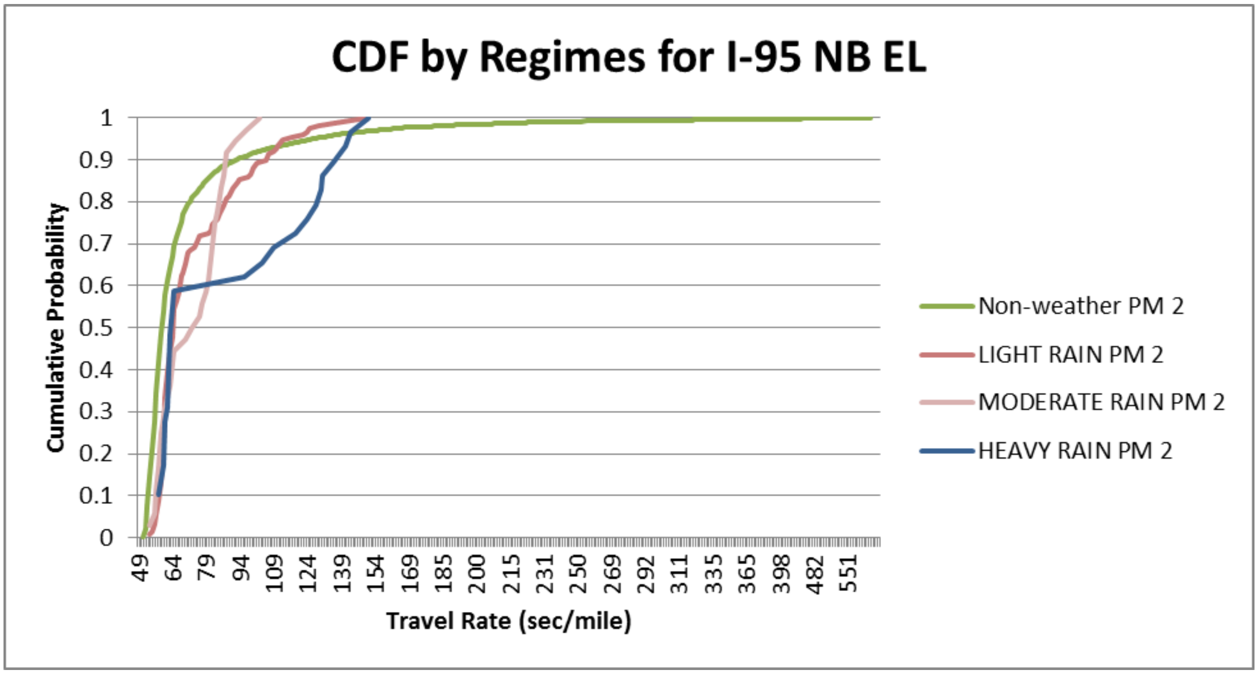
(a)



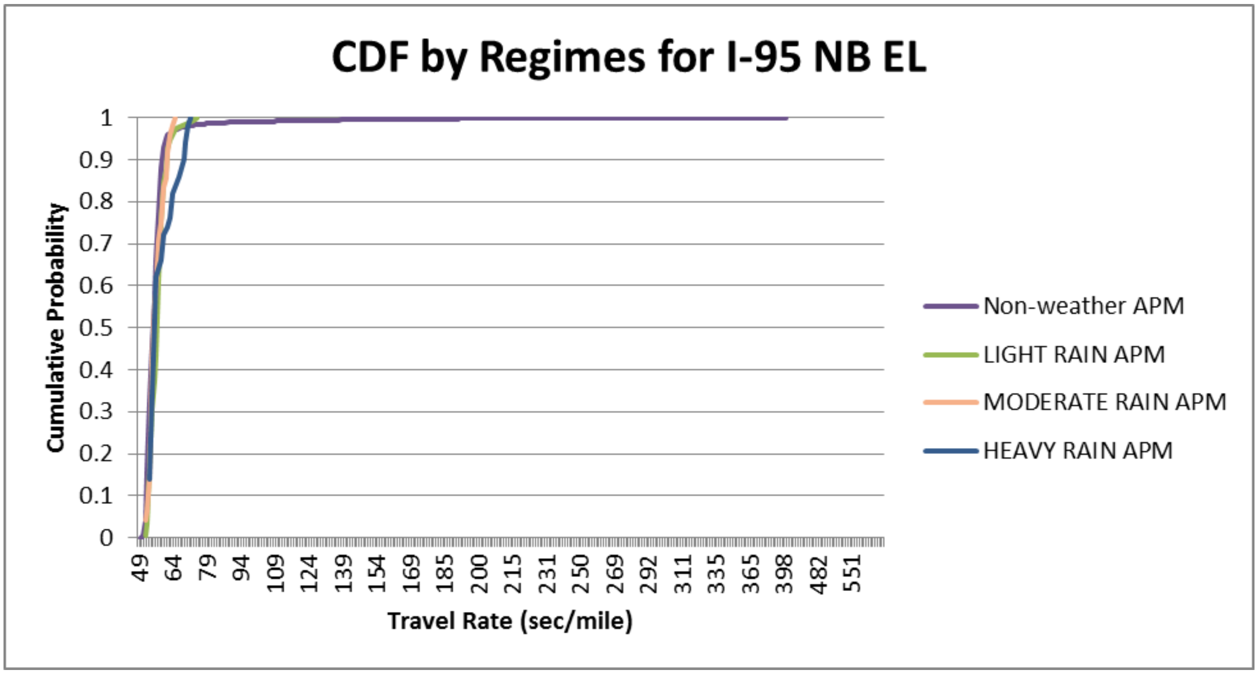
(b)


CDF by Regimes for I-95 NB EL
Cumulative Probability
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
49
64
79
94
109
124
139
154
169
185
200
215
231
250
269
292
311
335
365
398
482
551
Travel Rate (sec/mile)
Non-weather PM 1
LIGHT RAIN PM 1
MODERATE RAIN PM 1
HEAVY RAIN PM 1

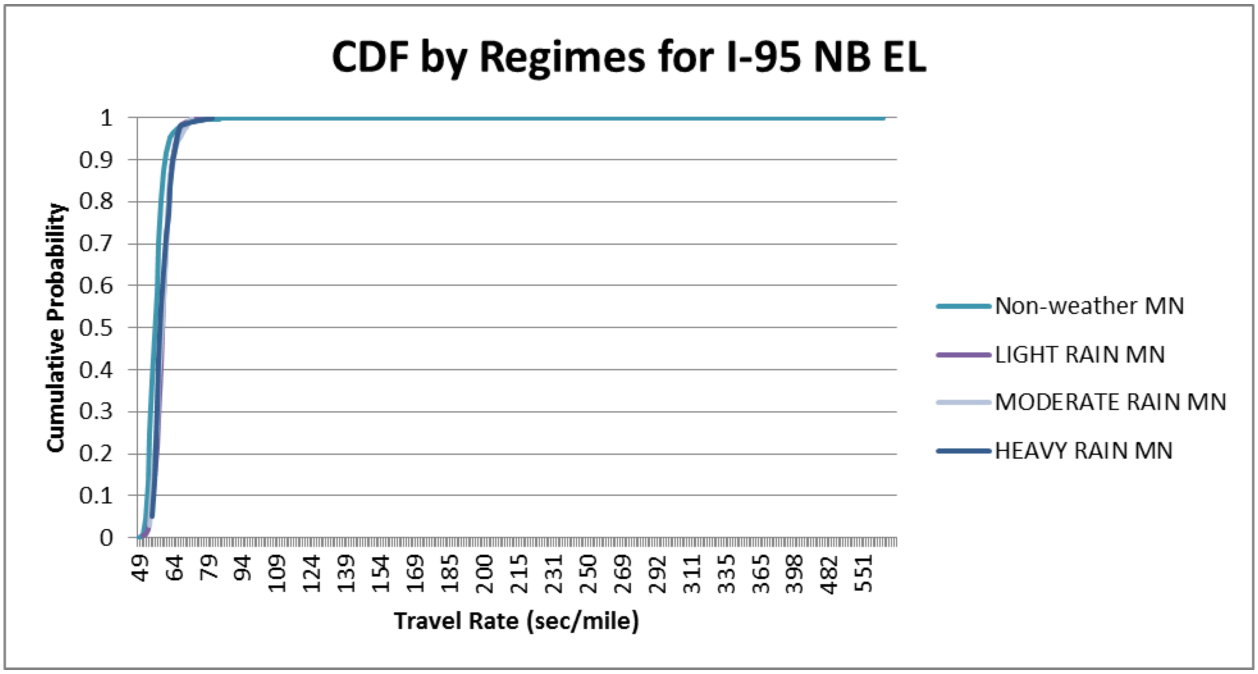
(c)


CDF by Regimes for I-95 NB EL
Cumulative Probability
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
49
64
79
94
109
124
139
154
169
185
200
215
231
250
269
292
311
335
365
398
482
551
Travel Rate (sec/mile)
Non-weather PM 2
LIGHT RAIN PM 2
MODERATE RAIN PM 2
HEAVY RAIN PM 2

(d)



(e)



(f)

Figure B.36. CDF by regimes for I-95 NB EL for (a) AM peak, (b) MD, (c) PM1, (d) PM2, (e) APM, and (f) MN periods.

Table B.10. Percentage of Occurrence

Time Period	Nonweather	Light Rain	Moderate Rain	Heavy Rain	Total
AM	11.75%	0.47%	0.15%	0.08%	12.45%
MD	25.70%	0.95%	0.17%	0.33%	27.15%
PM1	5.92%	0.20%	0.08%	0.07%	6.27%
PM2	8.02%	0.20%	0.05%	0.04%	8.31%
APM	11.86%	0.49%	0.07%	0.07%	12.48%
MN	31.94%	1.02%	0.24%	0.13%	33.34%

Table B.11. Percentage of Severity

Time Period	Nonweather	Light Rain	Moderate Rain	Heavy Rain	Total
AM	0.49%	0.44%	0.37%	5.01%	6.31%
MD	0.53%	0.40%	0.61%	0.71%	2.26%
PM1	16.22%	3.16%	12.38%	9.37%	41.13%
PM2	19.02%	5.92%	4.08%	16.43%	45.46%
APM	2.02%	0.26%	0.19%	0.48%	2.96%
MN	0.55%	0.44%	0.44%	0.45%	1.88%

Table B.12. Percentage of Unreliability Contribution

Time Period	Nonweather	Light Rain	Moderate Rain	Heavy Rain	Total
AM	1.81%	0.07%	0.02%	0.13%	2.02%
MD	4.35%	0.12%	0.03%	0.07%	4.58%
PM1	30.38%	0.20%	0.30%	0.21%	31.10%
PM2	48.26%	0.38%	0.06%	0.21%	48.91%
APM	7.57%	0.04%	0.00%	0.01%	7.62%
MN	5.58%	0.14%	0.03%	0.02%	5.77%

APPENDIX C
I-95 Southbound General-Purpose Lane

C.1 Overall Reliability Performance

The procedures used in the L02 project were also applied to investigate travel time reliability along the I-95 SB GPL. Figure C.1 and Figure C.2 present an assessment of the overall system performance. The percentage of unreliability contribution in Figure C.2 shows that the unreliability in the AM peak as measured by the semivariance contributed to 46% of the overall unreliability of the daily operations. It is interesting to note that the midday period contributed to 43% of unreliability. An important part of this high midday contribution to unreliability was that the analysis assumed that the AM peak extended from 7:00 to 9:00 a.m. The analysis results indicated that the unreliability of AM peaking ended at 10:00 to 10:30 a.m. Later discussion indicated that this finding was mainly due to the effects of incidents that prolonged the AM peak.

The SB GPL was unreliable from 7:00 to about 10:30 a.m. Between 7:00 and 9:00 a.m., the 50%, 80%, and 95% TTIs were 1.4, 1.7, and 2.5, respectively. The maximum five-minute 50th, 80th, and 95th percentile values during the AM peak were 1.6, 2.0, and 2.9, respectively. The midday period (assumed between 9:00 a.m. and 3:00 p.m.) also had a relatively high 95% TTI at about 1.9. Five-minute reliability analysis indicated that the main unreliability in the midday peak occurred between 9:00 and 11:00 a.m., at least in part due to the extension of the AM peak congestion beyond 9:00 a.m. on some of the days (most likely incident days).

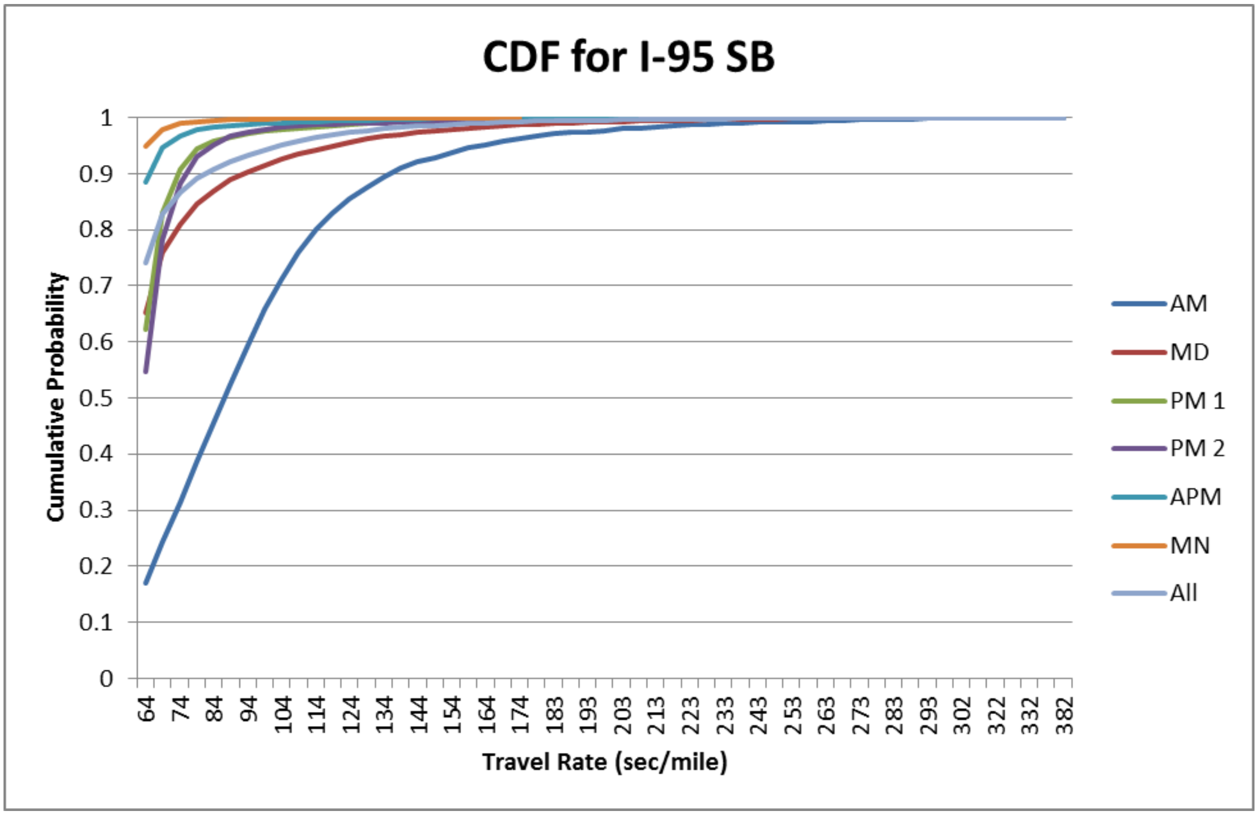


Figure C.1. CDF for I-95 SB GPL.

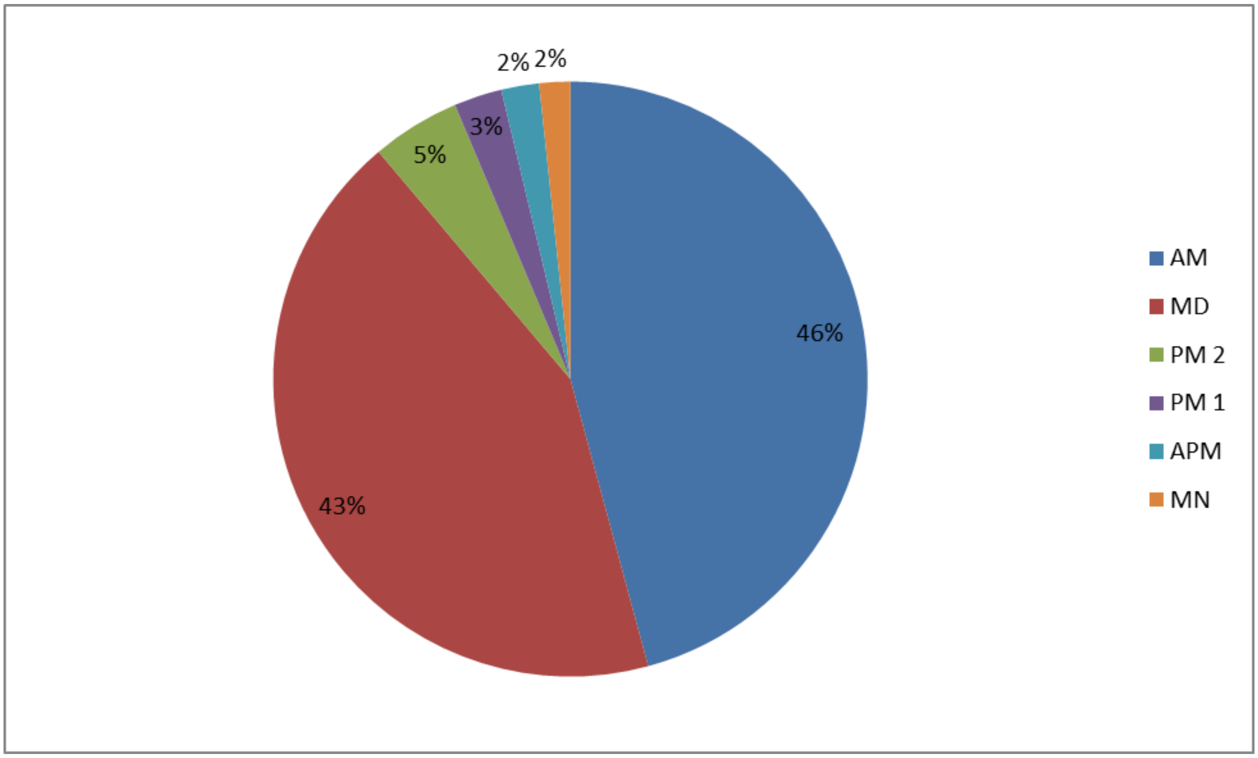


Figure C.2. Percentage of unreliability contribution for I-95 SB GPL.

Figures C.3 to C.5 show the travel time, speed, and TTI at the 50th, 80th, and 95th percentile levels for I-95 SB during different times of day. This information can be extracted from the CDF curves presented in Figure C.1; however, the presentation in Figures C.3 to C.5 can provide agencies with a more straightforward and more easily understandable visualization of reliability results.

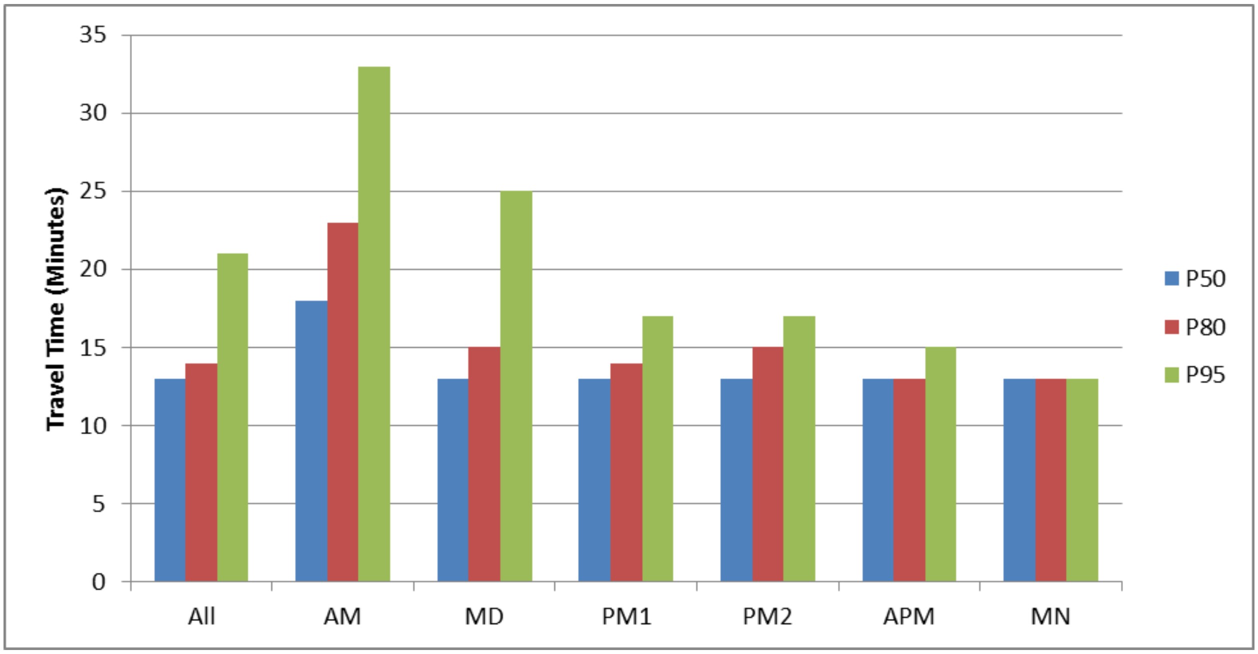


Figure C.3. I-95 SB GPL travel time.

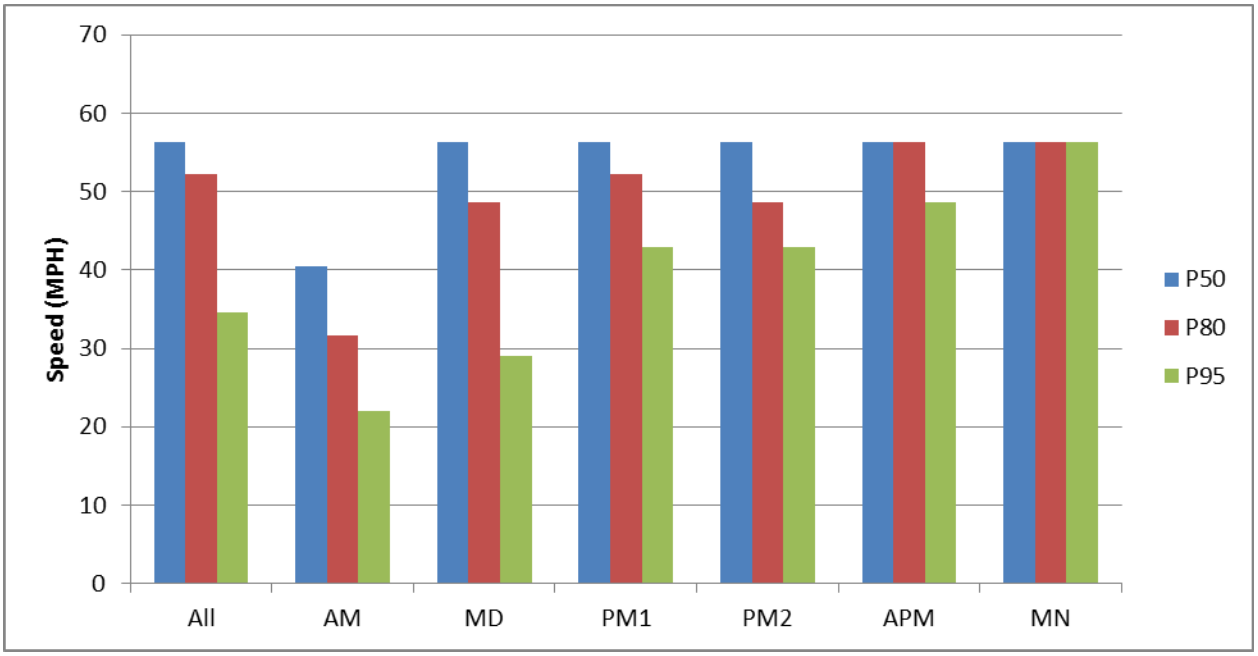


Figure C.4. I-95 SB GPL speed.

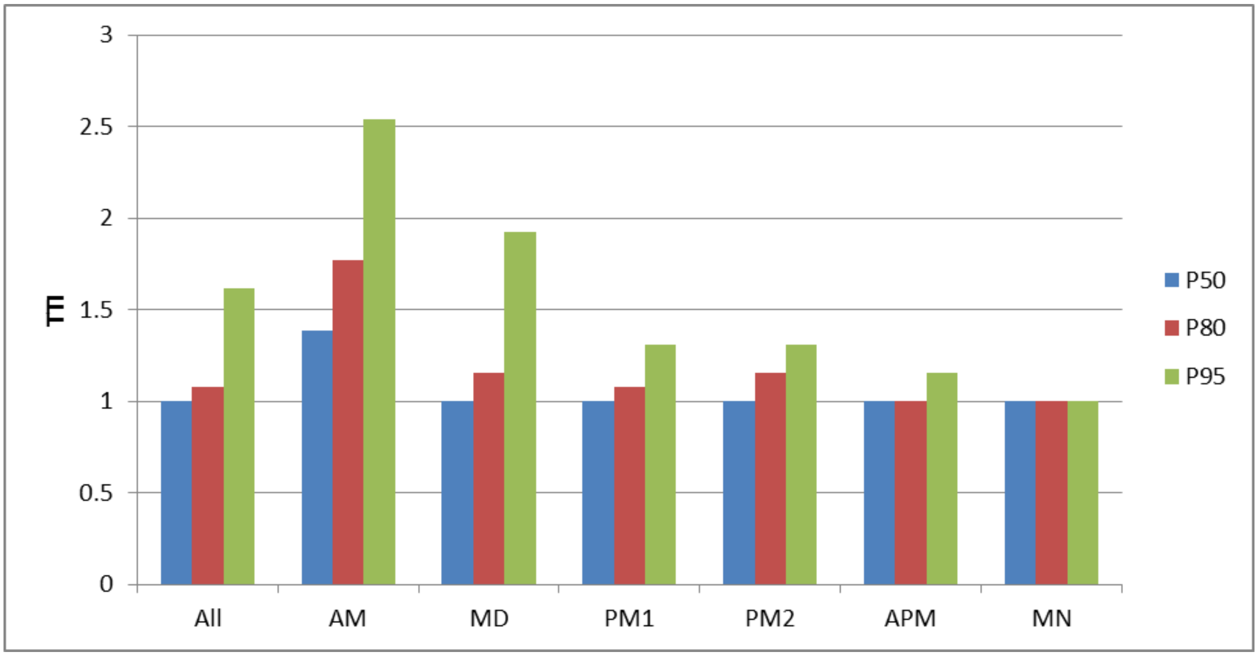


Figure C.5. I-95 SB GPL TTI.

Figures C.6 to C.8 show the variation of different performance measures by five-minute intervals for 24 hours. Figure C.6 shows that the 80th and 95th percentile TTIs began increasing at around 6:45 a.m. and returned to typical midday values on the facility by 10:00 a.m. The maximum 50th, 80th, and 95th percentile values during the AM were 1.6, 2.0, and 2.7 to 3.0, respectively. These values were similar to those observed in the PM peak in the NB direction. This finding indicated that the reliability of the I-95 SB GPL was greatly influenced by travel time outliers according to the L05 guide. The midday period (assumed between 9:00 a.m. and 3:00 p.m.) also had a relatively high 95th percentile TTI at about 1.9. Five-minute reliability analysis indicated that the main unreliability in the midday peak occurred between 9:00 and 11:00 a.m., due at least in part to the extension of the AM peak congestion beyond 9:00 a.m. some days. After 10:00 a.m., these values were 1.00, 1.1, and 1.4 for most of the day, indicating good performance.

Figure C.7 shows that the 1.1 and 1.25 on-time performance in the AM peak dropped to 55% and 70%, respectively. These drops were similar to those observed in the PM peak in the NB direction. The on-time performance ranged between 80% and 90% in the midday, again indicating that the midday period was more unreliable in the SB direction than the NB direction. The misery index and semistandard deviation were also the worst in the AM peak period, as shown in Figure C.8.

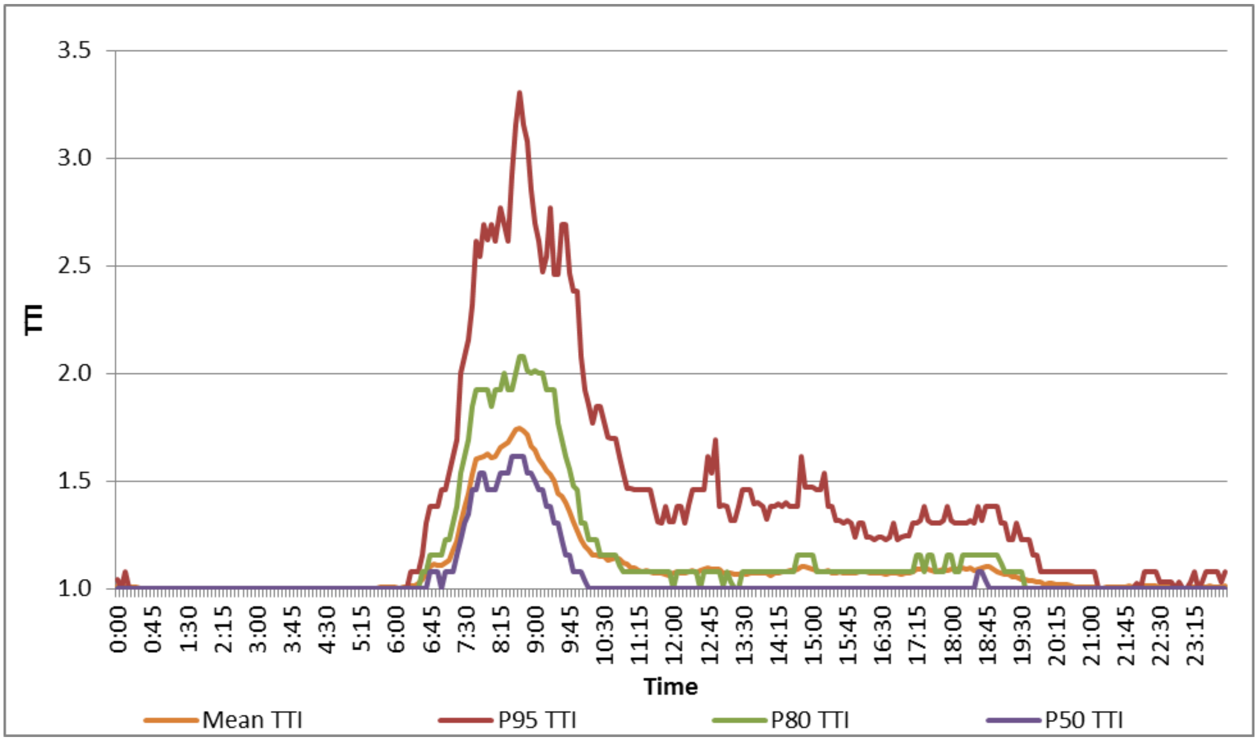


Figure C.6. I-95 SB GPL TTIs comparison.

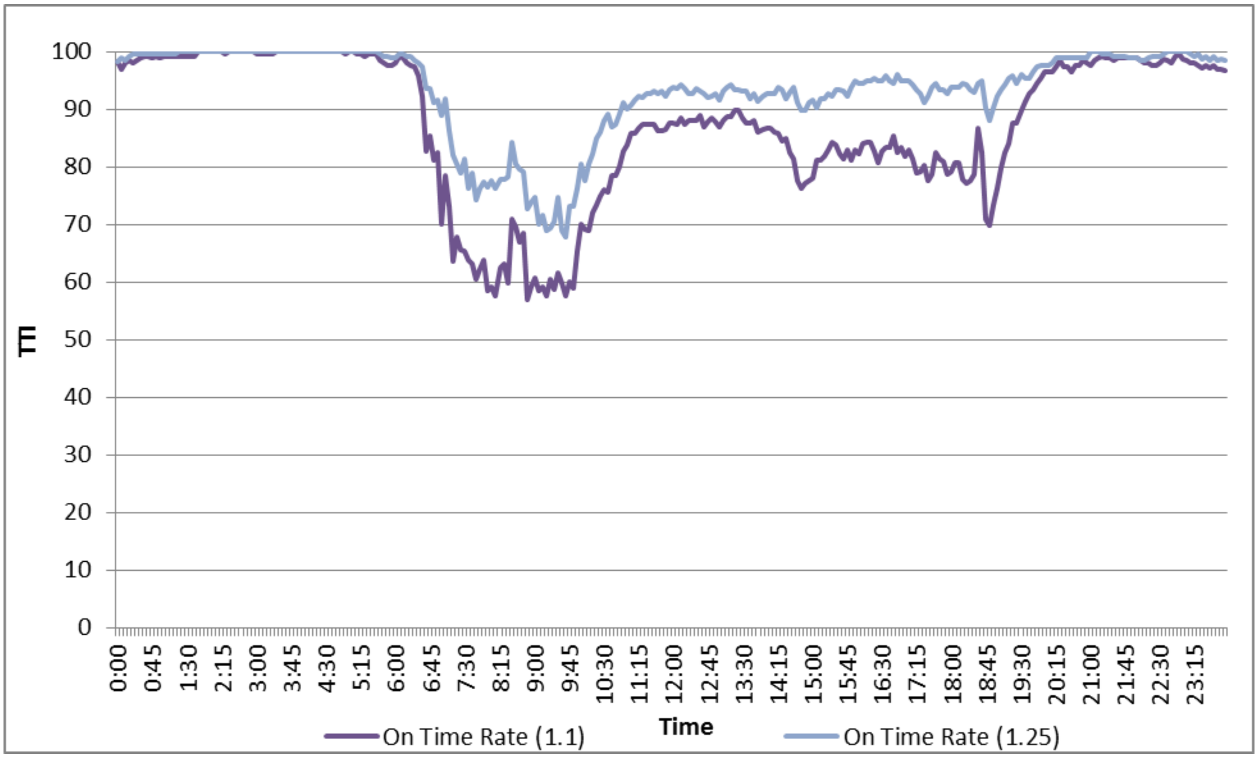


Figure C.7. I-95 SB GPL on-time performance.

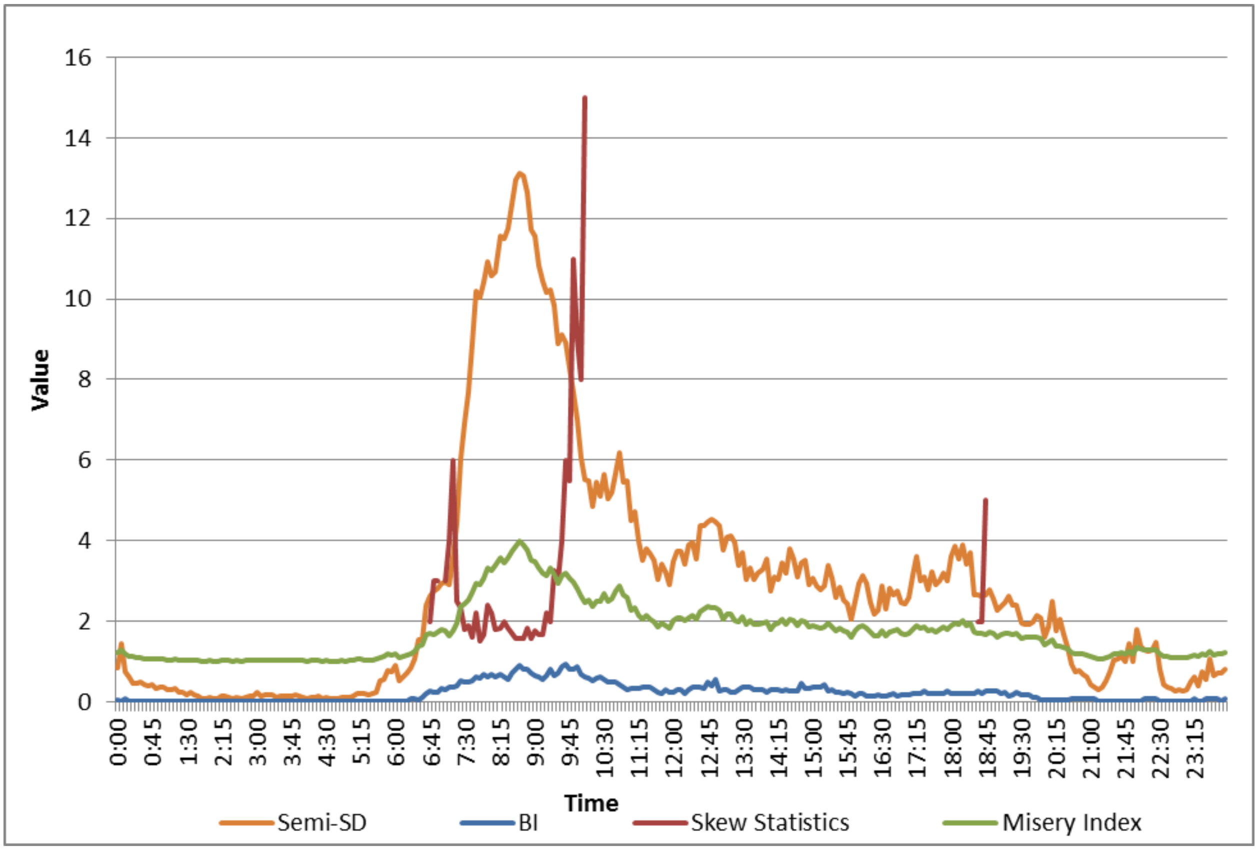


Figure C.8. I-95 SB GPL semistandard deviation, buffer index, skew statistics, and misery index.

To gain a complete picture of traffic conditions on I-95 SB, the time-dependent variation of VMT and VHT are presented in Figure C.9 and Figure C.10. VMT started to increase around 5:00 a.m. and maintained a relatively high value till 7:00 p.m. However, the VHT curve presented in Figure C.10 shows that the value of VHT during the AM peak period was 60% higher than the values in the midday and PM peak periods.

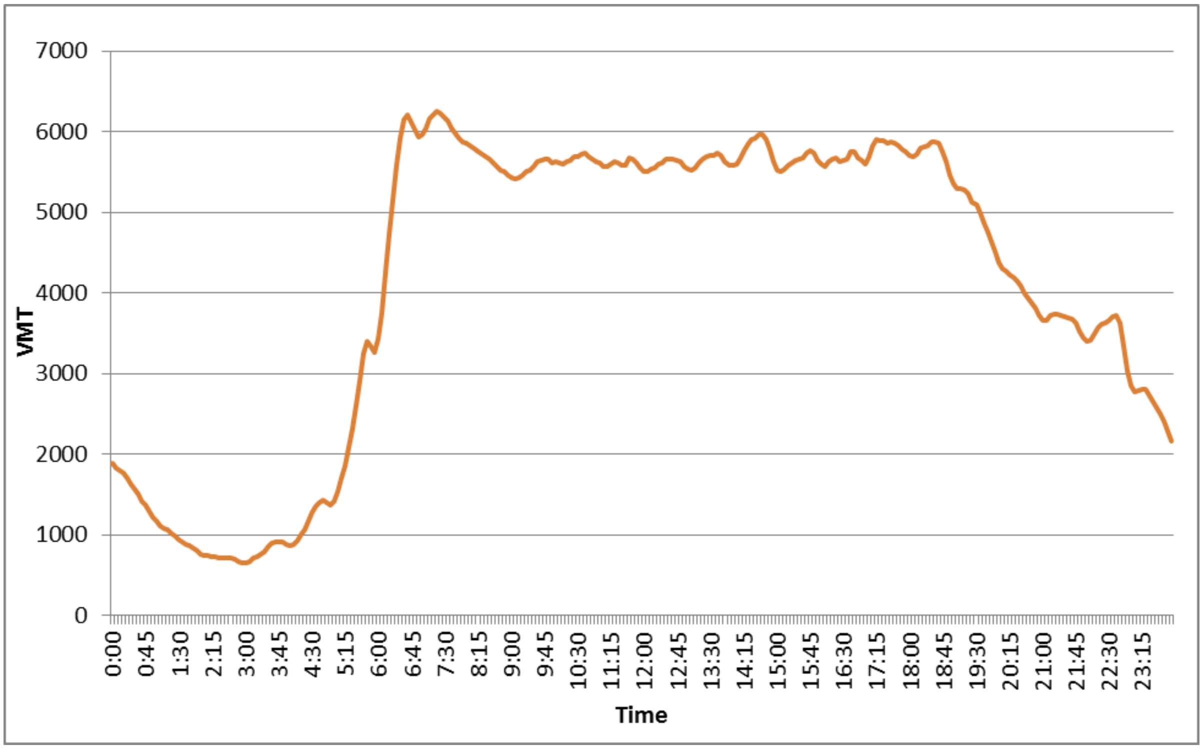


Figure C.9. I-95 SB GPL VMT.

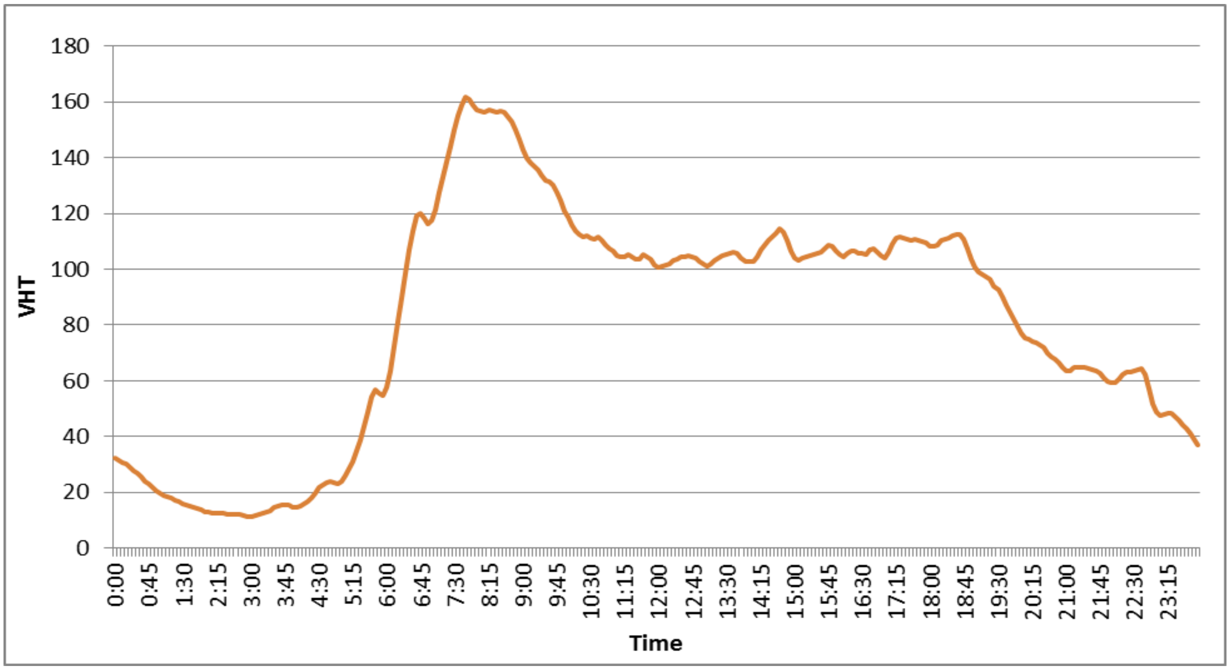


Figure C.10. I-95 SB GPL VHT.

C.2 Contributions of Influential Factors

The contributions of different factors to travel time reliability for I-95 SB GPL were analyzed following L02 procedures. Figures C.11 to C.14 and Tables C.1 to C.3 illustrate the distribution of CDF and the percentages of occurrence, severity, and unreliability contribution of four factors (no-event periods, incident, weather, and combined incident and weather) for different times of day. The corresponding 50th, 80th, and 95th percentile travel time, speed, and TTI values can be easily found from Figure C.15 to Figure C.17.

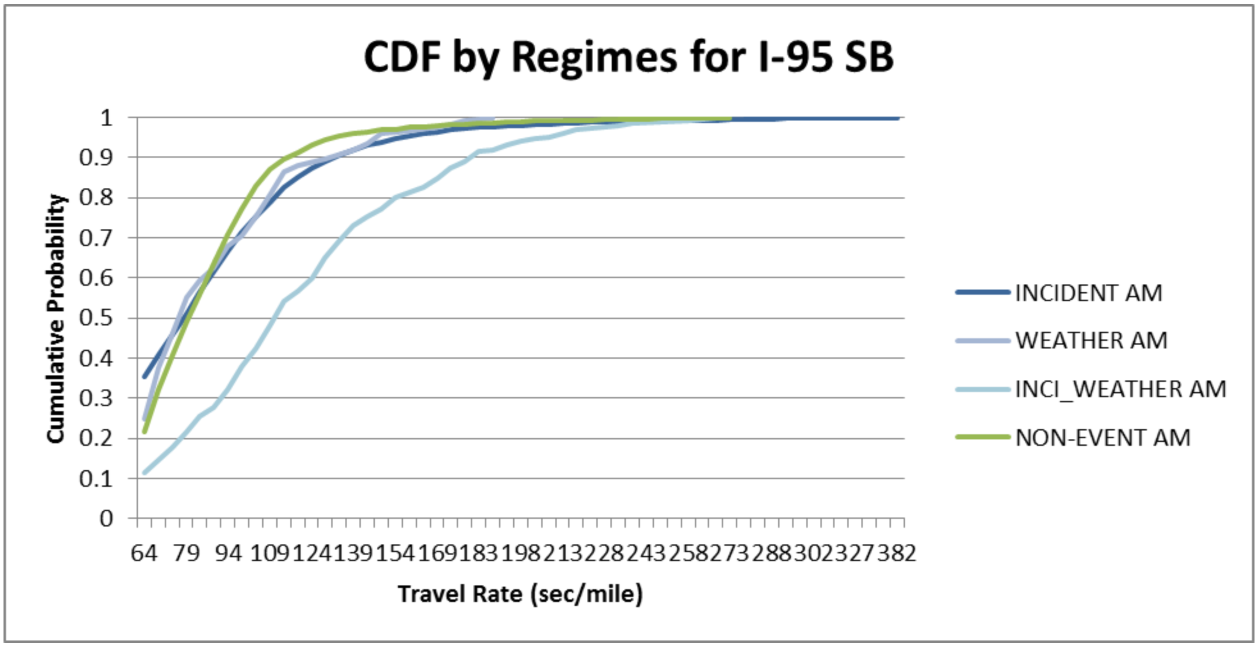
An important observation from Figure C.11, Figure C.14, and Table C.3 is that the contribution of the no-event periods to the unreliability of the SB direction in the AM peak period was smaller than the contribution in the NB direction during the PM peak. The contribution in the AM peak was only 10% and in the midday period, 7% (that value includes the lingering effect of the AM peak, as explained previously). However, as discussed later, although the contribution of no-event periods did not seem large in terms of semivariance, they still had considerable impacts on unreliability measures such as the TTIs.

The reliability analysis also indicated that incidents were a major contributor to reliability most of the day. Significant effects of these incidents were also observed in the midday and PM peak.

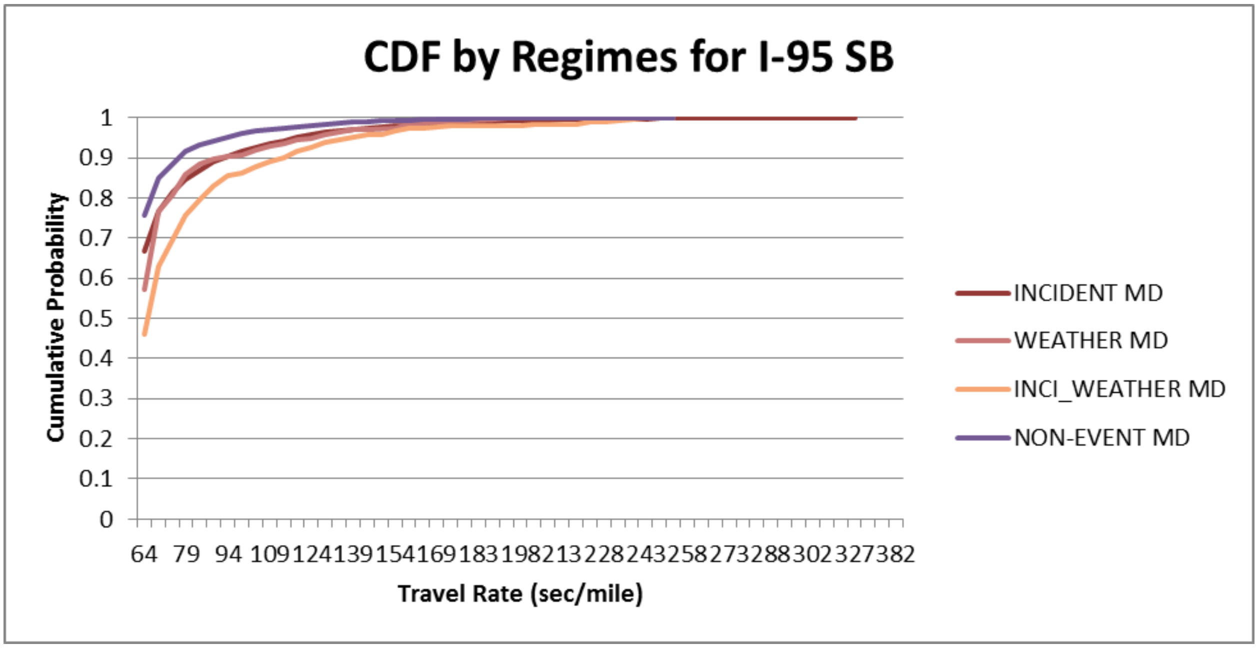
The travel time rate CDFs show that the travel time rate distribution was affected by incidents, but more significantly by incident plus weather in the AM peak, as demonstrated in Figure C.11. A significant effect of these incidents can also be observed in the midday and PM peak. In terms of semivariance, the contribution to unreliability of intervals with incidents was three time as much as intervals with no events (31% versus 10%) in the AM peak period and about four times in the midday (33% versus 7%). The incident plus weather combination contributed to a total of 8% of unreliability in the AM and midday peaks, although they were rare events. It appeared that the frequency of incidents was high in the SB direction (there were more five-minute intervals with incident than without incident). A single-incident interval relative contribution (in terms of NSV) was 16% compared to 8% for a no-event interval in the AM peak.

Although incident plus weather events did not influence the overall reliability because of the low frequency of these incidents, the impact of a single such incident in the AM peak and to a lesser degree in the PM and midday periods was high. In the AM peak, the impact of a single incident plus weather event was twice that of a single incident and 3.75 times that of a single no-event interval. The PM peak period between 5:00 and 7:00 p.m. (considered off-peak for the SB direction) during incident plus weather conditions in the SB direction was as bad as the AM peak.

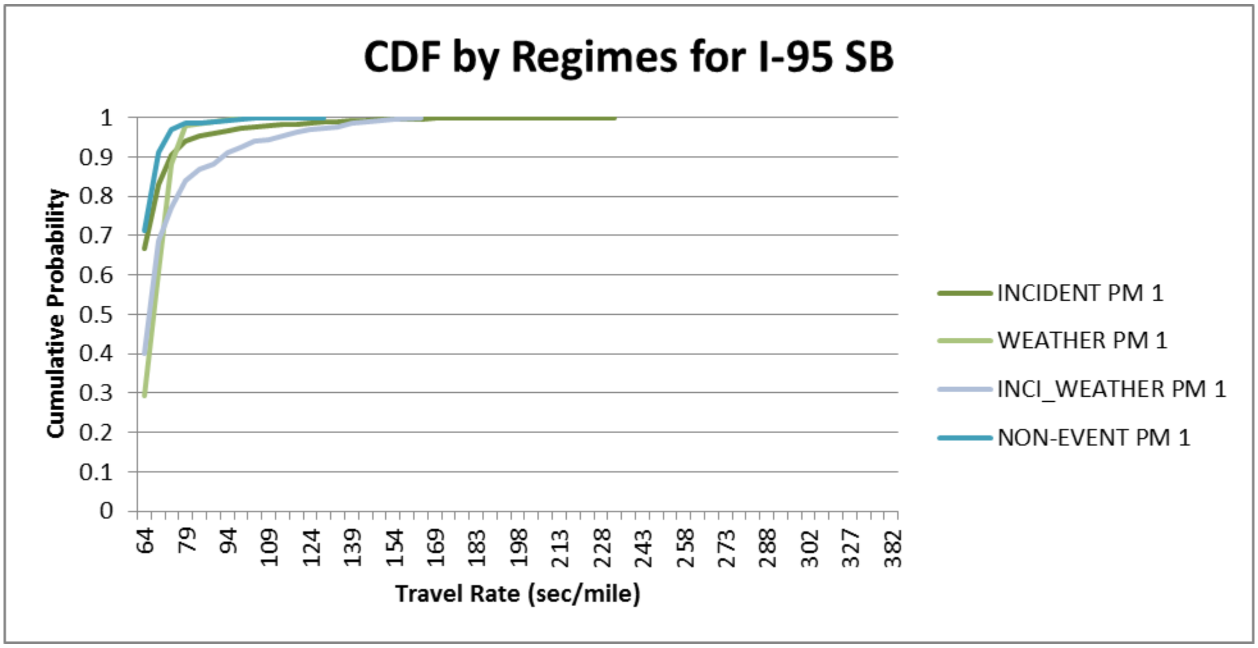
Weather events were relatively rare compared to incident occurrence. The overall contribution of weather event to unreliability was small, as shown in Table C.3. However, as illustrated in Figure C.11, the curves of CDF of travel time rates during rain events were similar to those during incident events.



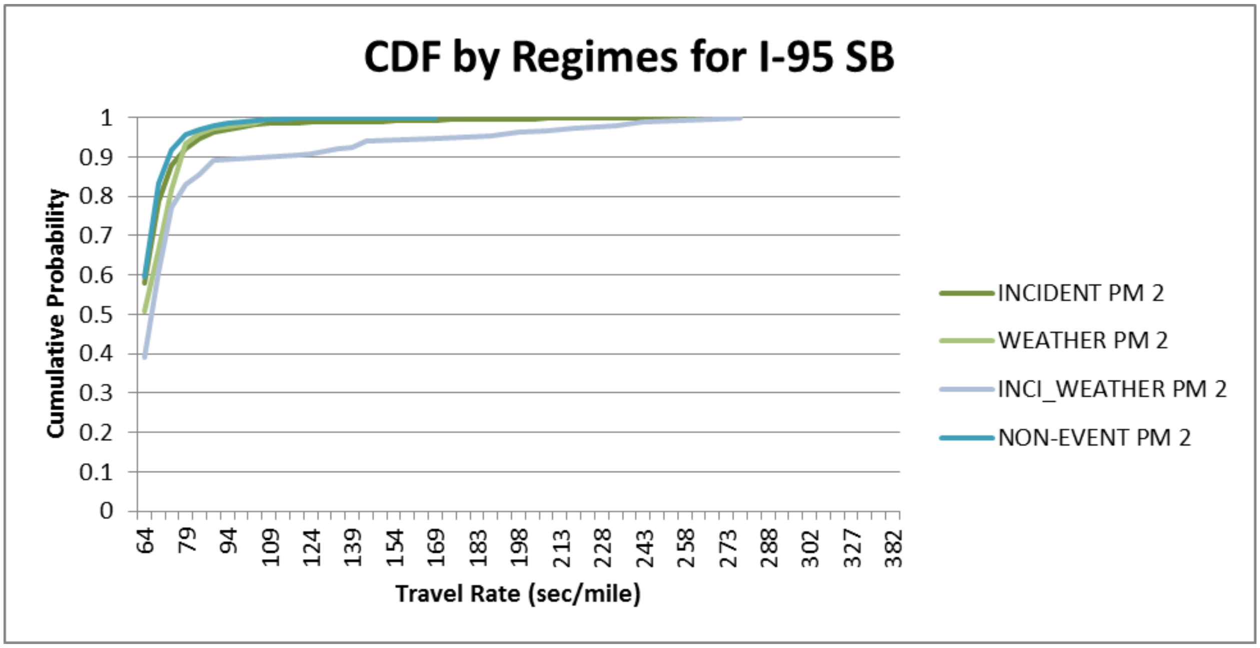
(a)


CDF by Regimes for I-95 SB
Cumulative Probability
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
64 79 94 109 124 139 154 169 183 198 213 228 243 258 273 288 302 327 382
Travel Rate (sec/mile)
INCIDENT MD
WEATHER MD
INCI_WEATHER MD
NON-EVENT MD

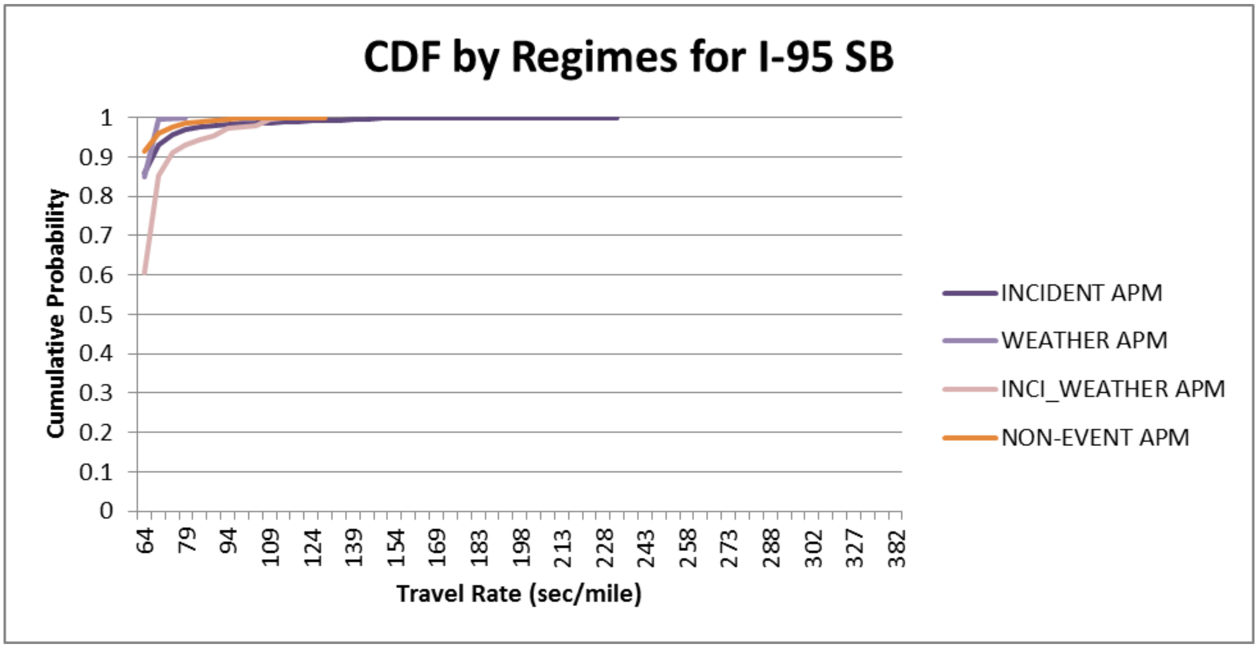
(b)


CDF by Regimes for I-95 SB
Cumulative Probability
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
64 79 94 109 124 139 154 169 183 198 213 228 243 258 273 288 302 327 382
Travel Rate (sec/mile)
INCIDENT PM 1
WEATHER PM 1
INCI_WEATHER PM 1
NON-EVENT PM 1

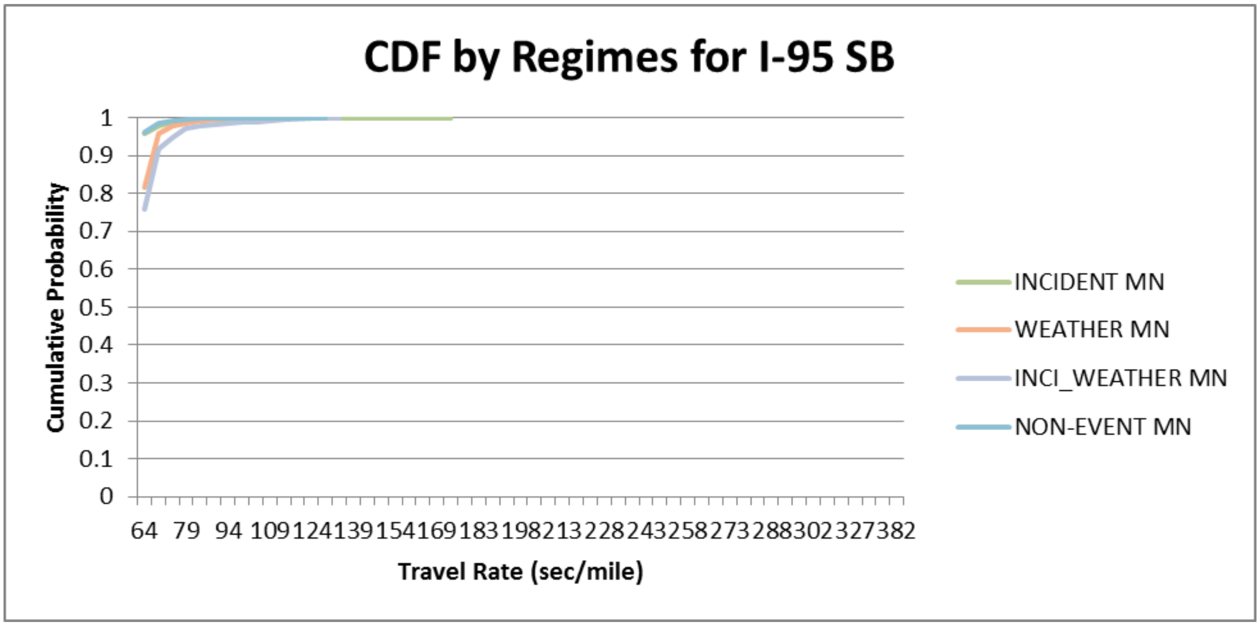
(c)


CDF by Regimes for I-95 SB
Cumulative Probability
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
64
79
94
109
124
139
154
169
183
198
213
228
243
258
273
288
302
327
382
Travel Rate (sec/mile)
INCIDENT PM 2
WEATHER PM 2
INCI_WEATHER PM 2
NON-EVENT PM 2

(d)


CDF by Regimes for I-95 SB
Cumulative Probability
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
64
79
94
109
124
139
154
169
183
198
213
228
243
258
273
288
302
327
382
Travel Rate (sec/mile)
INCIDENT APM
WEATHER APM
INCI_WEATHER APM
NON-EVENT APM

(e)



(f)

Figure C.11. CDF by regimes for I-95 SB GPL for (a) AM peak, (b) MD, (c) PM1, (d) PM2, (e) APM, and (f) MN periods.

Table C.1. Percentage of Occurrence

Time Period	Nonevent	Incident	Weather	Incident + Weather	Total
AM	3%	5%	0%	0%	8%
MD	10%	16%	1%	1%	27%
PM1	2%	4%	0%	0%	6%
PM2	3%	5%	0%	0%	8%
APM	6%	6%	0%	0%	12%
MN	20%	16%	1%	1%	37%

Table C.2. Percentage of Severity

Time Period	Nonevent	Incident	Weather	Incident + Weather	Total
AM	8%	16%	9%	30%	63%
MD	2%	5%	4%	7%	17%
PM1	0%	1%	1%	2%	5%
PM2	1%	2%	1%	10%	13%
APM	0%	1%	0%	1%	2%
MN	0%	0%	0%	0%	1%

Table C.3. Percentage of Unreliability Contribution

Time Period	Nonevent	Incident	Weather	Incident + Weather	Total
AM	10%	31%	1%	5%	46%
MD	7%	33%	1%	3%	43%
PM1	0%	2%	0%	0%	3%
PM2	1%	3%	0%	1%	5%
APM	0%	2%	0%	0%	2%
MN	0%	1%	0%	0%	2%

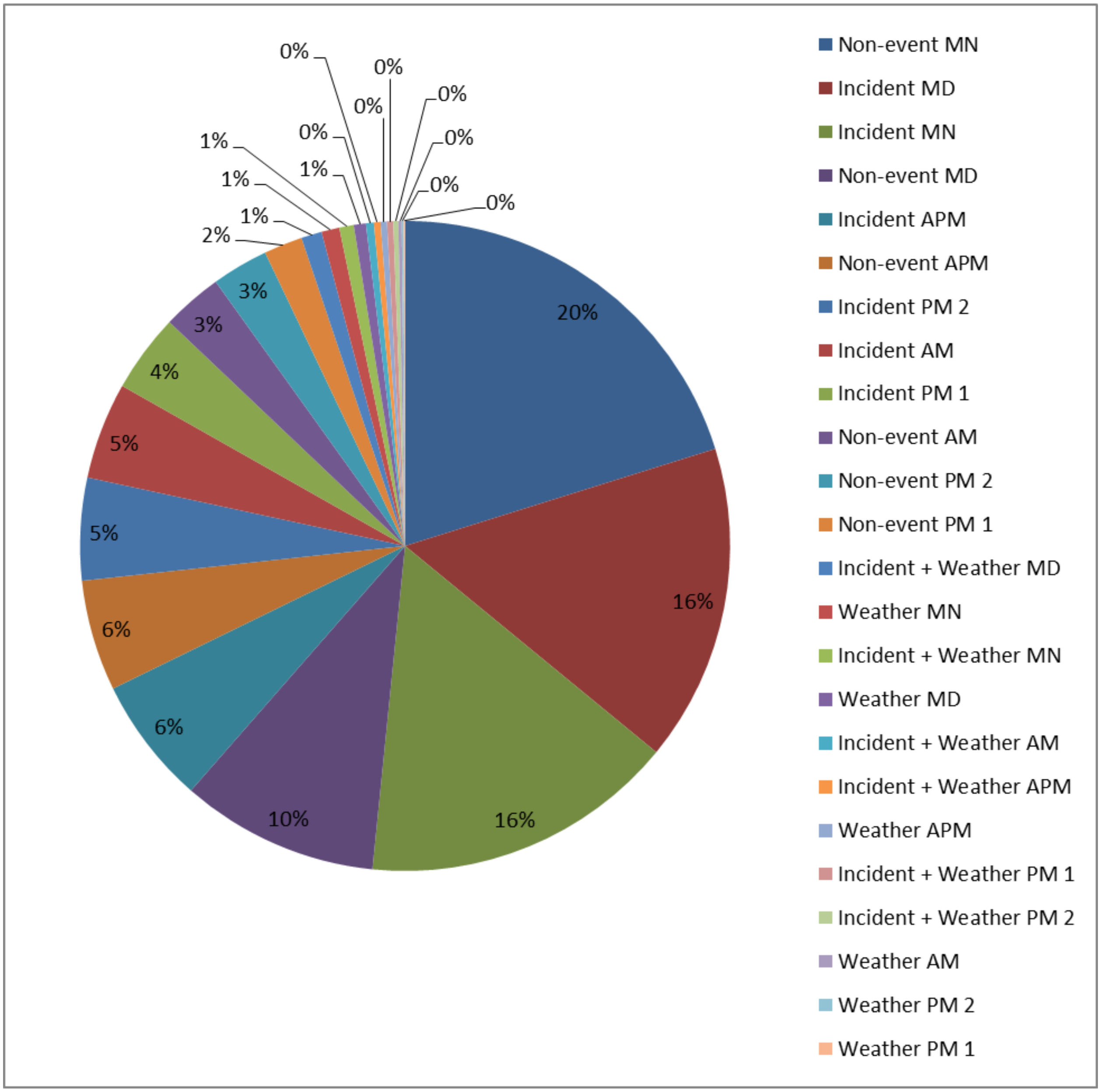


Figure C.12. Percentage of occurrence for I-95 SB GPL.

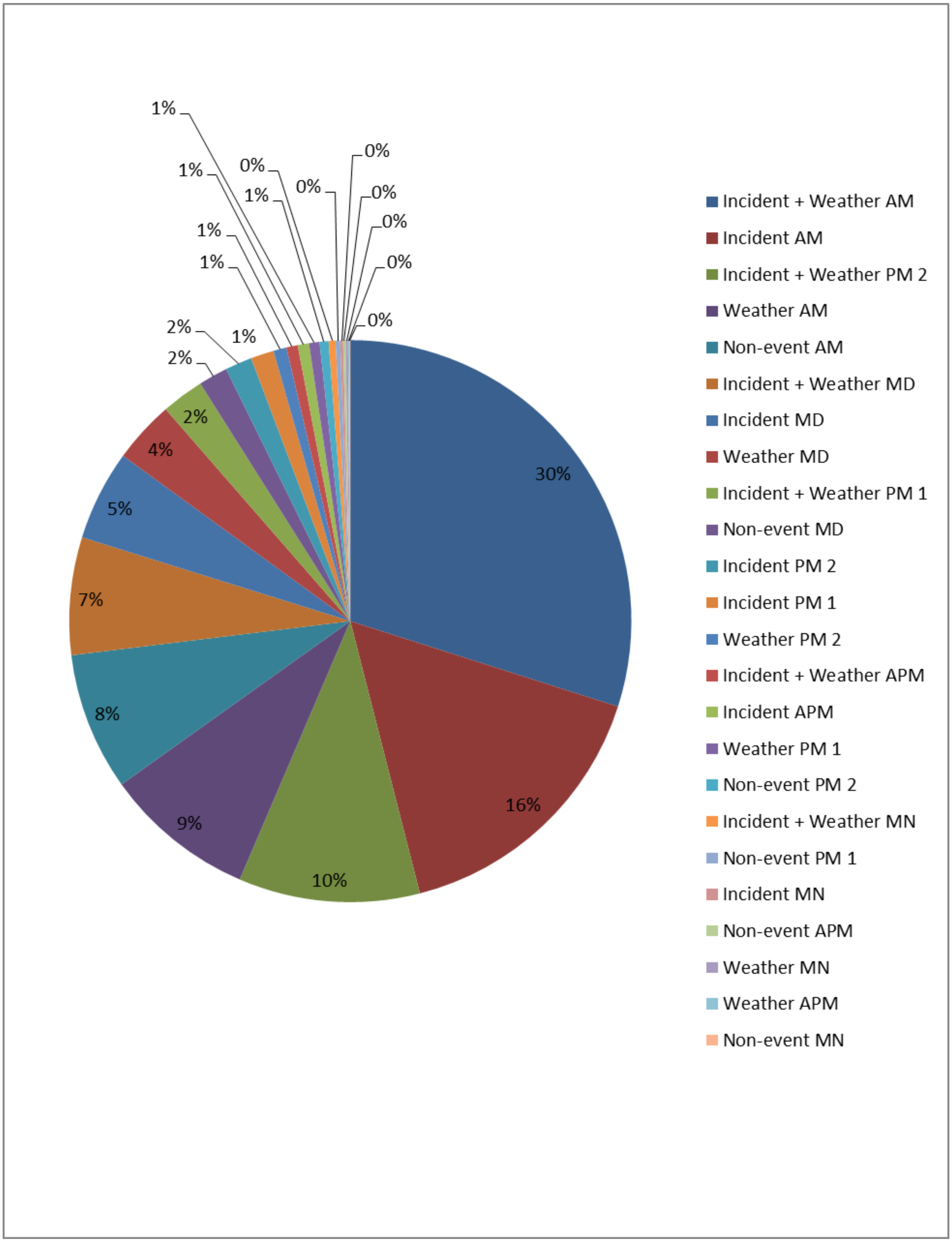


Figure C.13. Percentage of severity for I-95 SB GPL.

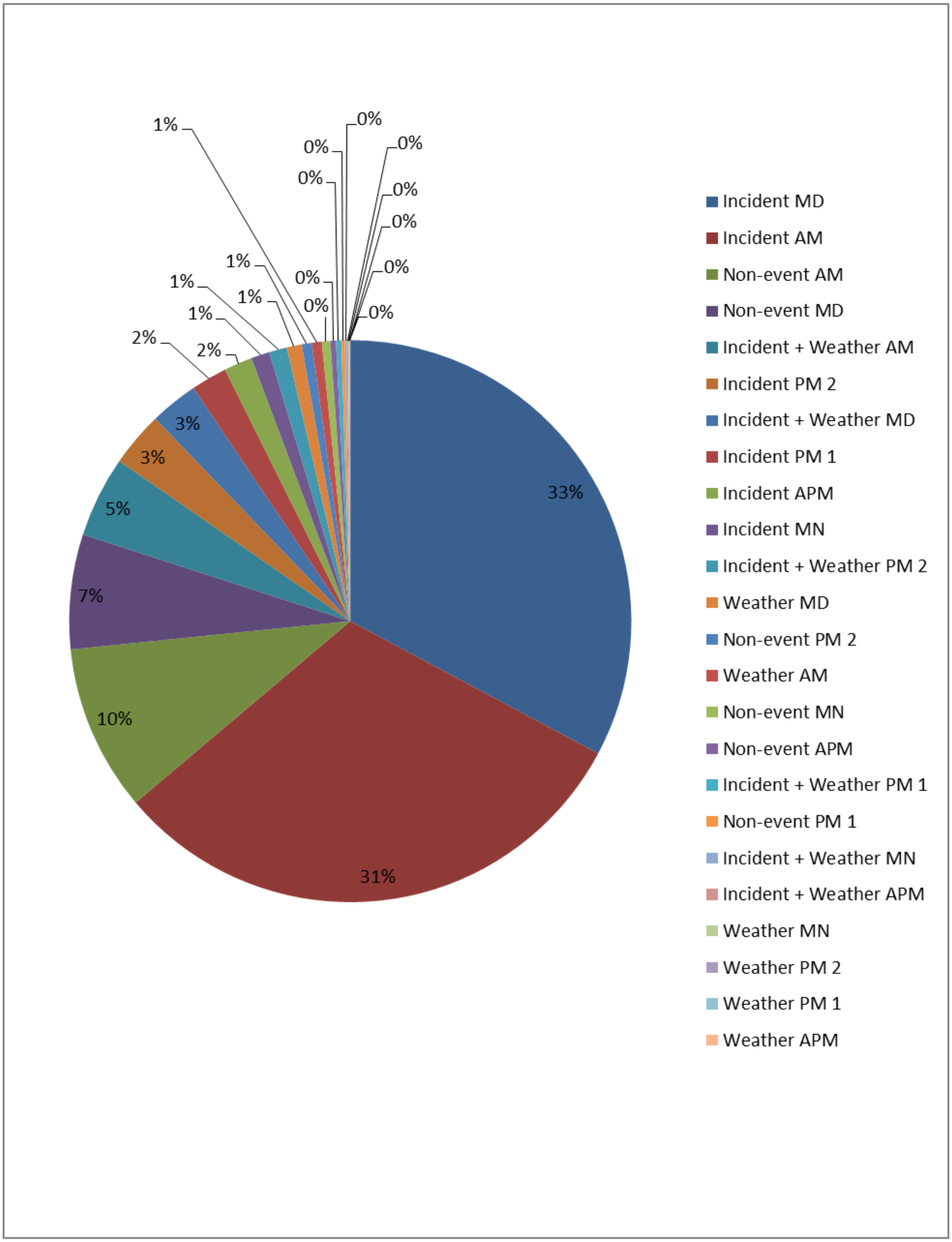
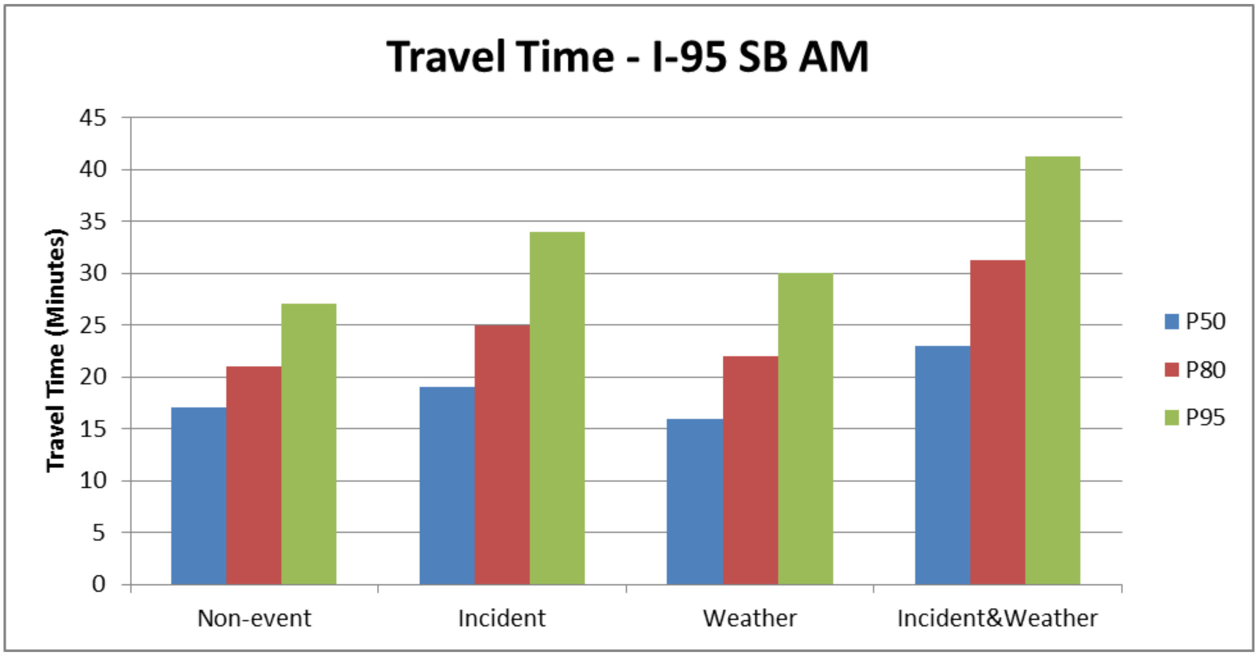
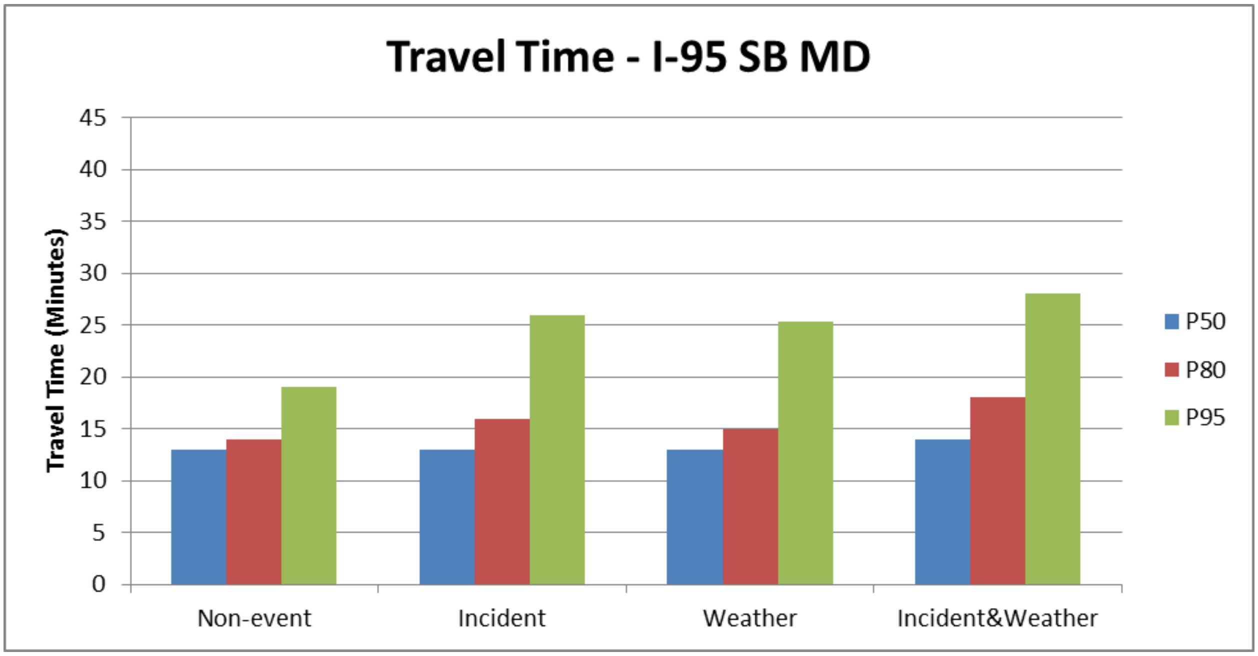


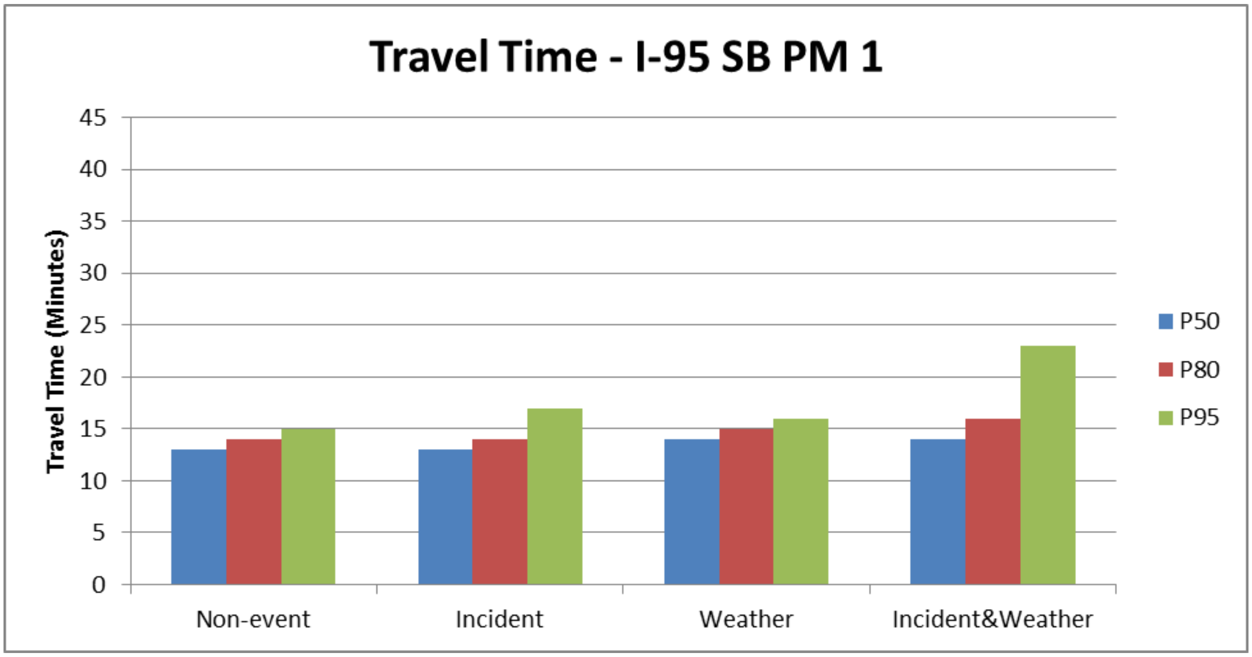
Figure C.14. Percentage of unreliability contribution for I-95 SB GPL.


Travel Time - I-95 SB AM
Travel Time (Minutes)
45
40
35
30
25
20
15
10
5
0
Non-event
Incident
Weather
Incident&Weather
P50
P80
P95

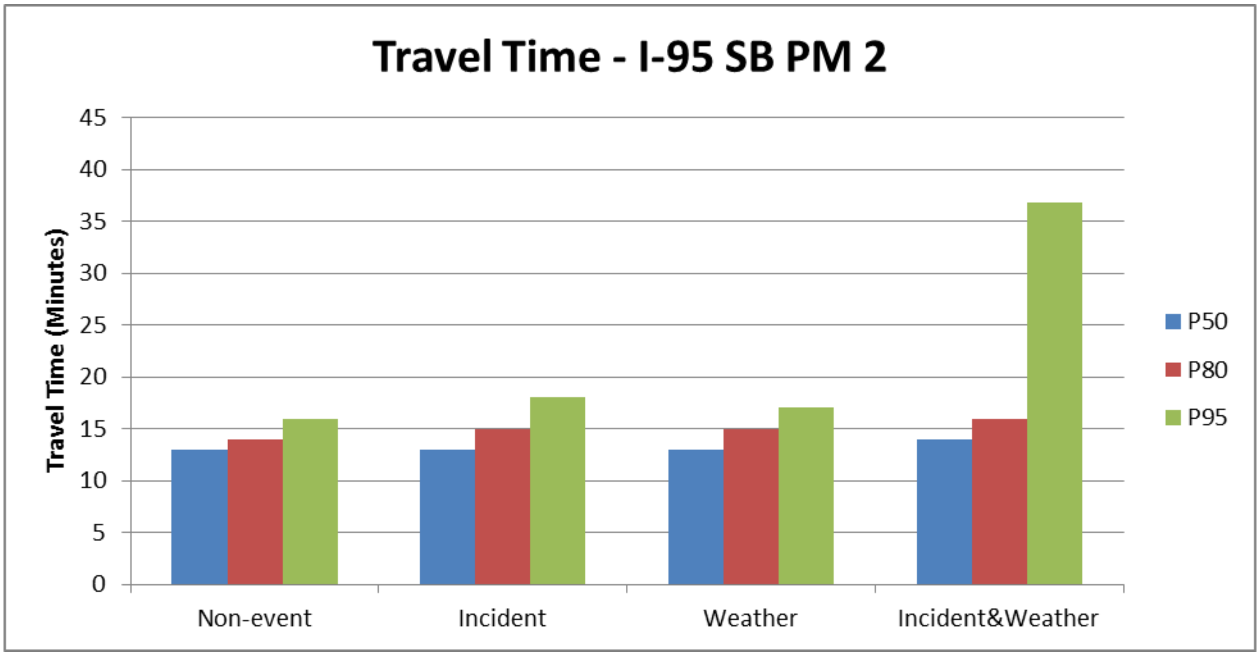
(a)


Travel Time - I-95 SB MD
Travel Time (Minutes)
45
40
35
30
25
20
15
10
5
0
Non-event
Incident
Weather
Incident&Weather
P50
P80
P95

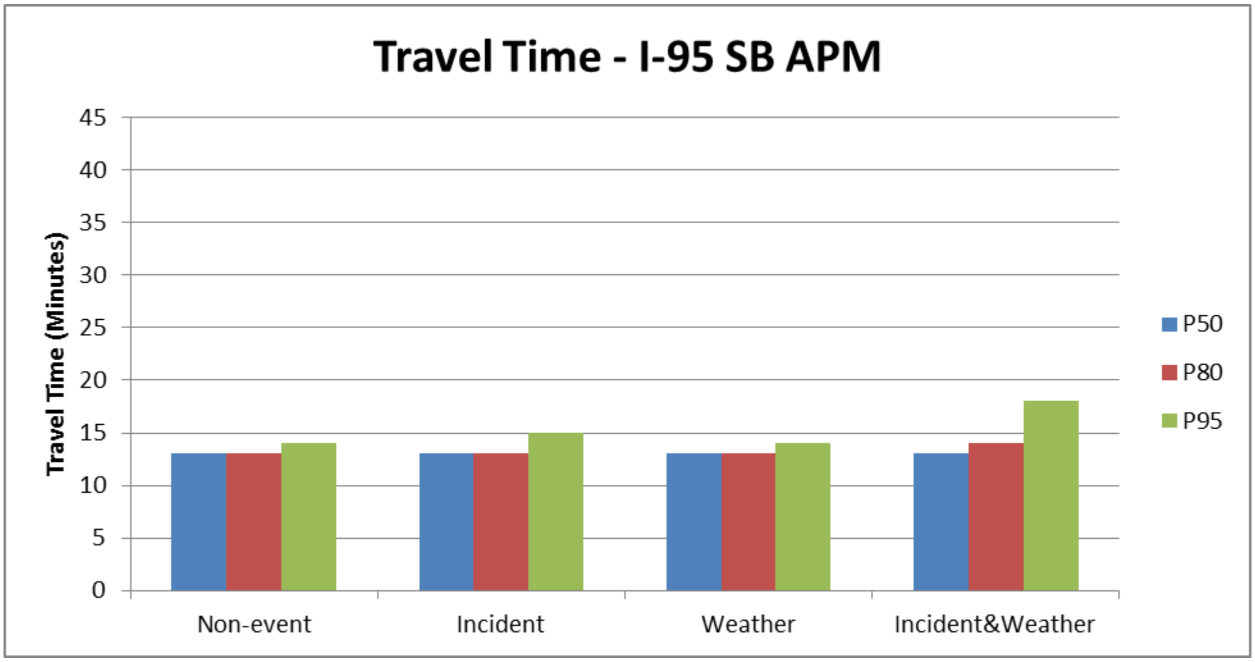
(b)


Travel Time - I-95 SB PM 1
Travel Time (Minutes)
45
40
35
30
25
20
15
10
5
0
Non-event
Incident
Weather
Incident&Weather
P50
P80
P95

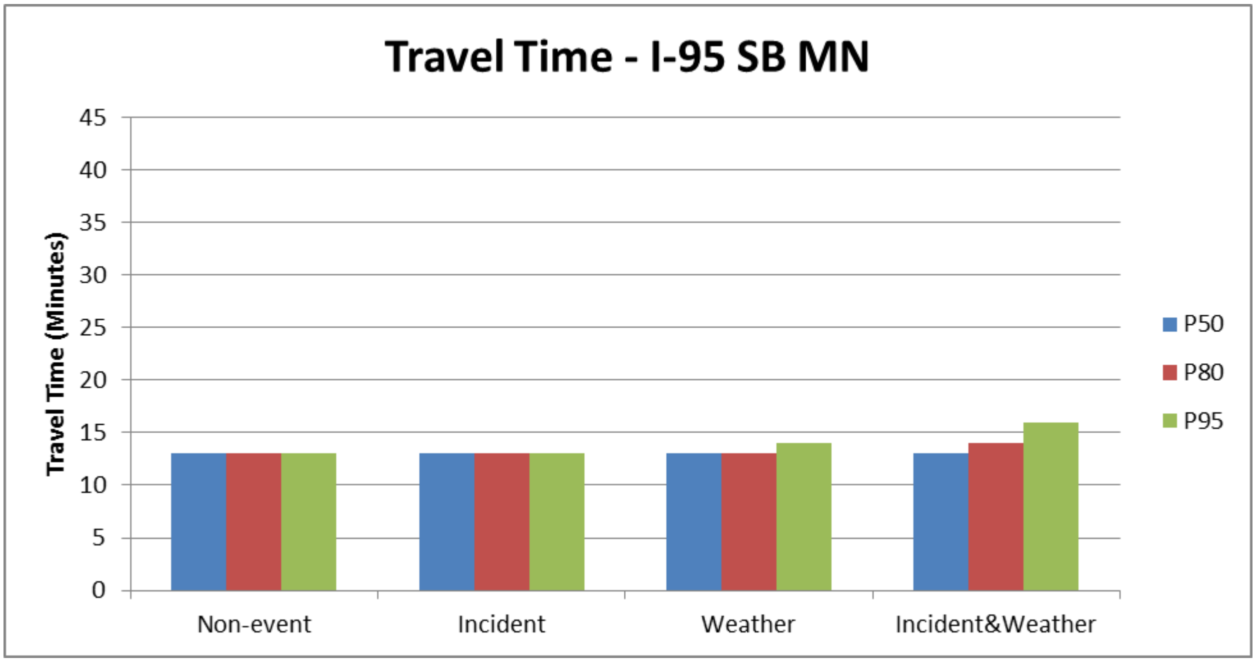
(c)


Travel Time - I-95 SB PM 2
Travel Time (Minutes)
45
40
35
30
25
20
15
10
5
0
Non-event
Incident
Weather
Incident&Weather
P50
P80
P95

(d)

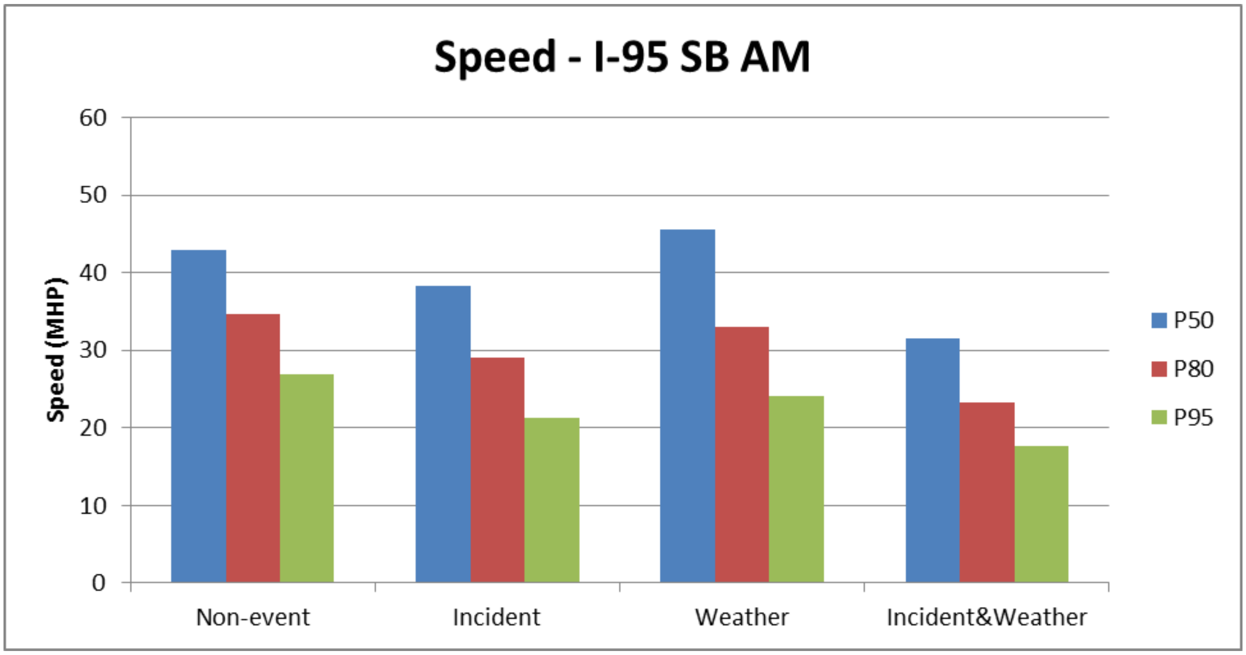


(e)

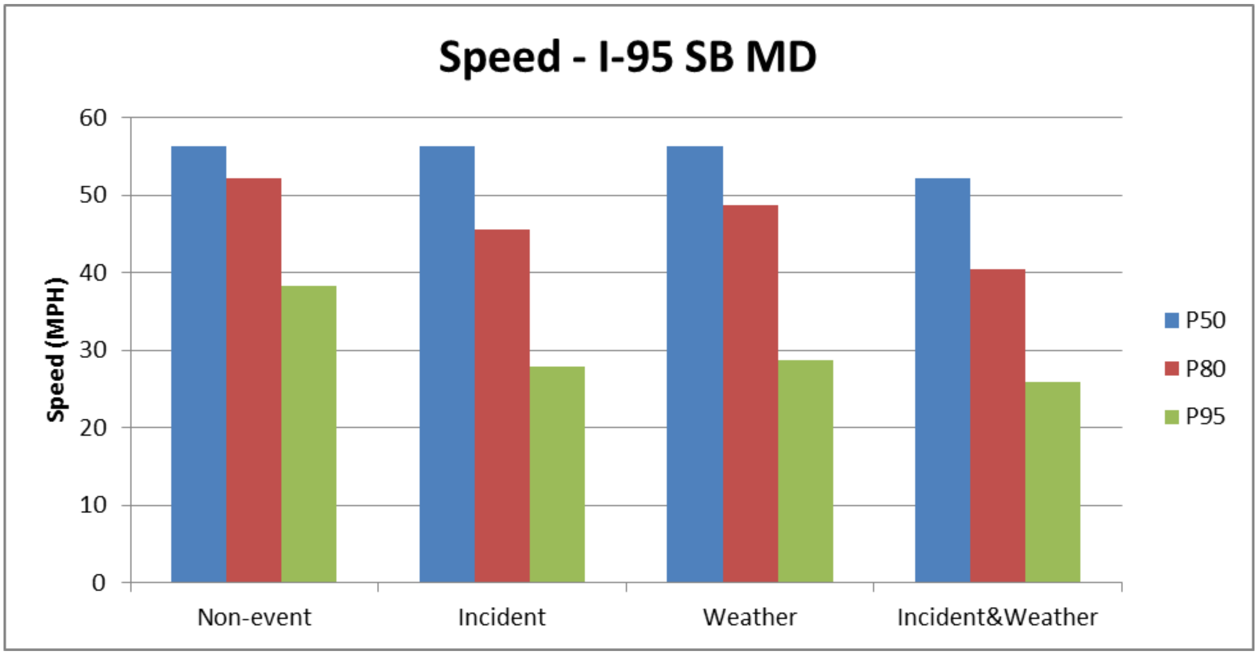


(f)

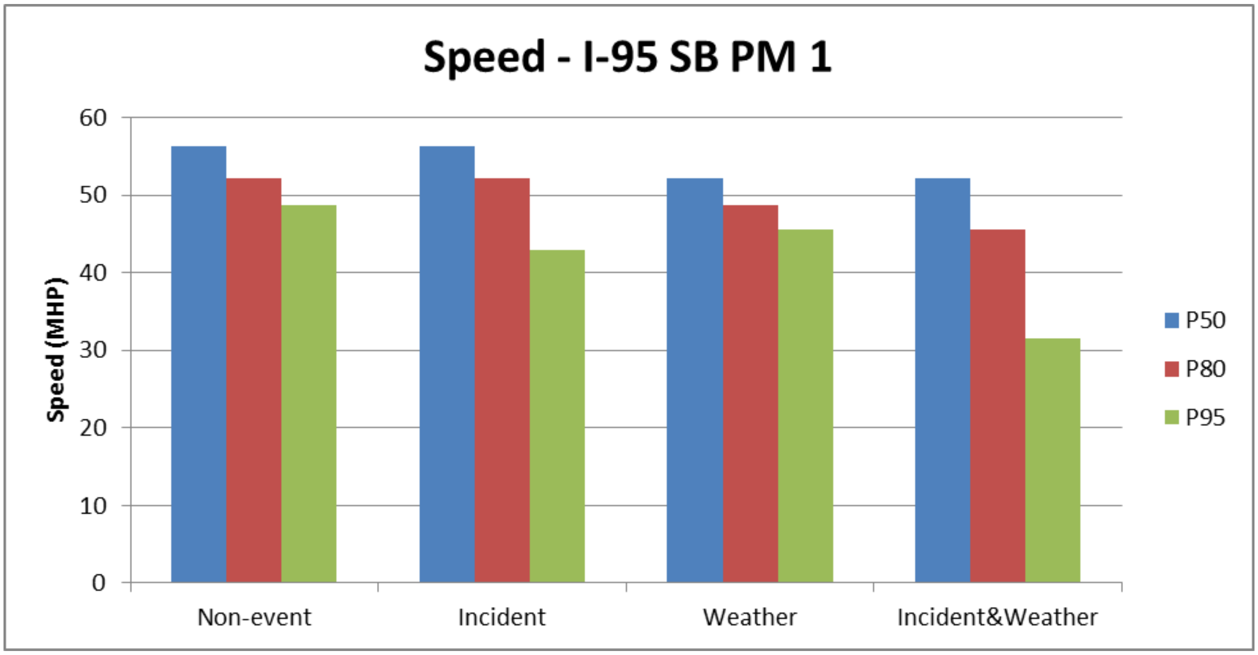
Figure C.15. Travel time for I-95 SB GPL for (a) AM peak, (b) MD, (c) PM1, (d) PM2, (e) APM, and (f) MN periods.


Speed - I-95 SB AM
Speed (MHP)
60
50
40
30
20
10
0
Non-event
Incident
Weather
Incident&Weather
P50
P80
P95

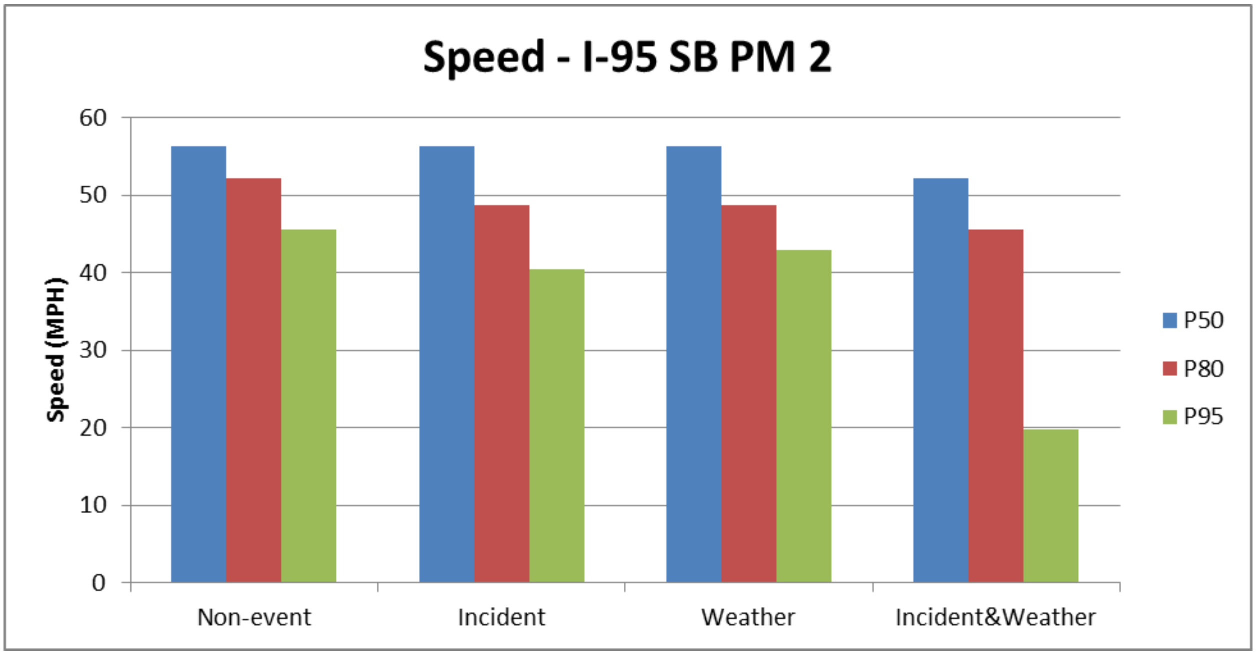
(a)


Speed - I-95 SB MD
Speed (MPH)
60
50
40
30
20
10
0
Non-event
Incident
Weather
Incident&Weather
P50
P80
P95

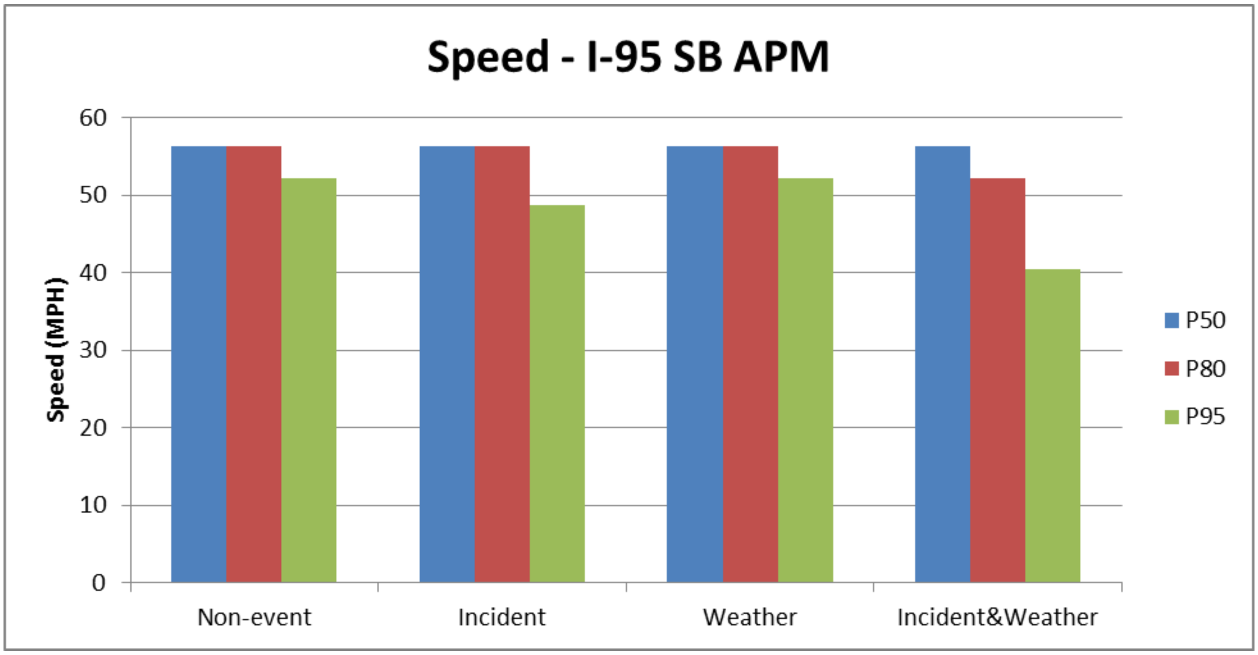
(b)


Speed - I-95 SB PM 1
Speed (MHP)
60
50
40
30
20
10
0
Non-event
Incident
Weather
Incident&Weather
P50
P80
P95

(c)


Speed - I-95 SB PM 2
Speed (MPH)
60
50
40
30
20
10
0
Non-event
Incident
Weather
Incident&Weather
P50
P80
P95

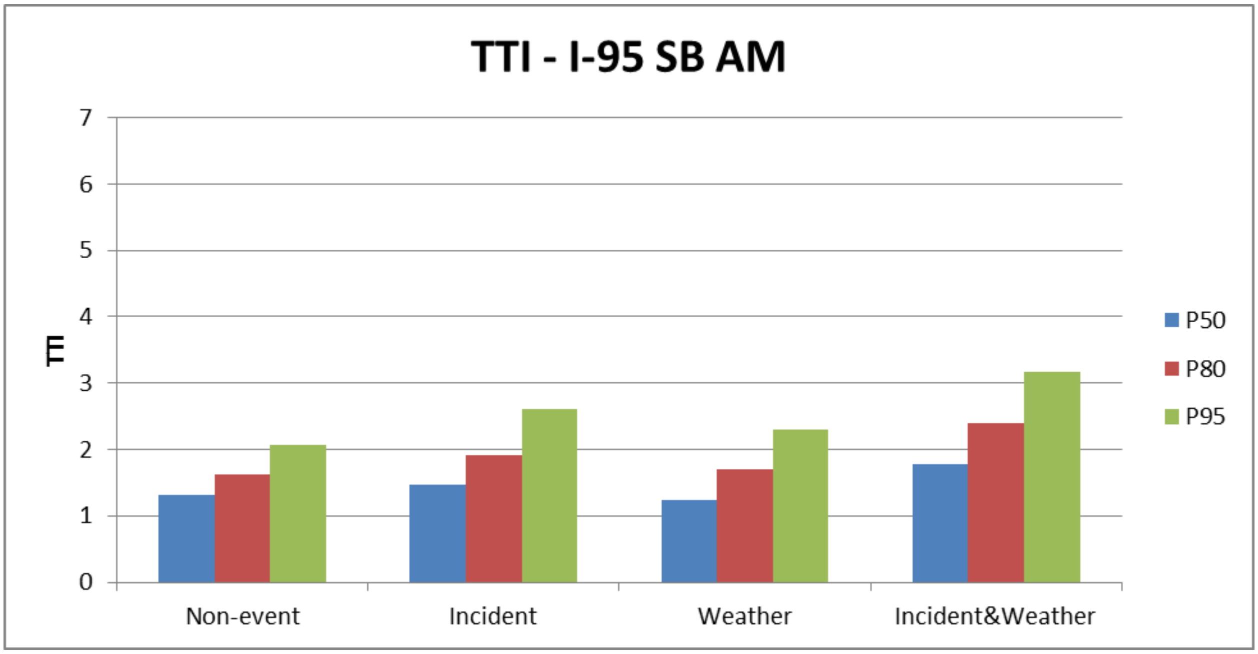
(d)



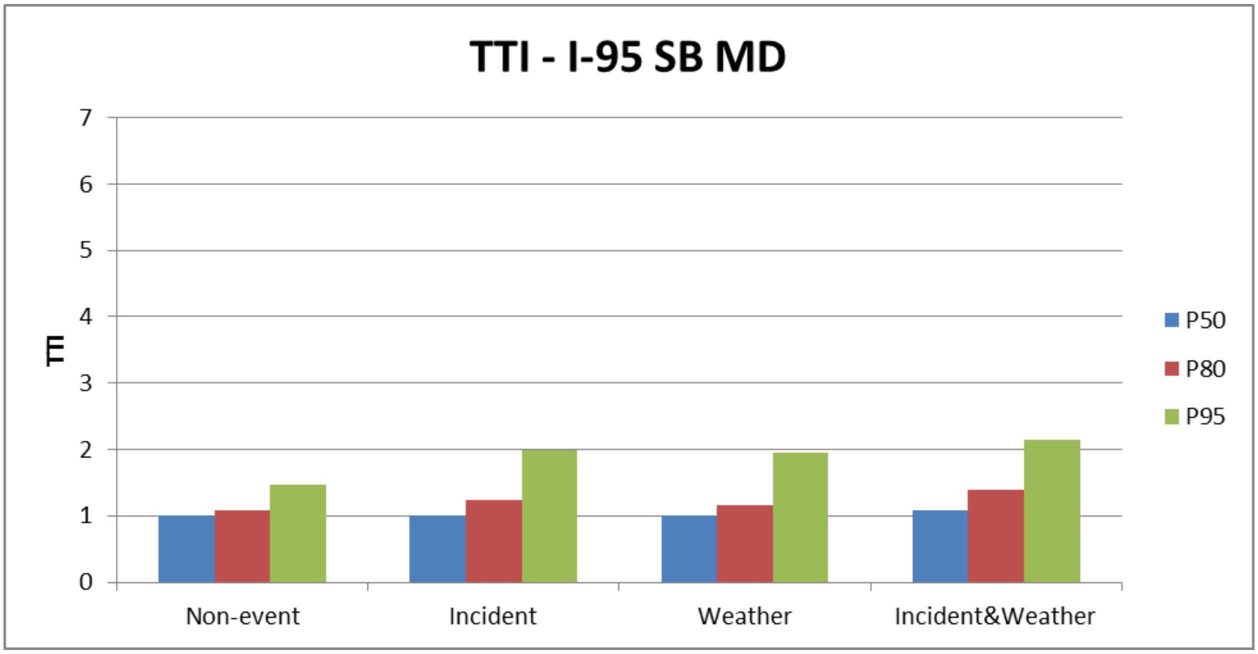
(e)

(f)

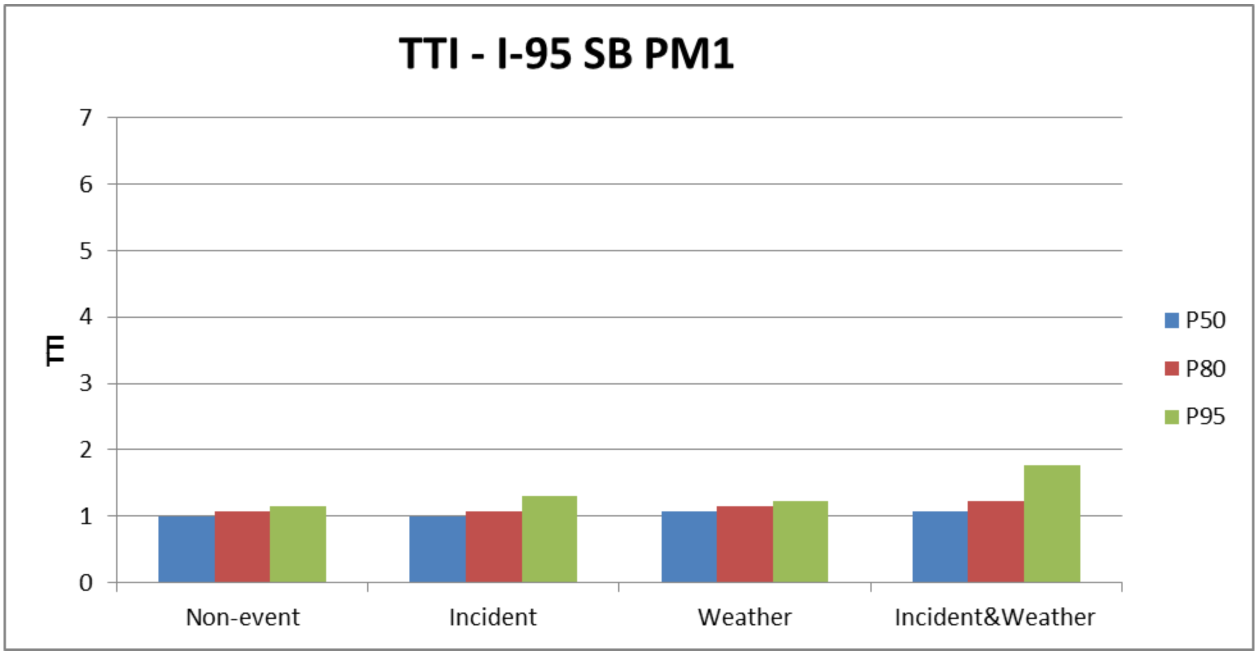
Figure C.16. Speed for I-95 SB GPL for (a) AM peak, (b) MD, (c) PM1, (d) PM2, (e) APM, and (f) MN periods.


TTI - I-95 SB AM
TTI
7
6
5
4
3
2
1
0
Non-event
Incident
Weather
Incident&Weather
P50
P80
P95

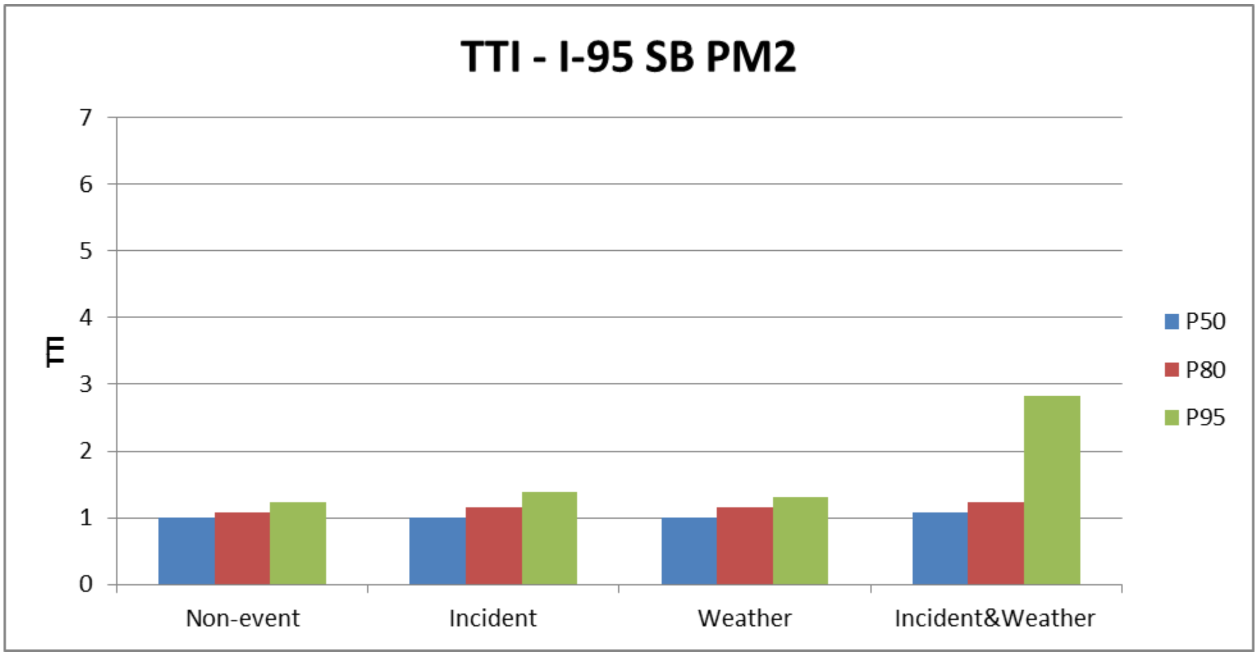
(a)


TTI - I-95 SB MD
TTI
7
6
5
4
3
2
1
0
Non-event
Incident
Weather
Incident&Weather
P50
P80
P95

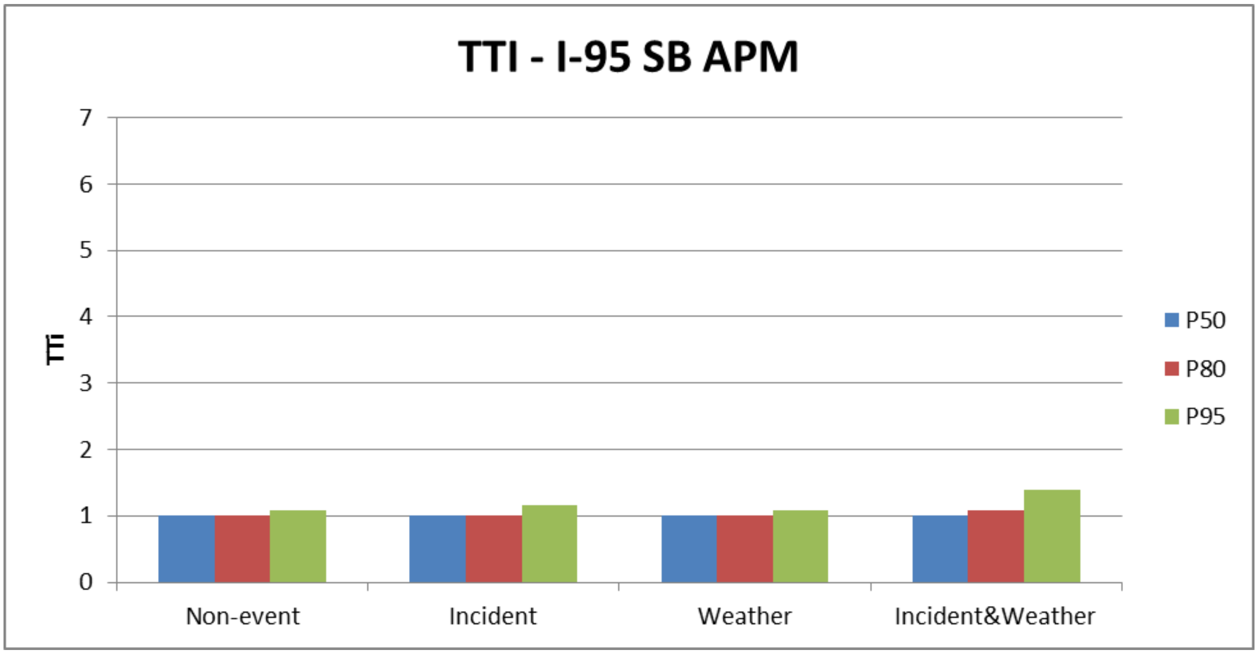
(b)


TTI - I-95 SB PM1
TTI
7
6
5
4
3
2
1
0
Non-event
Incident
Weather
Incident&Weather
P50
P80
P95

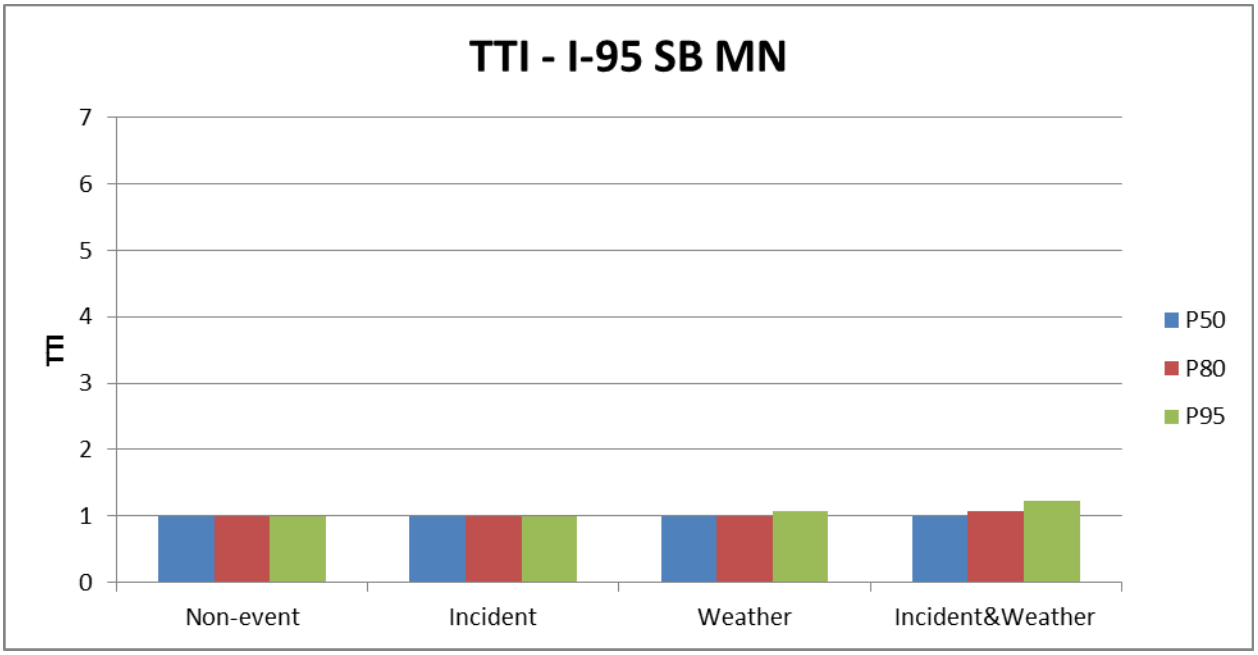
(c)


TTI - I-95 SB PM2
TTI
7
6
5
4
3
2
1
0
Non-event
Incident
Weather
Incident&Weather
P50
P80
P95

(d)



(e)



(f)

Figure C.17. TTI for I-95 SB GPL for (a) AM peak, (b) MD, (c) PM1, (d) PM2, (e) APM, and (f) MN periods.

The five-minute variations of other reliability performance measures, including mean and 50th, 80th, and 95th percentile TTI by time of the day, are presented in Figures C.18 to C.21. It can be observed from these figures that with no incidents, the 80th and 95th percentile TTIs were still high at 1.7 to 1.9 and 2.2 to 2.8, respectively. These results indicate that recurrent congestion contributes significantly to unreliability in the facility. Analyzing the data and visualizing the bottleneck impacts by using contour (heat) maps, as shown in Figure C.22 and Figure C.23, indicated that the main recurrent congestion in the AM peak was located at three merging areas: Miami Garden Drive, the NW 103rd ramp, and at the exit of the managed lane. The contour map of volume shown in Figure C.23 indicates that such congestion was caused by high demand. This analysis indicated that active traffic and demand management strategies that affect nonrecurrent congestion and solving the recurrent capacity problem could have significant impacts on improving system performance in the AM peak. These strategies should take advantage of the high-demand threshold to implement more aggressive management of traffic and demand as the measured or predicted demands start exceeding the thresholds.

As shown in Figure C.21, the 95th percentile TTI variation by five-minute periods was significantly affected by incidents, with the 95th percentile TTI increasing from 2.2 to 2.4 to a range of 2.6 to 3.1. During the midday and the rest of the day, the 95th percentile TTI increased from 1.2 to about 1.45 due to incidents. Thus, incident management strategies, particularly in the AM and part of the midday periods, are expected to provide significant benefits. Aggressive strategies such as restrictive ramp metering should be implemented during incident plus bad weather events and lane-blocking events.

Figure C.21 also shows that the variation of 95th percentile travel time rate after adding weather events indicates that weather events did not have significant impacts on I-95 SB GPL travel time reliability.

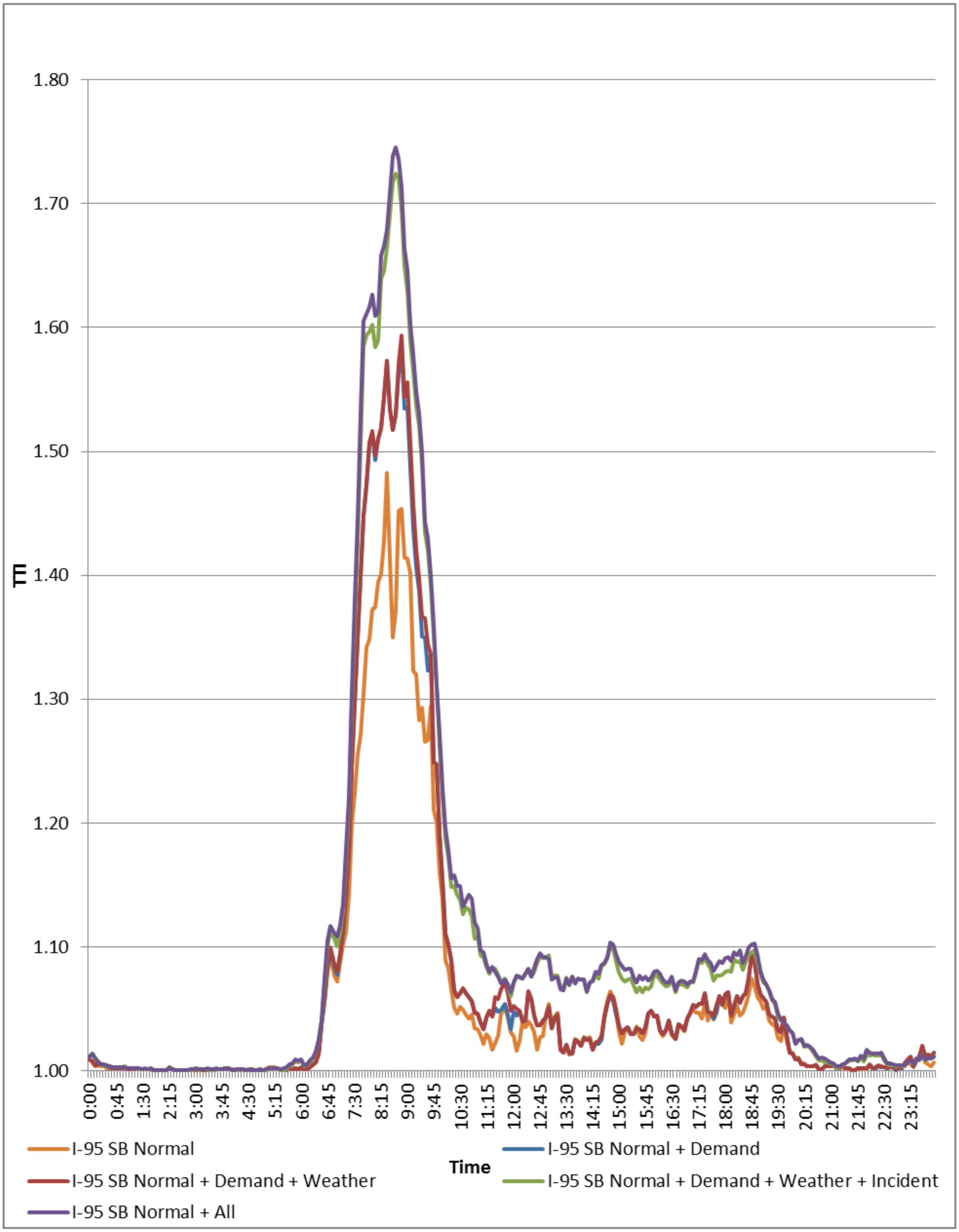


Figure C.18. Mean TTIs comparison for I-95 SB GPL.

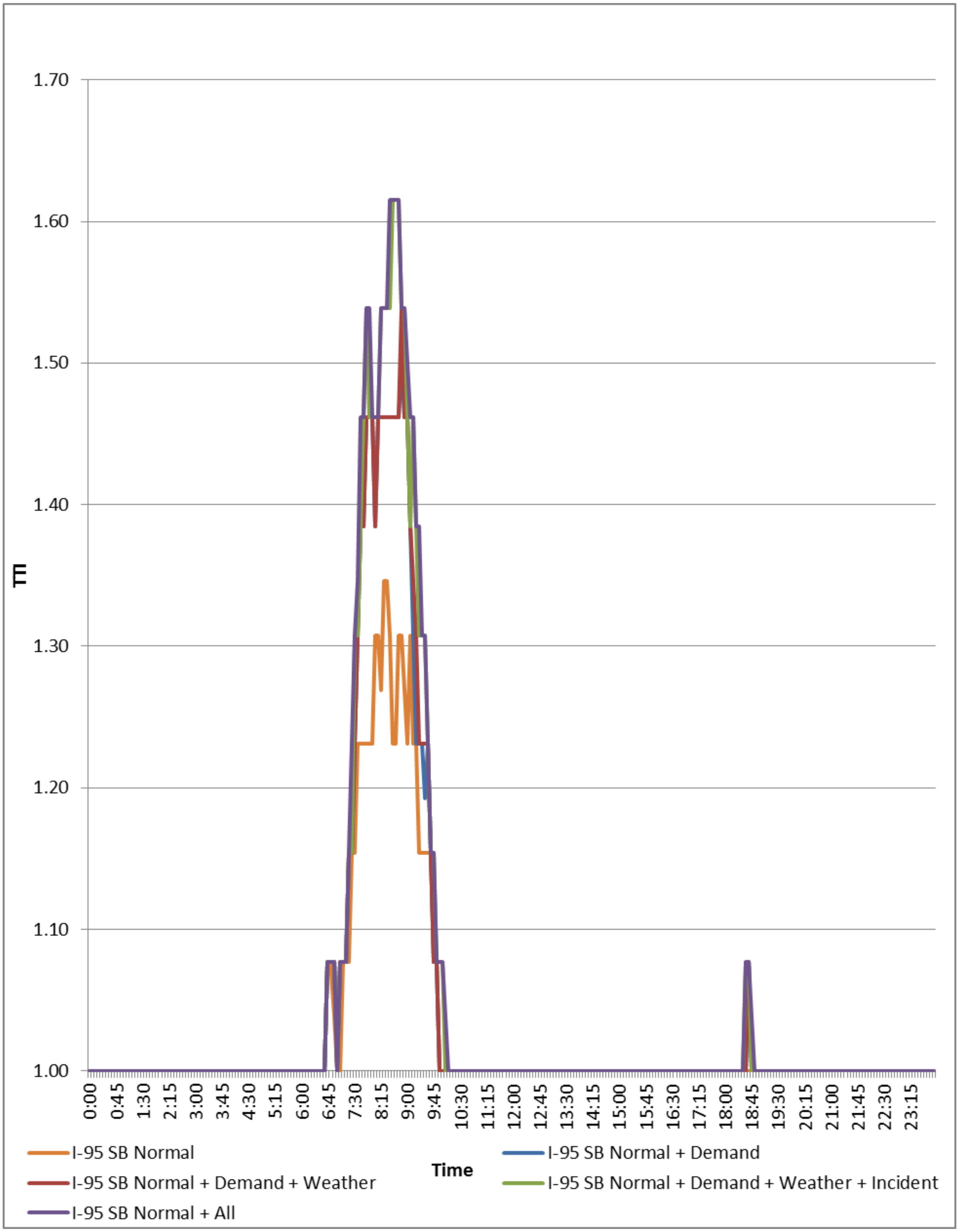


Figure C.19. 50th percentile TTIs comparison for I-95 SB GPL.

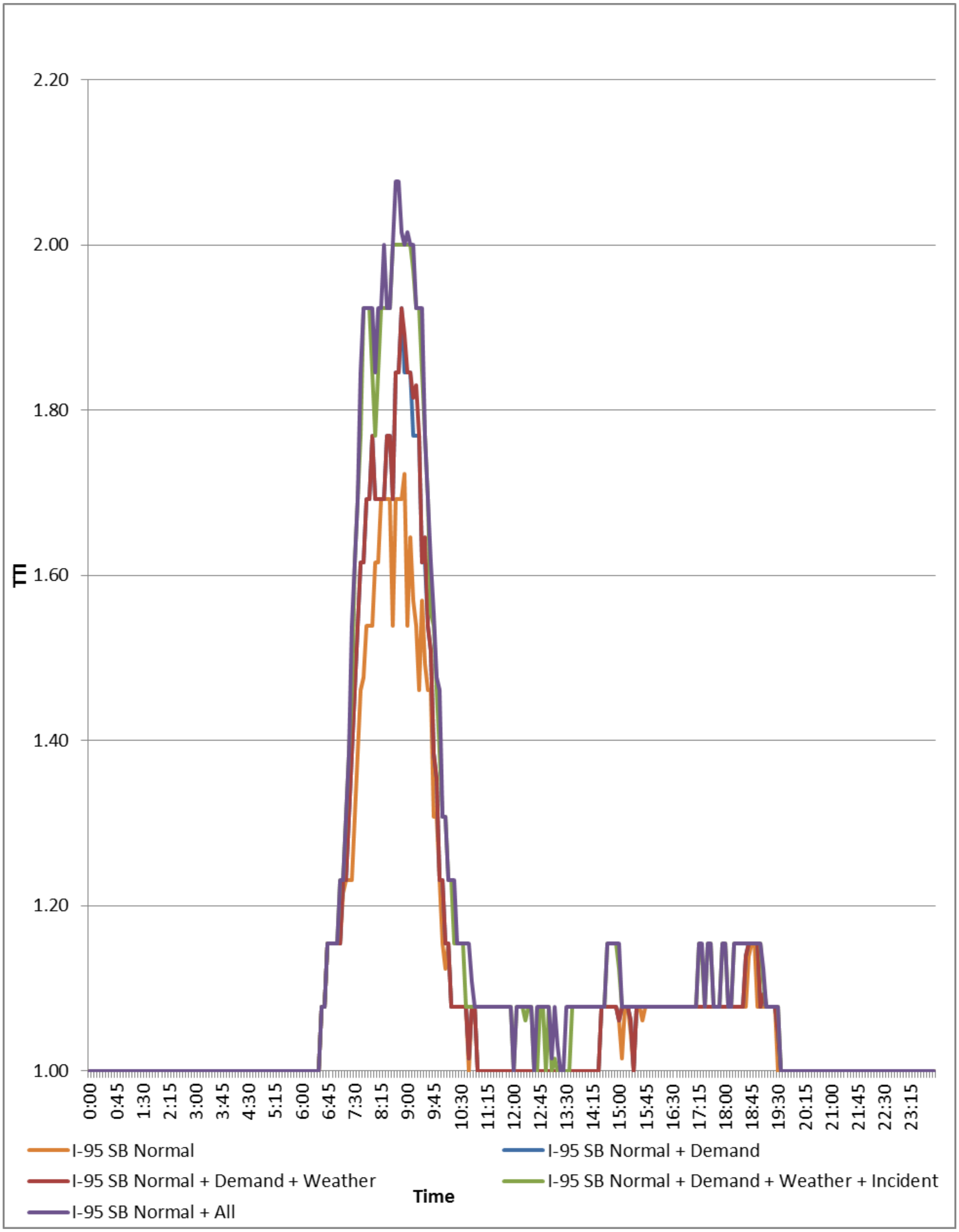


Figure C.20. 80th percentile TTIs comparison for I-95 SB GPL.

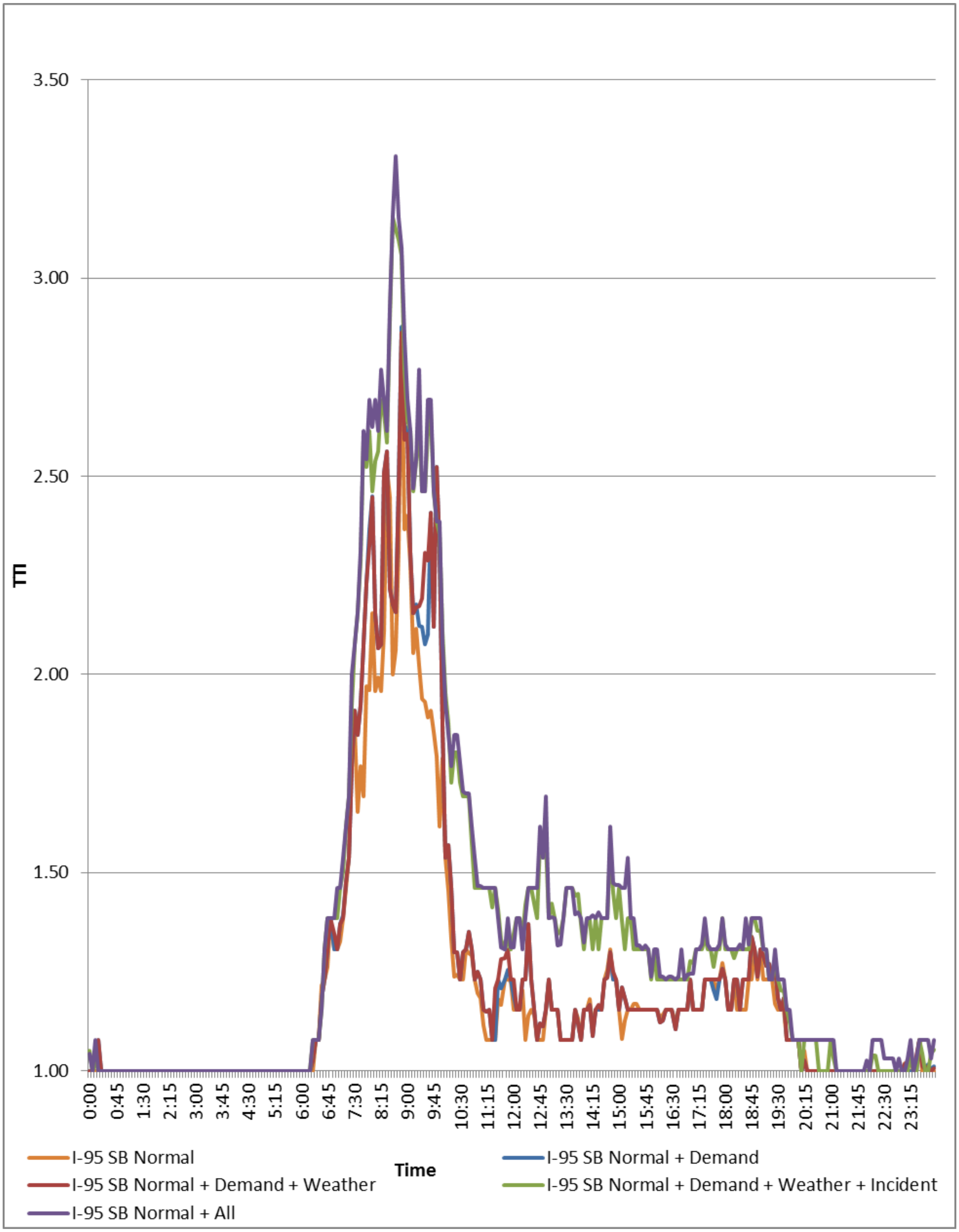


Figure C.21. 95th percentile TTIs comparison for I-95 SB GPL.

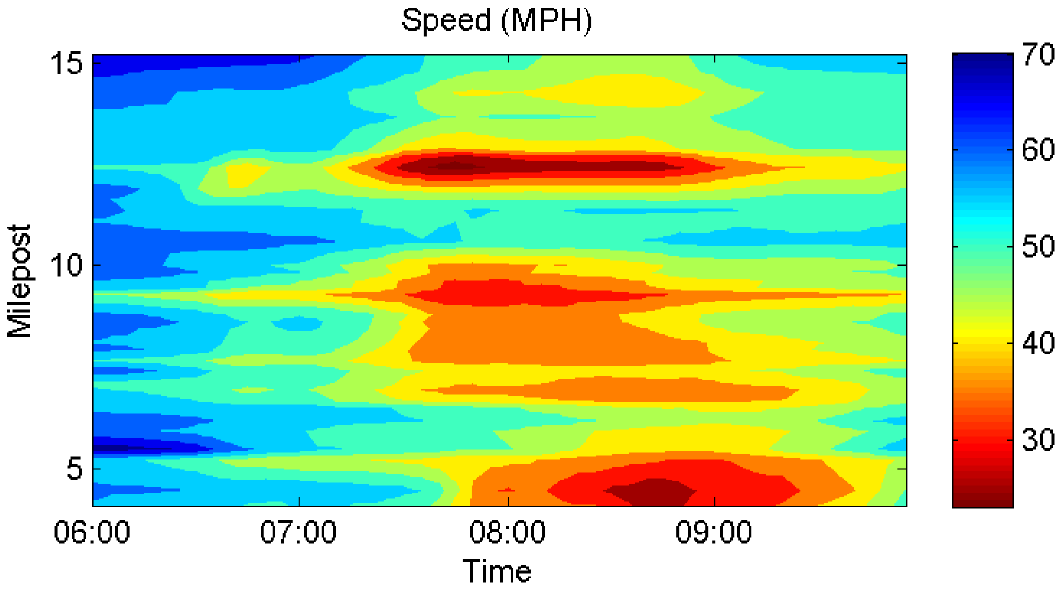


Figure C.22. I-95 SB GPL speed contour.

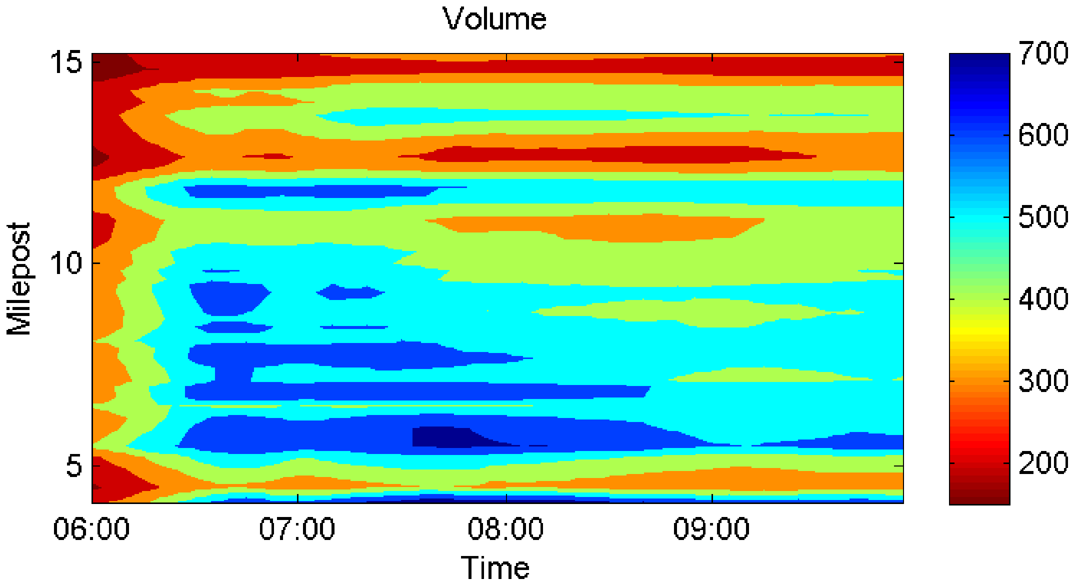
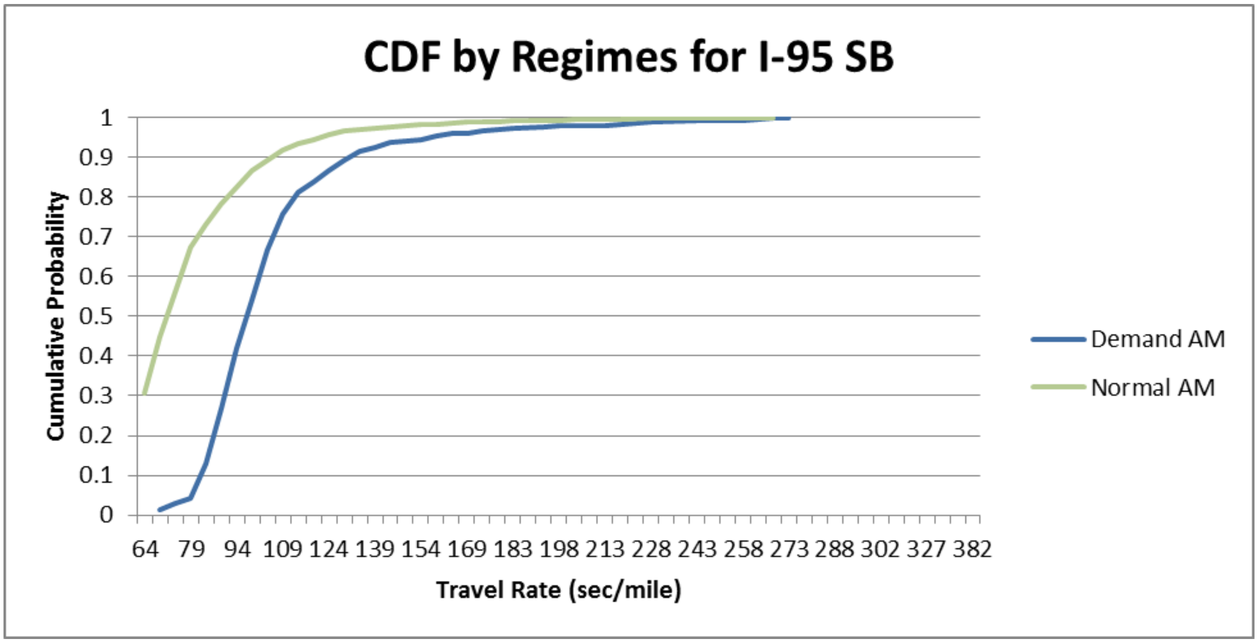


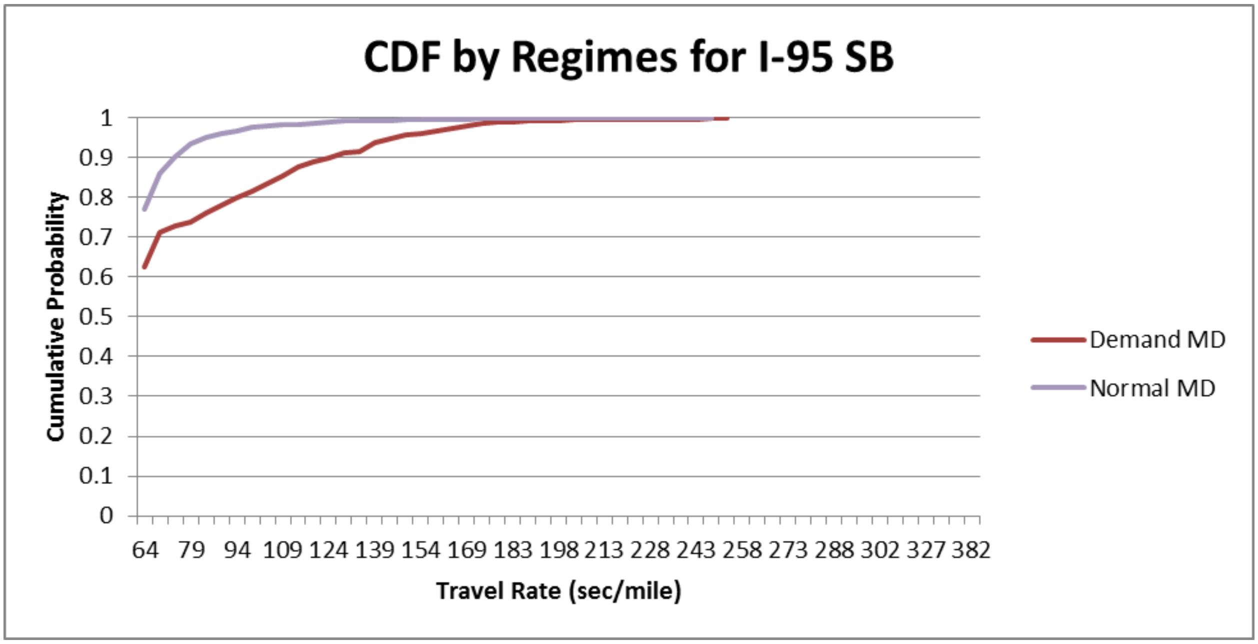
Figure C.23. I-95 SB GPL volume contour.

C.3 Contributions of the No-Event Periods

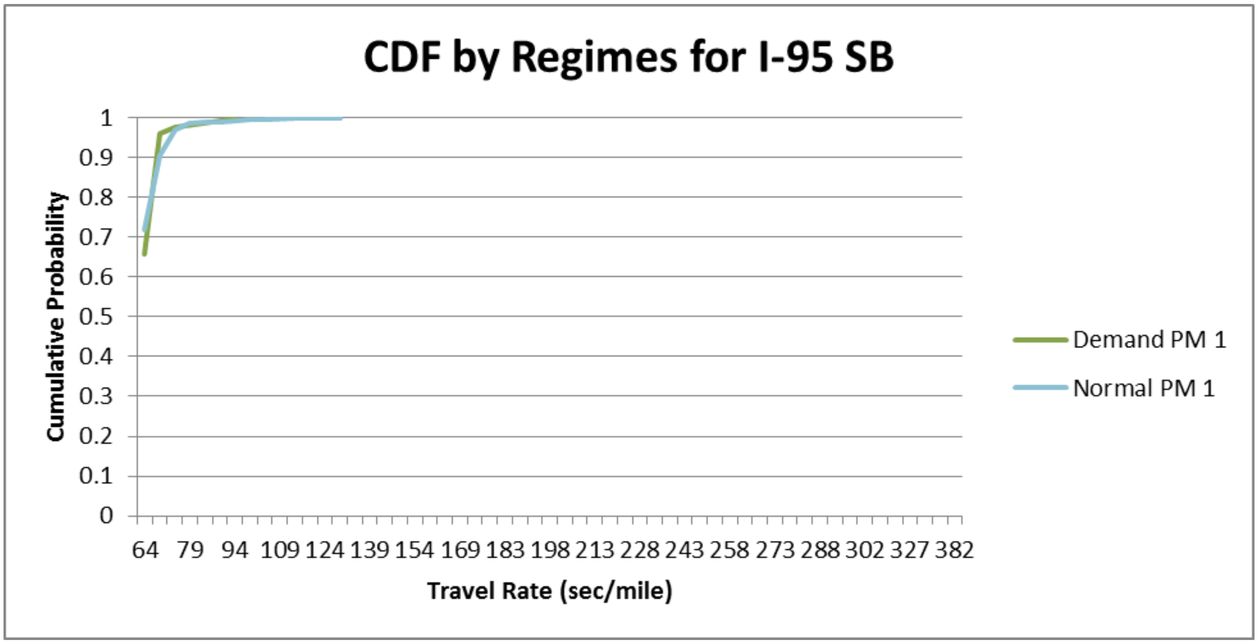
Because the no-event period included two possible conditions, normal traffic and high demand, the no-event regime was classified as such to study the influence of high demand on travel time reliability. Figure C.24 presents the distribution of travel time rate in terms of CDF along the I-95 SB GPL. Tables C.4, C.5, and C.6 list the percentages of occurrence, severity, and percentage of unreliability under normal traffic conditions and high-demand conditions for the same facility. Comparing the travel time rate CDF curves shown in Figure C.24 indicates that although the overall contribution to reliability of no-event periods was lower than that in the PM peak, as mentioned in the previous section, the no-event distribution was still unreliable, particularly when exceeding the high-demand threshold. The contribution of a single high-demand five-minute interval versus a normal-demand interval, as reflected by the NSV measure in Table C.5, was three time as high (44% versus 15%), although the contribution of normal- and high-demand intervals to the overall reliability was close (30% versus 24%) due to the higher frequency of the normal-demand intervals.



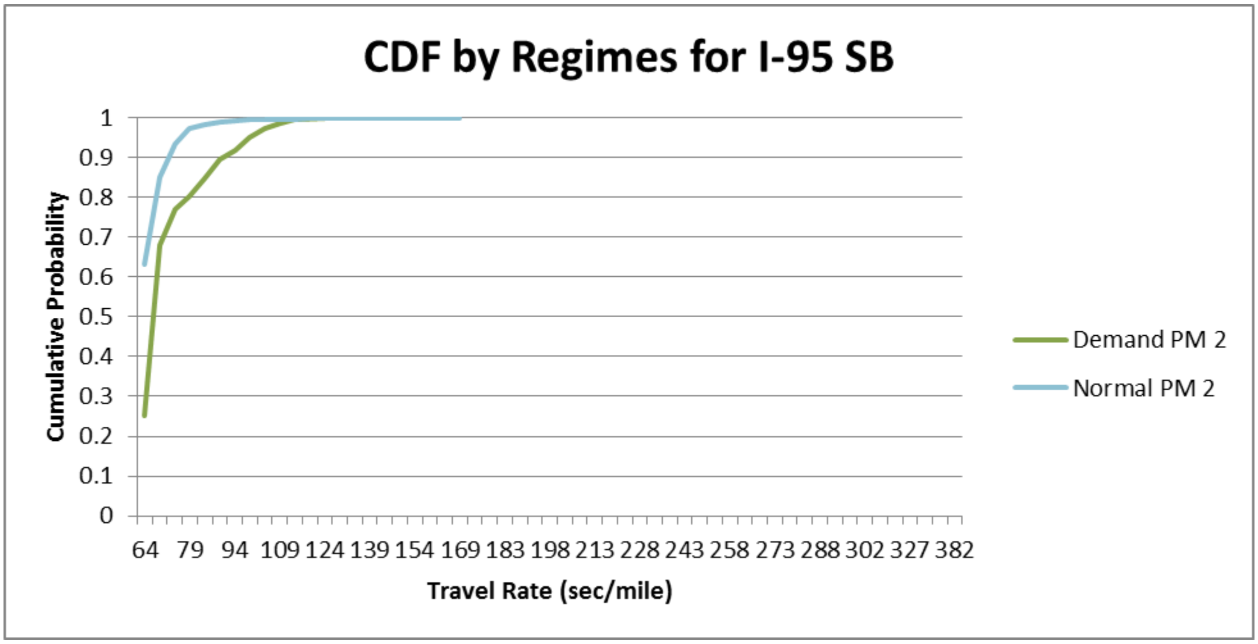
(a)



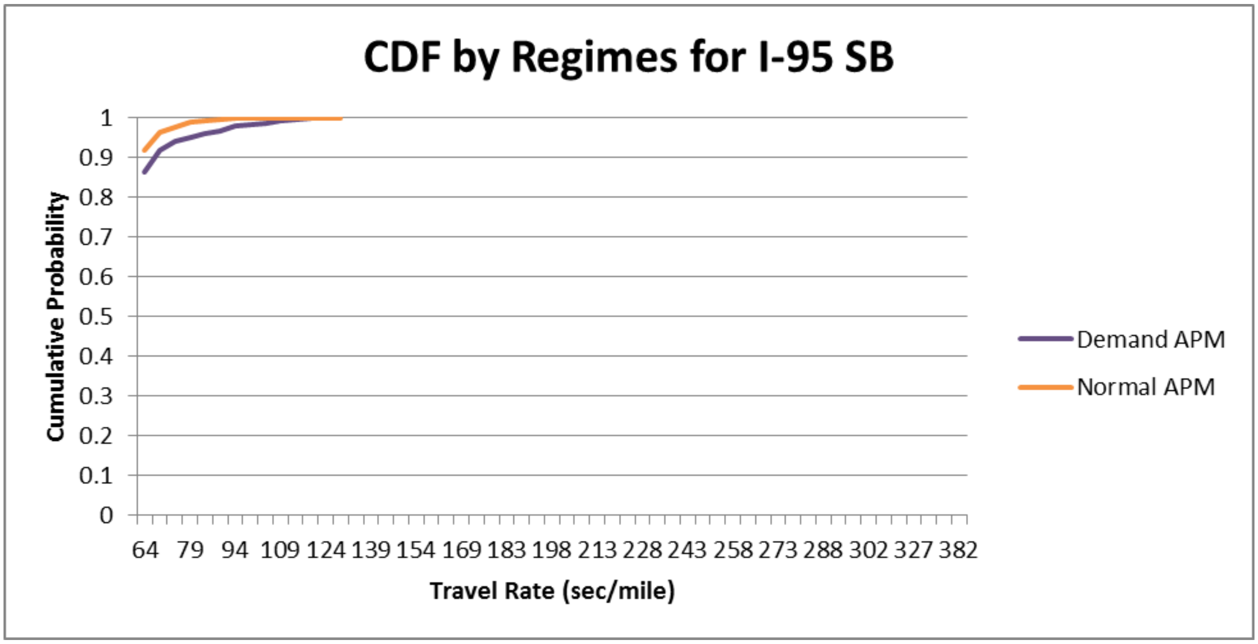
(b)


CDF by Regimes for I-95 SB
Cumulative Probability
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
64 79 94 109 124 139 154 169 183 198 213 228 243 258 273 288 302 327 382
Travel Rate (sec/mile)
Demand PM 1
Normal PM 1

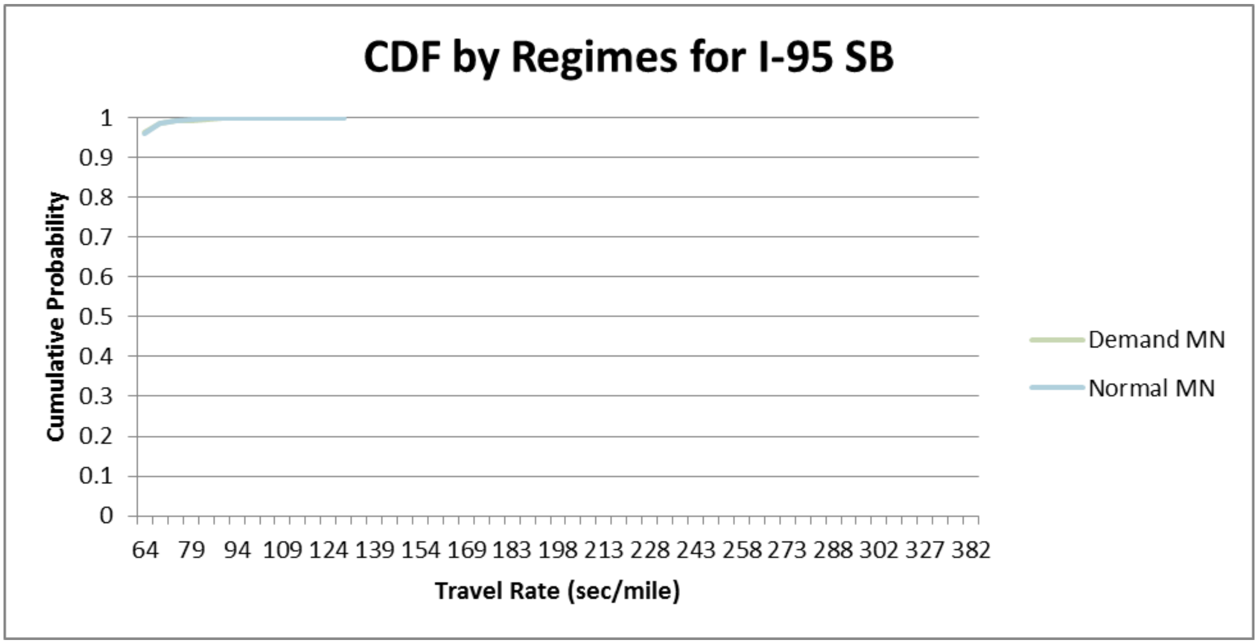
(c)


CDF by Regimes for I-95 SB
Cumulative Probability
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
64 79 94 109 124 139 154 169 183 198 213 228 243 258 273 288 302 327 382
Travel Rate (sec/mile)
Demand PM 2
Normal PM 2

(d)



(e)



(f)

Figure C.24. CDF by regimes for I-95 SB GPL for (a) AM peak, (b) MD, (c) PM1, (d) PM2, (e) APM, and (f) MN periods.

Table C.4. Percentage of Occurrence

Time Period	Demand	Normal	Total
AM	2%	5%	7%
MD	2%	21%	23%
PM1	0%	4%	4%
PM2	0%	6%	6%
APM	1%	12%	13%
MN	2%	45%	47%

Table C.5. Percentage of Severity

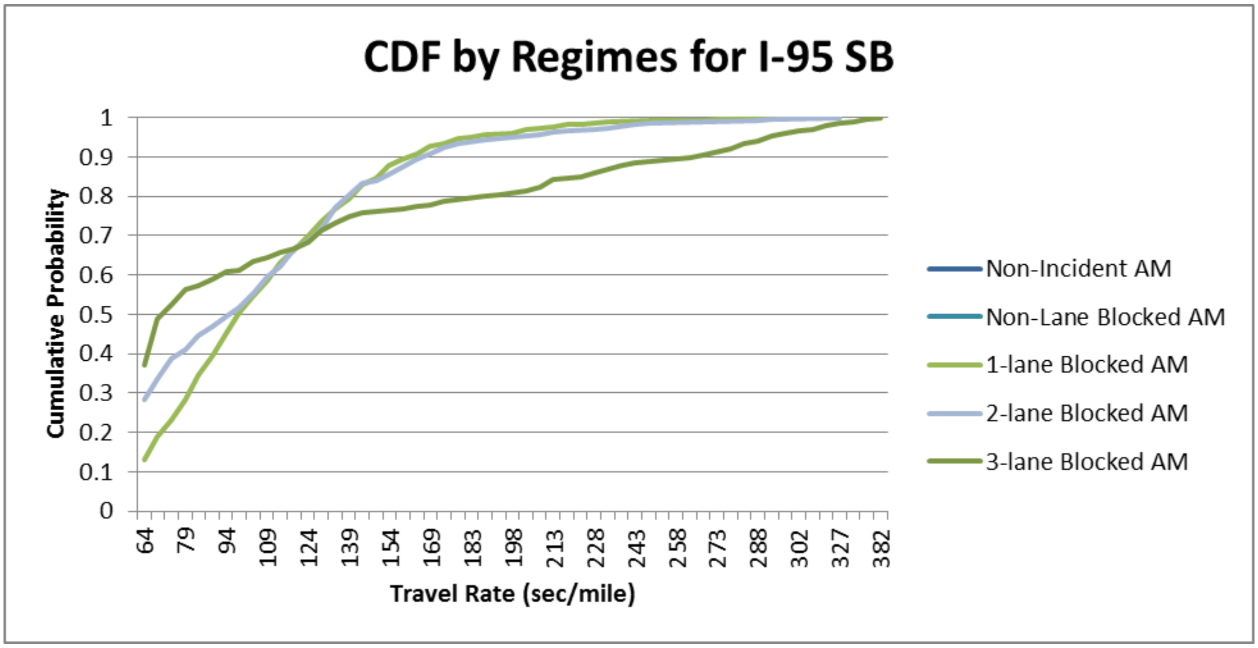
Time Period	Demand	Normal	Total
AM	44%	15%	59%
MD	27%	3%	30%
PM1	1%	1%	2%
PM2	5%	1%	6%
APM	1%	0%	2%
MN	0%	0%	1%

Table C.6. Percentage of Unreliability Contribution

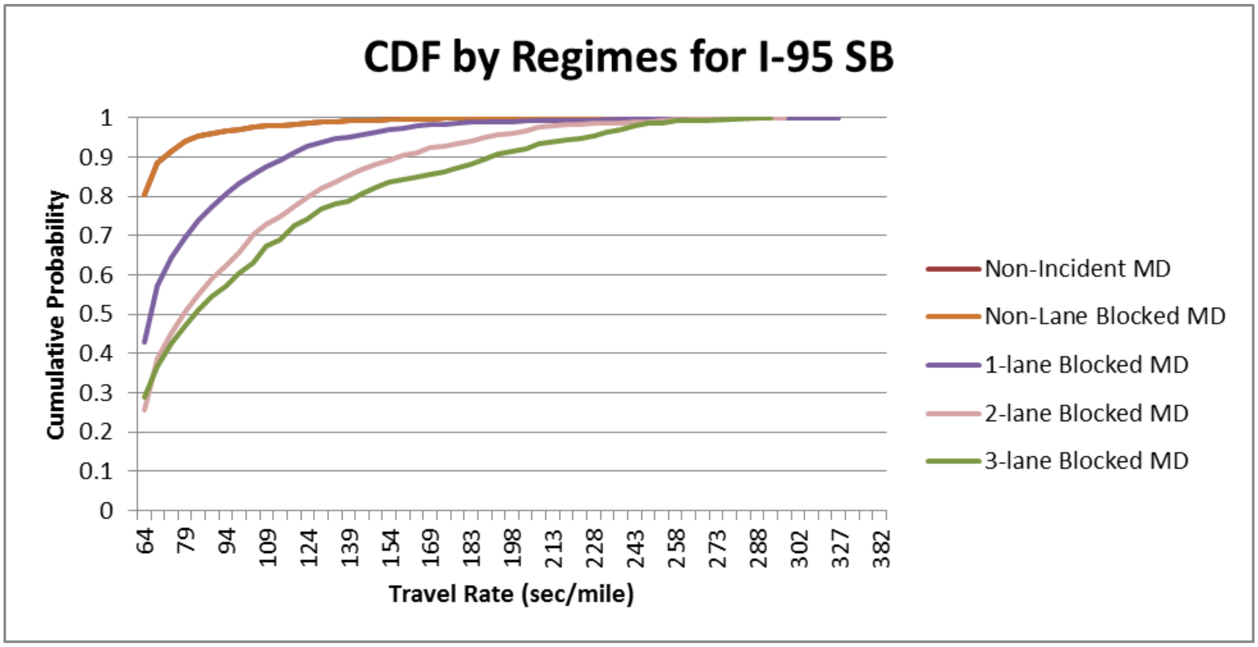
Time Period	Demand	Normal	Total
AM	30%	24%	54%
MD	15%	22%	37%
PM1	0%	1%	1%
PM2	1%	3%	3%
APM	0%	1%	2%
MN	0%	2%	3%

C.4 Contributions of Incidents by Lane Blockage and Duration

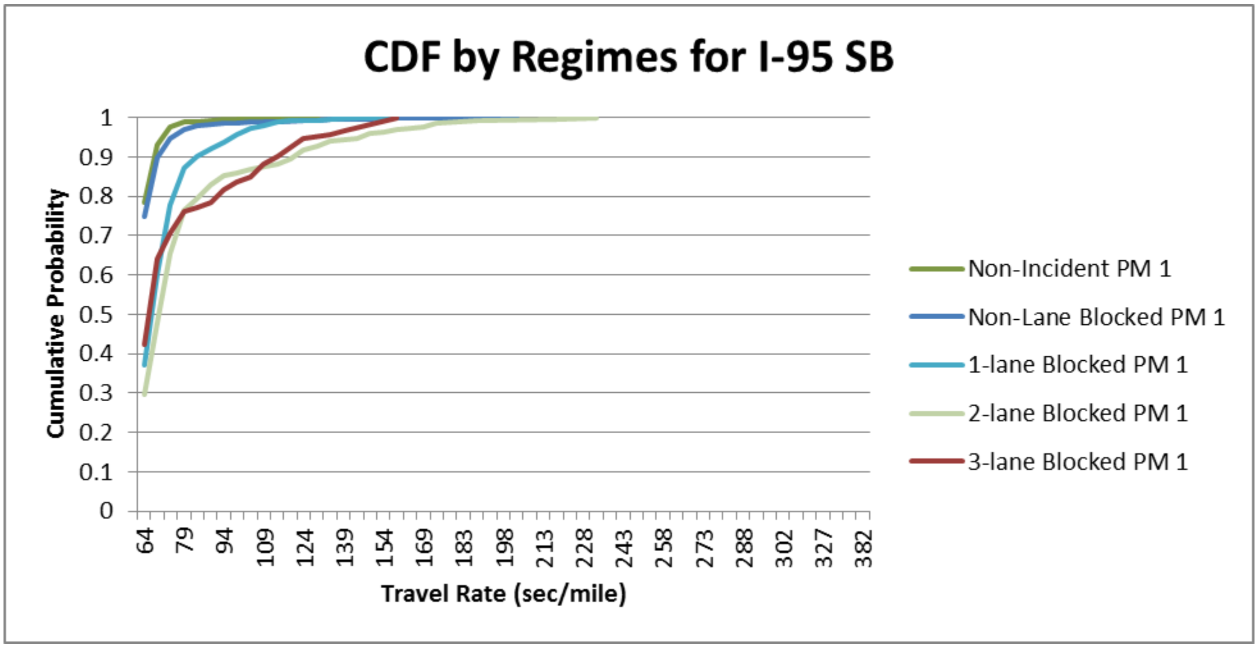
The impacts of incidents on travel time reliability along the I-95 SB GPL were further analyzed by differentiating the number of lane blockages and incident duration. The travel time rate CDF curves and the percentages of occurrence, severity, and unreliability contribution for I-95 SB GPL are presented in Figure C.25, Table C.7, Table C.8, and Table C.9, respectively. As shown in the figure and tables, the analysis by lane blockage indicated that the main contributions of lane-blocking incidents were in the AM peak and, to a lesser extent, the midday peak. Although on a per event basis the impact of shoulder incidents was small, they still contributed to unreliability. Lane-blocking incident contribution per event was high (particularly for 2 and 3+ lane blockage), as shown by the travel time rate CDF curves and also by the NSV values in Table C.8. For example, the 2+ lane-blocking–incident contribution during the AM peak was still relatively high (13%), although the intervals with these incidents constituted only about 0.4% of the total number of intervals in the same period. One lane–blocking incident intervals contributed 10.7%.



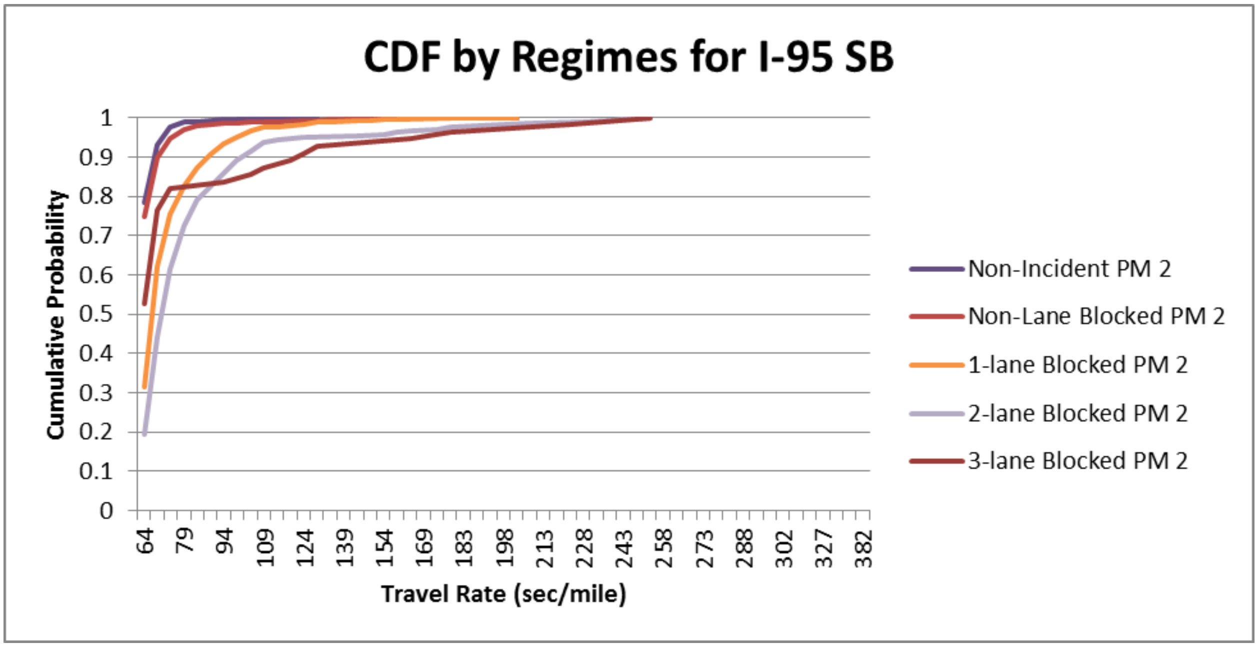
(a)


CDF by Regimes for I-95 SB
Cumulative Probability
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
64
79
94
109
124
139
154
169
183
198
213
228
243
258
273
288
302
327
382
Travel Rate (sec/mile)
Non-Incident MD
Non-Lane Blocked MD
1-lane Blocked MD
2-lane Blocked MD
3-lane Blocked MD

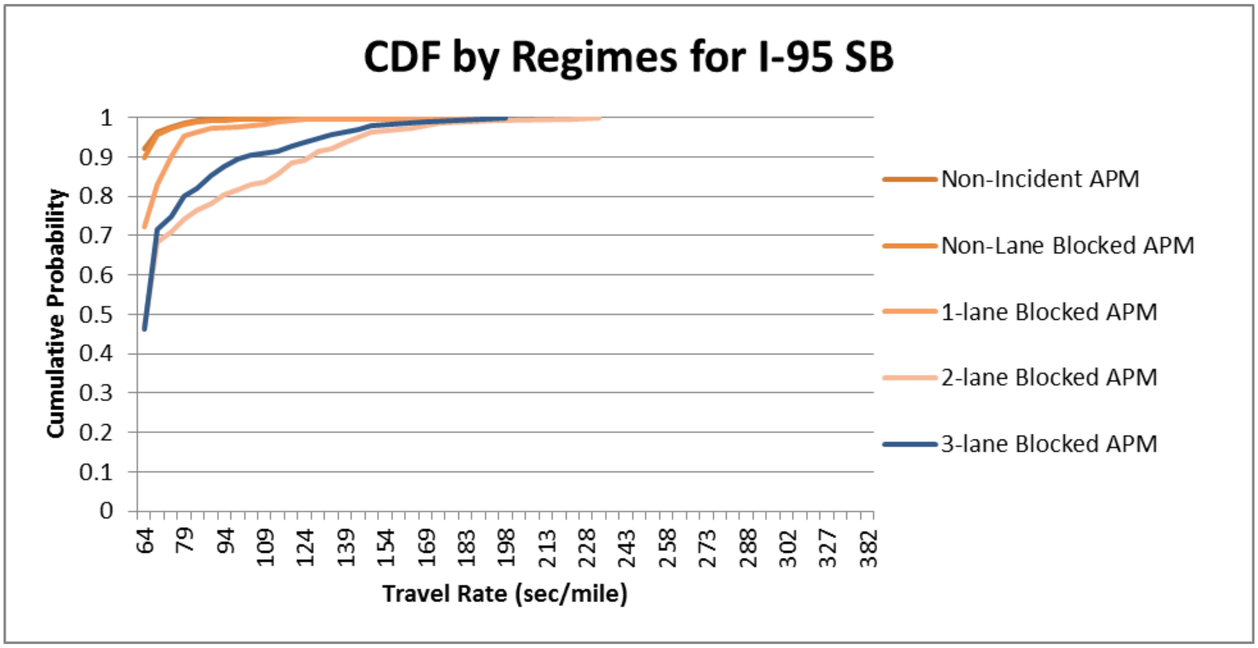
(b)


CDF by Regimes for I-95 SB
Cumulative Probability
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
64
79
94
109
124
139
154
169
183
198
213
228
243
258
273
288
302
327
382
Travel Rate (sec/mile)
Non-Incident PM 1
Non-Lane Blocked PM 1
1-lane Blocked PM 1
2-lane Blocked PM 1
3-lane Blocked PM 1

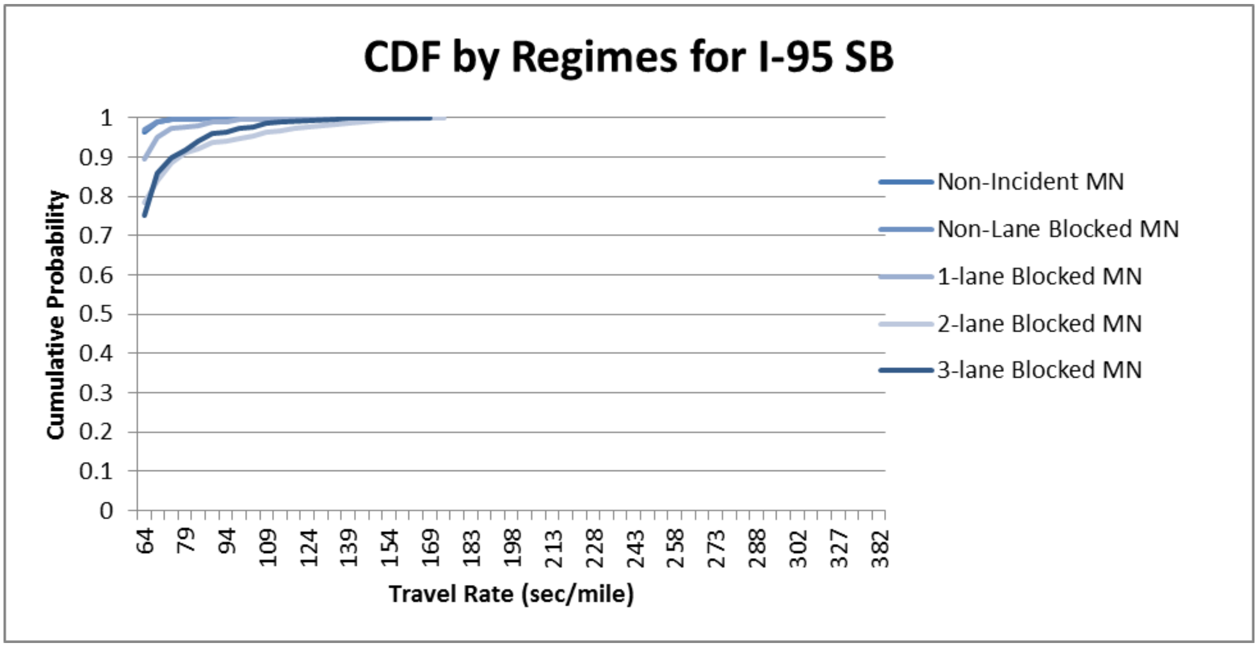
(c)


CDF by Regimes for I-95 SB
Cumulative Probability
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
64
79
94
109
124
139
154
169
183
198
213
228
243
258
273
288
302
327
382
Travel Rate (sec/mile)
Non-Incident PM 2
Non-Lane Blocked PM 2
1-lane Blocked PM 2
2-lane Blocked PM 2
3-lane Blocked PM 2

(d)


CDF by Regimes for I-95 SB
Cumulative Probability
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
64
79
94
109
124
139
154
169
183
198
213
228
243
258
273
288
302
327
382
Travel Rate (sec/mile)
Non-Incident APM
Non-Lane Blocked APM
1-lane Blocked APM
2-lane Blocked APM
3-lane Blocked APM

(e)



(f)

Figure C.25. CDF by regimes for I-95 SB GPL for (a) AM peak, (b) MD, (c) PM1, (d) PM2, (e) APM, and (f) MN periods.

Table C.7. Percentage of Occurrence

Time Period	Nonincident	0 Lanes Blocked	1 Lane Blocked	2 Lanes Blocked	3+ Lanes Blocked
AM	3.2%	3.8%	0.8%	0.3%	0.1%
MD	10.4%	12.6%	2.7%	1.0%	0.4%
PM1	2.0%	3.2%	0.6%	0.3%	0.1%
PM2	3.0%	4.3%	0.8%	0.3%	0.1%
APM	5.8%	5.9%	0.6%	0.1%	0.1%
MN	21.3%	15.0%	0.9%	0.4%	0.3%

Table C.8. Percentage of Severity

Time Period	Nonincident	0 Lanes Blocked	1 Lane Blocked	2 Lanes Blocked	3+ Lanes Blocked
AM	2.6%	3.1%	7.8%	10.9%	38.4%
MD	0.6%	0.8%	2.6%	6.2%	13.3%
PM1	0.1%	0.2%	0.5%	2.2%	1.5%
PM2	0.2%	0.4%	0.7%	0.7%	3.4%
APM	0.0%	0.1%	0.2%	3.5%	2.1%
MN	0.0%	0.0%	0.1%	0.8%	0.3%

Table C.9. Percentage of Unreliability Contribution

Time Period	Nonincident	0 Lanes Blocked	1 Lane Blocked	2 Lanes Blocked	3+ Lanes Blocked
AM	13.5%	19.5%	10.7%	5.3%	7.7%
MD	9.9%	16.0%	11.5%	10.2%	8.1%
PM1	0.3%	1.3%	0.5%	0.9%	0.2%
PM2	0.8%	2.8%	0.9%	0.3%	0.4%
APM	0.4%	1.0%	0.2%	0.8%	0.3%
MN	0.7%	0.7%	0.2%	0.5%	0.1%

The incident lane blockage influence was also examined using the proposed approach in this study. Figure C.26 to Figure C.29 present the five-minute variations of the mean and 50th, 80th, and 95th percentile TTIs for three traffic conditions: all types of traffic conditions, traffic condition after removing lane-blocking incidents, and traffic after removing all incidents. The difference in TTI between the first and second scenarios demonstrates the impacts of lane-blocking incident, and the difference between the second and third scenarios corresponds to the impacts of non-lane-blocking incidents. As measured by 80th and 95th percentile TTIs, the analysis results further confirmed that lane-blocking incidents were the main contributors to incident-related unreliability, although to a lesser degree non-lane-blocking incidents also affected reliability.

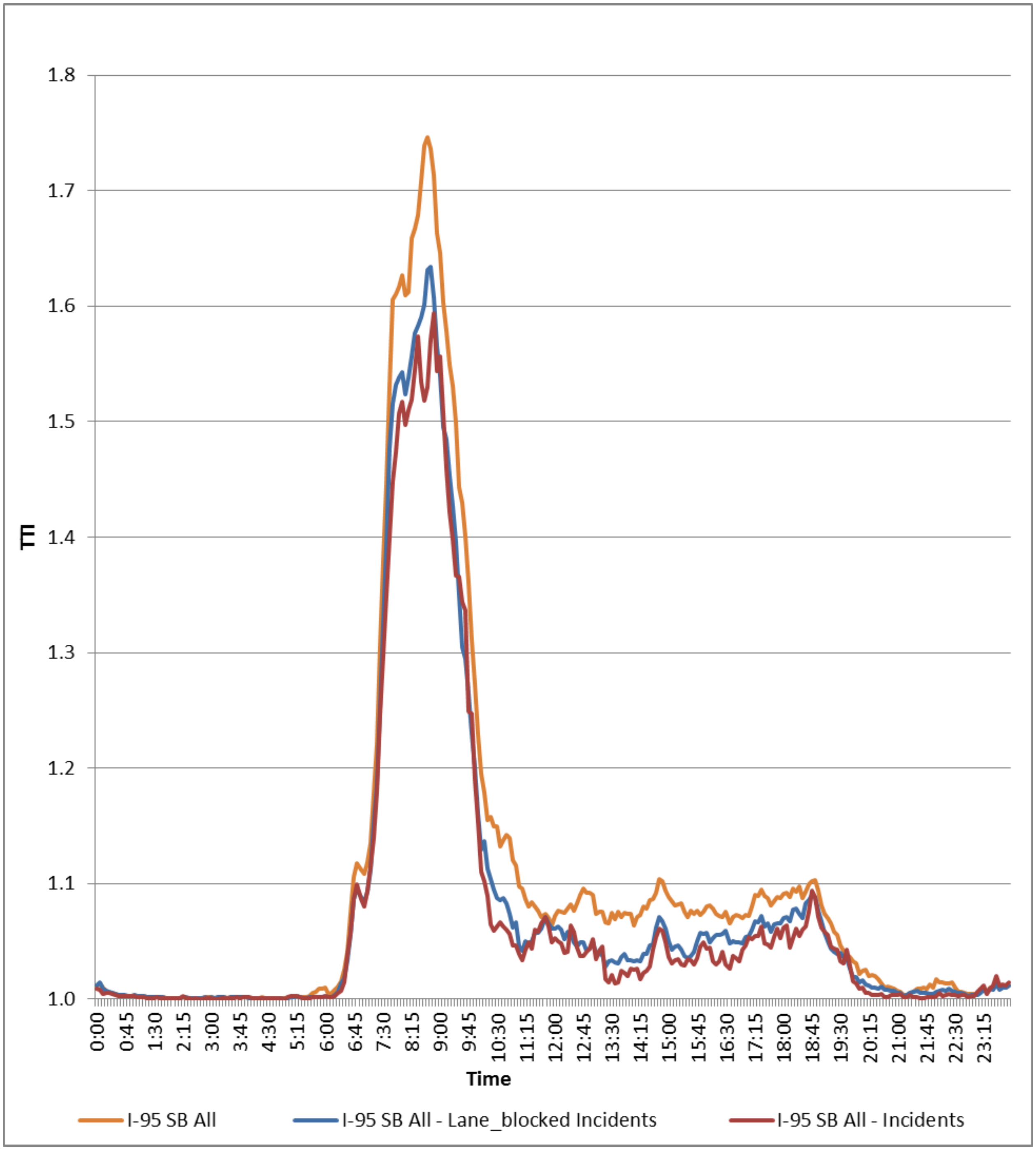


Figure C.26. Mean TTIs comparison for I-95 SB GPL.

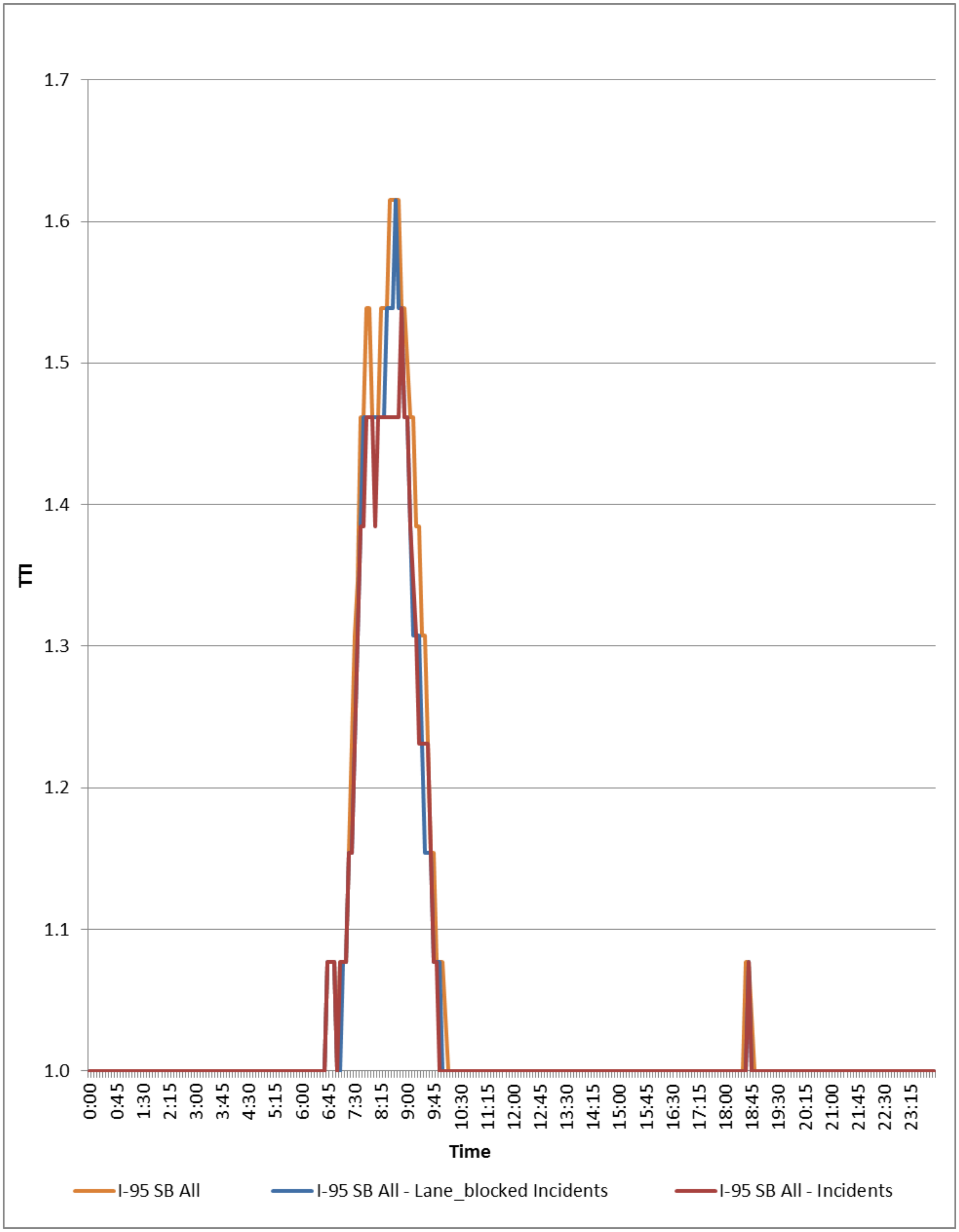


Figure C.27. 50th percentile TTIs comparison for I-95 SB GPL.

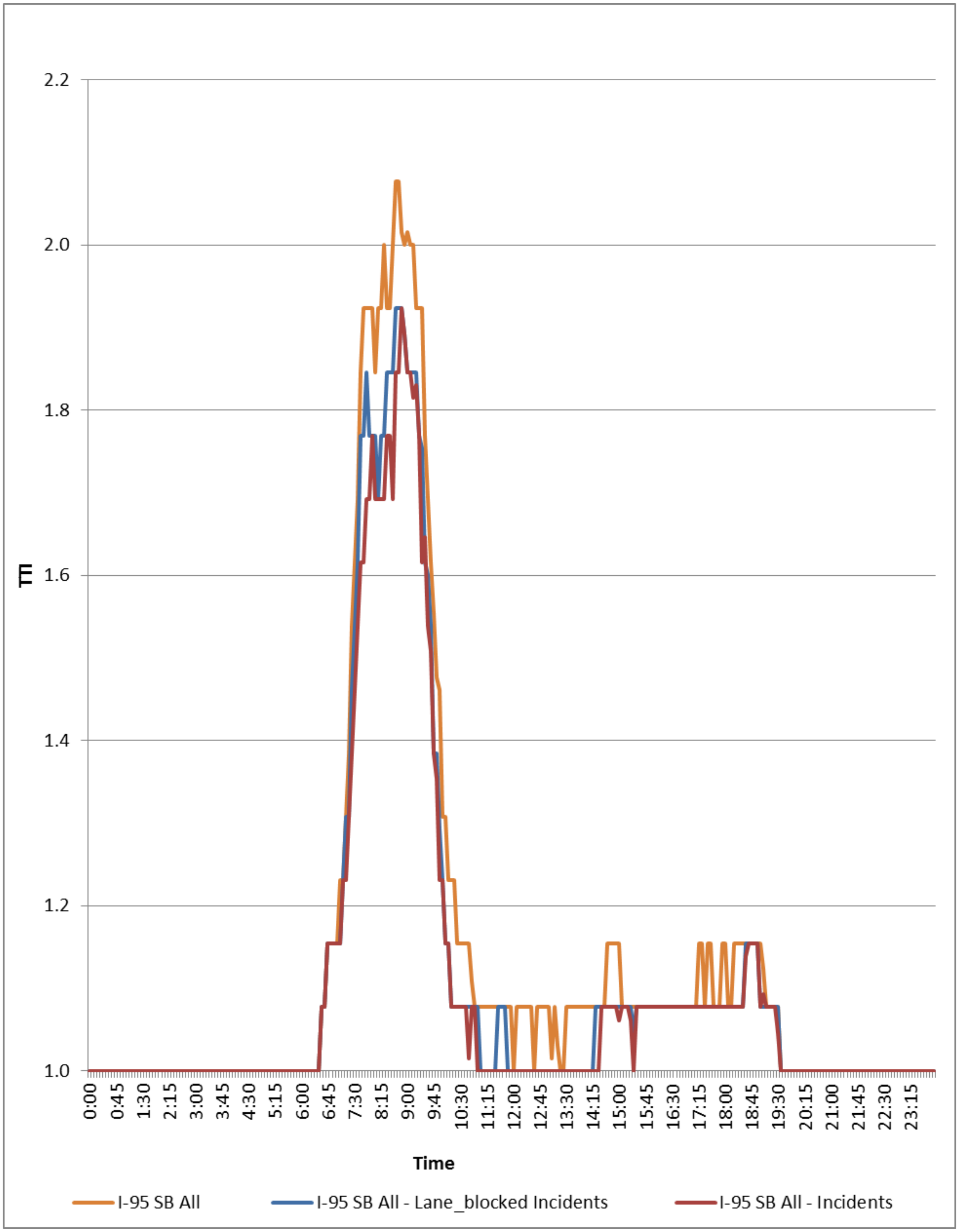


Figure C.28. 80th percentile TTIs comparison for I-95 SB GPL.

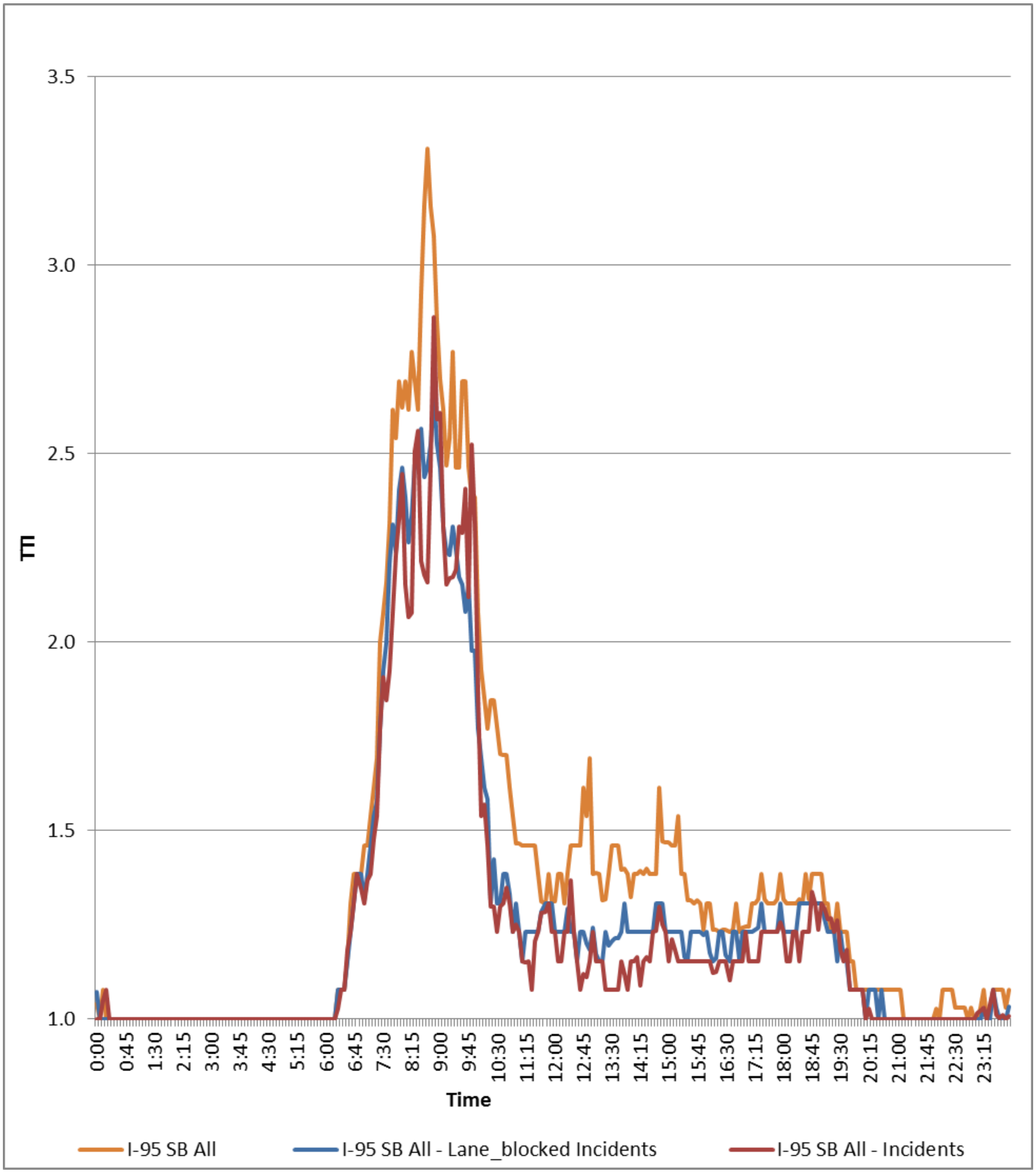


Figure C.29. 95th percentile TTIs comparison for I-95 SB GPL.

Similarly, Figure C.30 to Figure C.33 present the results of mean and 50th, 80th, and 95th percentile TTIs for all types of traffic conditions, traffic conditions after removing incident with duration greater than one hour, traffic conditions after removing incident with duration greater than 30 minutes, and traffic without any incidents. The results show that the major impacts of incident duration on travel time reliability for I-95 SB GPL were in the AM peak period. There was no significant difference in TTI for different incident durations during the remaining periods of the day.

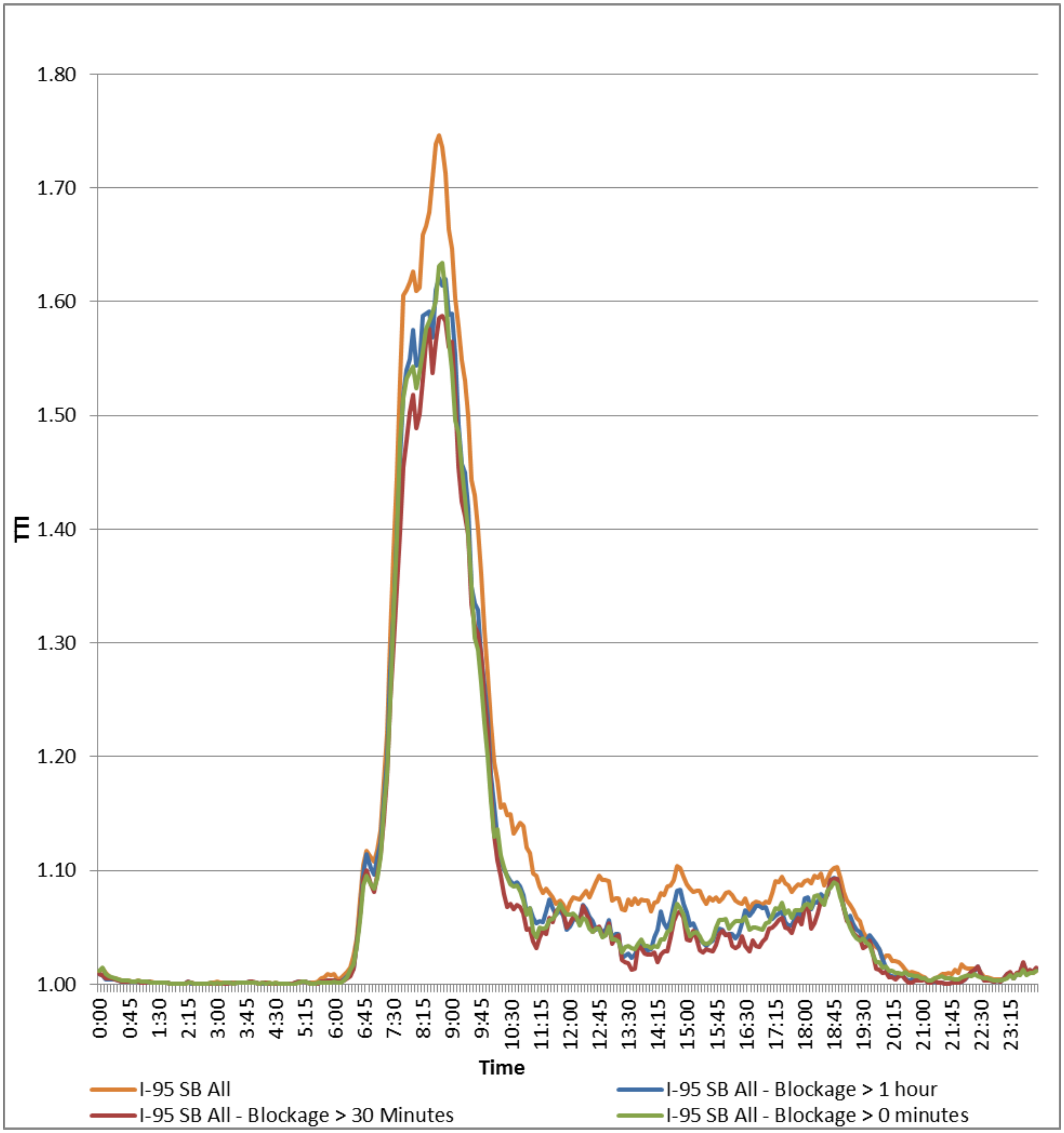


Figure C.30. Mean TTIs comparison for I-95 SB GPL.

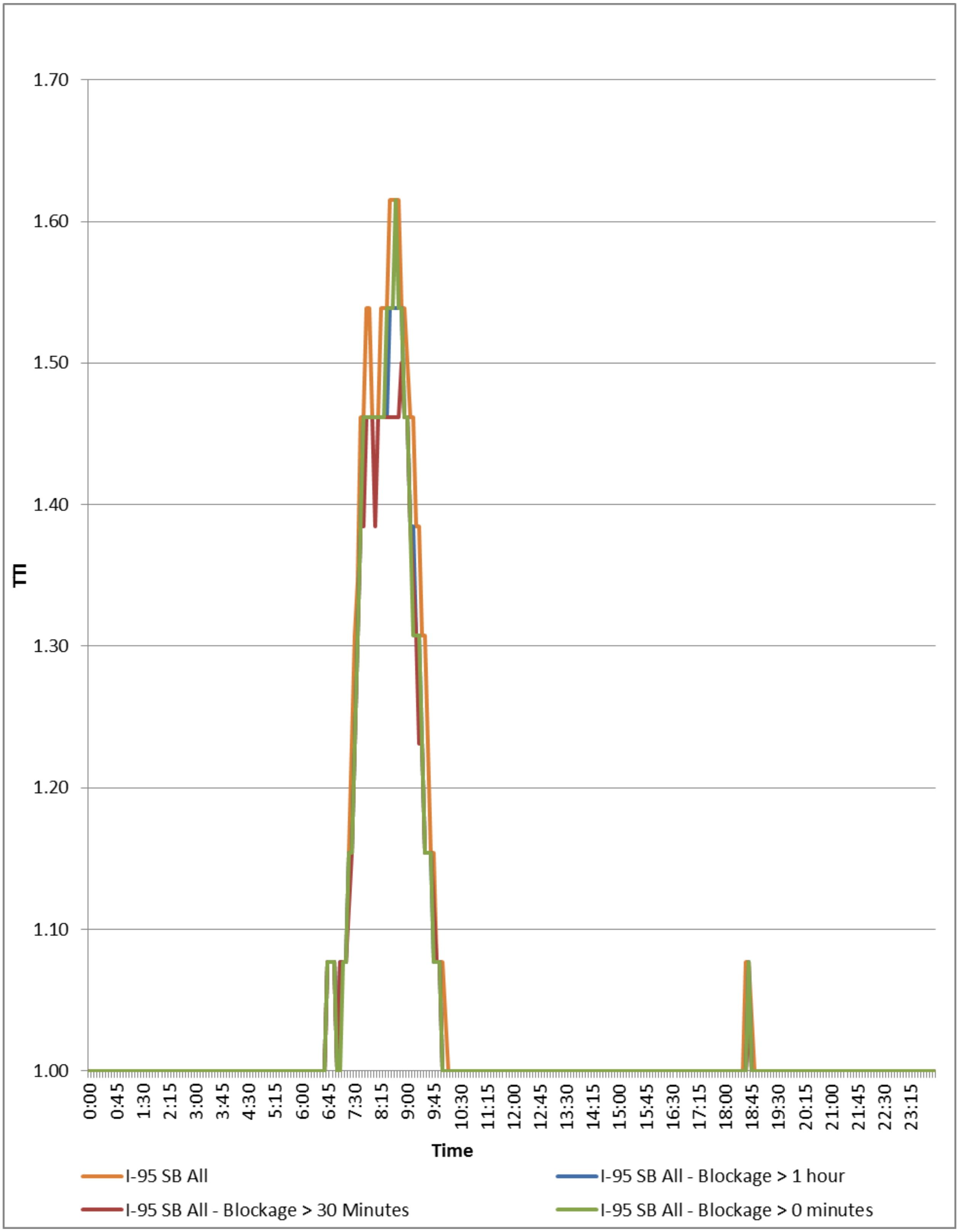


Figure C.31. 50th percentile TTIs comparison for I-95 SB GPL.

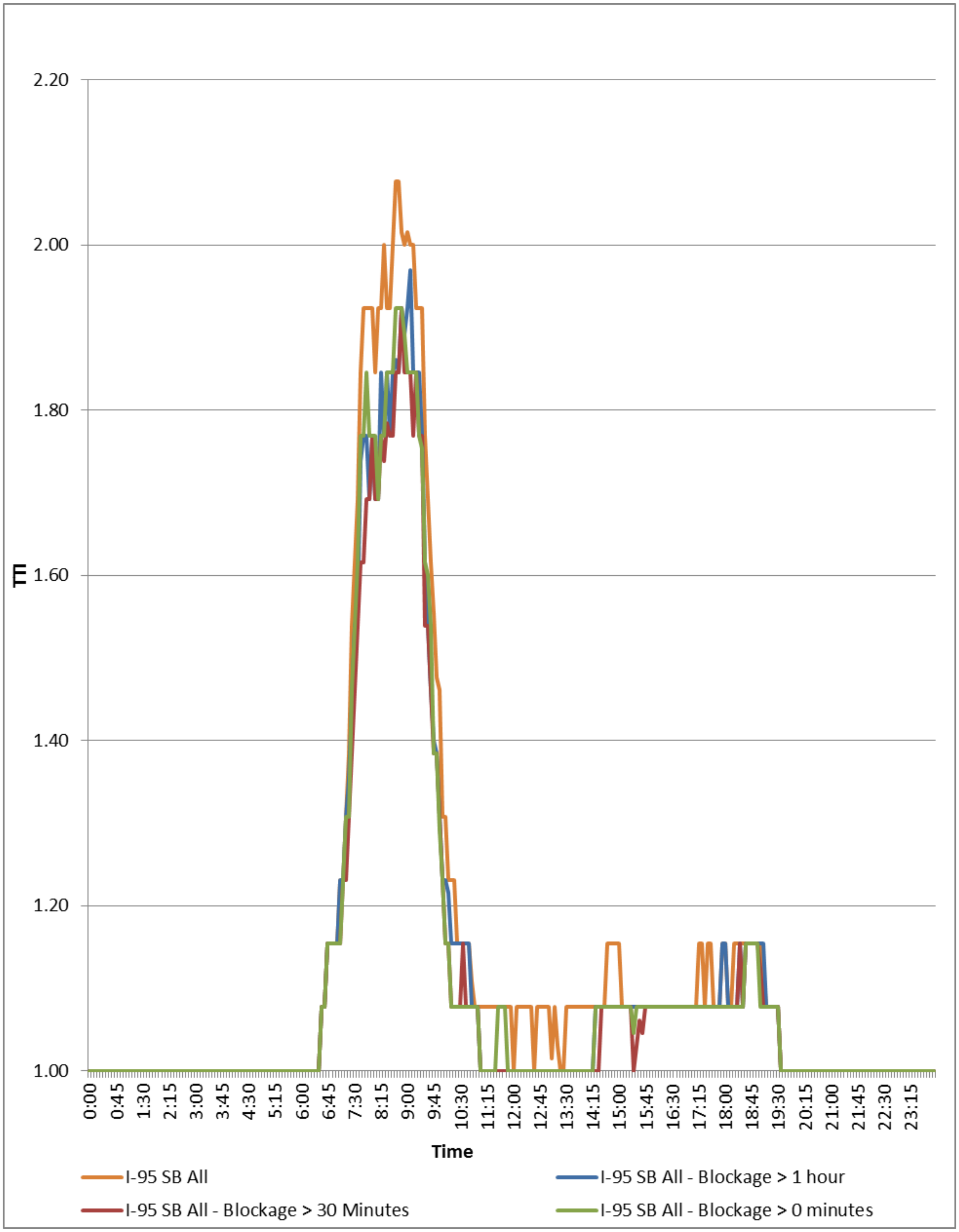


Figure C.32. 80th percentile TTIs comparison for I-95 SB GPL.

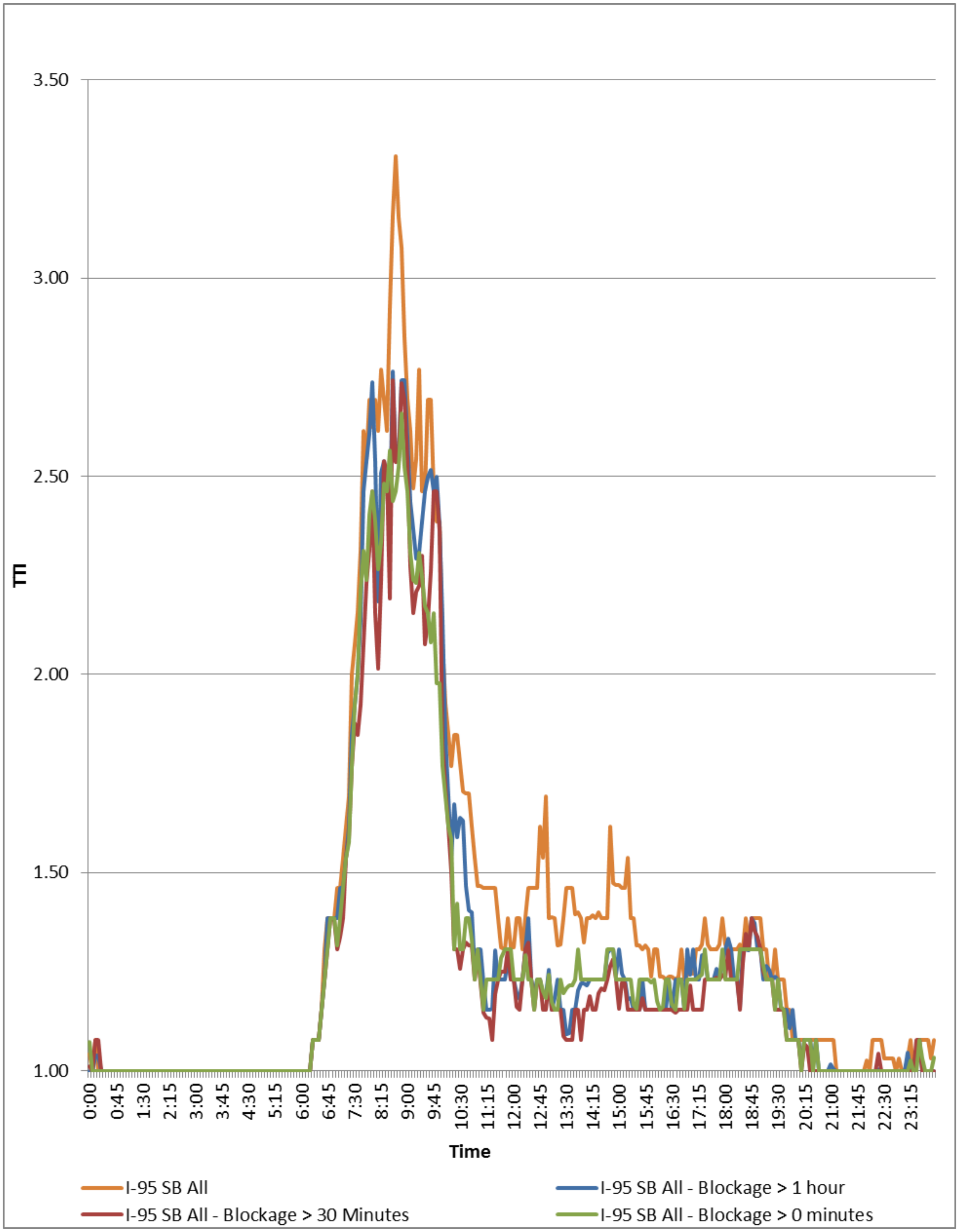
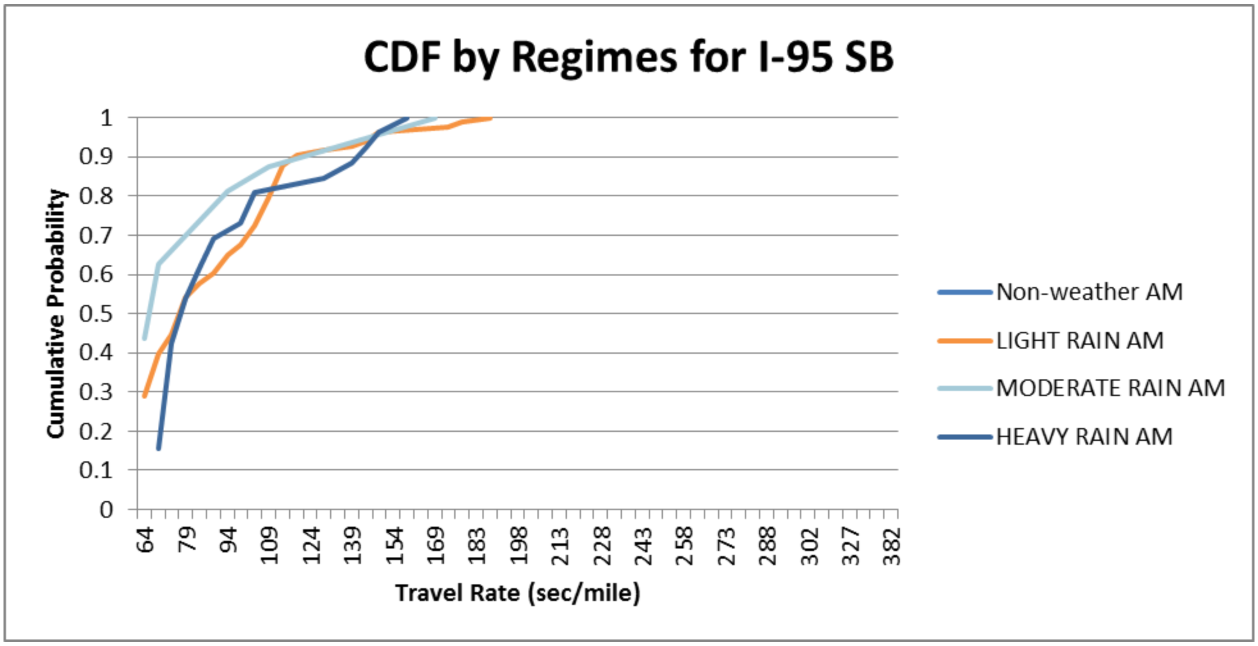


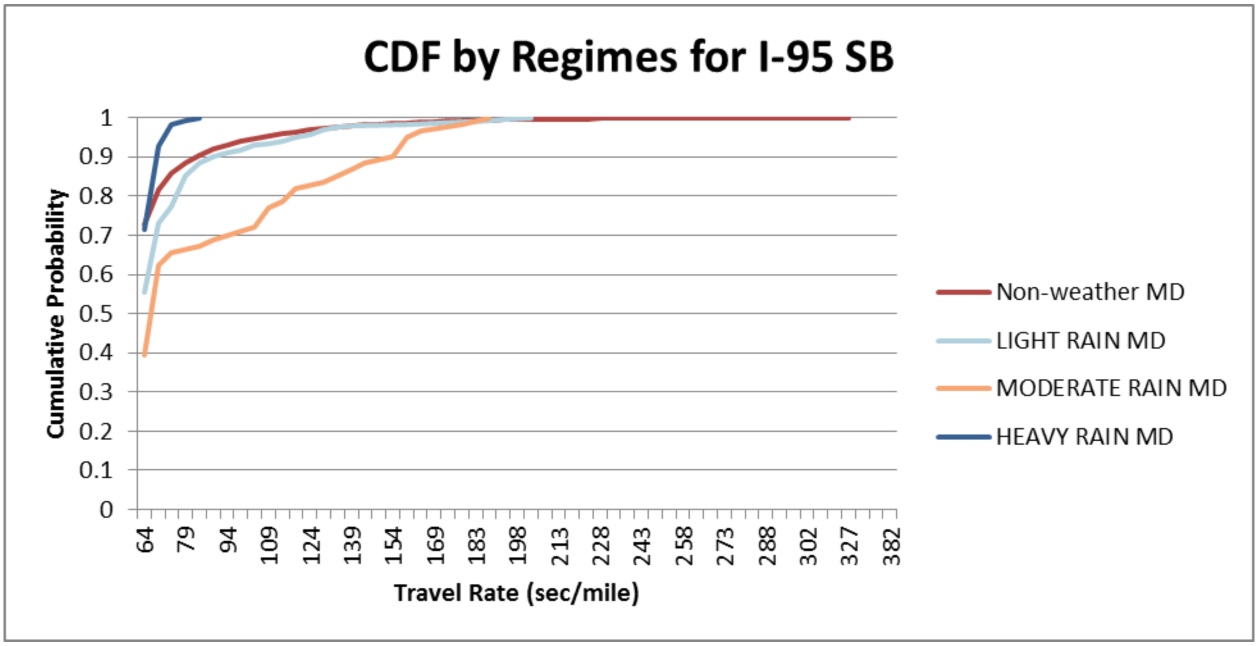
Figure C.33. 95th percentile TTIs comparison for I-95 SB GPL.

C.5 Contributions of Weather by Severity

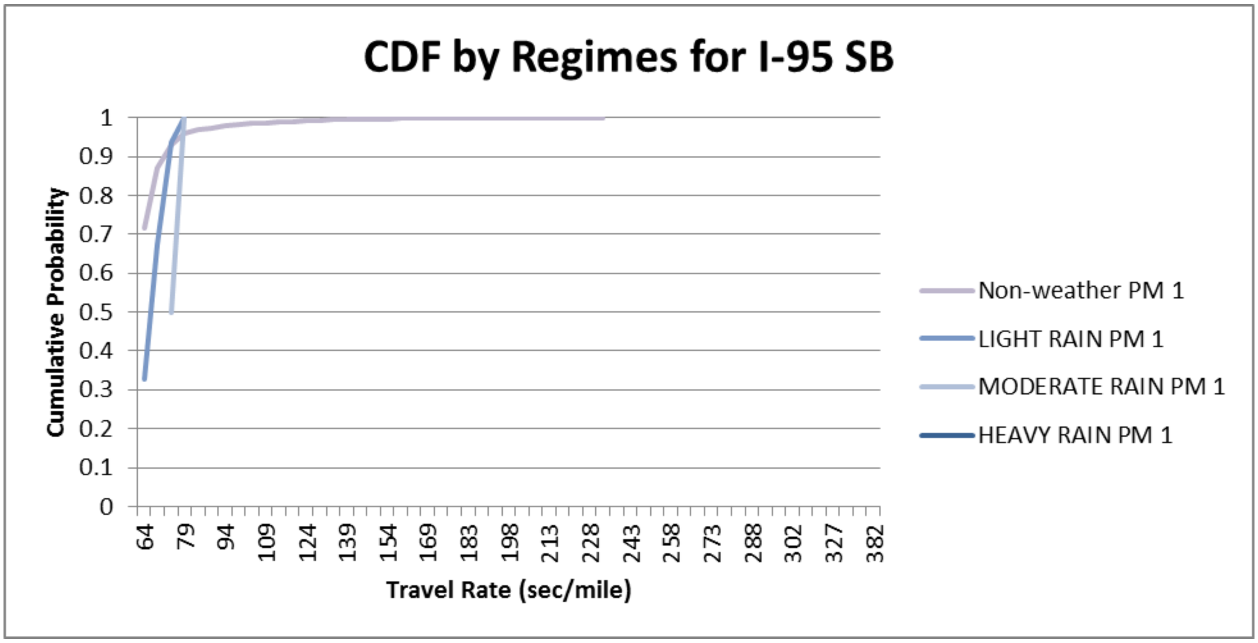
The analysis results showed that the overall contribution of weather on I-95 SB GPL unreliability was not significant; however, weather events affected the travel time rate distribution in certain time periods. This section provides a closer study of the impacts of different precipitation levels. Figure C.34 shows the CDF curves for four regimes (no-weather events, with light rain, with moderate rain, and with heavy rain) during different time periods. Table C.10 to Table C.12 present the relative percentages of each regime's contribution to occurrence, severity, and total unreliability. It appears that moderate-to-heavy rain had a high impact on travel time reliability of I-95 SB GPL on a single-event basis in the AM and midday peaks. However, the impacts of weather events on the overall reliability were not significant for most of the day.



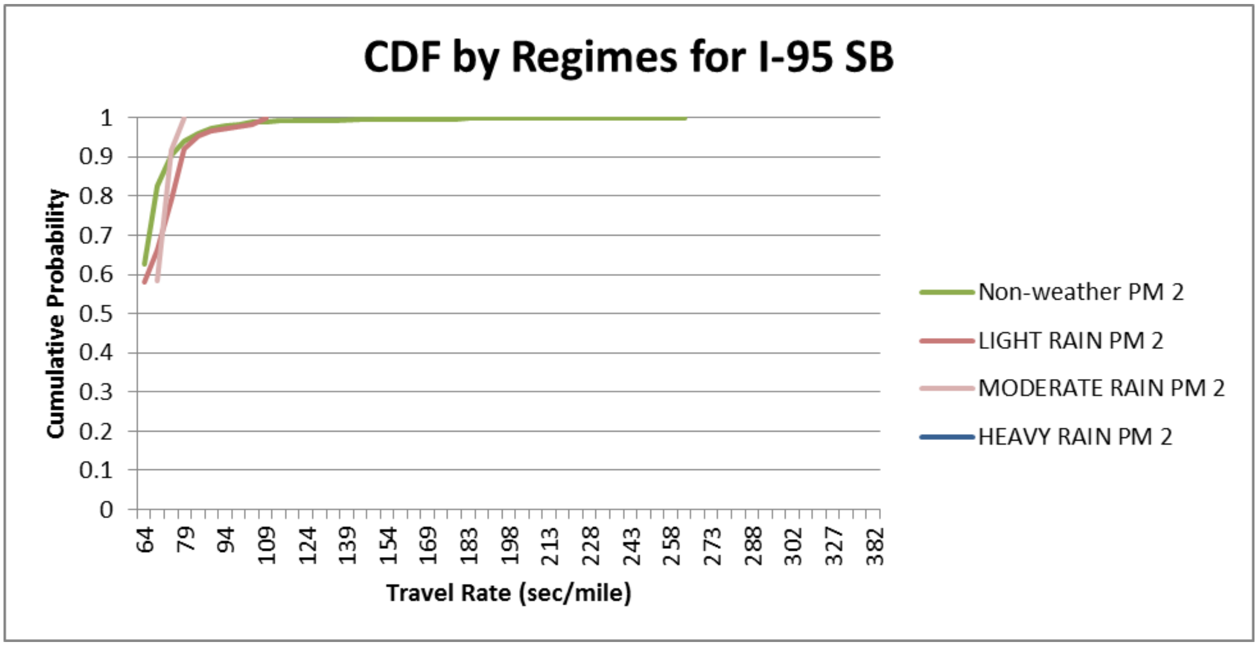
(a)


CDF by Regimes for I-95 SB
Cumulative Probability
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
64
79
94
109
124
139
154
169
183
198
213
228
243
258
273
288
302
327
382
Travel Rate (sec/mile)
Non-weather MD
LIGHT RAIN MD
MODERATE RAIN MD
HEAVY RAIN MD

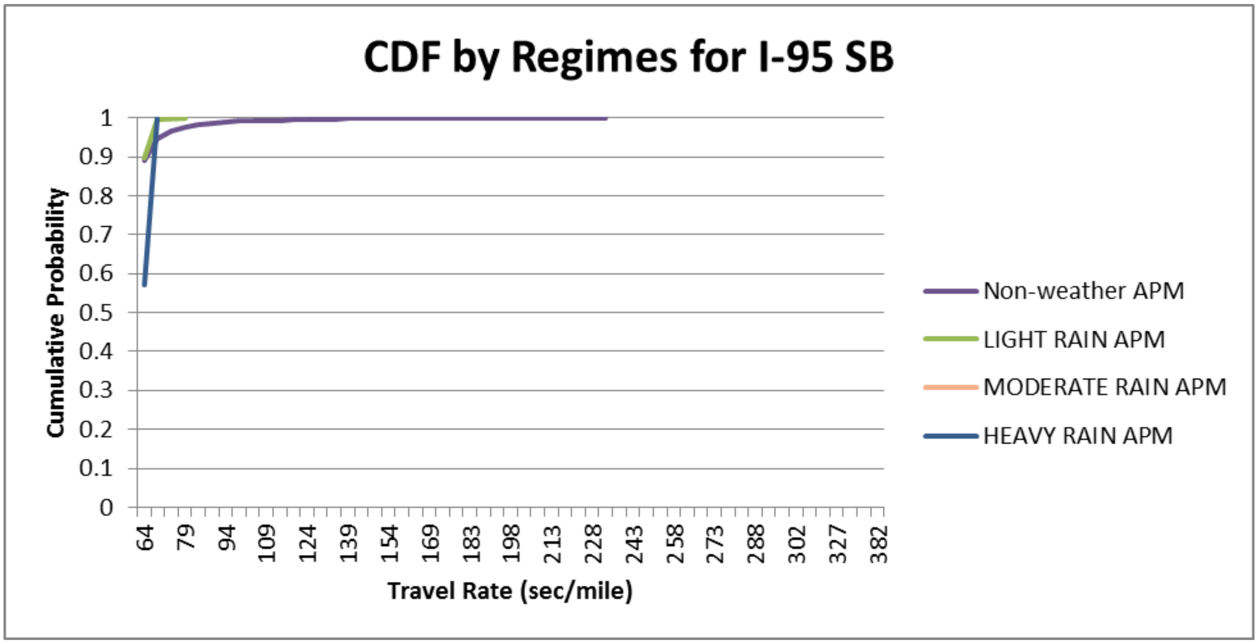
(b)


CDF by Regimes for I-95 SB
Cumulative Probability
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
64
79
94
109
124
139
154
169
183
198
213
228
243
258
273
288
302
327
382
Travel Rate (sec/mile)
Non-weather PM 1
LIGHT RAIN PM 1
MODERATE RAIN PM 1
HEAVY RAIN PM 1

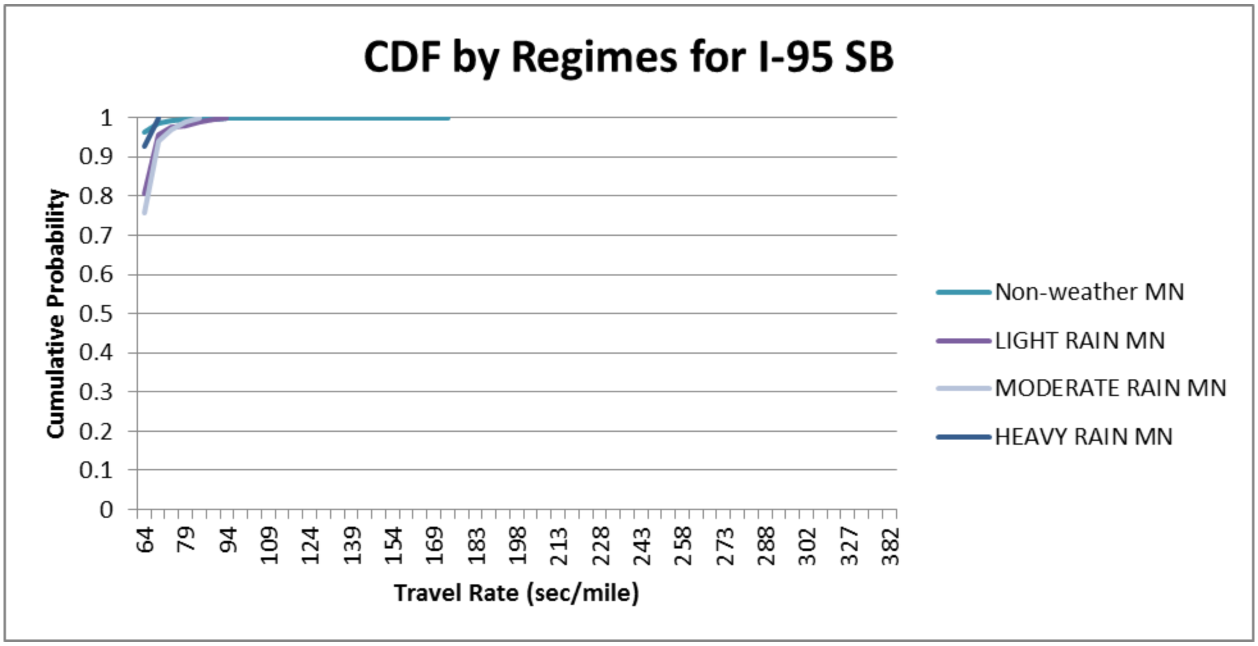
(c)


CDF by Regimes for I-95 SB
Cumulative Probability
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
64
79
94
109
124
139
154
169
183
198
213
228
243
258
273
288
302
327
382
Travel Rate (sec/mile)
Non-weather PM 2
LIGHT RAIN PM 2
MODERATE RAIN PM 2
HEAVY RAIN PM 2

(d)


CDF by Regimes for I-95 SB
Cumulative Probability
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
64
79
94
109
124
139
154
169
183
198
213
228
243
258
273
288
302
327
382
Travel Rate (sec/mile)
Non-weather APM
LIGHT RAIN APM
MODERATE RAIN APM
HEAVY RAIN APM

(e)



(f)

Figure C.34. CDF by regimes for I-95 SB GPL for (a) AM peak, (b) MD, (c) PM1, (d) PM2, (e) APM, and (f) MN periods.

Table C.10. Percentage of Occurrence

Time Period	Nonweather	Light Rain	Moderate Rain	Heavy Rain	Total
AM	8%	0%	0%	0%	8%
MD	26%	0%	0%	0%	27%
PM1	6%	0%	0%	0%	6%
PM2	8%	0%	0%	0%	8%
APM	12%	0%	0%	0%	12%
MN	37%	1%	0%	0%	38%

Table C.11. Percentage of Severity

Time Period	Nonweather	Light Rain	Moderate Rain	Heavy Rain	Total
AM	18%	12%	11%	13%	55%
MD	6%	5%	15%	0%	26%
PM1	1%	1%	2%	11%	14%
PM2	2%	1%	1%	0%	4%
APM	1%	0%	0%	0%	1%
MN	0%	0%	0%	0%	1%

Table C.12. Percentage of Unreliability Contribution

Time Period	Nonweather	Light Rain	Moderate Rain	Heavy Rain	Total
AM	45%	0%	0%	0%	45%
MD	43%	1%	0%	0%	44%
PM1	3%	0%	0%	0%	3%
PM2	4%	0%	0%	0%	4%
APM	2%	0%	0%	0%	2%
MN	2%	0%	0%	0%	2%

APPENDIX D

I-95 Southbound Express Lane

The results of the I-95 SB EL analysis are presented in Figures D.1 to D.6 and Tables D.1 to D.3. The results show that the SB EL was unreliable in the AM peak. However, the reliability was significantly better than the I-95 SB GPL, and the unreliability lasted for a shorter period of time. A large proportion of the unreliability occurred in the AM peak and midday. However, the midday unreliability appeared to occur at the shoulder of the AM peak, from 9:00 to 10:00 a.m. Between 7:30 and 9:30 a.m., the 50th, 80th, and 95th TTIs were 1.08, 1.2, and 1.7, respectively.

The main contributing factor to unreliability in the EL in the SB direction was incidents in the AM peak and, to a lesser degree, the midday peak. In the AM peak, the contribution of a single incident event was very high, indicating that, as in the case with the NB EL, the geometry and operational constraints on the EL increased the incident impacts.

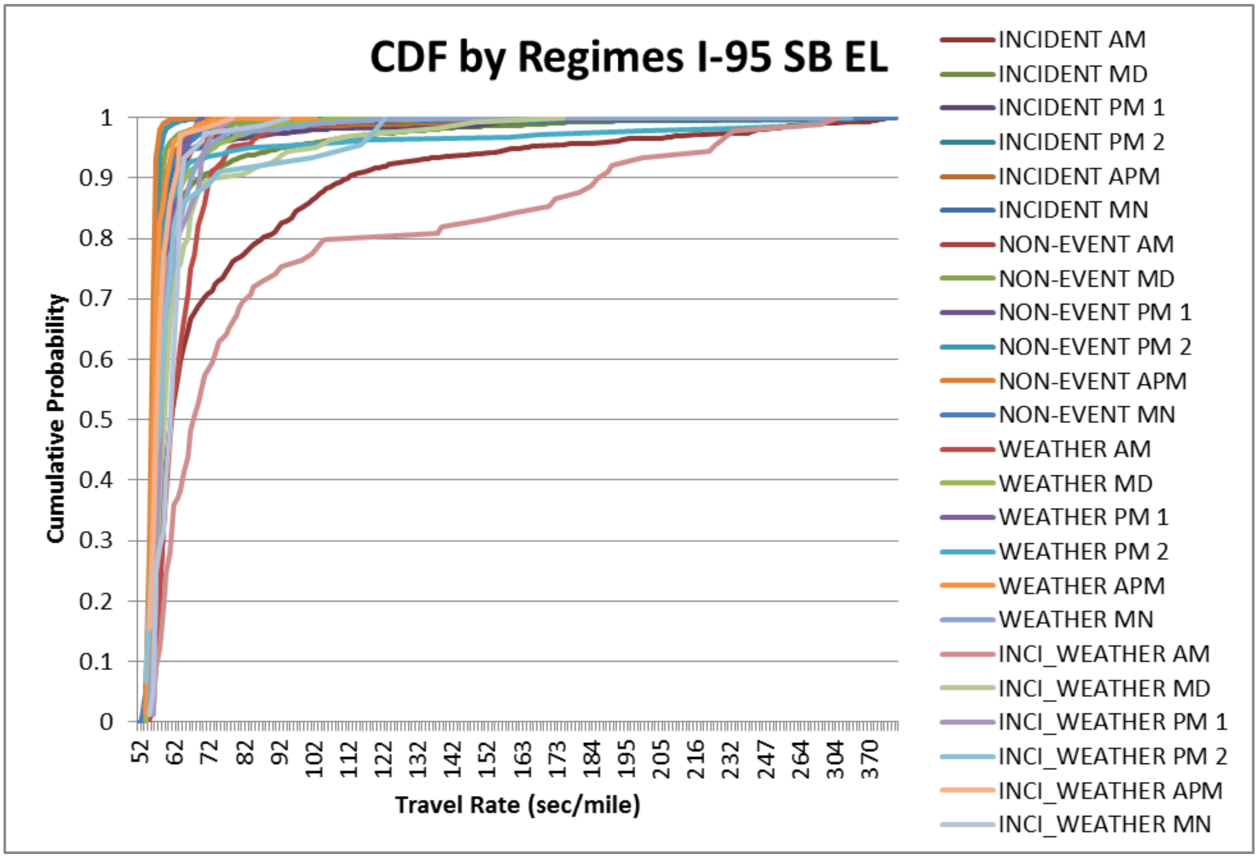
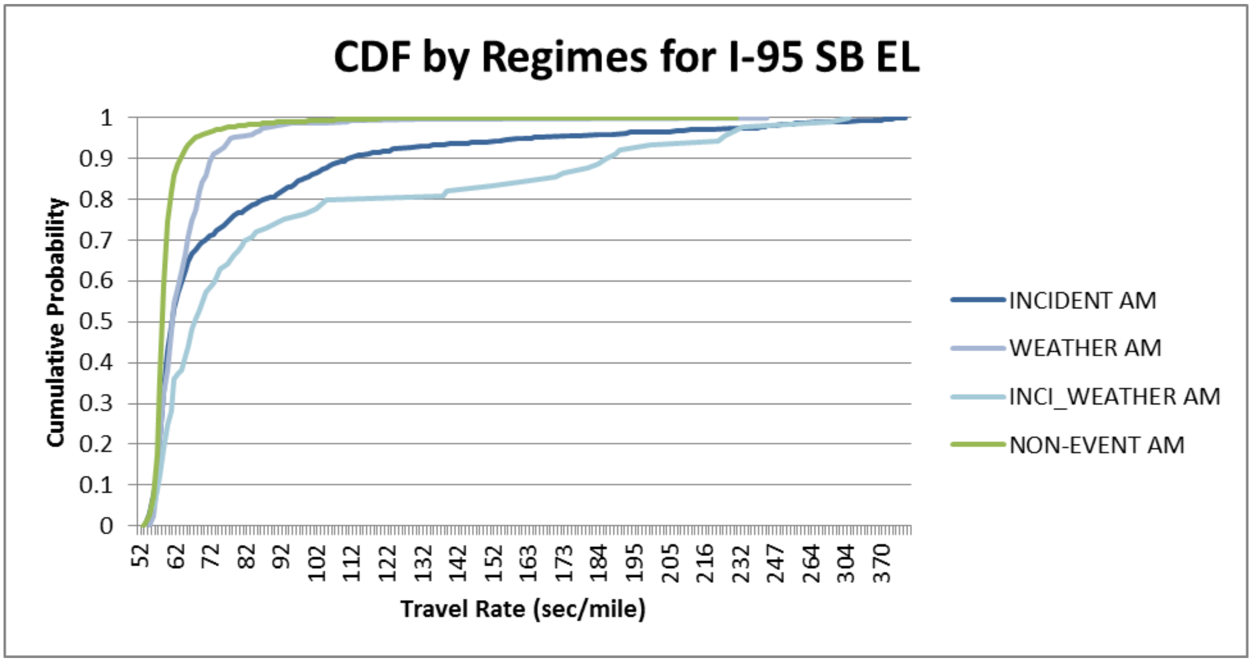
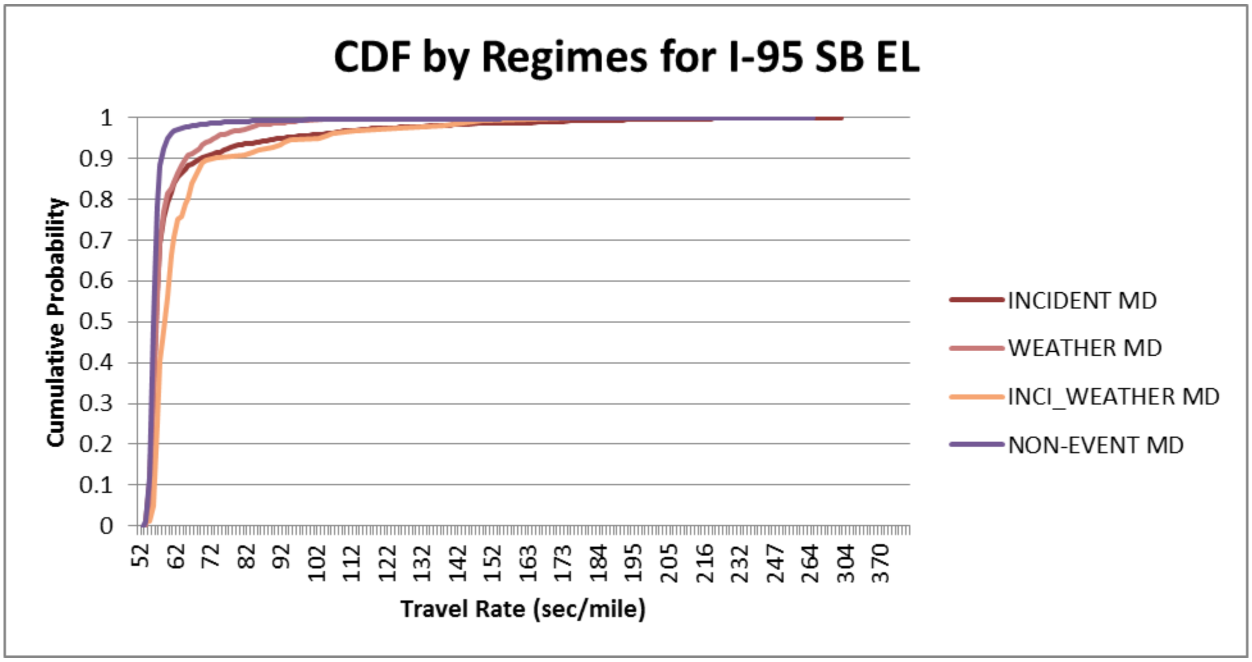


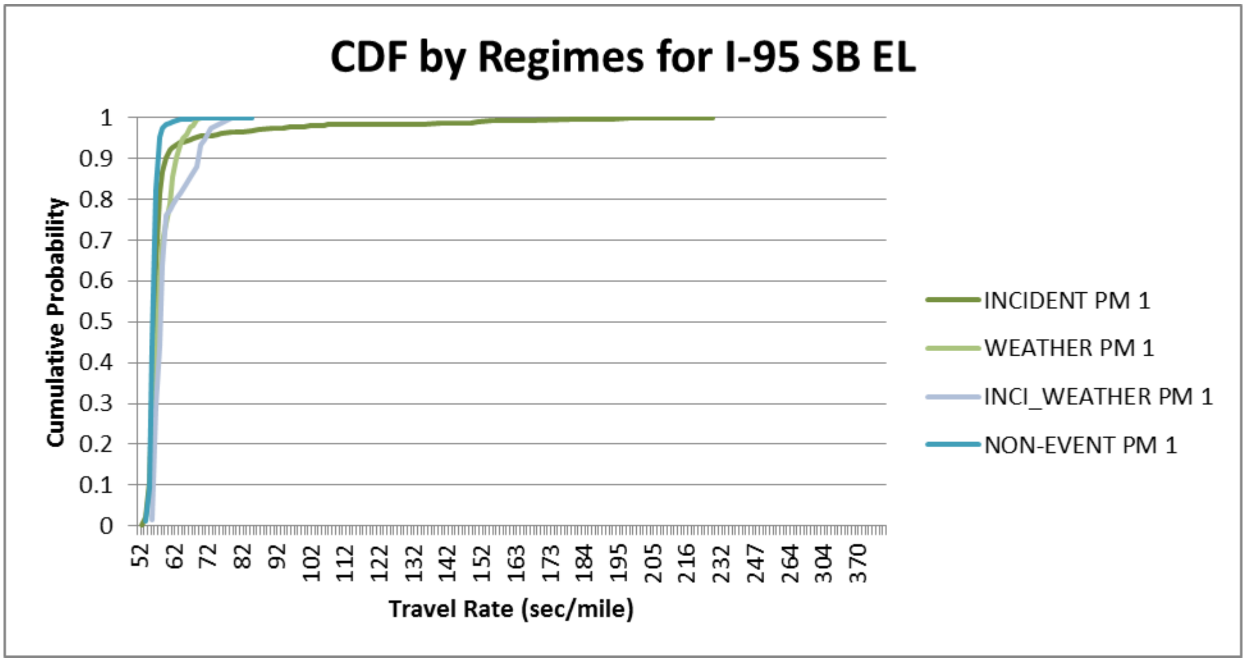
Figure D.1. CDF by regimes for I-95 SB EL.


CDF by Regimes for I-95 SB EL
Cumulative Probability
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
52
62
72
82
92
102
112
122
132
142
152
163
173
184
195
205
216
232
247
264
304
370
Travel Rate (sec/mile)
INCIDENT AM
WEATHER AM
INCI_WEATHER AM
NON-EVENT AM

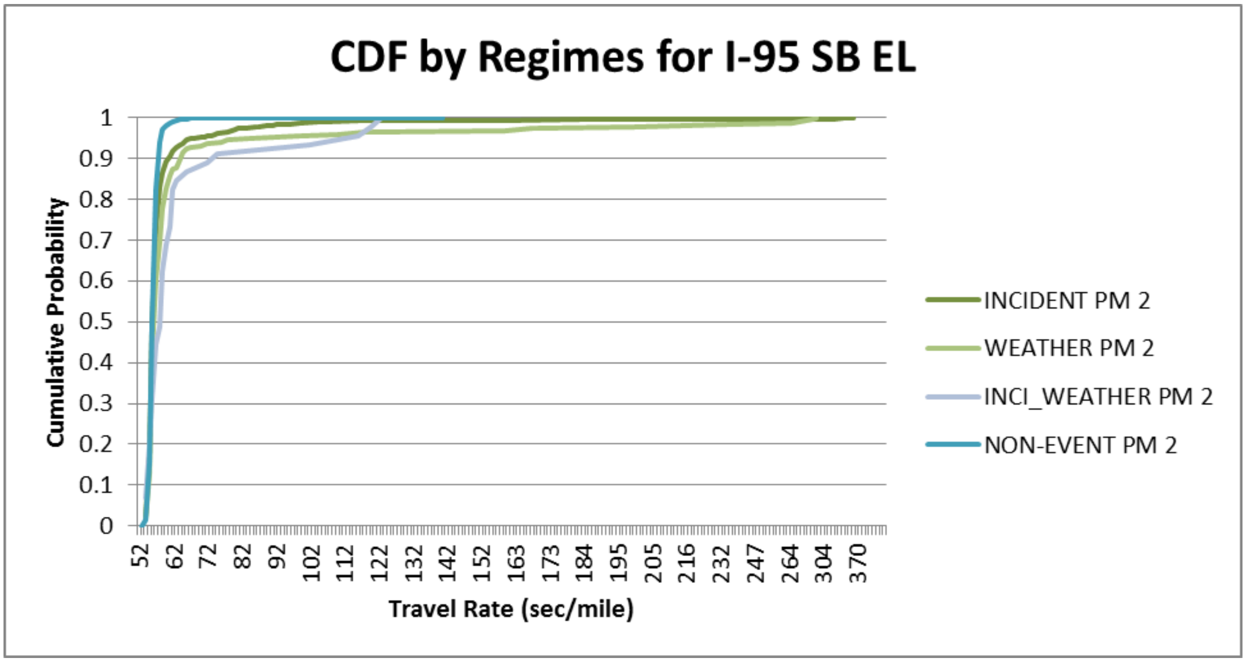
(a)


CDF by Regimes for I-95 SB EL
Cumulative Probability
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
52
62
72
82
92
102
112
122
132
142
152
163
173
184
195
205
216
232
247
264
304
370
Travel Rate (sec/mile)
INCIDENT MD
WEATHER MD
INCI_WEATHER MD
NON-EVENT MD

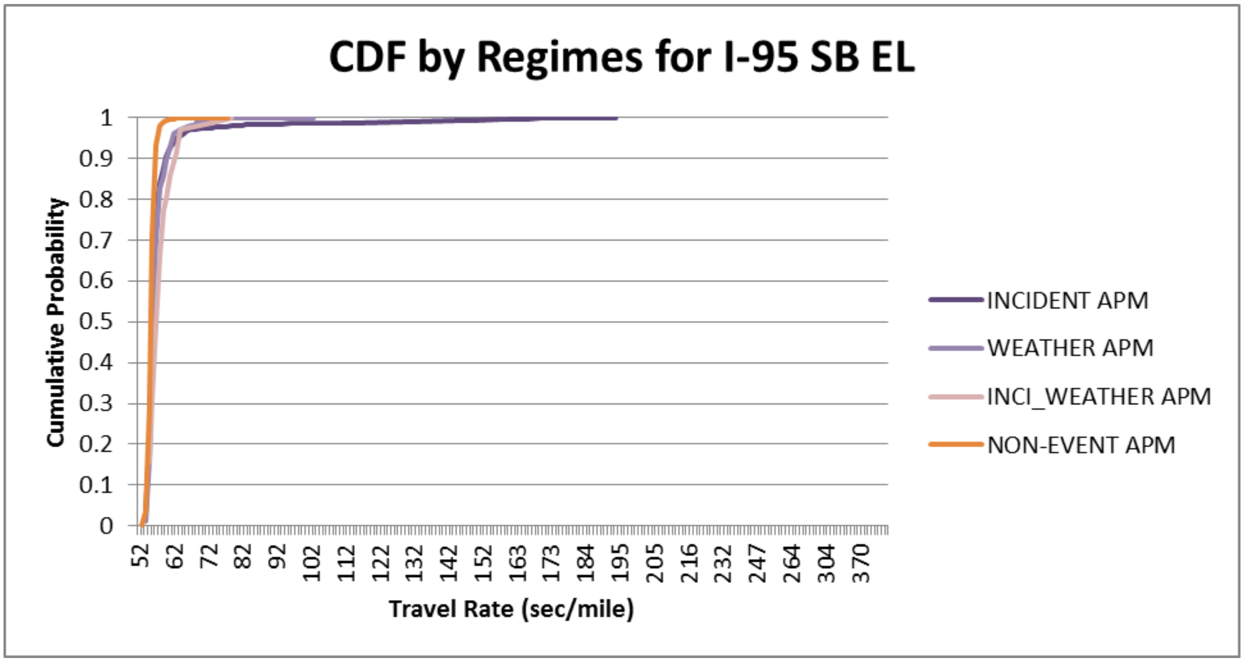
(b)


CDF by Regimes for I-95 SB EL
Cumulative Probability
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
52
62
72
82
92
102
112
122
132
142
152
163
173
184
195
205
216
232
247
264
304
370
Travel Rate (sec/mile)
INCIDENT PM 1
WEATHER PM 1
INCI_WEATHER PM 1
NON-EVENT PM 1

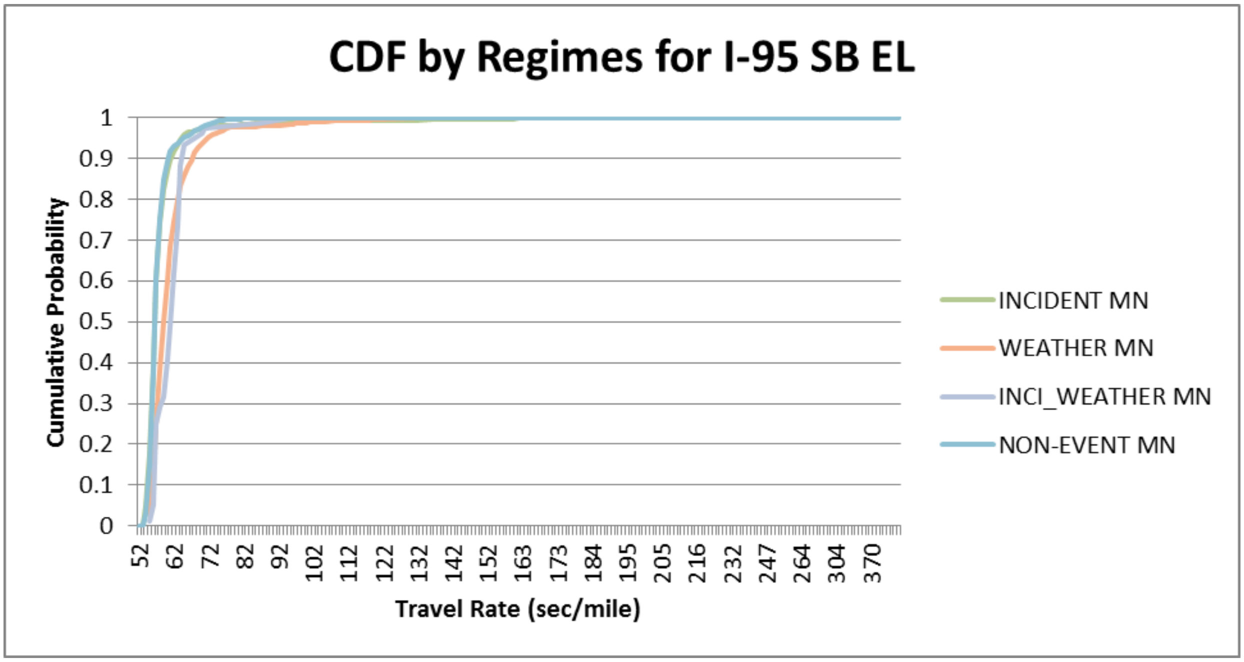
(c)


CDF by Regimes for I-95 SB EL
Cumulative Probability
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
52
62
72
82
92
102
112
122
132
142
152
163
173
184
195
205
216
232
247
264
304
370
Travel Rate (sec/mile)
INCIDENT PM 2
WEATHER PM 2
INCI_WEATHER PM 2
NON-EVENT PM 2

(d)



(e)



(f)

Figure D.2. CDF by regimes for I-95 SB EL for (a) AM peak, (b) MD, (c) PM1, (d) PM2, (e) APM, and (f) MN periods.

Table D.1. Percentage of Occurrence

Time Period	Nonevent	Incident	Weather	Incident + Weather	Total
AM	7%	1%	0%	0%	8%
MD	22%	3%	1%	0%	27%
PM1	5%	1%	0%	0%	6%
PM2	7%	1%	0%	0%	8%
APM	11%	1%	1%	0%	12%
MN	35%	1%	2%	0%	37%

Table D.2. Percentage of Severity

Time Period	Nonevent	Incident	Weather	Incident + Weather	Total
AM	1%	25%	2%	37%	65%
MD	1%	5%	1%	3%	9%
PM1	0%	3%	0%	0%	3%
PM2	0%	5%	11%	3%	18%
APM	0%	1%	0%	0%	1%
MN	0%	1%	1%	1%	3%

Table D.3. Percentage of Unreliability Contribution

Time Period	Nonevent	Incident	Weather	Incident + Weather	Total
AM	4%	30%	1%	4%	40%
MD	14%	15%	1%	1%	30%
PM1	0%	2%	0%	0%	2%
PM2	0%	4%	3%	0%	8%
APM	0%	1%	0%	0%	1%
MN	16%	1%	2%	0%	19%

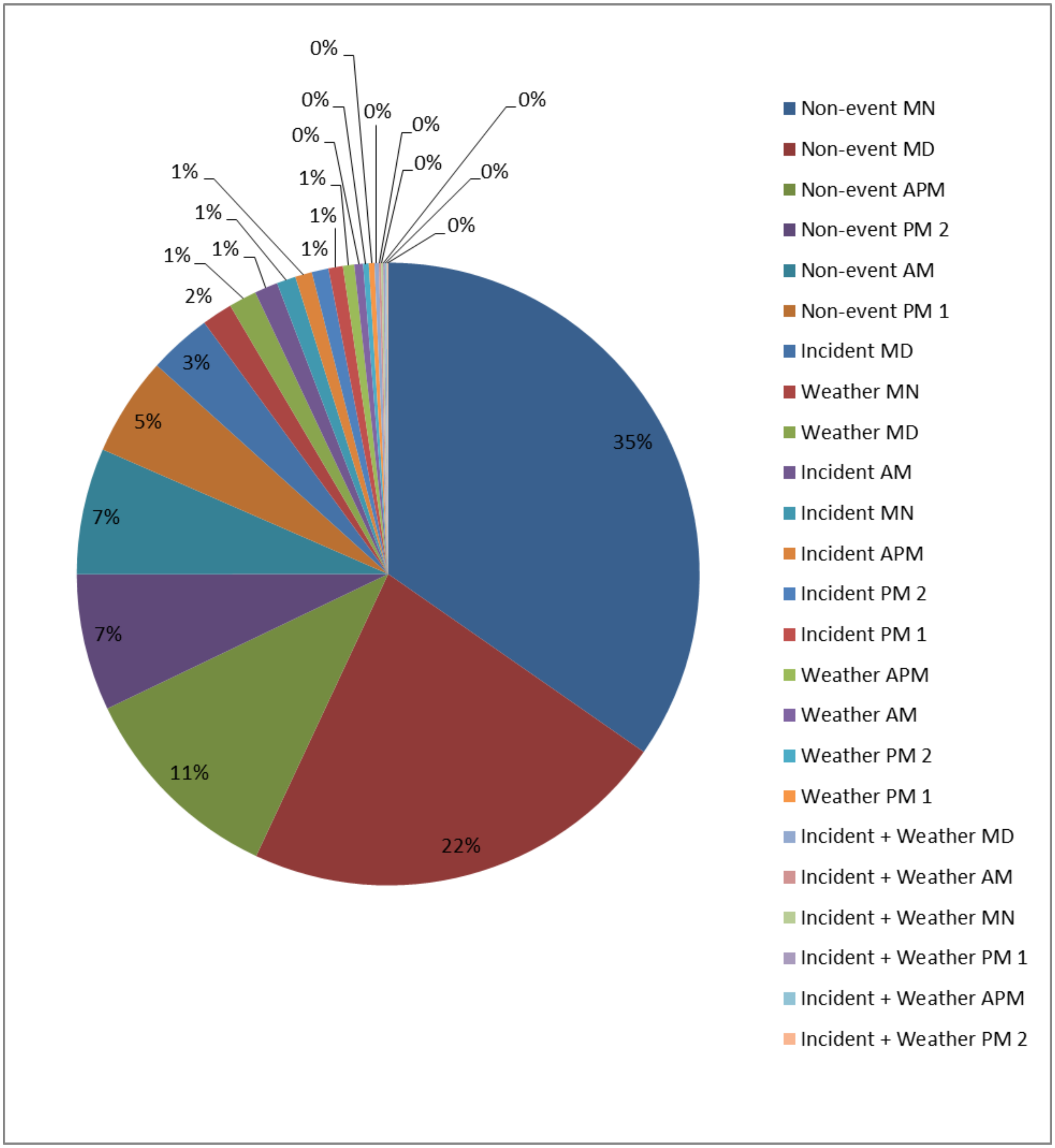


Figure D.3. Percentage of occurrence for I-95 SB EL.

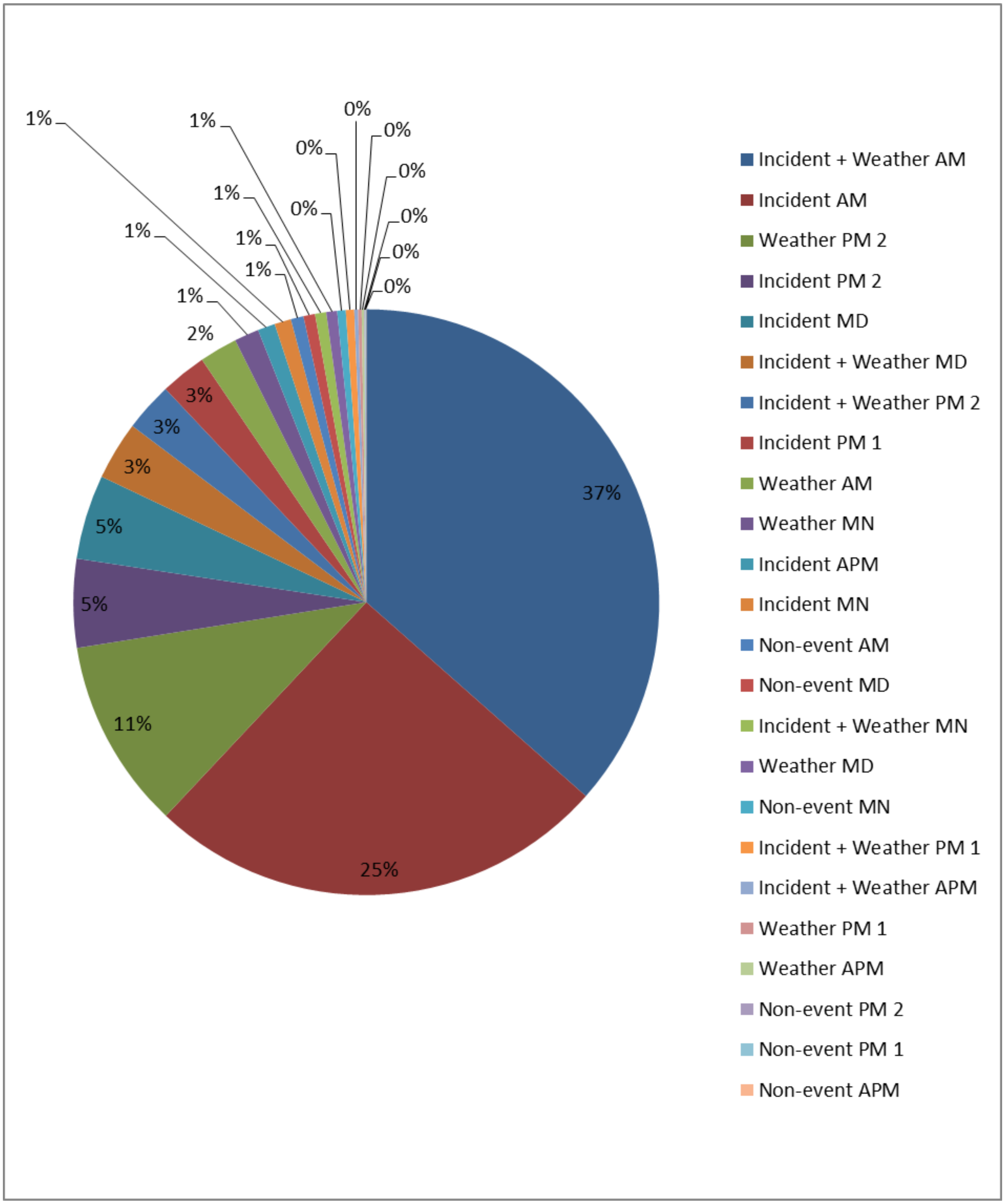


Figure D.4. Percentage of severity for I-95 SB EL.

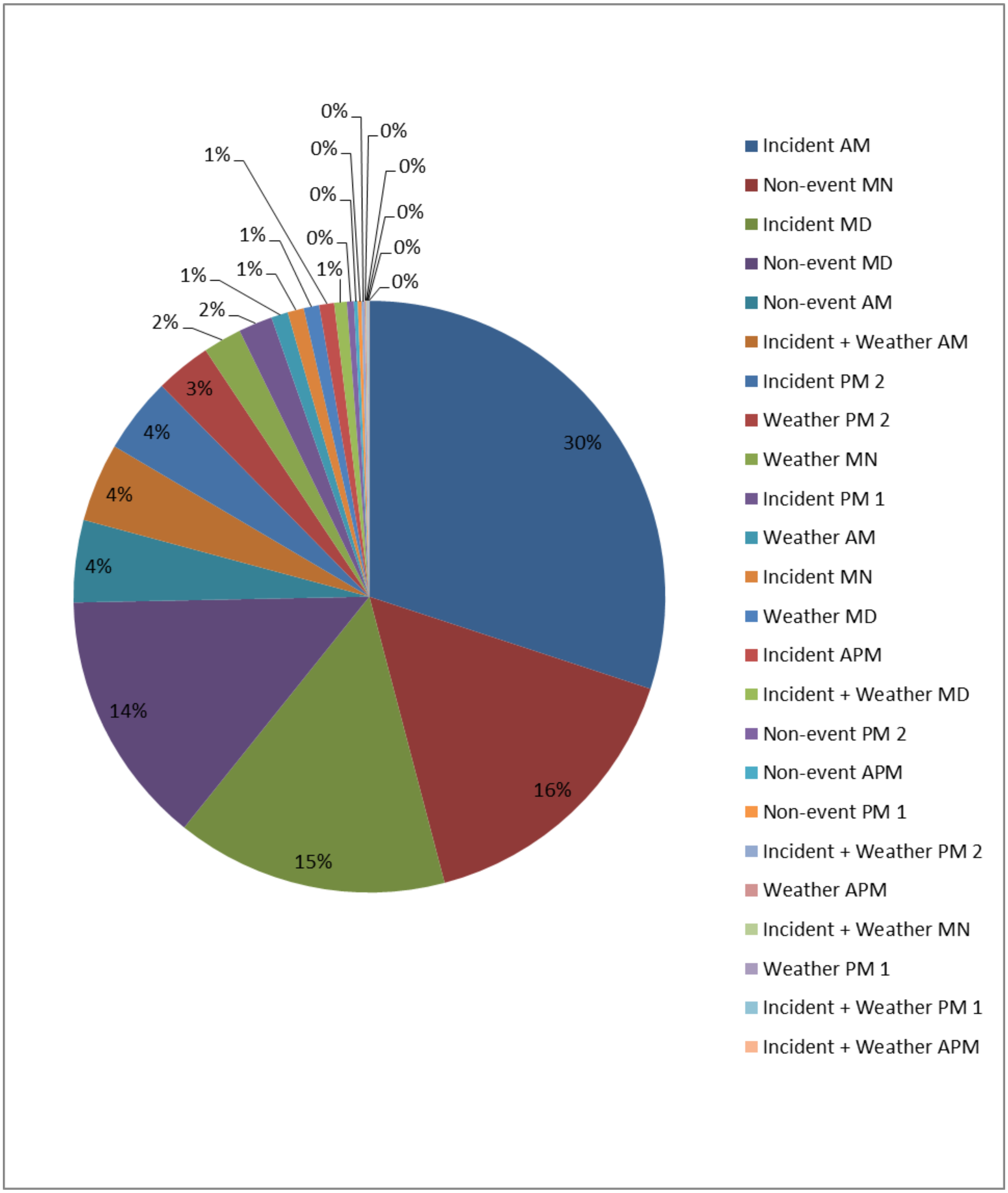


Figure D.5. Percentage of unreliability contribution for I-95 SB EL.

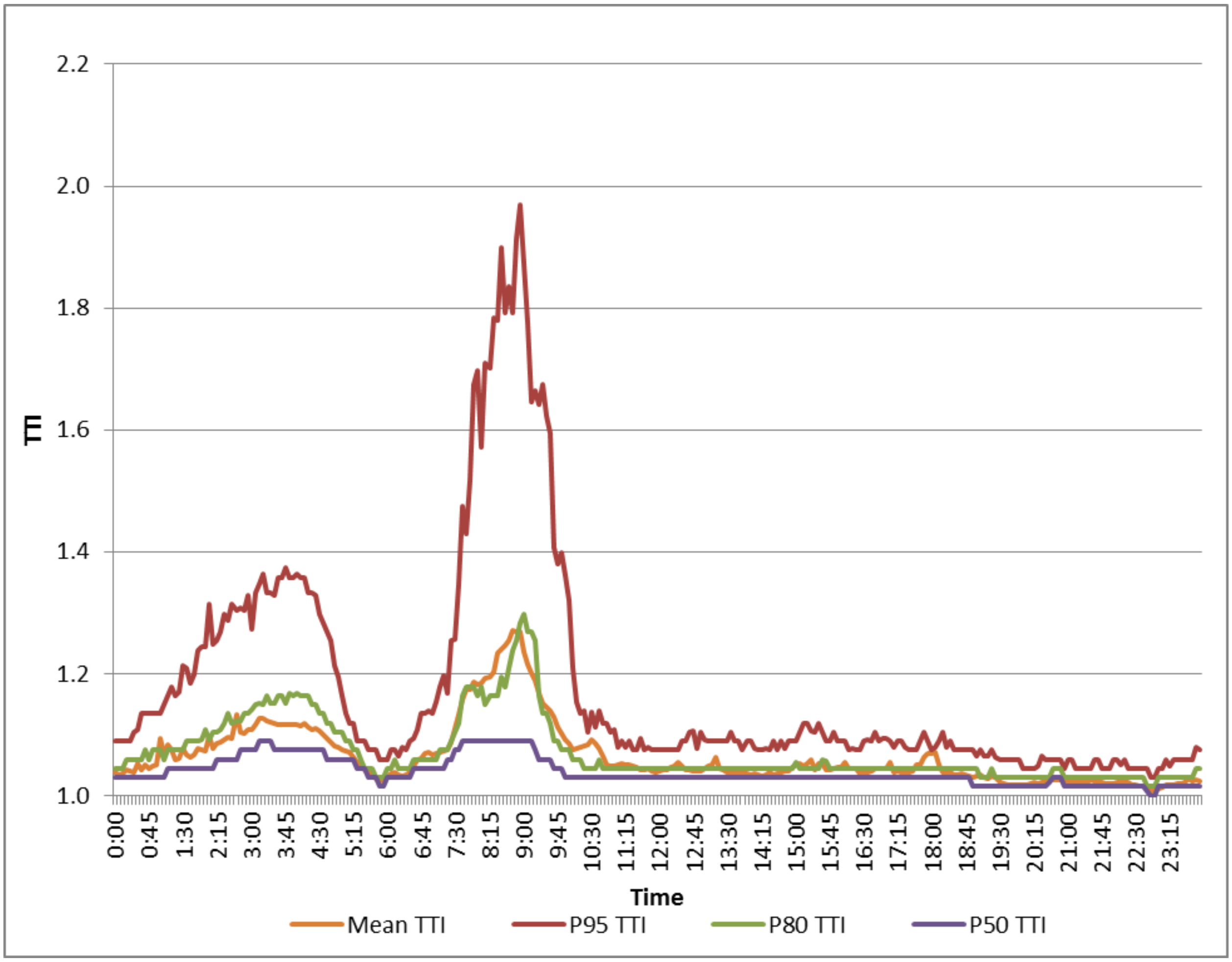


Figure D.6. Five-minute variation of TTIs for I-95 SB EL.

APPENDIX E
SR-7 Northbound

E.1 Overall Reliability Performance

Unlike the data-rich environment for I-95, SR-7 is a relatively data-poor facility. The field data that were applied to estimate travel time reliability relied completely on private-sector data (INRIX data). Figures E.1 to E.4 present the overall reliability performance for SR-7 NB for different times of the day. Table E.1 shows the starting and ending times for each time period.

Table E.1. Study Time Periods

Time Period	Starting and Ending Times
Late night/early morning	10:00 p.m.– 6:00 a.m.
AM	6:00 – 9:00 a.m.
Midday	9:00 a.m.– 4:00 p.m.
PM	4:00 – 7:00 p.m.
Evening	7:00 – 10:00 p.m.

Figure E.1 shows the PDF for the travel time rate along SR-7 NB, and Figure E.2 presents the corresponding CDF. Figure E.1 shows that during the late night and early morning period, the travel time rate was distributed around a relatively small travel time rate of about 100 second/mile. The PDF curves shifted to the right for other time periods, which indicates a longer travel time rate. Figure E.2 clearly shows that the PM peak traffic experienced the most unreliable travel time, followed by the vehicles traveling during the midday and in the evening. The AM peak traffic had a relatively better travel time reliability. Again, this conclusion can be confirmed by the values of the travel time rate semivariance in Figure E.3. The semivariance of travel time rate for a single PM peak instant was close to double the midday or evening values. However, including the occurrence of each time period, most unreliability contribution resulted in the midday. The PM peak ranked second, as shown in Figure E.4.

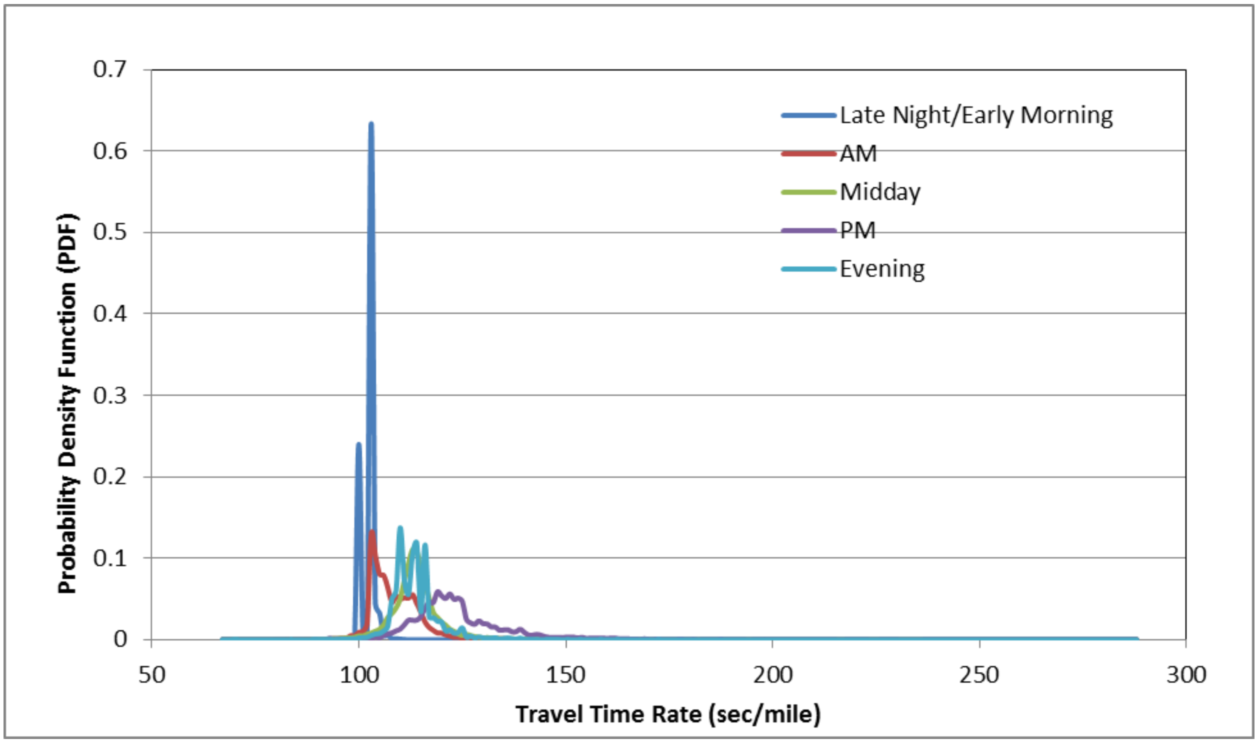


Figure E.1. PDF for SR-7 NB.

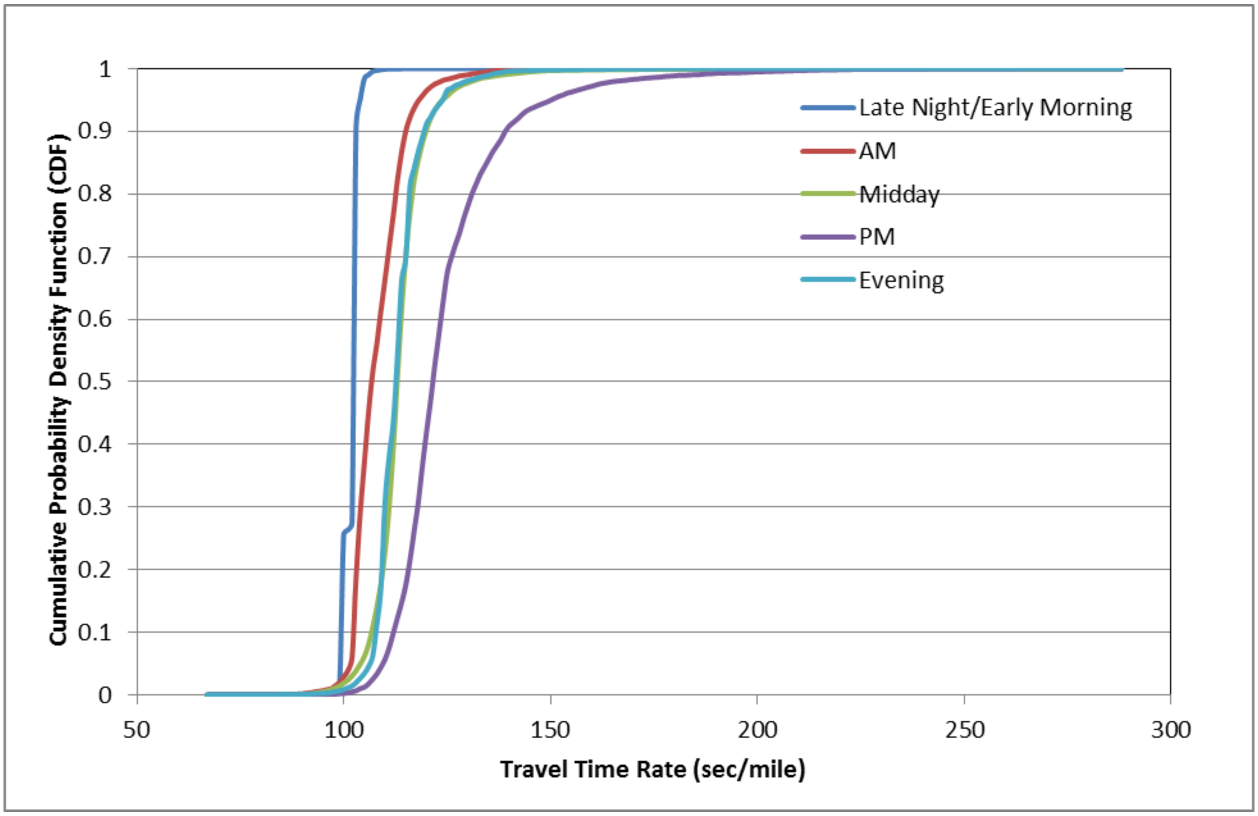


Figure E.2. CDF for SR-7 NB.

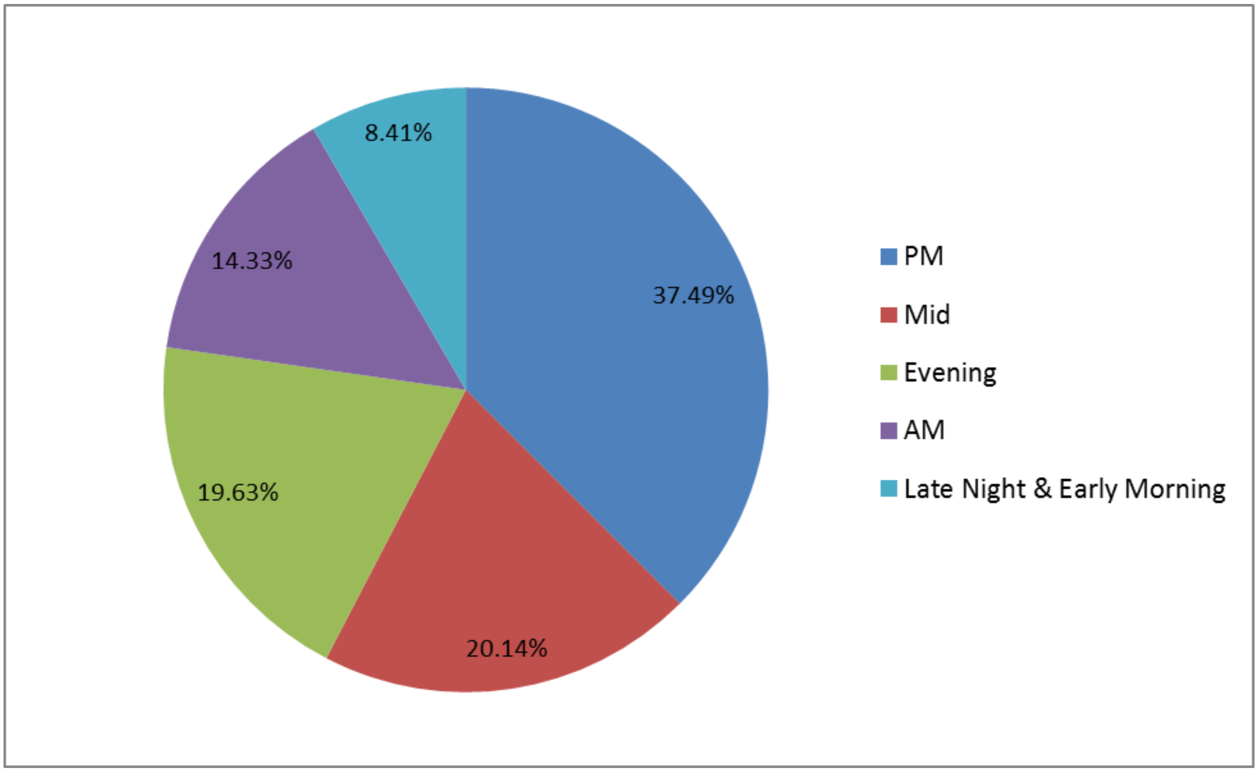


Figure E.3. Percentage of severity for SR-7 NB.

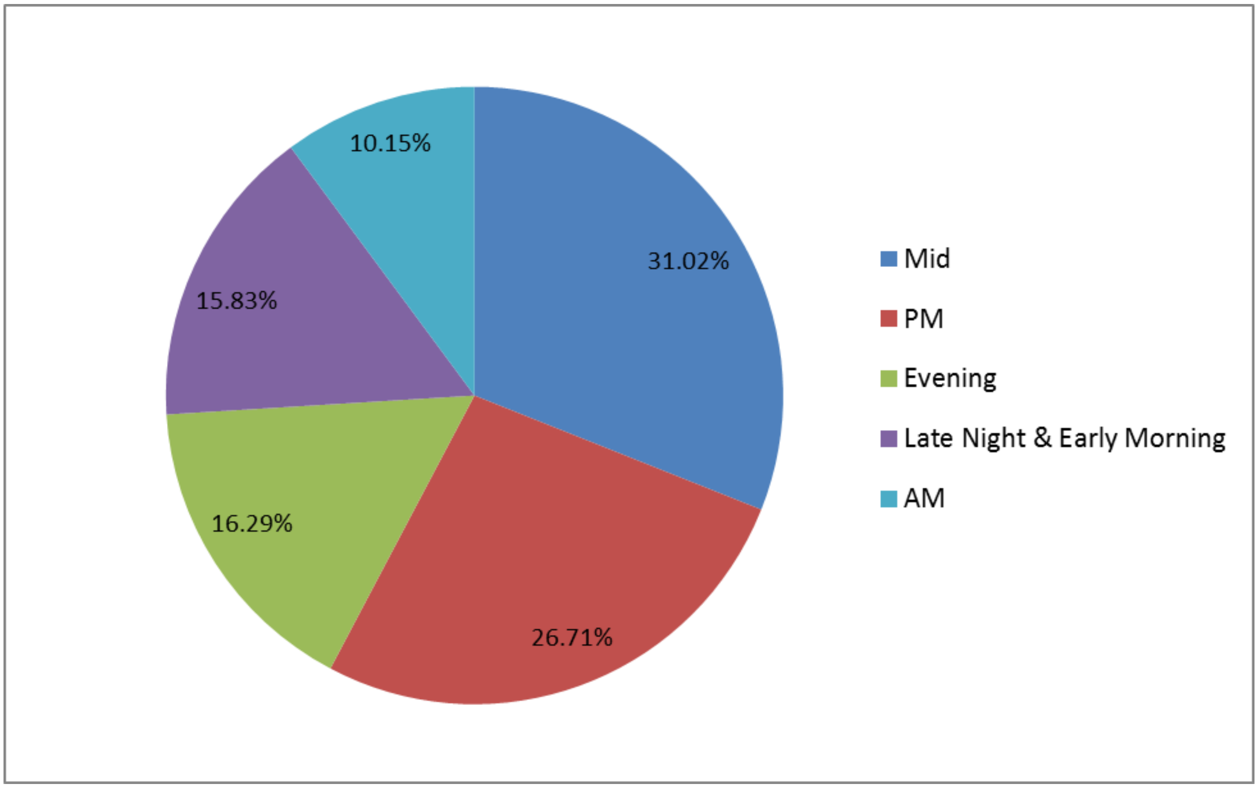
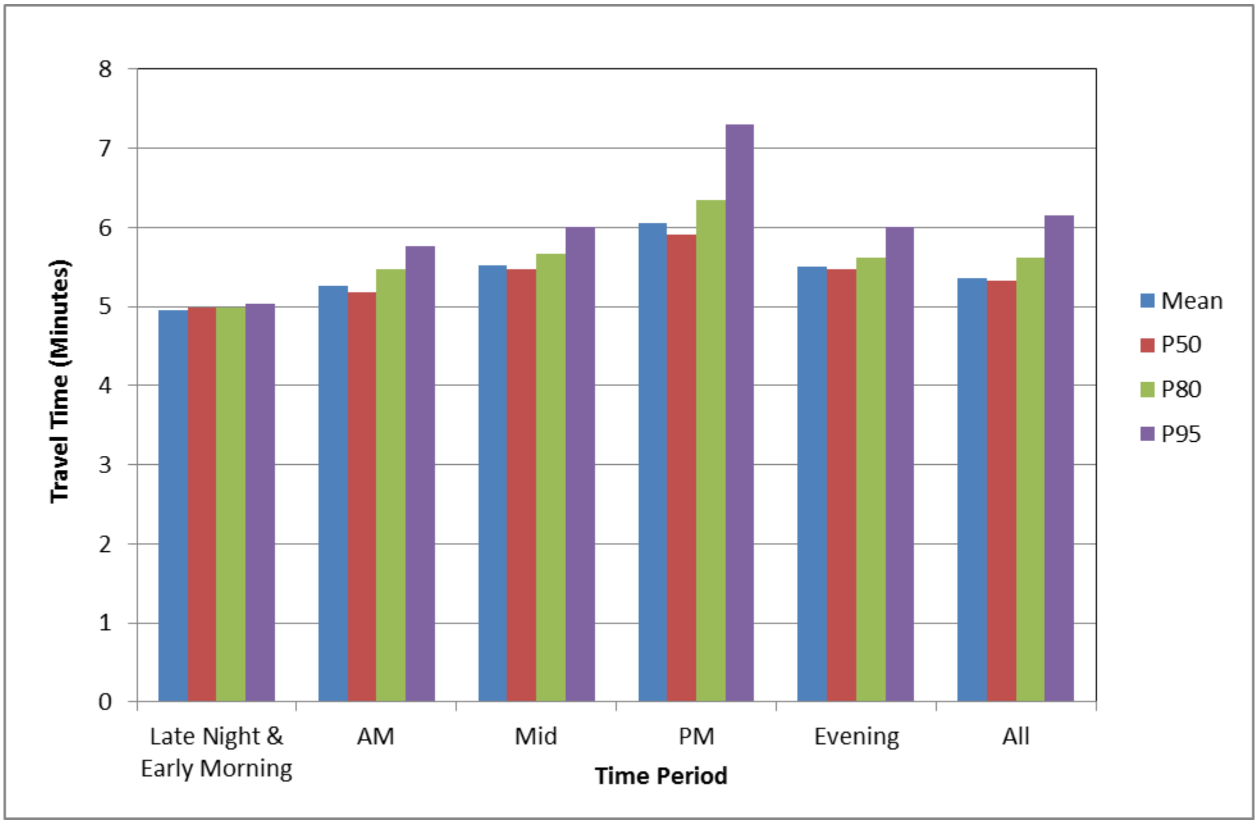
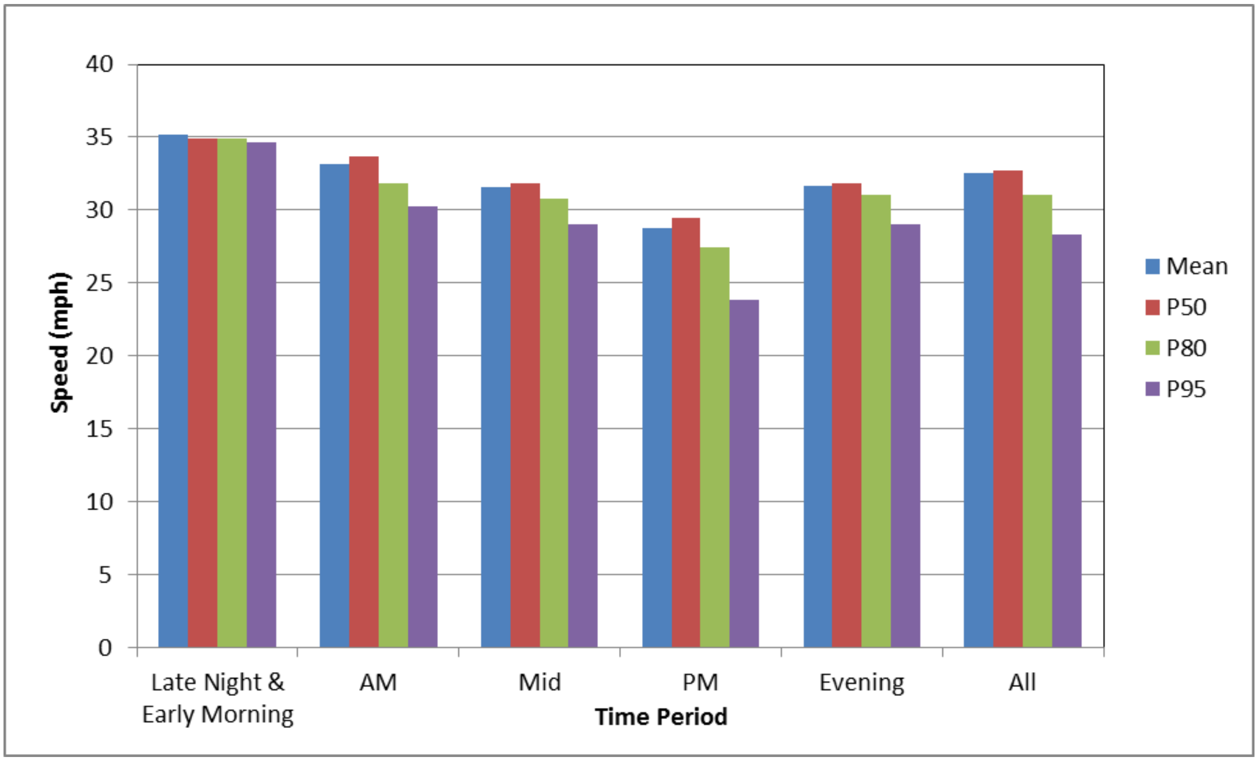


Figure E.4. Percentage of unreliability contribution for SR-7 NB.

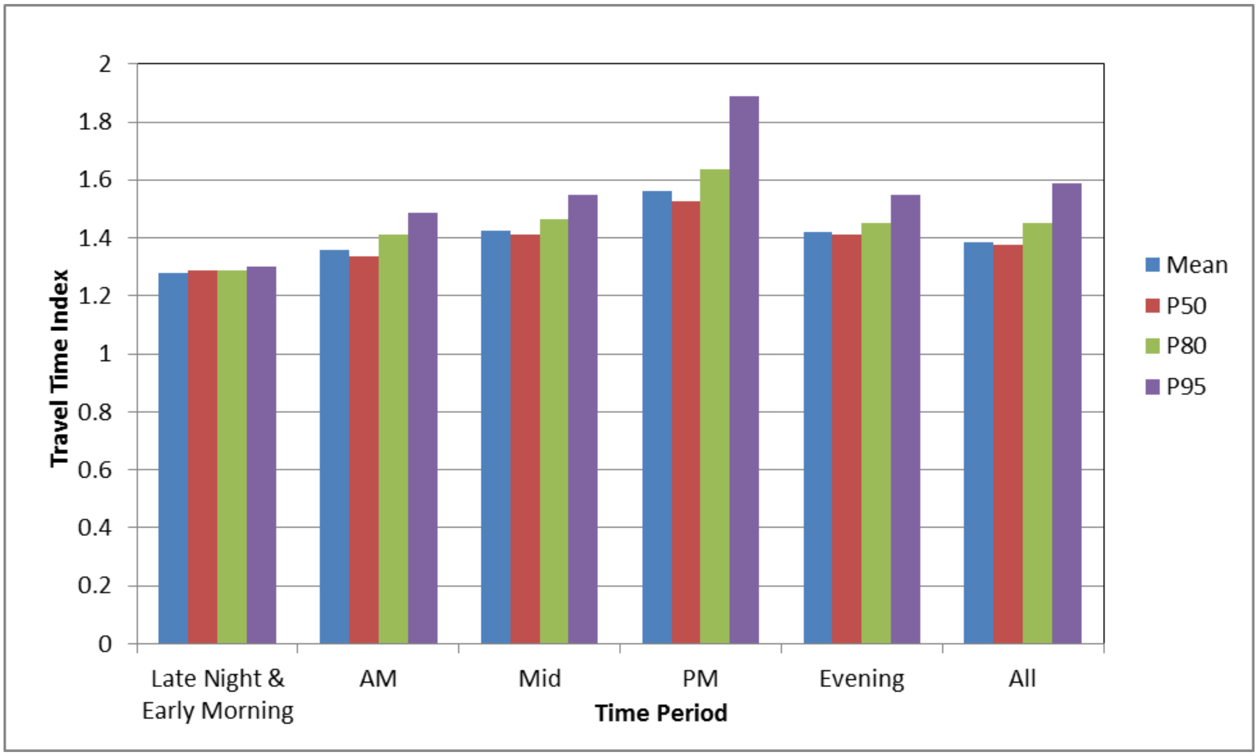
Another approach to visualize the distribution of travel time is presented in Figure E.5, which shows travel time, speed, and TTI at the mean and 50th, 80th, and 95th percentile levels. As shown in Figure E.5a, the PM travel time was higher than in other time periods; the corresponding speed shown in Figure E.5b dropped to below 30 mph, and less than 25 mph at the 95th percentile level. Figure E.5c shows that the worst 95th percentile TTI was about 1.9.



(a)



(b)



(c)

Figure E.5. SR-7 NB (a) travel time, (b) speed, and (c) TTI.

Figure E.6 presents the five-minute variation of TTIs. As shown in this figure, the mean and 50th, 80th, 85th, and 95th percentile TTIs were close to each other, and only the 95th percentile TTI showed a significant difference from the other indexes, especially during the PM peak period. The maximum 95th percentile TTI was around 2.0, indicating a travel time that was twice free-flow travel time. The on-time performance shown in Figure E.7 reveals that when a threshold of 1.1 was selected, travel time for about 80% of trips was 10% higher than the median travel time; this number increased to more than 90% if a threshold of 1.25 was applied. Figure E.8 presents the variation of reliability performance for semistandard deviation, misery index, and buffer index. It is seen from the figure that most unreliability occurred between 4:00 and 6:00 p.m.

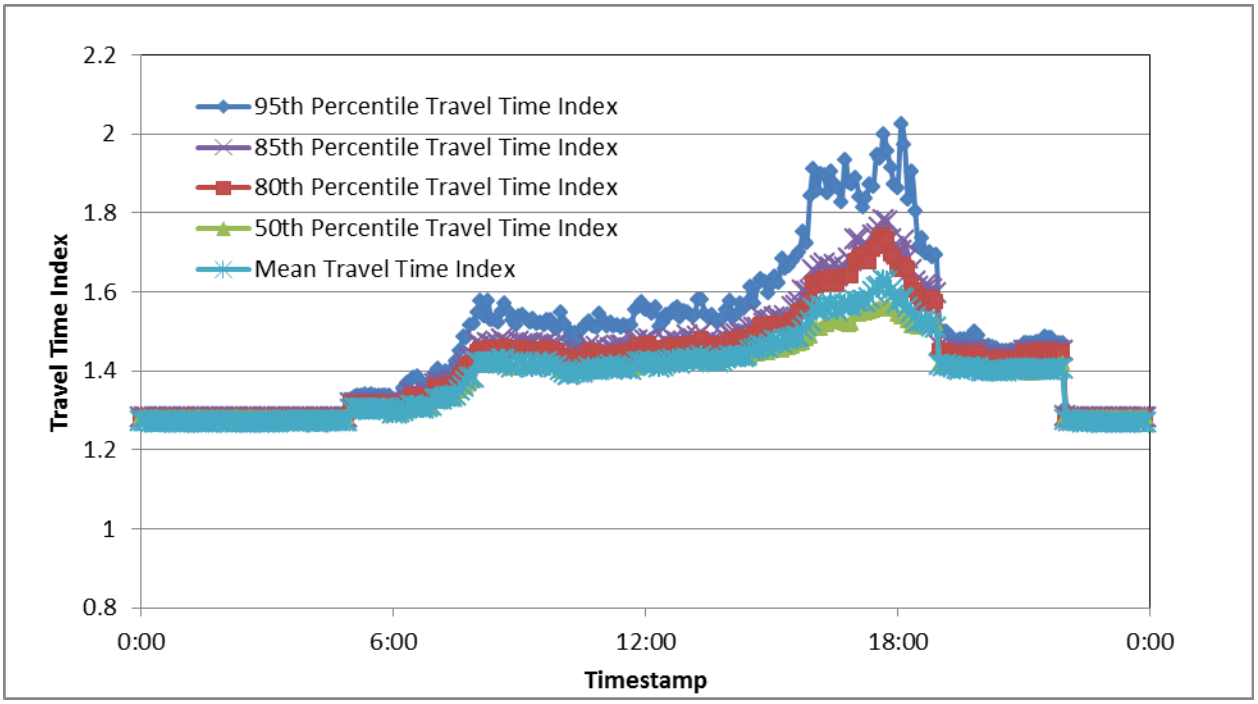


Figure E.6. SR-7 NB TTI comparison.

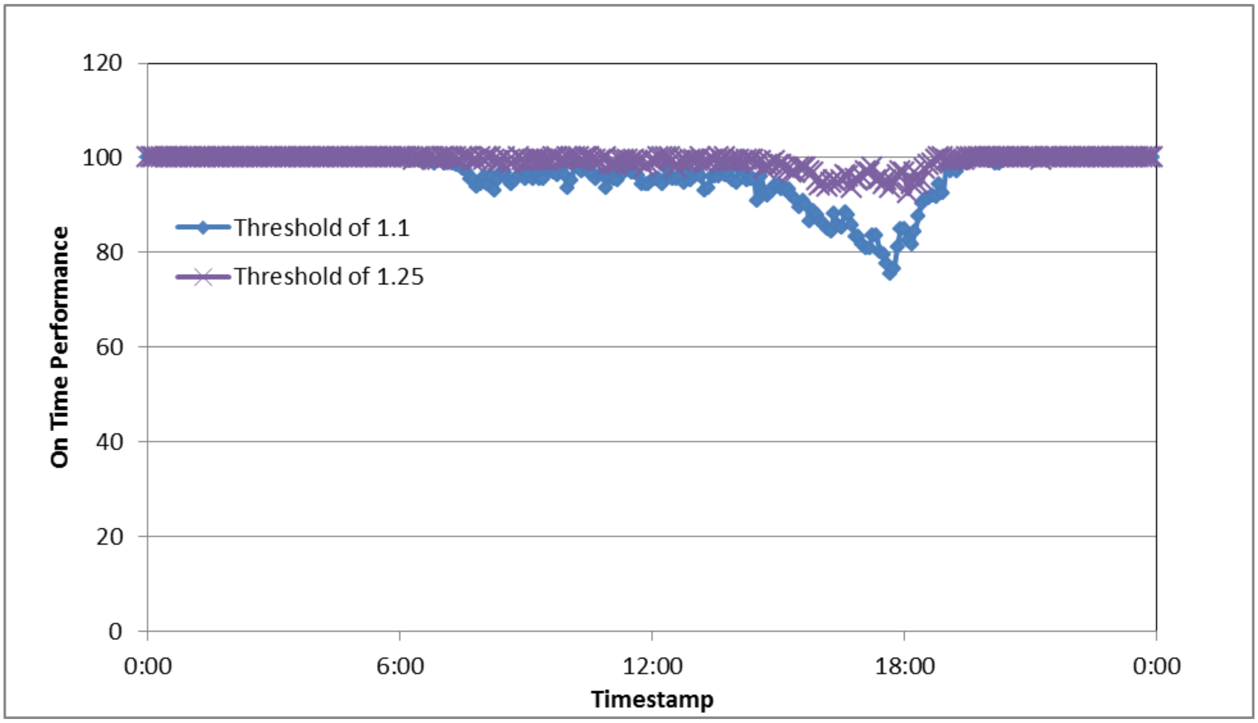


Figure E.7. SR-7 NB on-time performance.

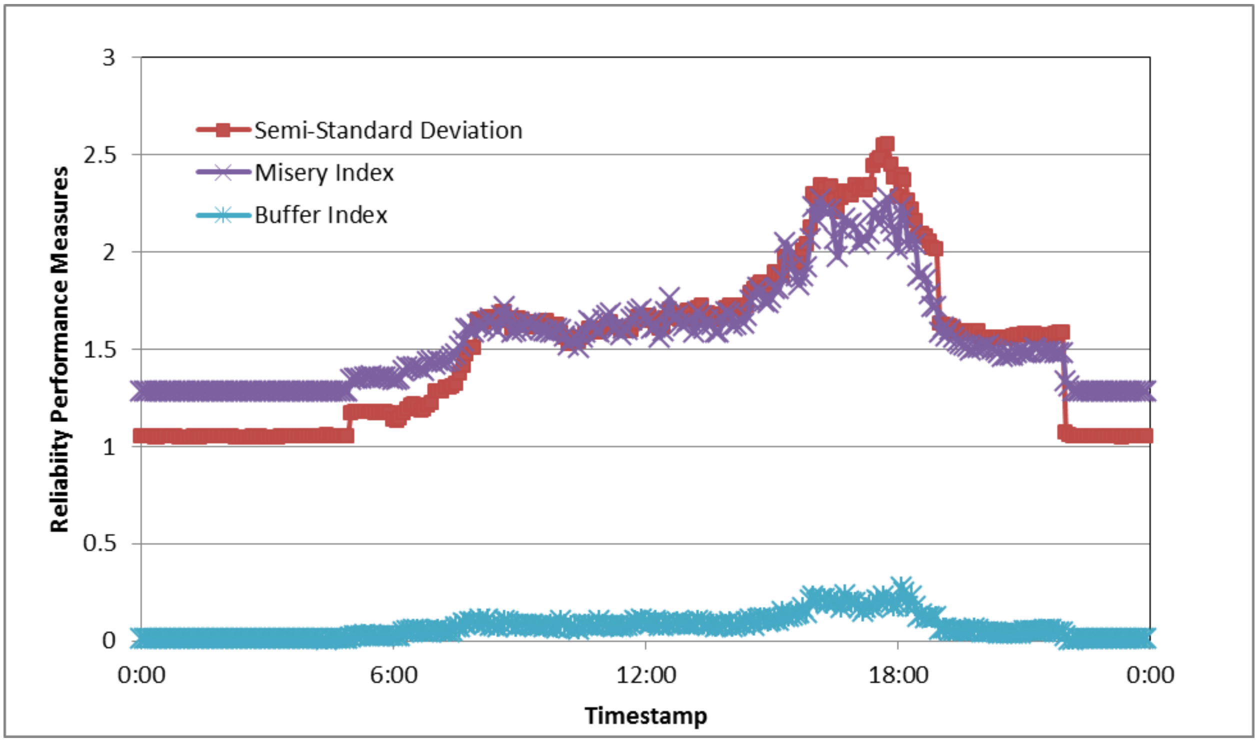


Figure E.8. SR-7 NB semistandard deviation, misery index, and buffer index.

E.2 Contributions of Influential Factors

The impacts of various factors on travel time reliability along SR-7 NB were examined following the L02 procedures. Note that in the initial analysis, congestion level was applied to classify regimes; however, it was found that the determination of semistandard deviation thresholds for identifying congestion levels was subjective, and therefore instead of congestion level, time of day was used in the analysis. Figure E.9 shows the CDF of travel time rate by regimes along SR-7 NB. Tables E.2 to E.4 list the percentages of occurrence, severity, and unreliability contributions by regimes. Figures E.10 to E.12 present the corresponding pie charts for a better visualization. It should be mentioned that to make those pie charts more readable, only the top 10 regimes were shown in each pie chart. Because the crash data obtained in this study did not include crash duration information, an assumption had to be made in the analysis. It was assumed that crashes had an average duration of 15 minutes for the analysis presented in Figures E.9 to E.12 and Tables E.2 to E.4. Due to lack of volume data, the regime of high demand cannot be differentiated from the regime of normal traffic.

Figure E.9 shows that the regimes for normal conditions during the PM peak period and PM peak with weather events had a larger variation in the CDF than other regimes. This finding can also be observed in Table E.3 and Figure E.11, which show that the semivariance percentage for the regime of normal and PM peak period was 12% and for the regime of weather and PM peak period was 11%, followed by the regime of crash and PM peak period. However, when taking occurrence into consideration, the normal conditions during the midday and PM periods had larger contributions to overall unreliability along SR-7 NB.

Similar analysis was repeated under the assumption of an average 30-minute crash duration. The corresponding results are presented in Figures E.13 to E.16 and Tables E.5 to E.7. Comparing the curves in Figure E. 9 and those in Figure E.13 indicates that with longer crash duration, such as 30 minutes, the variation of travel time rate CDF under the crash conditions during the PM peak period became as significant as other regimes, such as normal and weather in the PM peak periods. Again, the overall unreliability contributions originated from the normal conditions due to their more numerous occurrences.

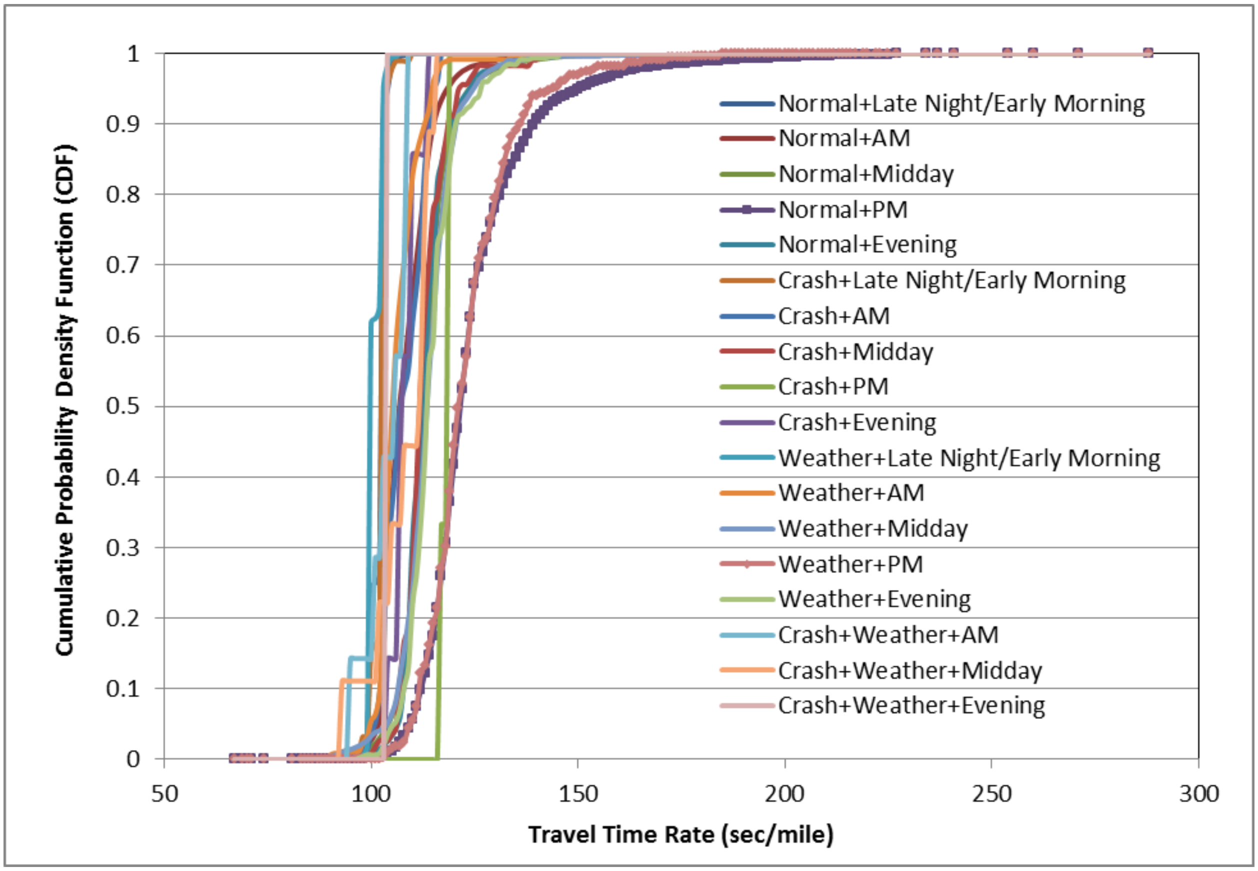


Figure E.9. CDF for SR-7 NB by regimes (crash duration = 15 minutes).

Table E.2. Percentage of Occurrence (Crash Duration = 15 minutes)

Time Period	Normal	Crash	Weather	Crash + Weather	Total
Late night and early morning	31.84%	0.13%	1.22%	0.00%	33.18%
AM	11.89%	0.11%	0.48%	0.01%	12.48%
Midday	25.90%	0.16%	1.08%	0.01%	27.16%
PM	12.11%	0.00%	0.45%	0.00%	12.56%
Evening	13.99%	0.01%	0.62%	0.00%	14.62%

Table E.3. Percentage of Severity (Crash Duration = 15 minutes)

Time Period	Normal	Crash	Weather	Incident + Weather	Total
Late night and early morning	2.72%	2.77%	2.43%	0.00%	7.93%
AM	4.64%	4.45%	4.05%	3.35%	16.49%
Midday	6.49%	6.11%	6.59%	4.63%	23.82%
PM	12.12%	7.95%	11.04%	0.00%	31.10%
Evening	6.31%	4.46%	6.79%	3.11%	20.67%

Table E.4. Percentage of Unreliability Contribution (Crash Duration = 15 minutes)

Time Period	Normal	Crash	Weather	Incident + Weather	Total
Late night and early morning	15.25%	0.06%	0.52%	0.00%	15.83%
AM	9.72%	0.08%	0.34%	0.01%	10.15%
Midday	29.59%	0.17%	1.26%	0.01%	31.02%
PM	25.83%	0.01%	0.87%	0.00%	26.71%
Evening	15.54%	0.01%	0.74%	0.00%	16.29%

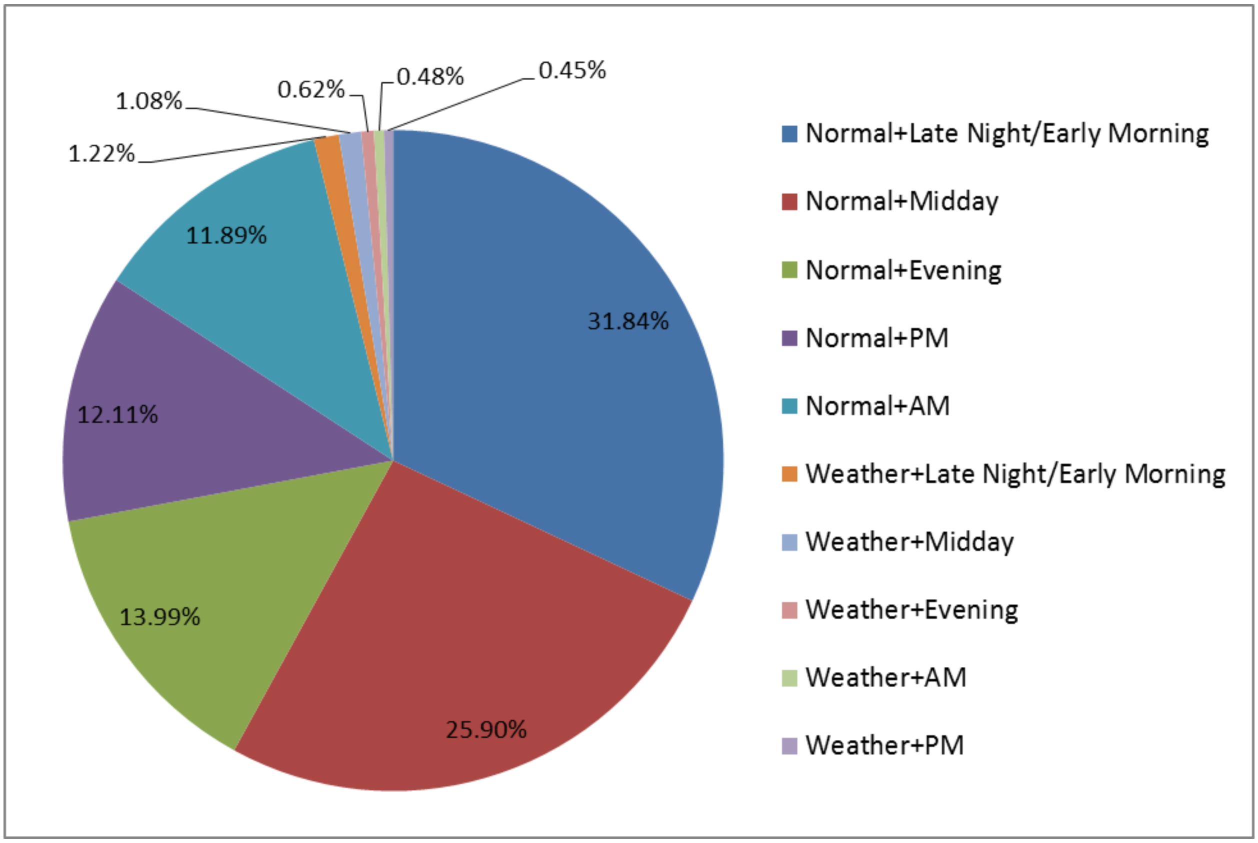


Figure E.10. Percentage of occurrence for SR-7 NB (crash duration = 15 minutes).

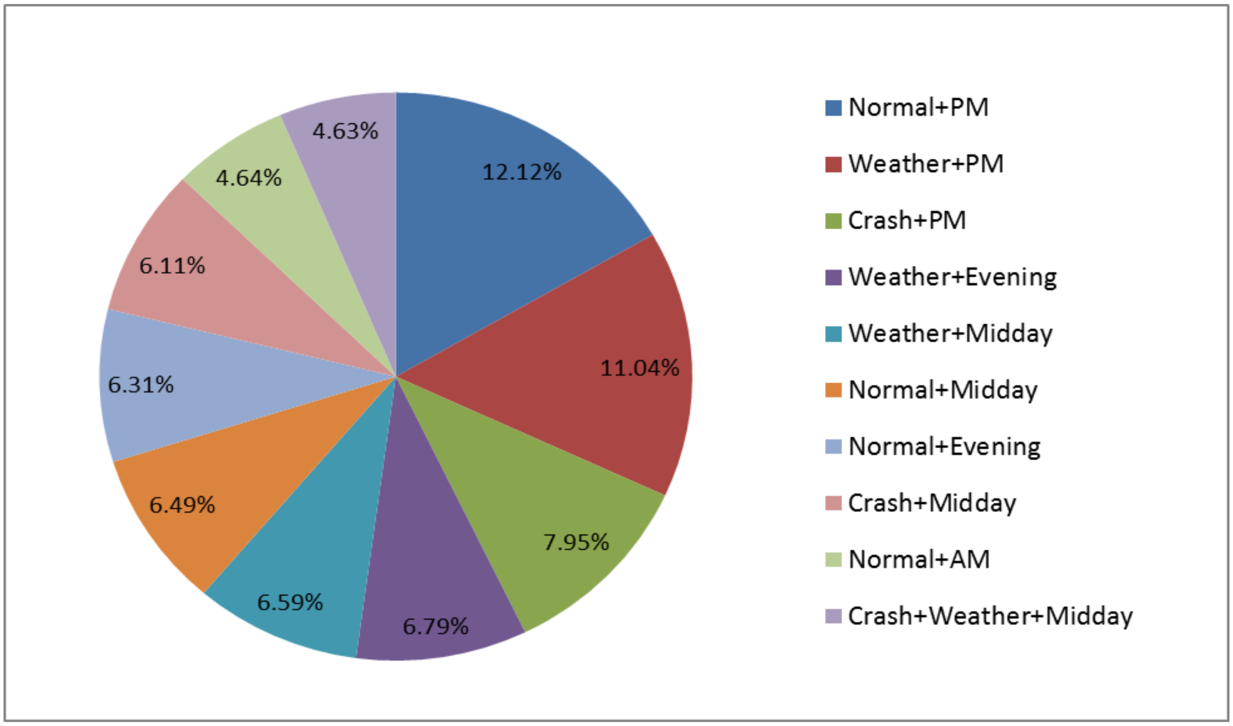


Figure E.11. Percentage of severity for SR-7 NB (crash duration = 15 minutes).

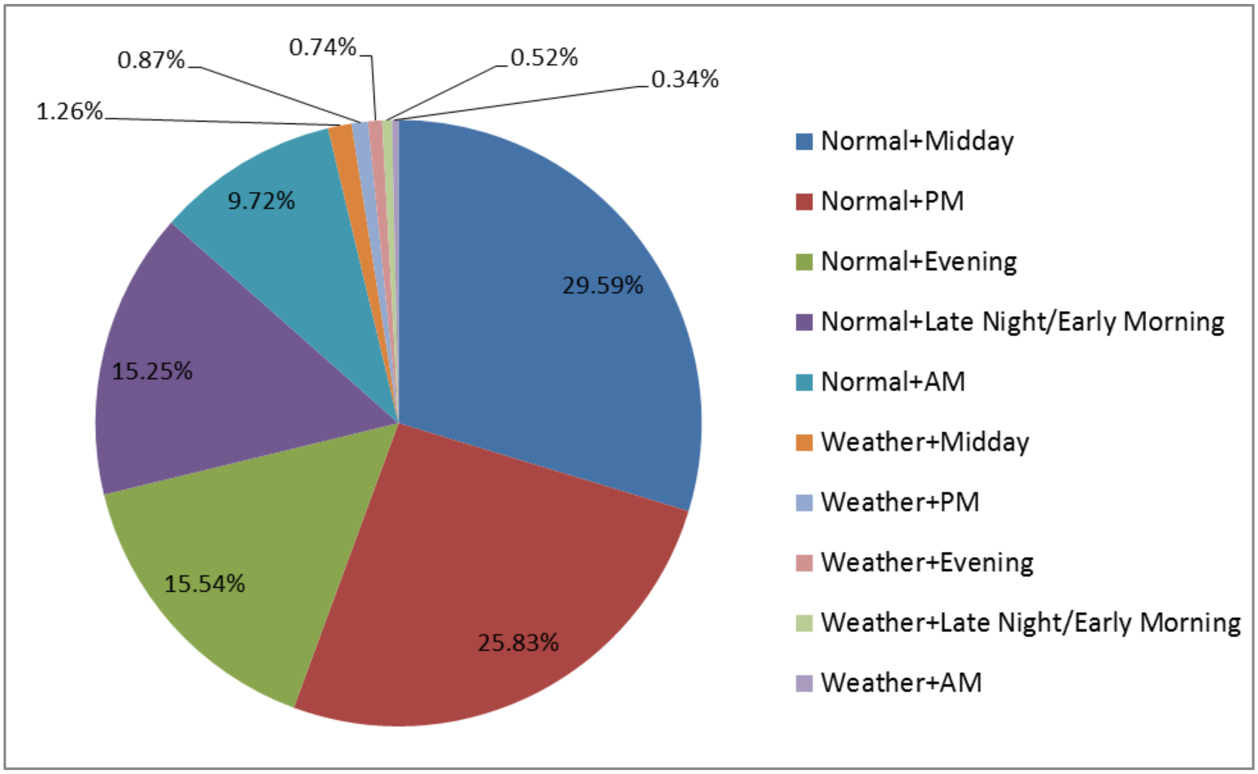


Figure E.12. Percentage of unreliability contributions for SR-7 NB (crash duration = 15 minutes).

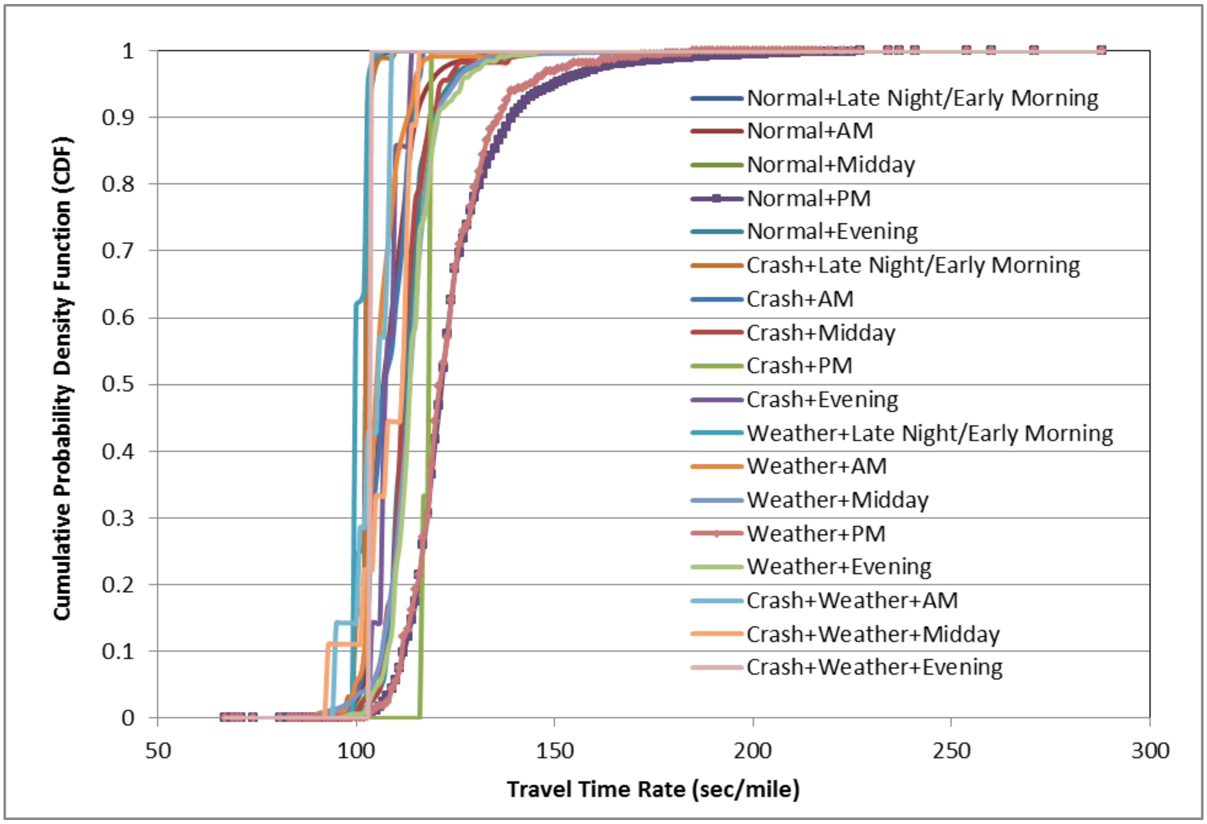


Figure E.13. CDF for SR-7 NB by regimes (crash duration = 30 minutes).

Table E.5. Percentage of Occurrence (Crash Duration = 30 minutes)

Time Period	Normal	Crash	Weather	Crash + Weather	Total
Late night and early morning	31.72%	0.25%	1.22%	0.00%	33.18%
AM	11.77%	0.22%	0.47%	0.02%	12.48%
Midday	25.74%	0.32%	1.08%	0.02%	27.16%
PM	12.10%	0.01%	0.45%	0.00%	12.56%
Evening	13.98%	0.02%	0.62%	0.00%	14.62%

Table E.6. Percentage of Severity (Crash Duration = 30 minutes)

Time Period	Normal	Crash	Weather	Incident + Weather	Total
Late night and early morning	2.59%	2.64%	2.32%	0.00%	7.56%
AM	4.42%	4.41%	3.88%	3.10%	15.81%
Midday	6.18%	6.13%	6.29%	4.77%	23.37%
PM	11.55%	11.29%	10.52%	0.00%	33.36%
Evening	6.01%	4.45%	6.47%	2.97%	19.90%

Table E.7. Percentage of Unreliability Contribution (Crash Duration = 30 minutes)

Time Period	Normal	Crash	Weather	Incident + Weather	Total
Late night and early morning	15.19%	0.12%	0.52%	0.00%	15.83%
AM	9.62%	0.18%	0.34%	0.01%	10.15%
Midday	29.40%	0.36%	1.25%	0.02%	31.02%
PM	25.82%	0.02%	0.87%	0.00%	26.71%
Evening	15.53%	0.02%	0.74%	0.00%	16.29%

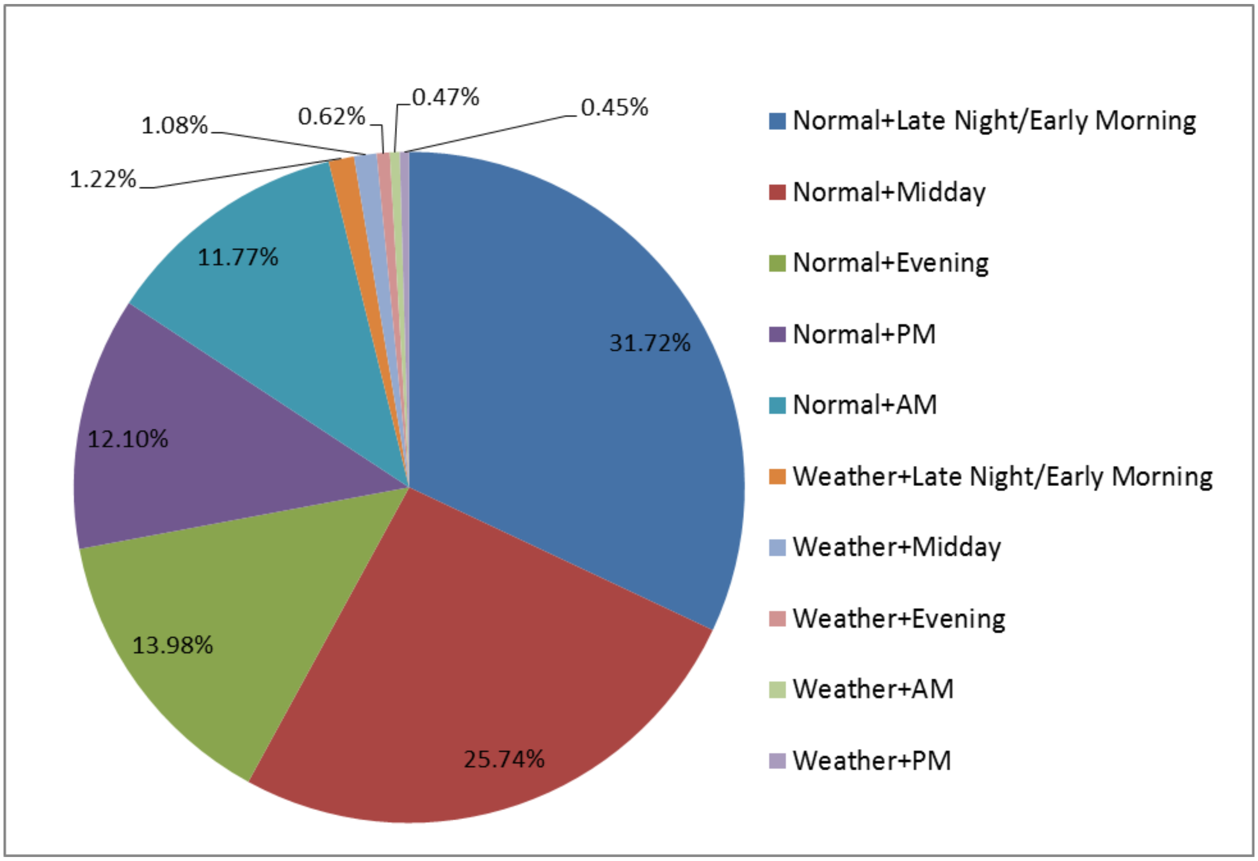


Figure E.14. Percentage of occurrence for SR-7 NB (crash duration = 30 minutes).

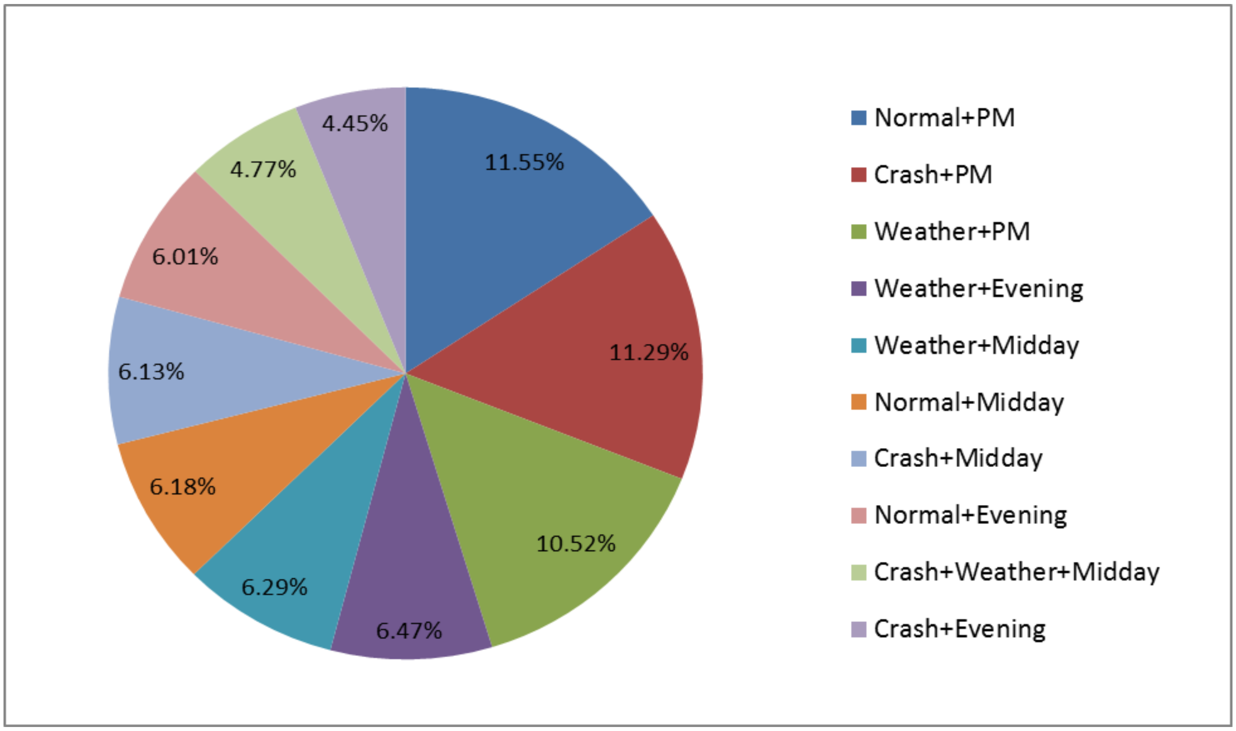


Figure E.15. Percentage of severity for SR-7 NB (crash duration = 30 minutes).

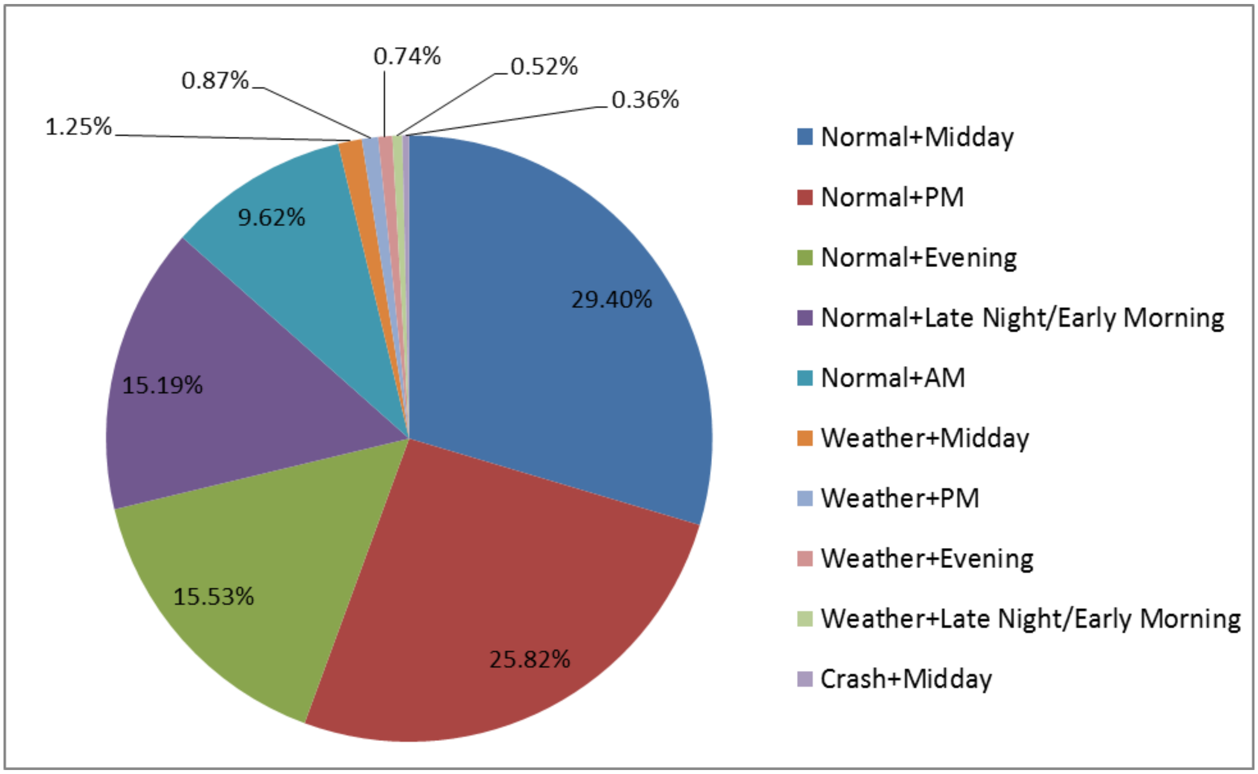
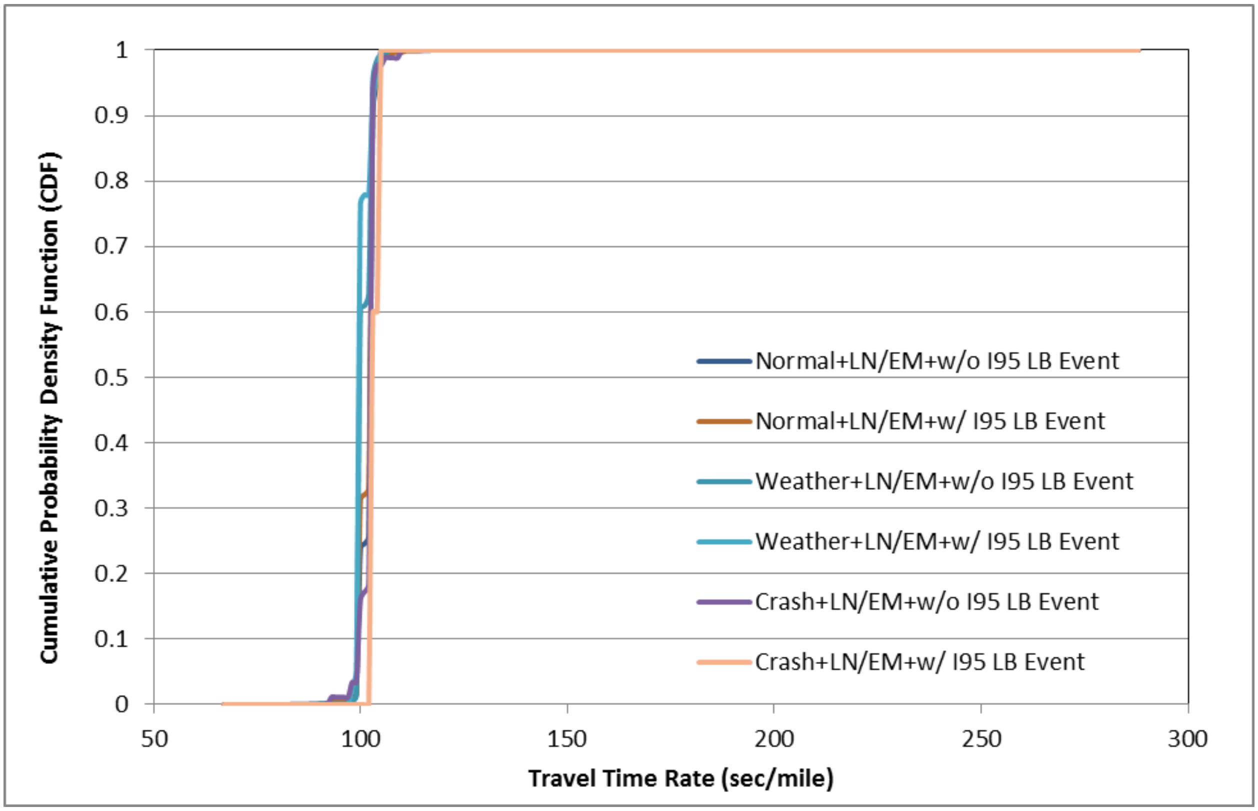


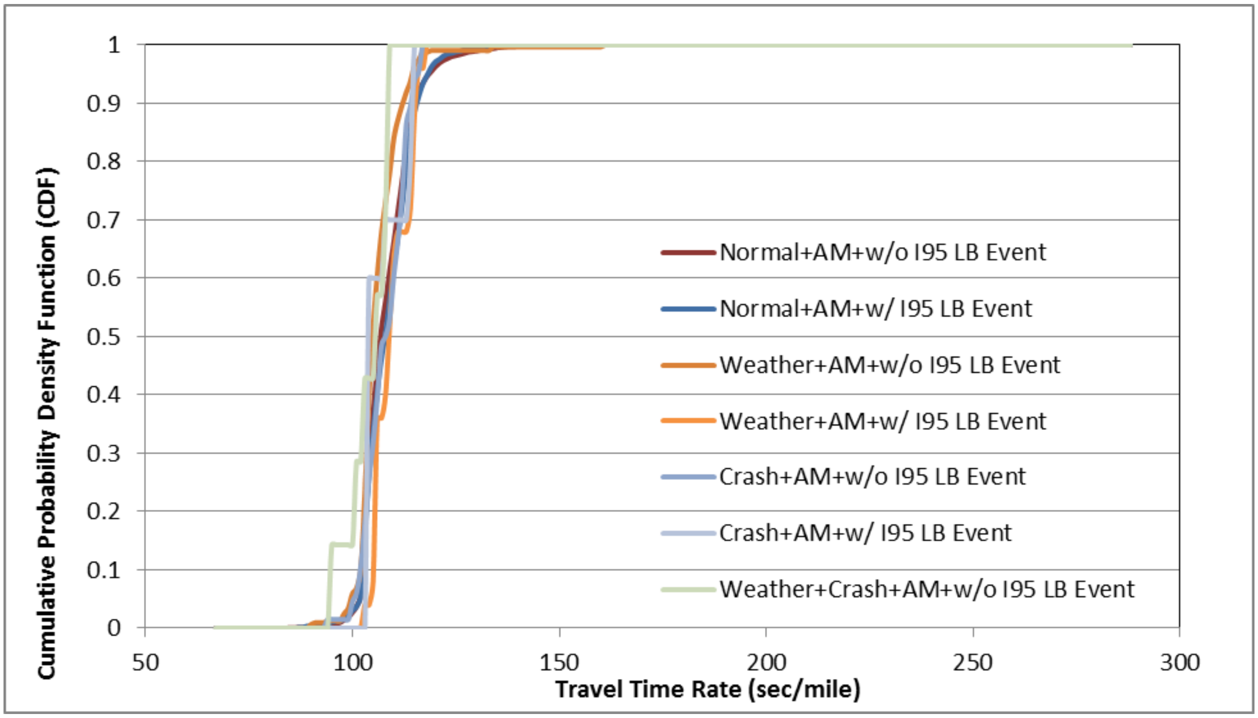
Figure E.16. Percentage of unreliability contribution for SR-7 NB (crash duration = 30 minutes).

E.3 Impacts of I-95 Northbound Lane-Blocking Incidents on SR-7 Northbound

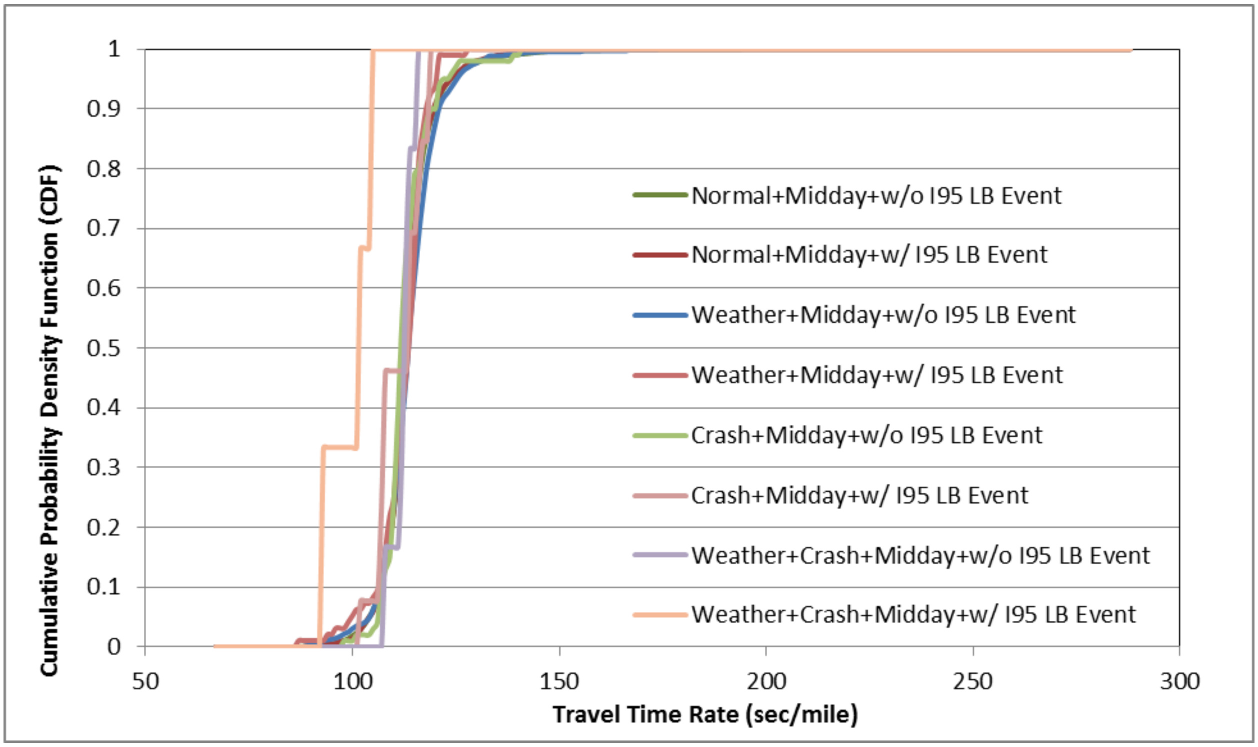
This study also examined the impacts of I-95 NB lane-blocking incidents on travel time reliability along SR-7 NB. Each analyzed regime in the previous section was further divided into two regimes, with or without I-95 lane-blocking events. Figure E.17 presents the CDFs of travel time rates for different time periods; LB in the legend refers to lane blockage. Note that depending on the occurrence of specific types of events, the number of curves in each figure may vary. As shown in Figure E.17, no significant impacts of I-95 lane-blocking incidents were found on the travel time reliability of SR-7 NB. It should be pointed out that some extreme CDFs in the figure, such as the one for crash, weather, and I-95 lane-blocking events during the midday, may have occurred due to the very small sample sizes compared to other regimes.


Cumulative Probability Density Function (CDF)
Travel Time Rate (sec/mile)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
50
100
150
200
250
300
Normal+LN/EM+w/o I95 LB Event
Normal+LN/EM+w/ I95 LB Event
Weather+LN/EM+w/o I95 LB Event
Weather+LN/EM+w/ I95 LB Event
Crash+LN/EM+w/o I95 LB Event
Crash+LN/EM+w/ I95 LB Event

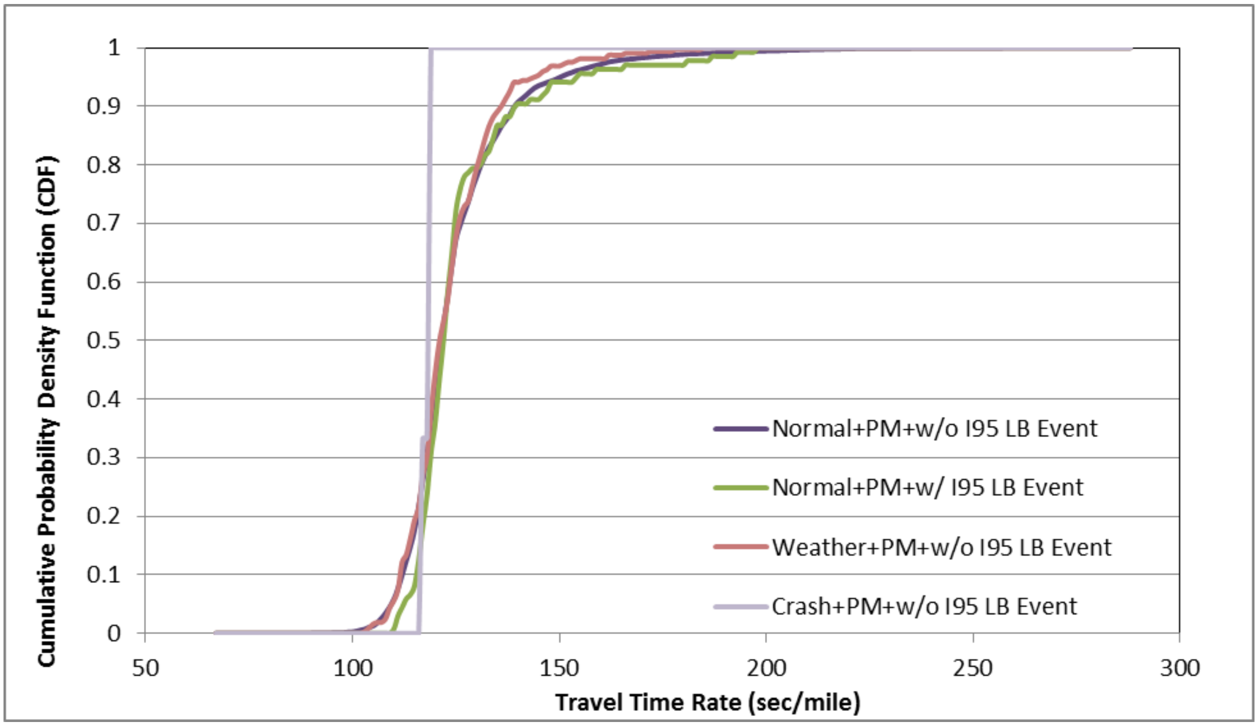
(a)


Cumulative Probability Density Function (CDF)
Travel Time Rate (sec/mile)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
50
100
150
200
250
300
Normal+AM+w/o I95 LB Event
Normal+AM+w/ I95 LB Event
Weather+AM+w/o I95 LB Event
Weather+AM+w/ I95 LB Event
Crash+AM+w/o I95 LB Event
Crash+AM+w/ I95 LB Event
Weather+Crash+AM+w/o I95 LB Event

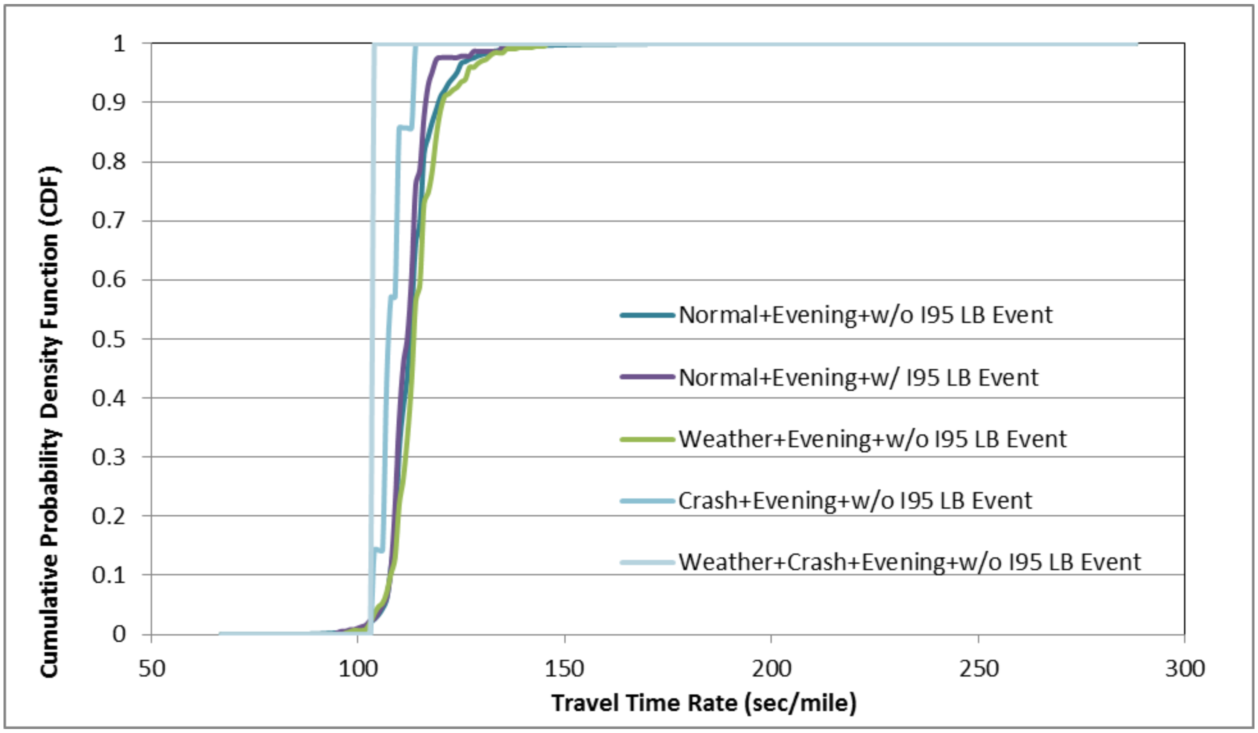
(b)


Cumulative Probability Density Function (CDF)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
50
100
150
200
250
300
Travel Time Rate (sec/mile)
Normal+Midday+w/o I95 LB Event
Normal+Midday+w/ I95 LB Event
Weather+Midday+w/o I95 LB Event
Weather+Midday+w/ I95 LB Event
Crash+Midday+w/o I95 LB Event
Crash+Midday+w/ I95 LB Event
Weather+Crash+Midday+w/o I95 LB Event
Weather+Crash+Midday+w/ I95 LB Event

(c)


Cumulative Probability Density Function (CDF)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
50
100
150
200
250
300
Travel Time Rate (sec/mile)
Normal+PM+w/o I95 LB Event
Normal+PM+w/ I95 LB Event
Weather+PM+w/o I95 LB Event
Crash+PM+w/o I95 LB Event

(d)



(e)

Figure E.17. CDF by regimes for SR-7 NB for (a) late night and early morning, (b) AM peak, (c) midday, (d) PM peak, and (e) evening periods.

Figures E.18 to E.20 present the percentages of occurrence, severity, and unreliability contribution for the top 10 regimes along SR-7 NB considering the I-95 lane-blocking events. Figure E.19 shows that these events slightly increased the semivariance of travel time rates along SR-7 NB in the PM peak period.

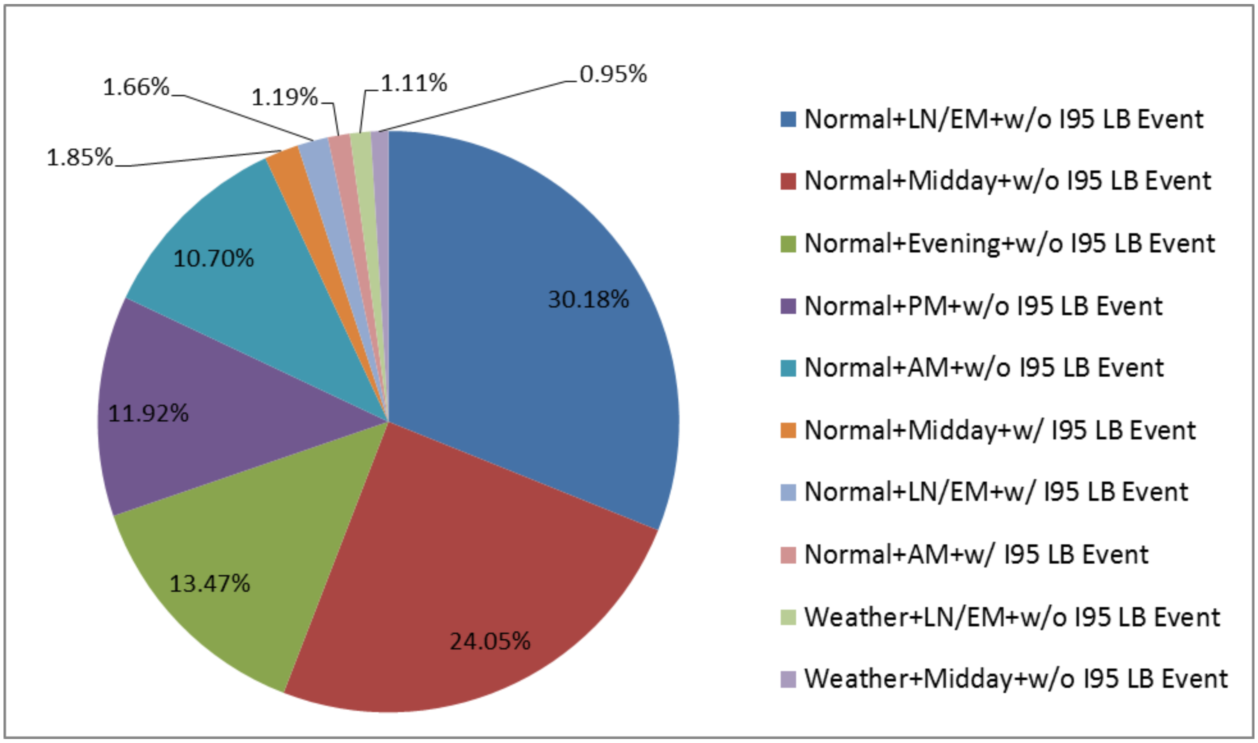


Figure E.18. Percentage of occurrence for SR-7 NB.

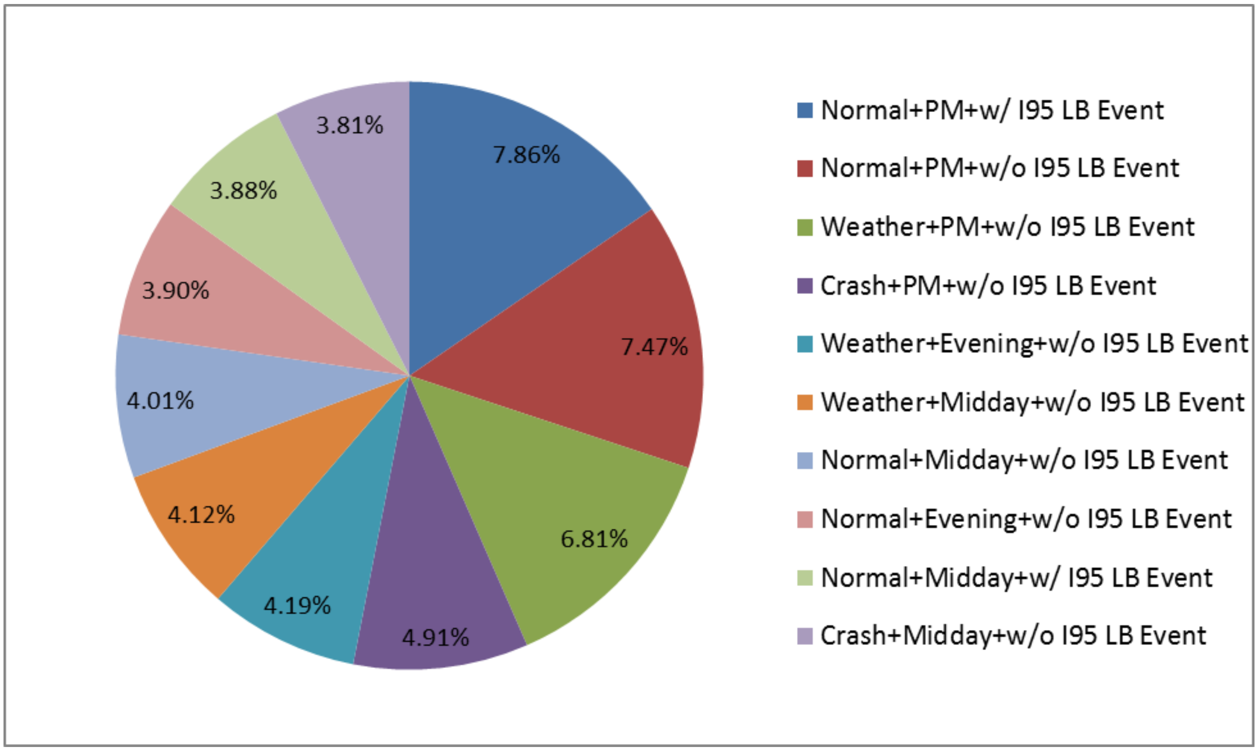


Figure E.19. Percentage of severity for SR-7 NB.

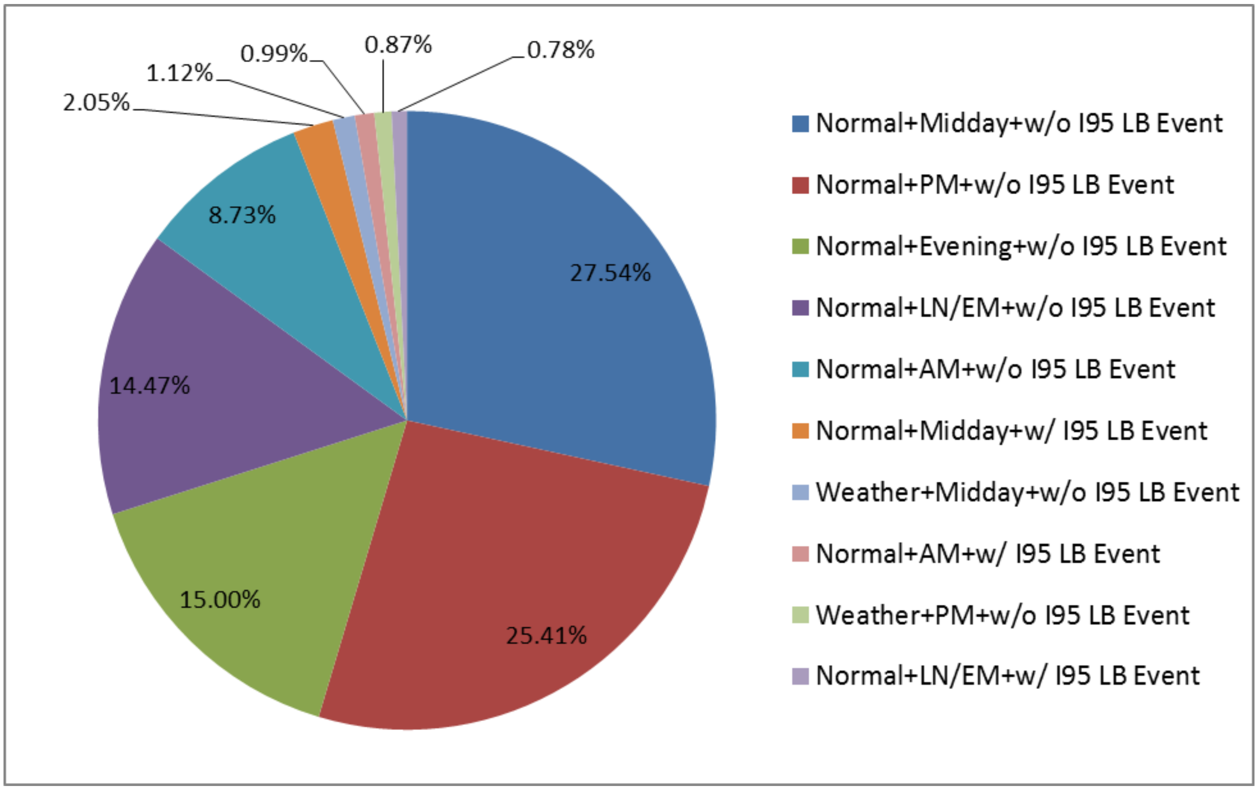


Figure E.20. Percentage of unreliability contribution for SR-7 NB.

APPENDIX F
SR-7 Southbound

F.1 Overall Reliability Performance

Similar to the analysis of the SR-7 NB traffic, the overall reliability performance for SR-7 SB was examined first. Figure F.1 presents the PDF and Figure F.2 shows the CDF for the travel time rate in different time periods of the day. It is seen from the CDF plot that there was no significant difference in reliability when the travel time rate was less than the 80th percentile for the midday, PM, or evening peak periods, and AM peak traffic showed an even better reliability performance under this percentile. However, the distribution of travel time rate varied with the higher percentile cumulative density for different time periods. Figure F.3 shows the percentage of severity in travel time rate for the different time periods. Again, the numbers in this figure indicate that the reliability performance was similar for different time periods, except late night and early morning. As shown in Figure F.4, the greatest unreliability contribution occurred in the midday.

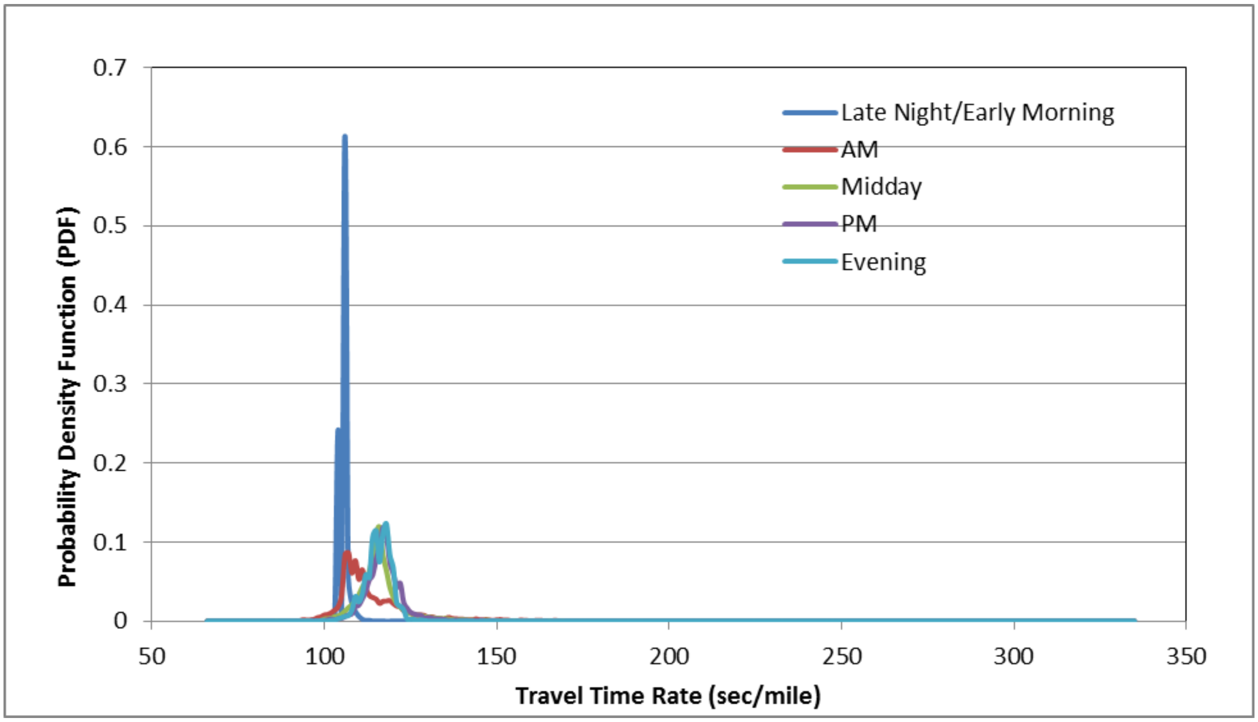


Figure F.1. PDF for SR-7 SB.

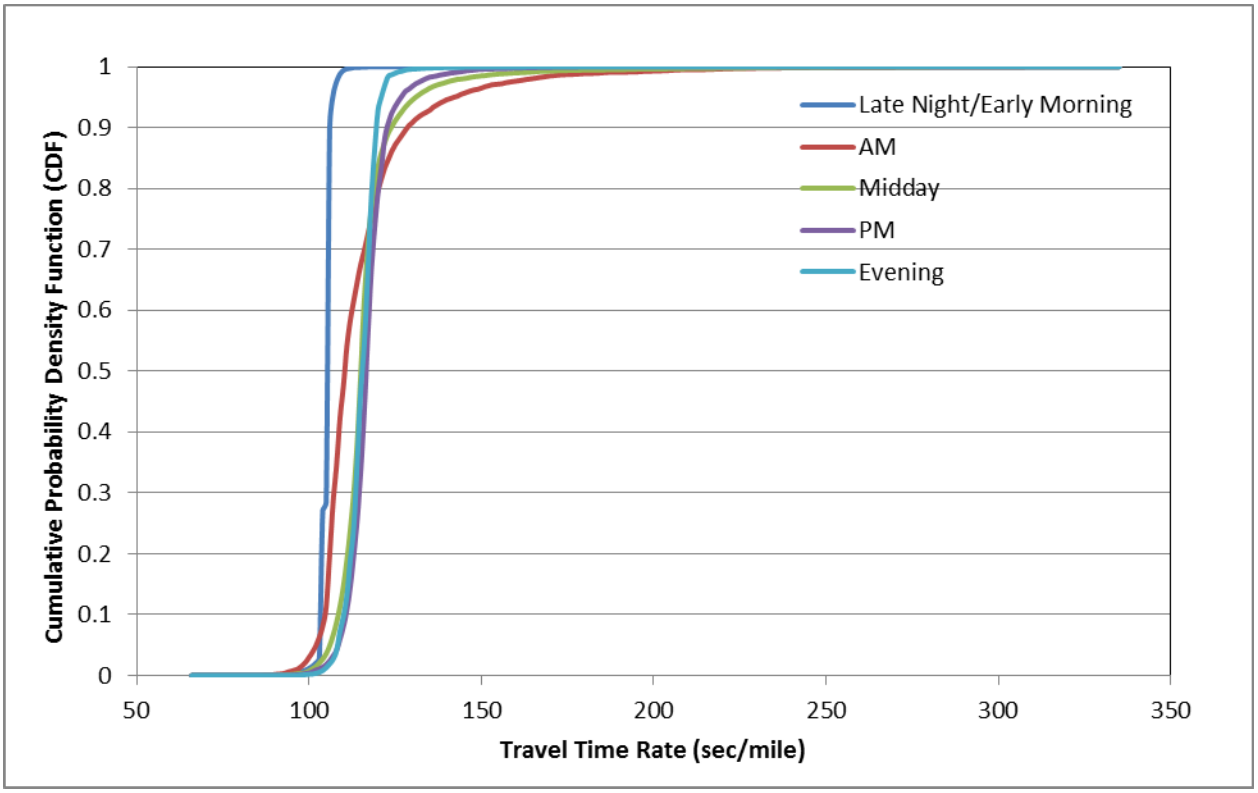


Figure F.2. CDF for SR-7 SB.

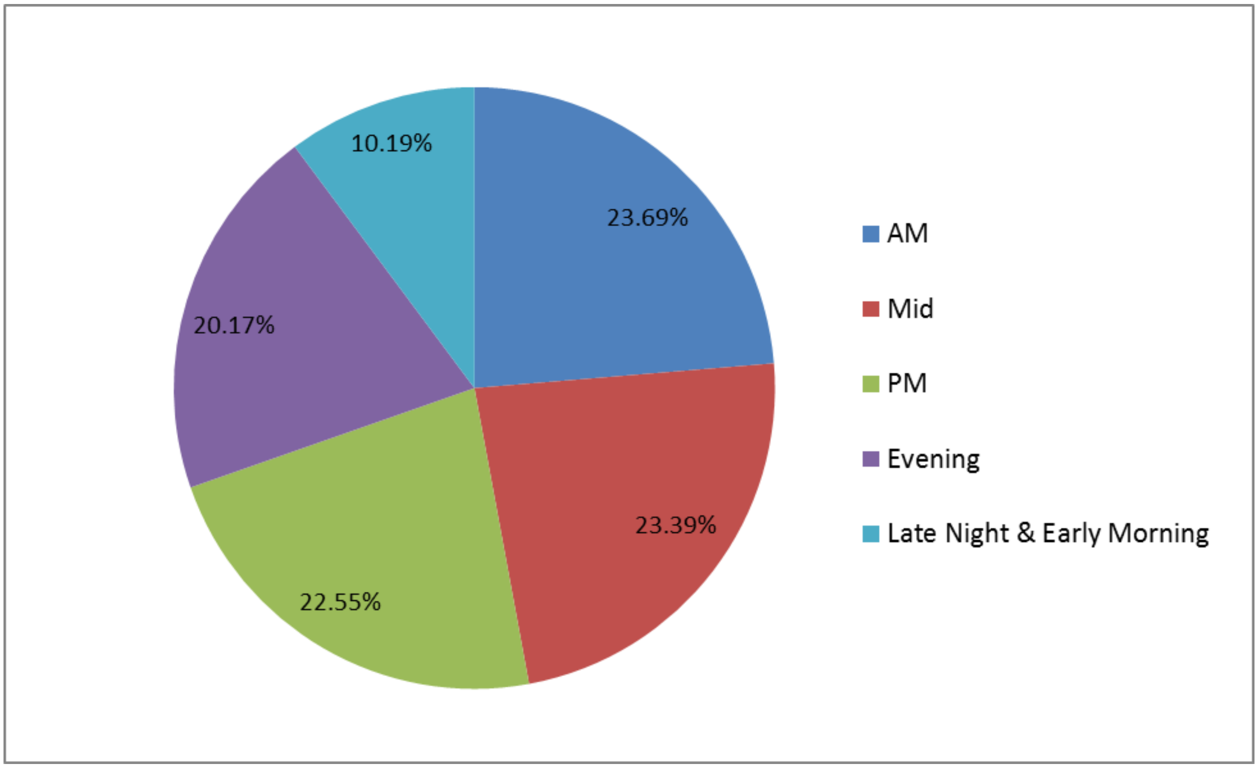


Figure F.3. Percentage of severity for SR-7 SB.

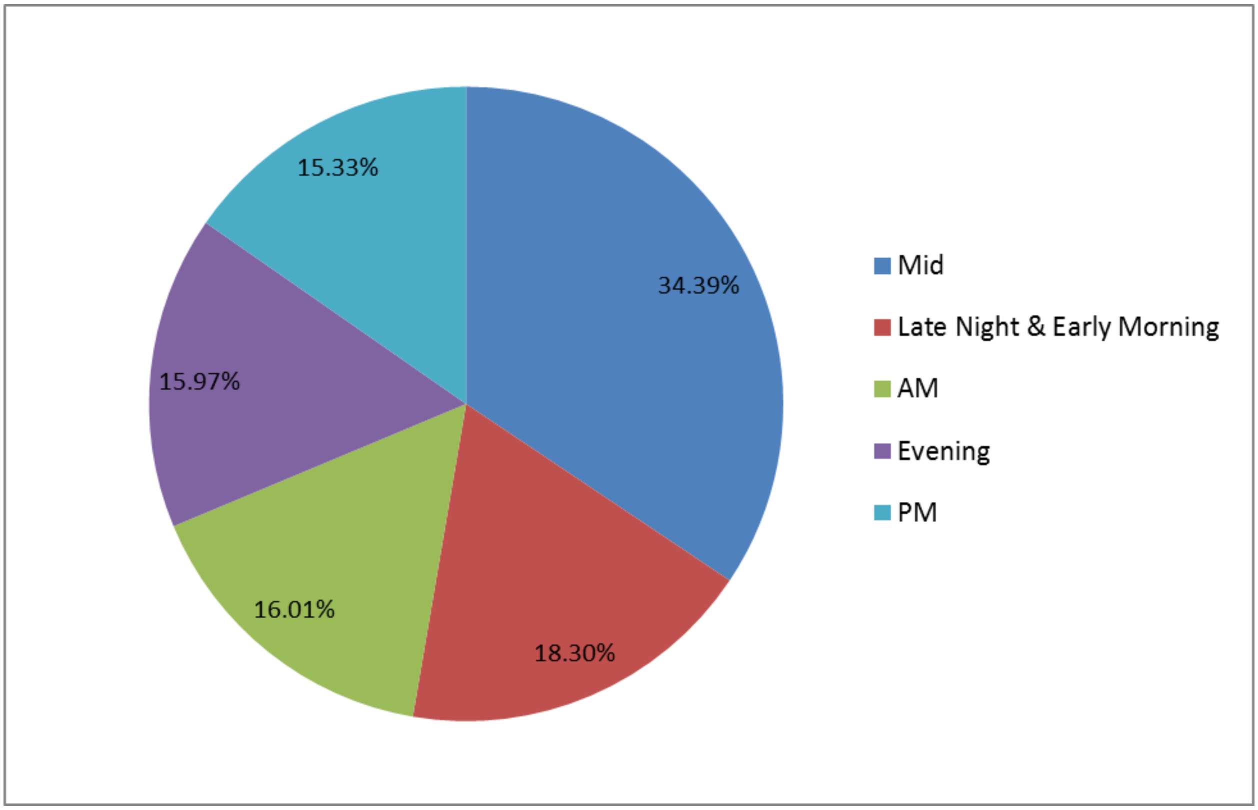
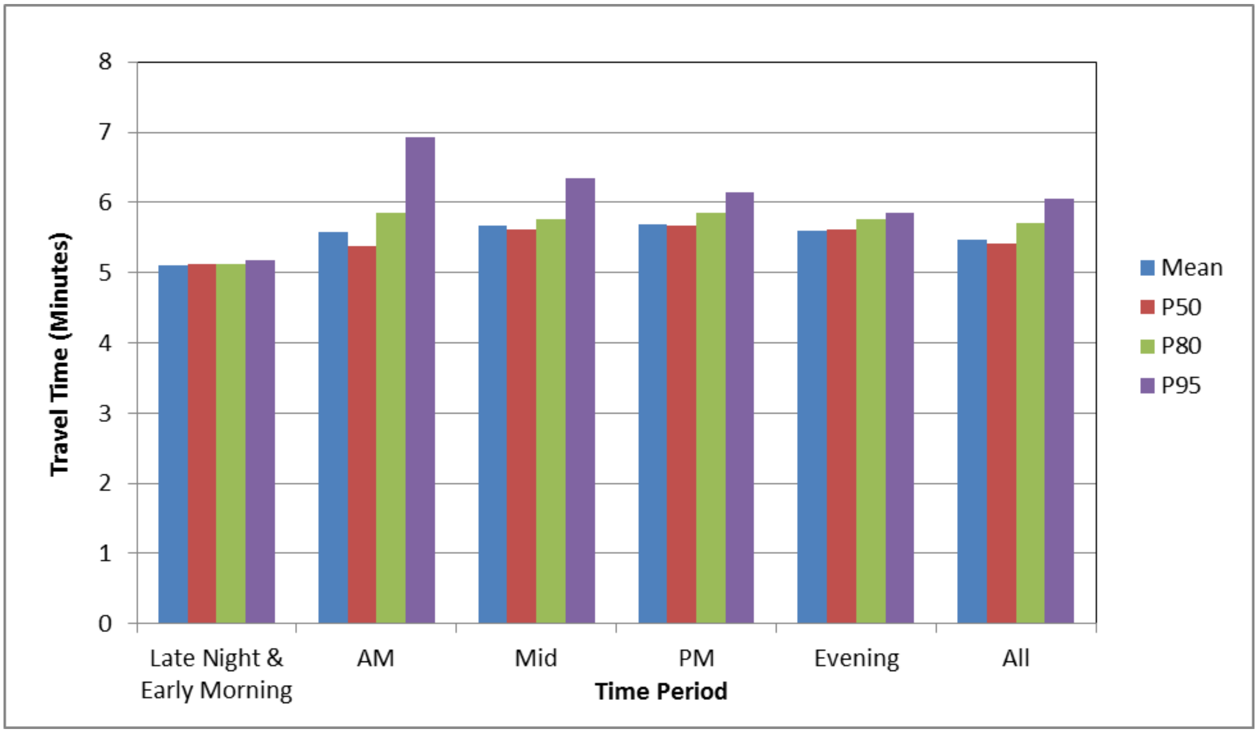
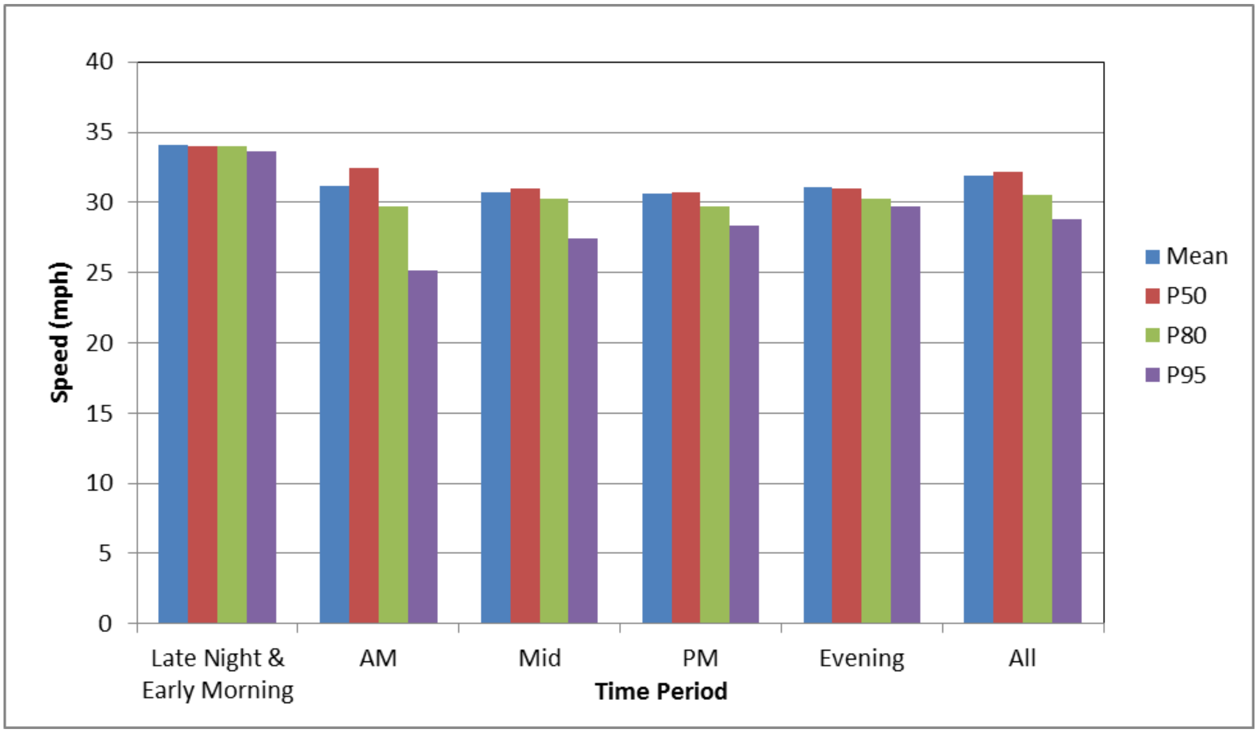


Figure F.4. Percentage of unreliability contribution for SR-7 SB.

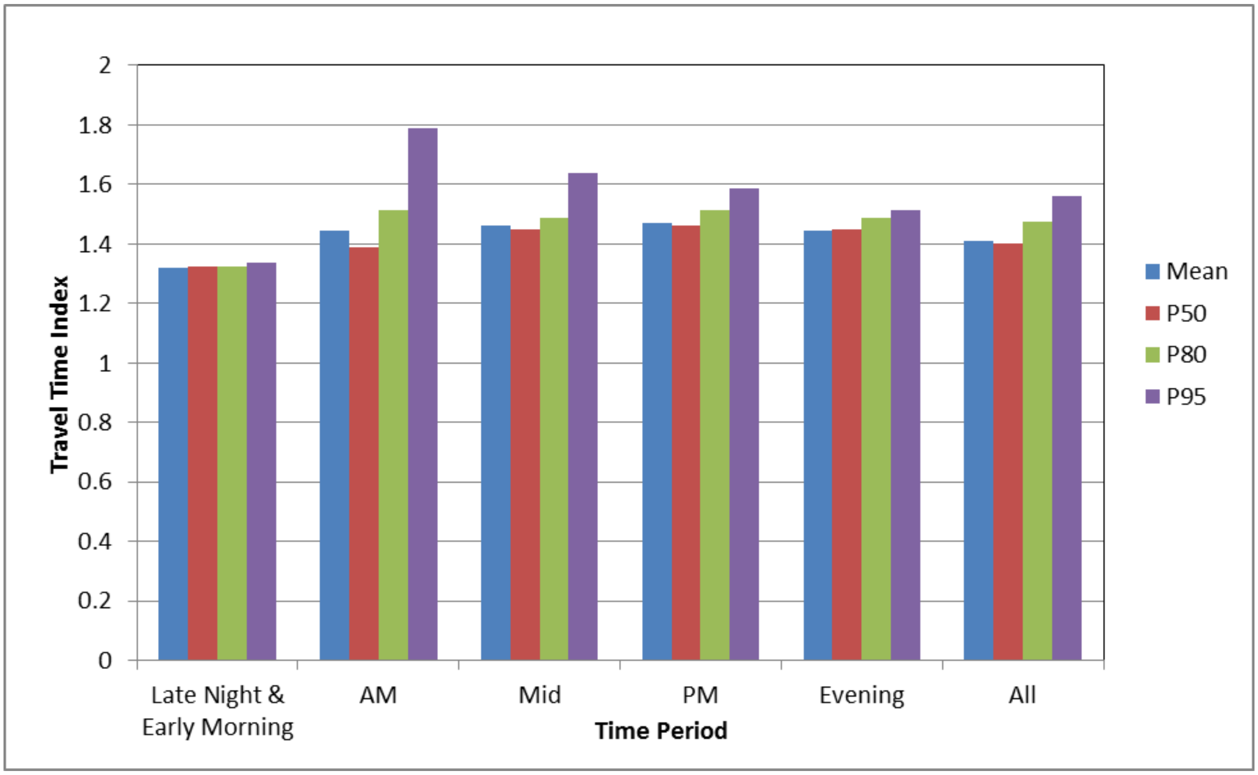
Different percentile values of travel time, speed, and TTI for SR-7 SB are presented in Figure F.5. It is seen that the worst condition occurred in the AM peak period at the 95th percentile level, under which the TTI was about 1.8 and the corresponding speed was about 25 mph. Traffic conditions were about the same for the remaining time periods except that traffic during the late night and early morning period had a better reliability.


Travel Time (Minutes)
8
7
6
5
4
3
2
1
0
Late Night & Early Morning
AM
Mid
PM
Evening
All
Time Period
Mean
P50
P80
P95

(a)


Speed (mph)
40
35
30
25
20
15
10
5
0
Late Night & Early Morning
AM
Mid
PM
Evening
All
Time Period
Mean
P50
P80
P95

(b)



(c)

Figure F.5. SR-7 SB (a) travel time, (b) speed, and (c) TTI.

The five-minute variations of various TTIs for SR-7 SB are presented in Figure F.6, which shows that during the morning peak period, the maximum 95th percentile TTI was about 2.2, which is much higher than the 85th percentile TTI (i.e., 1.8) and mean TTI of 1.6. These values indicate that most of the traffic along SR-7 SB in the AM peak period experienced consistent travel time, and only during some nonrecurrent events was the travel time possibly much higher. The other reliability performance measures, including on-time performance and semistandard deviation, misery index, and buffer index, are presented in Figure F.7 and Figure F.8, respectively.

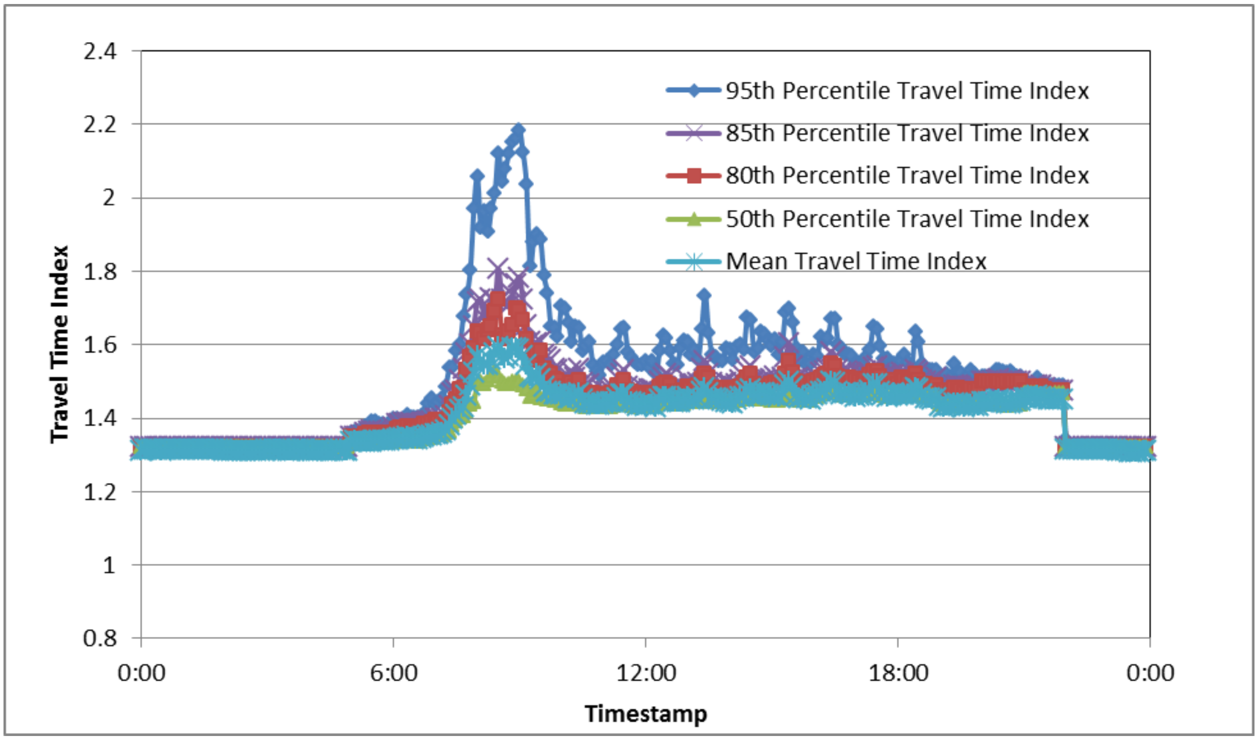


Figure F.6. SR-7 SB TTI comparison.

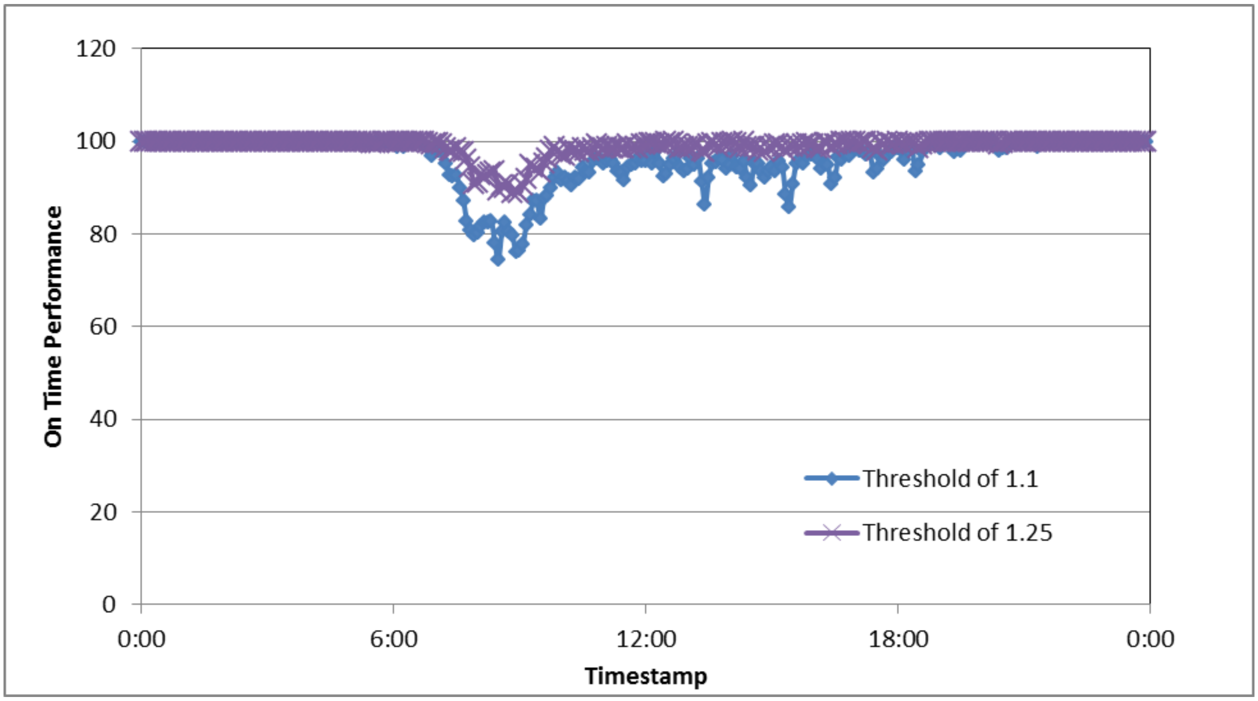


Figure F.7. SR-7 SB on-time-performance.

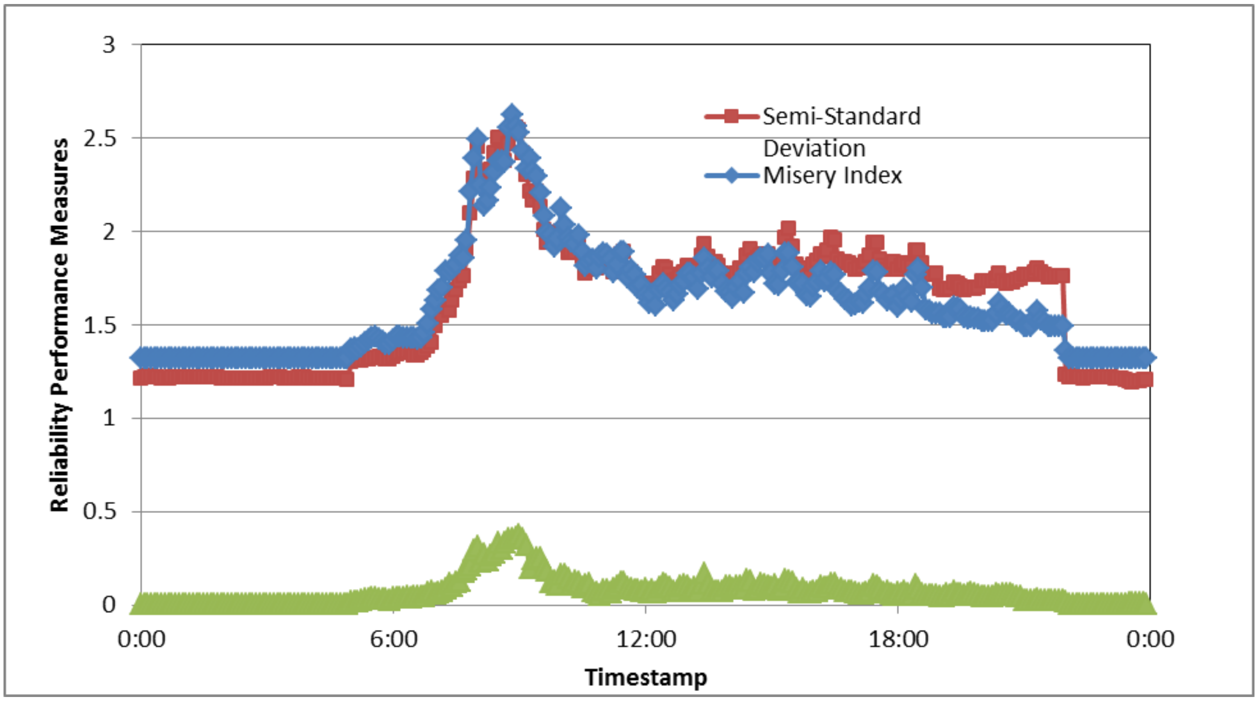


Figure F.8. SR-7 SB semistandard deviation, misery index, and buffer index.

F.2 Contributions of Influential Factors

The impacts of crashes and weather on the travel time reliability of the SR-7 SB study segments were investigated in a similar way as the SR-7 NB analysis. Two sets of analysis were conducted, one for average crash duration of 15 minutes and another for crash duration of 30 minutes. Figures F.9 to F.12 and Tables F.1 to F.3 show the results for the duration of 15 minutes, and Figures F.13 to F.16 and Tables F.4 to F.6 present the analysis results for the duration of 30 minutes. As shown in Table F.2, the occurrence of crashes may have caused a slight increase in the unreliability of SR-7 SB traffic. It appeared that the weather events had impacts on unreliability comparable to the effects of crashes. The percentage of semivariance was also high during the day, which indicates that further improvement in the existing roadway configuration and signal timing may need to be considered.

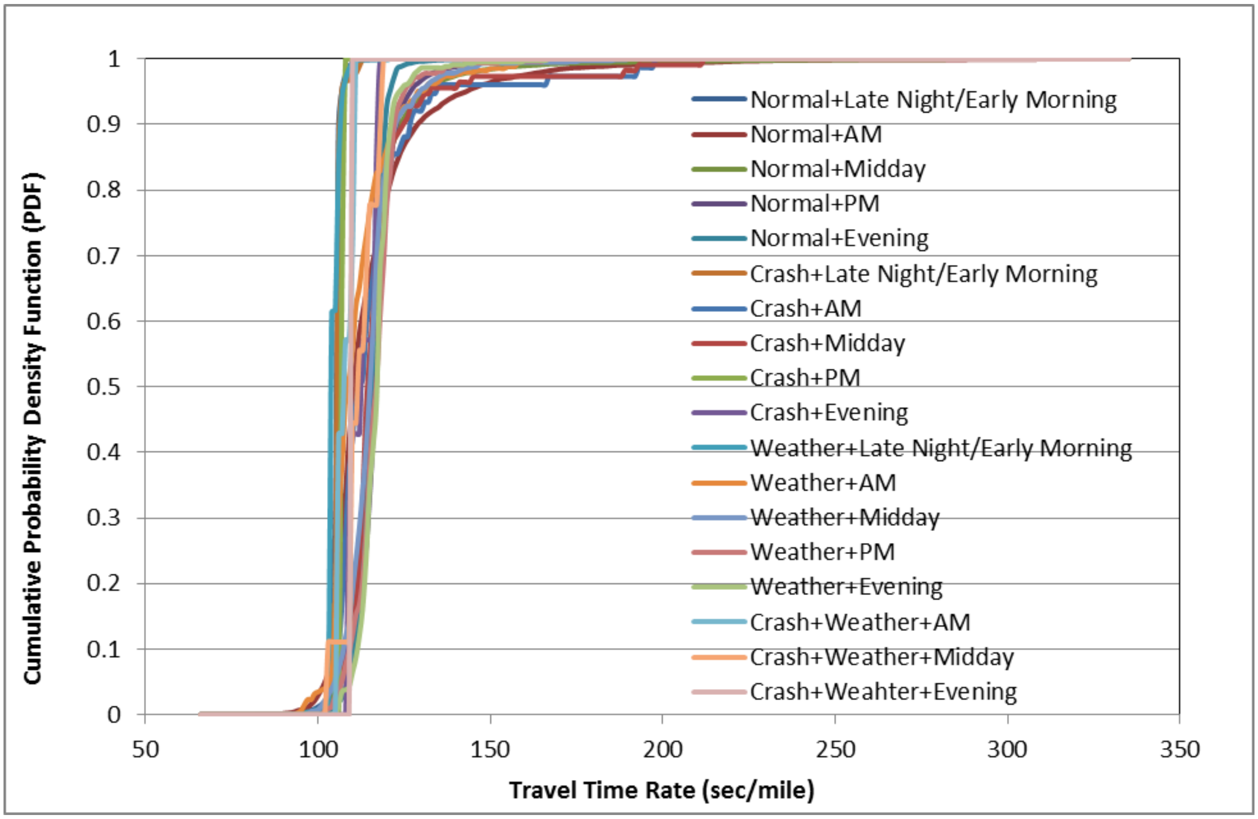


Figure F.9. CDF by regimes for SR-7 SB (crash duration = 15 minutes).

Table F.1. Percentage of Occurrence (Crash Duration = 15 minutes)

Time Period	Normal	Crash	Weather	Crash + Weather	Total
Late night and early morning	31.84%	0.13%	1.22%	0.00%	33.18%
AM	11.89%	0.11%	0.48%	0.01%	12.48%
Midday	25.90%	0.16%	1.08%	0.01%	27.16%
PM	12.11%	0.00%	0.45%	0.00%	12.56%
Evening	13.99%	0.01%	0.62%	0.00%	14.62%

Table F.2. Percentage of Severity (Crash Duration = 15 minutes)

Time Period	Normal	Crash	Weather	Incident + Weather	Total
Late night and early morning	3.12%	3.21%	2.99%	0.00%	9.32%
AM	7.33%	7.55%	5.36%	3.83%	24.07%
Midday	7.19%	7.93%	6.54%	5.08%	26.74%
PM	6.91%	3.56%	6.81%	0.00%	17.28%
Evening	6.15%	5.34%	6.80%	4.29%	22.58%

Table F.3. Percentage of Unreliability Contribution (Crash Duration = 15 minutes)

Time Period	Normal	Crash	Weather	Incident + Weather	Total
Late night and early morning	17.58%	0.07%	0.64%	0.00%	18.30%
AM	15.41%	0.14%	0.45%	0.01%	16.01%
Midday	32.91%	0.22%	1.25%	0.01%	34.39%
PM	14.79%	0.00%	0.54%	0.00%	15.33%
Evening	15.21%	0.01%	0.75%	0.00%	15.97%

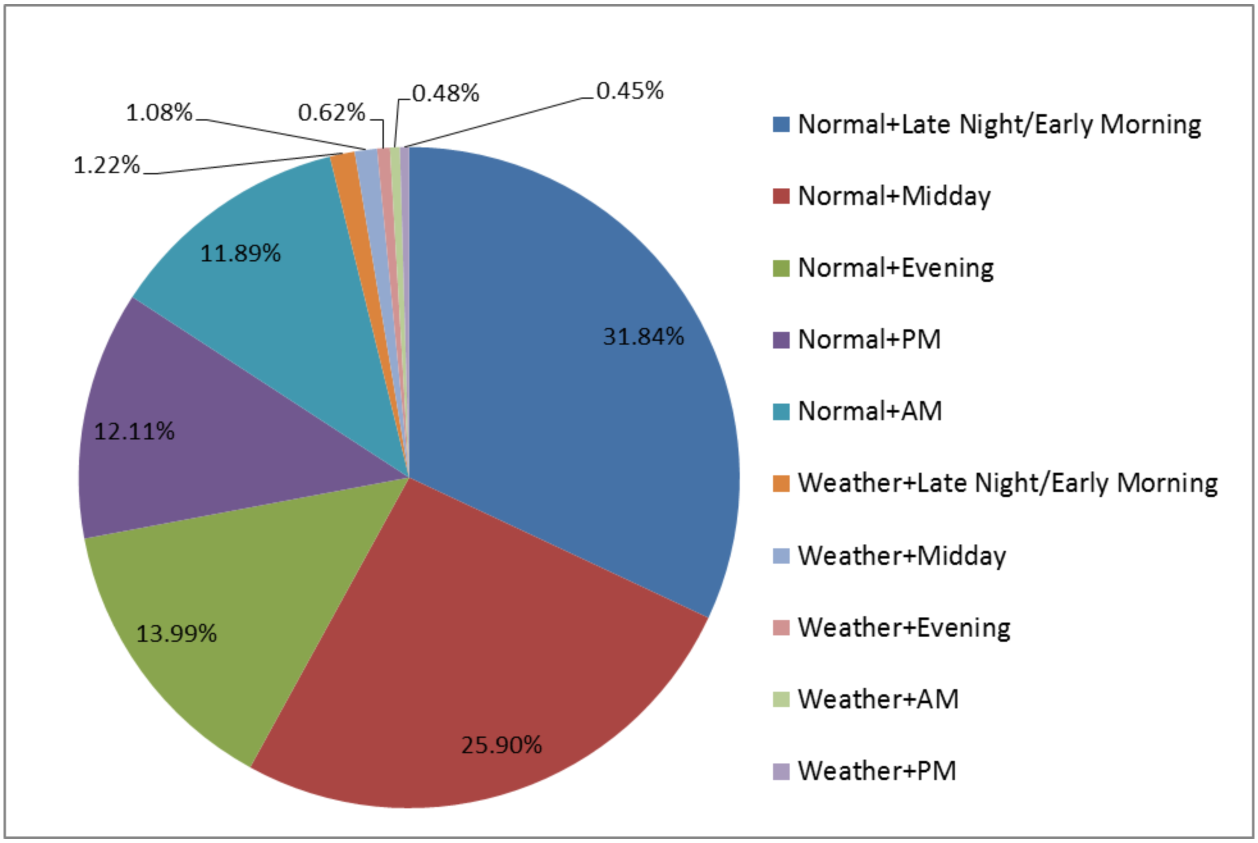


Figure F.10. Percentage of occurrence for SR-7 SB (crash duration = 15 minutes).

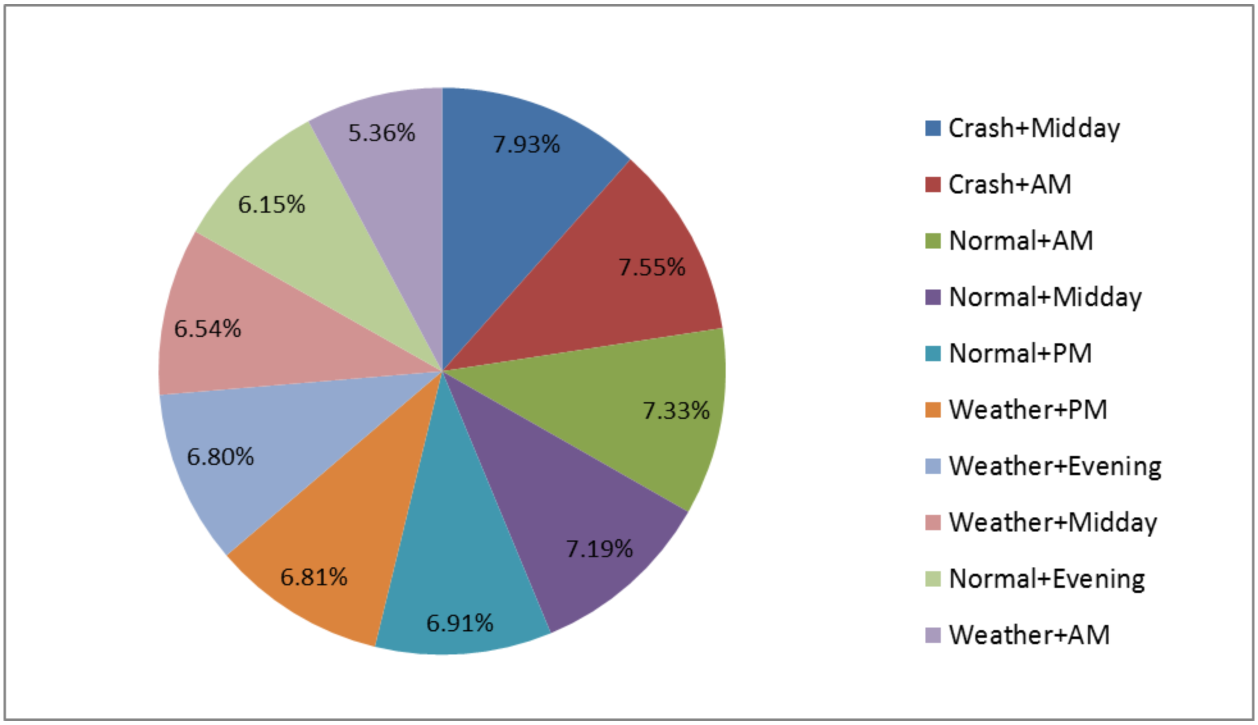


Figure F.11. Percentage of severity for SR-7 SB (crash duration = 15 minutes).

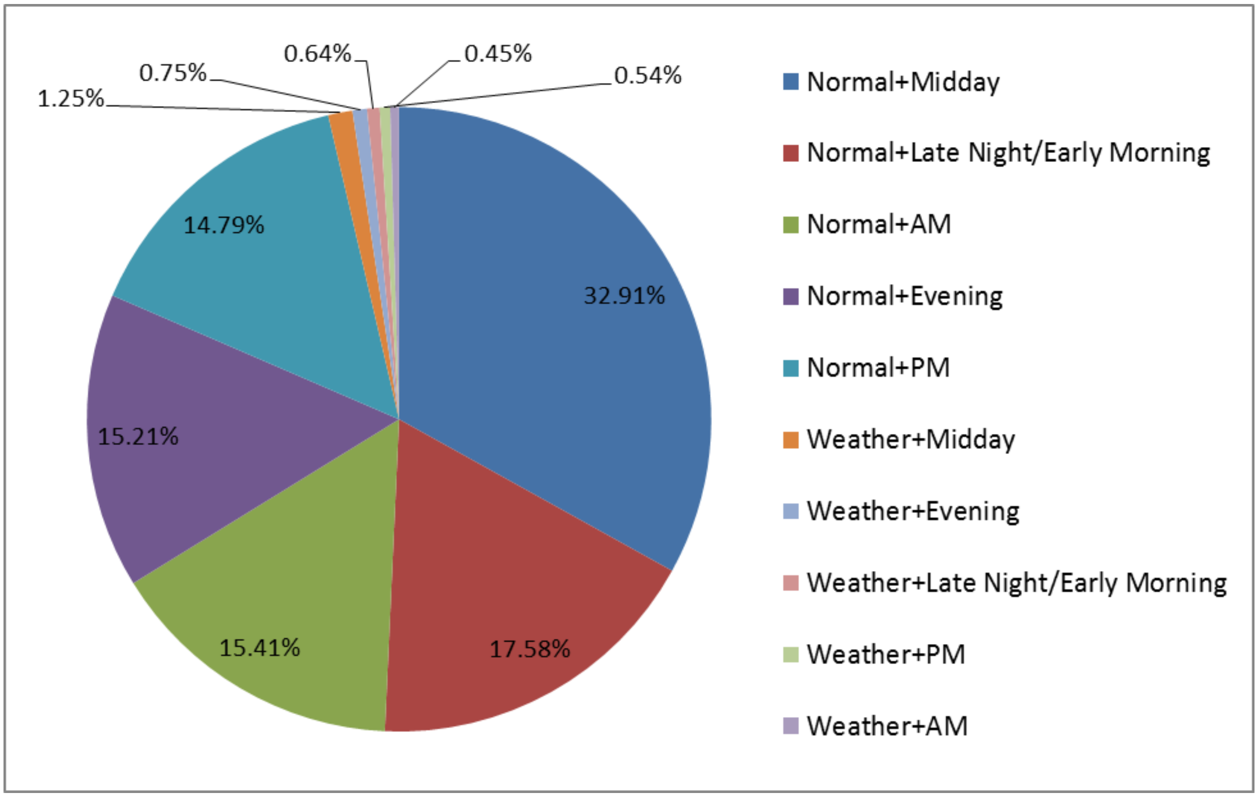


Figure F.12. Percentage of unreliability contribution for SR-7 SB (crash duration = 15 minutes).

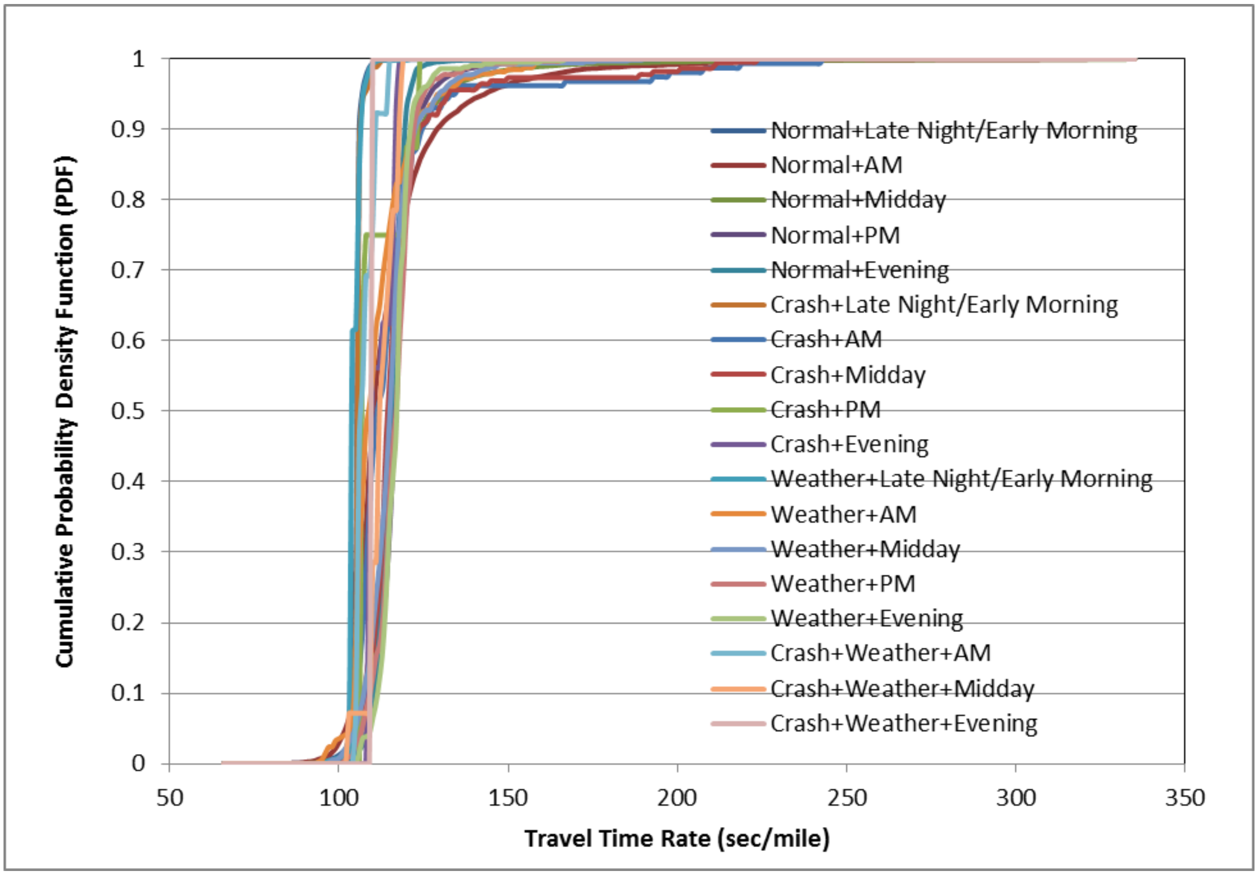


Figure F.13. CDF by regimes for SR-7 SB (crash duration = 30 minutes).

Table F.4. Percentage of Occurrence (Crash Duration = 30 minutes)

Time Period	Normal	Crash	Weather	Crash + Weather	Total
Late night and early morning	31.72%	0.25%	1.22%	0.00%	33.18%
AM	11.77%	0.22%	0.47%	0.02%	12.48%
Midday	25.74%	0.32%	1.08%	0.02%	27.16%
PM	12.10%	0.01%	0.45%	0.00%	12.56%
Evening	13.98%	0.02%	0.62%	0.00%	14.62%

Table F.5. Percentage of Severity (Crash Duration = 30 minutes)

Time Period	Normal	Crash	Weather	Incident + Weather	Total
Late night and early morning	3.07%	3.15%	2.94%	0.00%	9.16%
AM	7.19%	8.00%	5.29%	3.72%	24.20%
Midday	7.05%	7.94%	6.43%	5.17%	26.60%
PM	6.79%	4.66%	6.69%	0.00%	18.13%
Evening	6.04%	4.98%	6.68%	4.21%	21.91%

Table F.6. Percentage of Unreliability Contribution (Crash Duration = 30 minutes)

Time Period	Normal	Crash	Weather	Incident + Weather	Total
Late night and early morning	17.52%	0.14%	0.64%	0.00%	18.30%
AM	15.23%	0.32%	0.45%	0.01%	16.01%
Midday	32.67%	0.45%	1.25%	0.02%	34.39%
PM	14.78%	0.01%	0.54%	0.00%	15.33%
Evening	15.20%	0.02%	0.75%	0.00%	15.97%

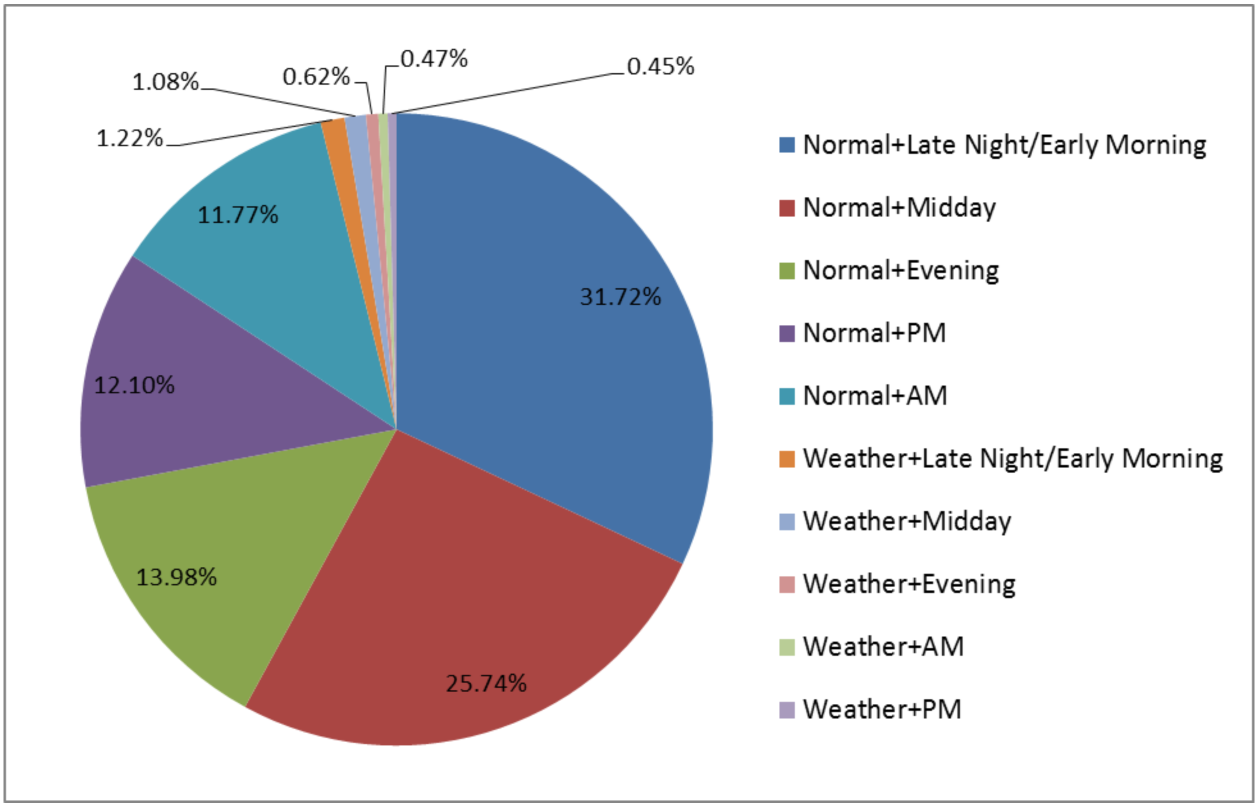


Figure F.14. Percentage of occurrence for SR-7 SB (crash duration = 30 minutes).

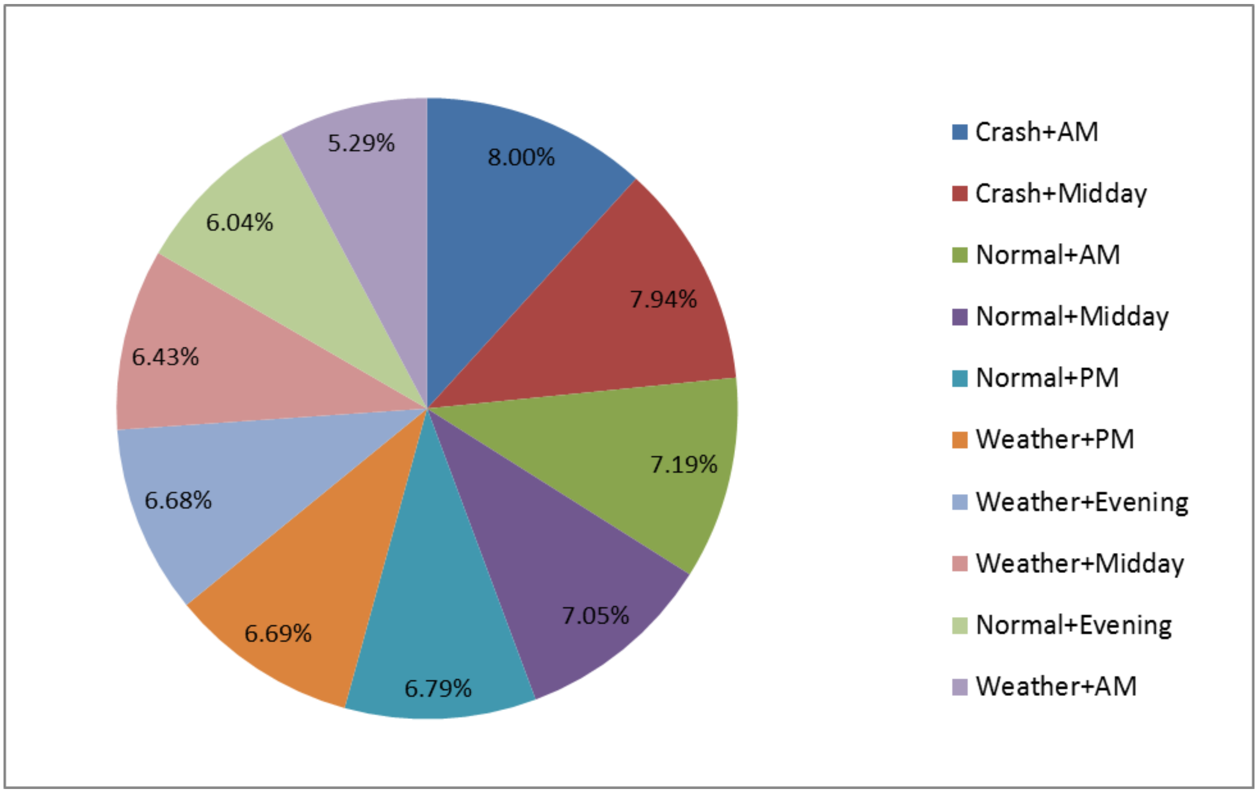


Figure F.15. Percentage of severity for SR-7 SB (crash duration = 30 minutes).

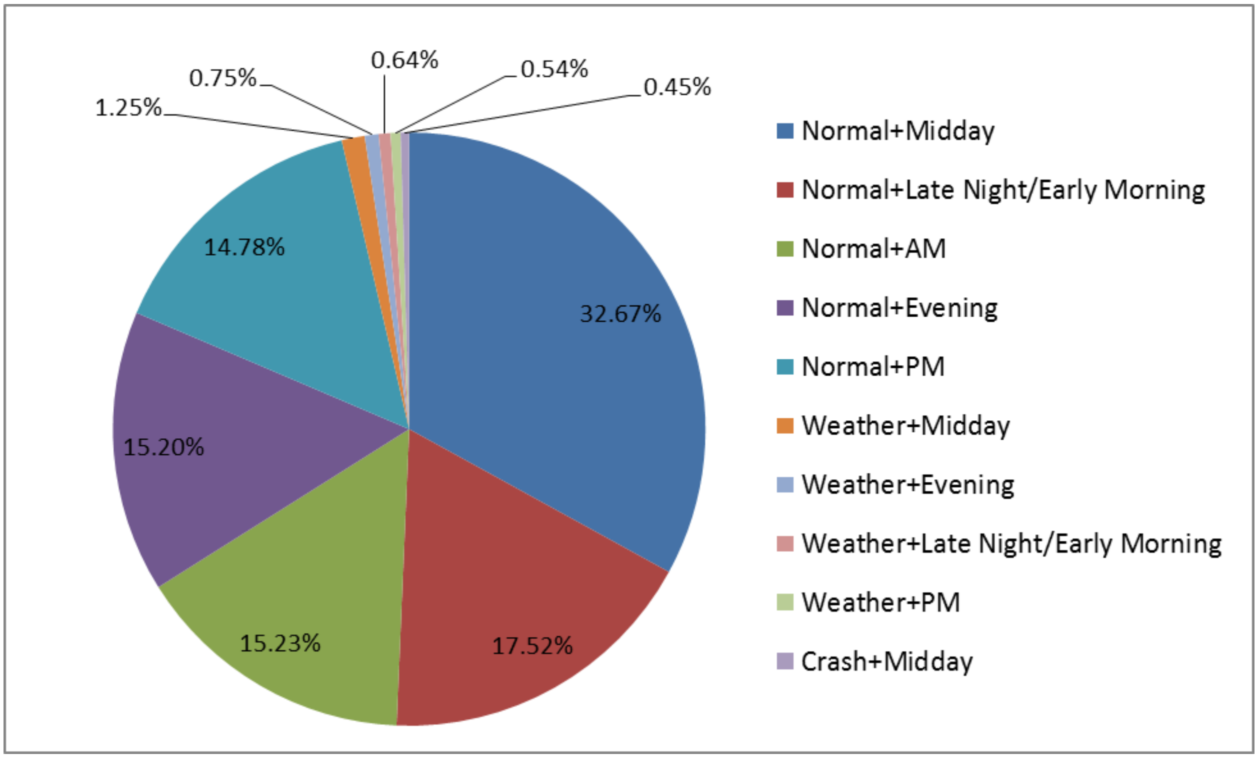
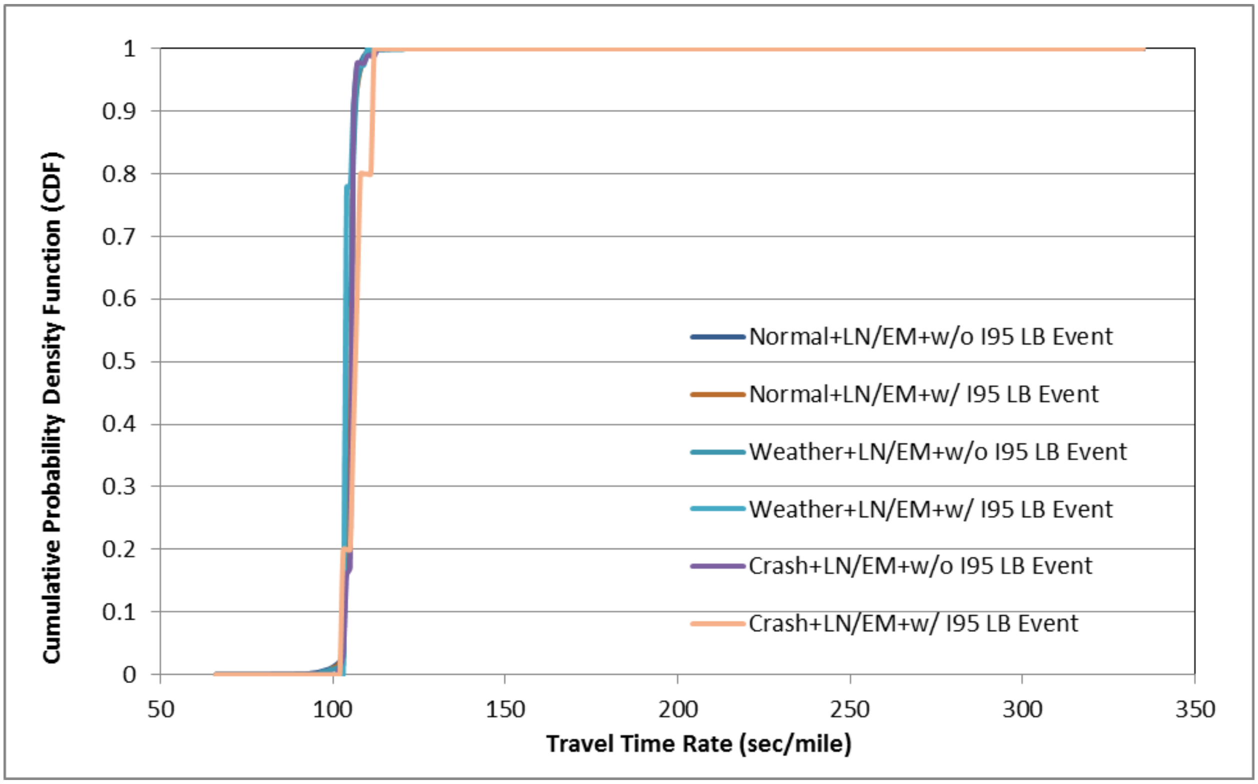


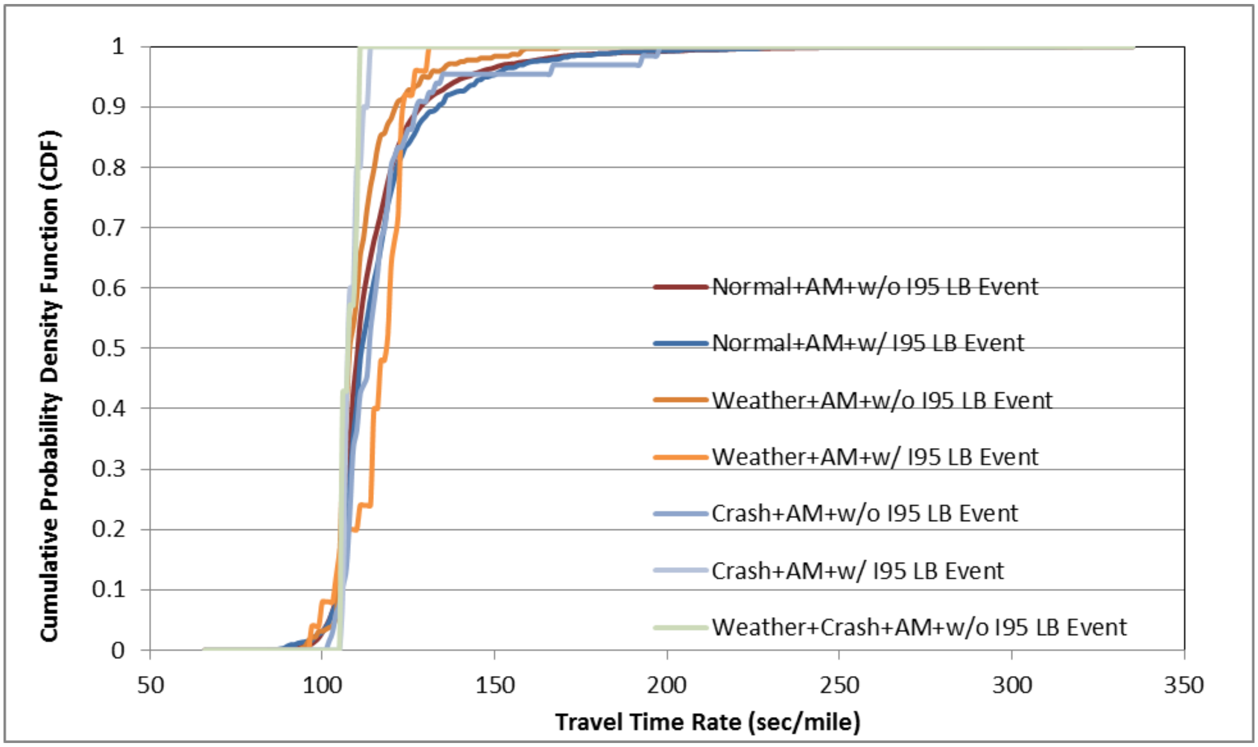
Figure F.16. Percentage of unreliability contribution for SR-7 SB (crash duration = 30 minutes).

F.3 Impacts of I-95 Southbound Lane-Blocking Incidents on SR-7 Southbound

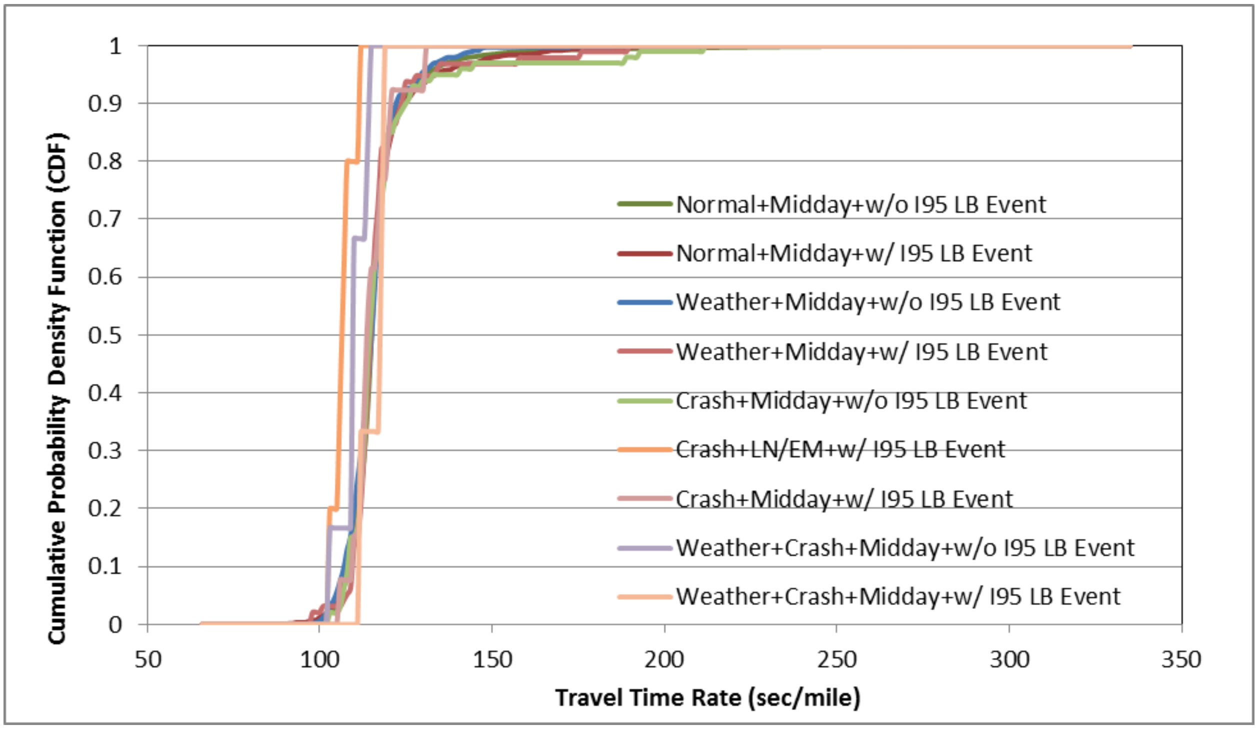
Figures F.17 to F.20 display the analysis results for the impacts of I-95 SB lane-blocking incidents on the reliability of SR-7 SB study segments. To make the figures more readable, only the top 10 regimes are displayed in each pie chart. Figure F.17 shows that the I-95 lane-blocking incidents mostly affected the travel time rate at the 90th percentile level. The rankings in Figure F.19 also show that the crashes occurring on the SR-7 SB study segments during the midday and AM had slightly higher contributions to the semivariance of travel time rate, followed by the normal SR-7 SB traffic conditions, but with the I-95 SB lane-blocking incidents.


Cumulative Probability Density Function (CDF)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
50
100
150
200
250
300
350
Travel Time Rate (sec/mile)
Normal+LN/EM+w/o I95 LB Event
Normal+LN/EM+w/ I95 LB Event
Weather+LN/EM+w/o I95 LB Event
Weather+LN/EM+w/ I95 LB Event
Crash+LN/EM+w/o I95 LB Event
Crash+LN/EM+w/ I95 LB Event

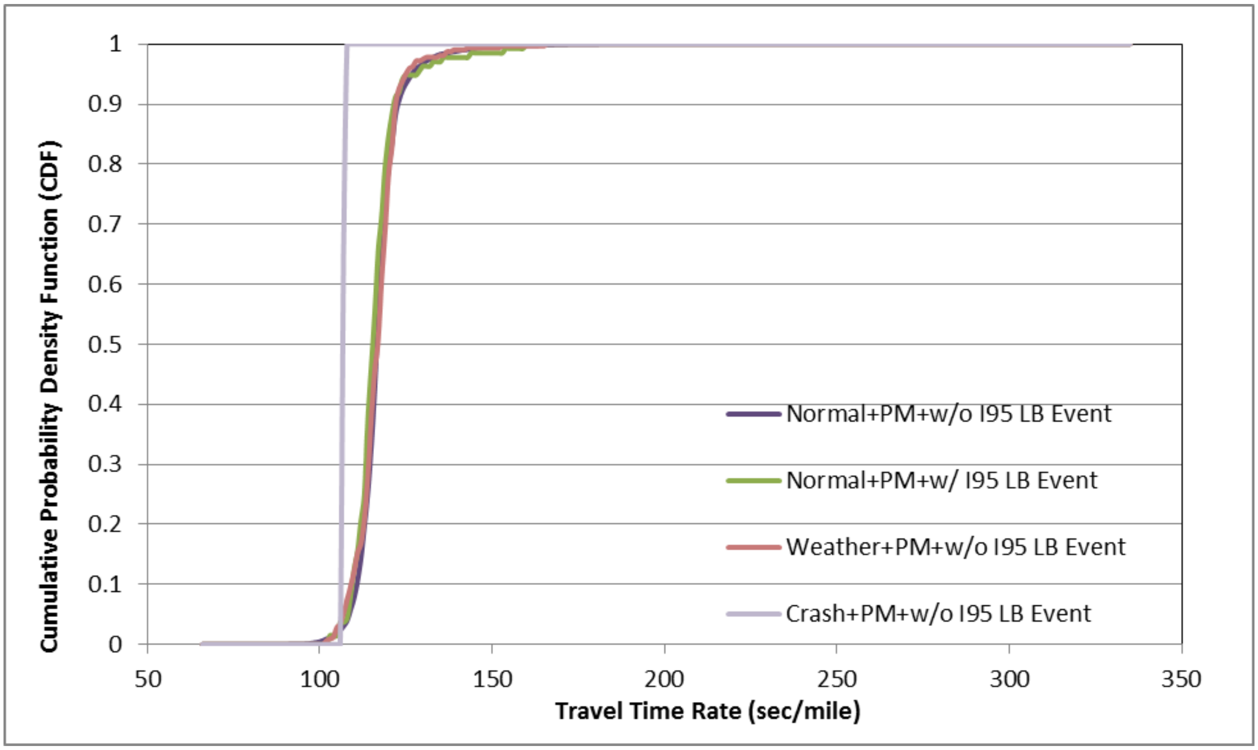
(a)


Cumulative Probability Density Function (CDF)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
50
100
150
200
250
300
350
Travel Time Rate (sec/mile)
Normal+AM+w/o I95 LB Event
Normal+AM+w/ I95 LB Event
Weather+AM+w/o I95 LB Event
Weather+AM+w/ I95 LB Event
Crash+AM+w/o I95 LB Event
Crash+AM+w/ I95 LB Event
Weather+Crash+AM+w/o I95 LB Event

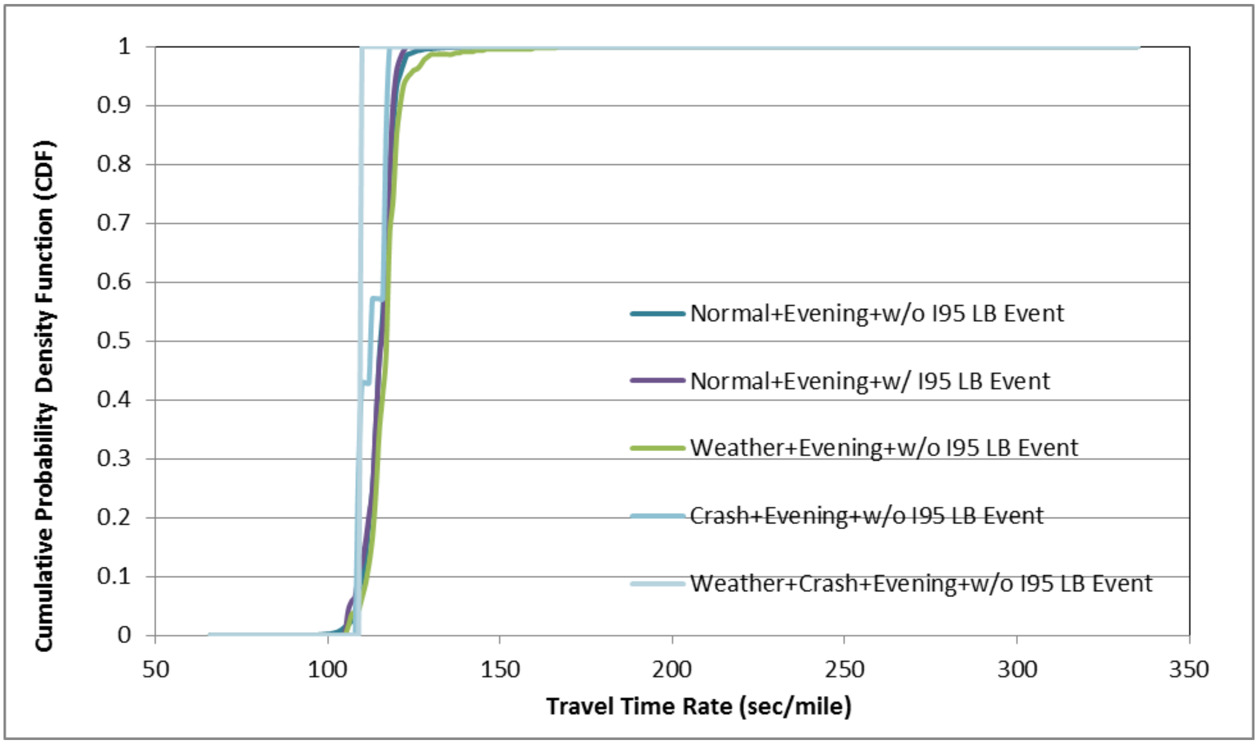
(b)


Cumulative Probability Density Function (CDF)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
50
100
150
200
250
300
350
Travel Time Rate (sec/mile)
Normal+Midday+w/o I95 LB Event
Normal+Midday+w/ I95 LB Event
Weather+Midday+w/o I95 LB Event
Weather+Midday+w/ I95 LB Event
Crash+Midday+w/o I95 LB Event
Crash+LN/EM+w/ I95 LB Event
Crash+Midday+w/ I95 LB Event
Weather+Crash+Midday+w/o I95 LB Event
Weather+Crash+Midday+w/ I95 LB Event

(c)


Cumulative Probability Density Function (CDF)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
50
100
150
200
250
300
350
Travel Time Rate (sec/mile)
Normal+PM+w/o I95 LB Event
Normal+PM+w/ I95 LB Event
Weather+PM+w/o I95 LB Event
Crash+PM+w/o I95 LB Event

(d)



(e)

Figure F.17. CDF by regimes for SR-7 SB for (a) late night and early morning, (b) AM peak, (c) midday, (d) PM peak, and (e) evening periods.

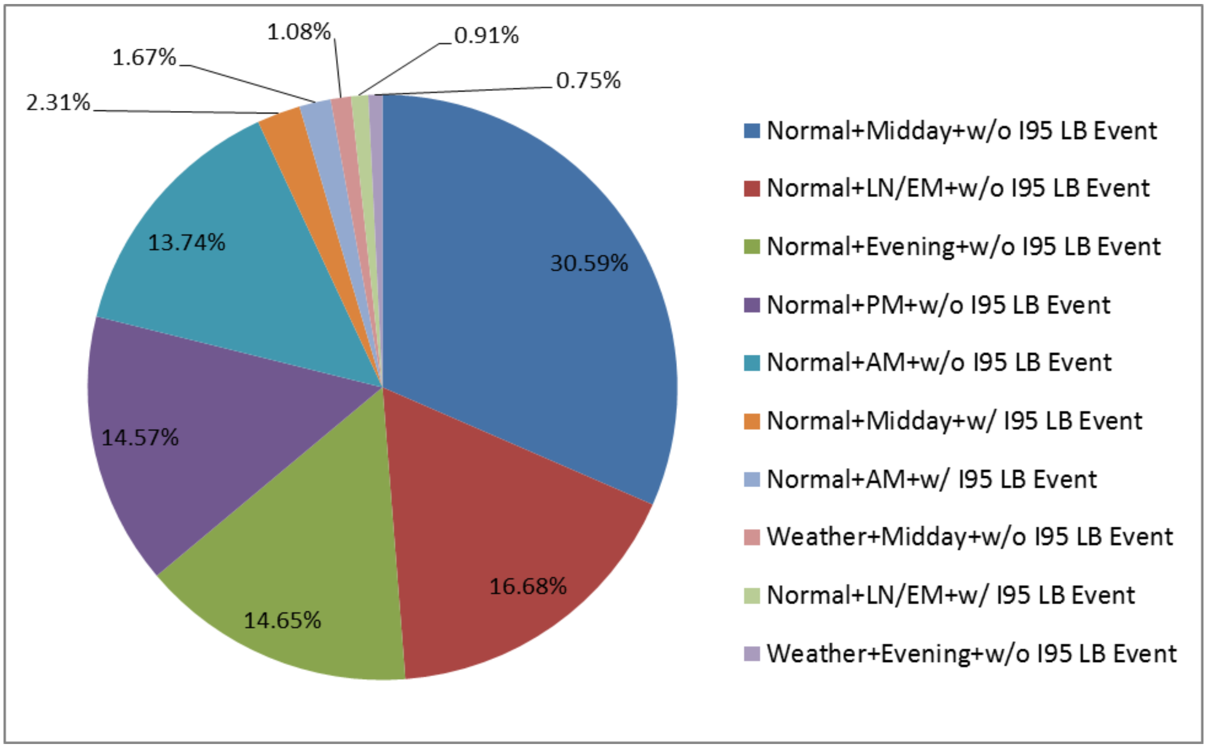


Figure F.18. Percentage of occurrence for SR-7 SB.

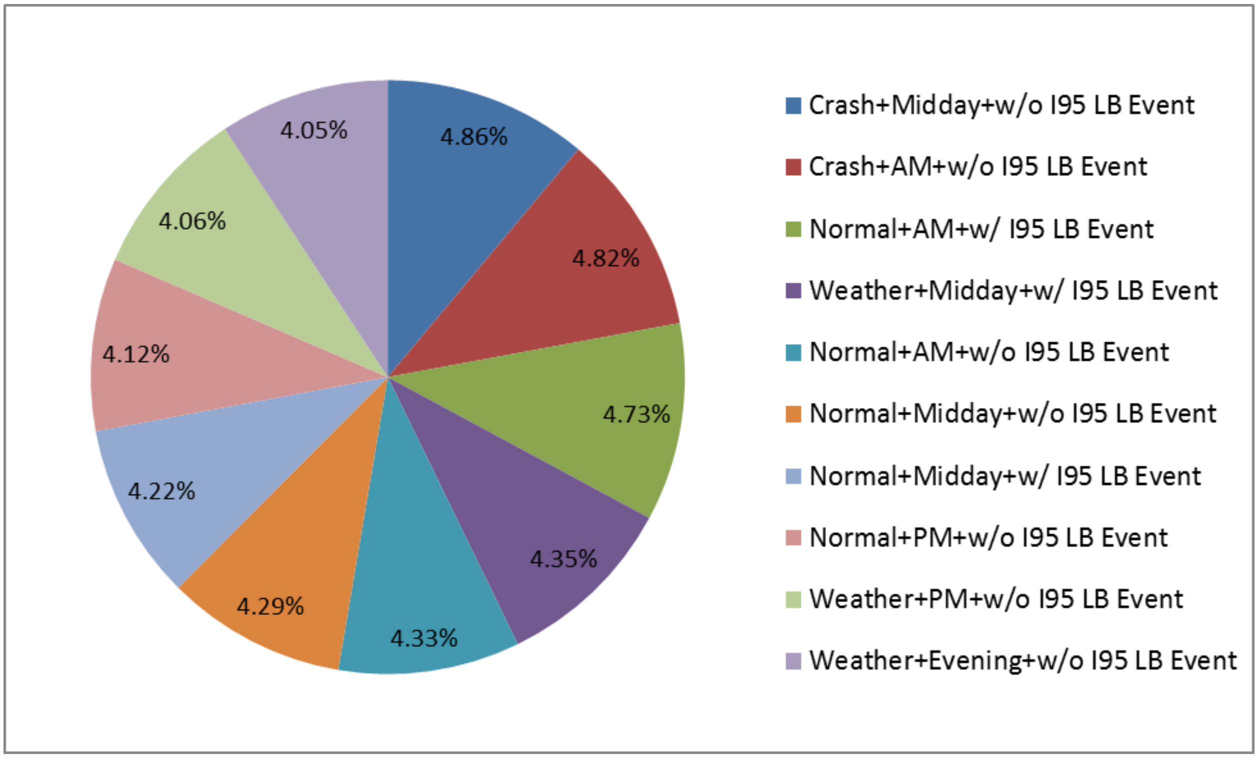


Figure F.19. Percentage of severity for SR-7 SB.

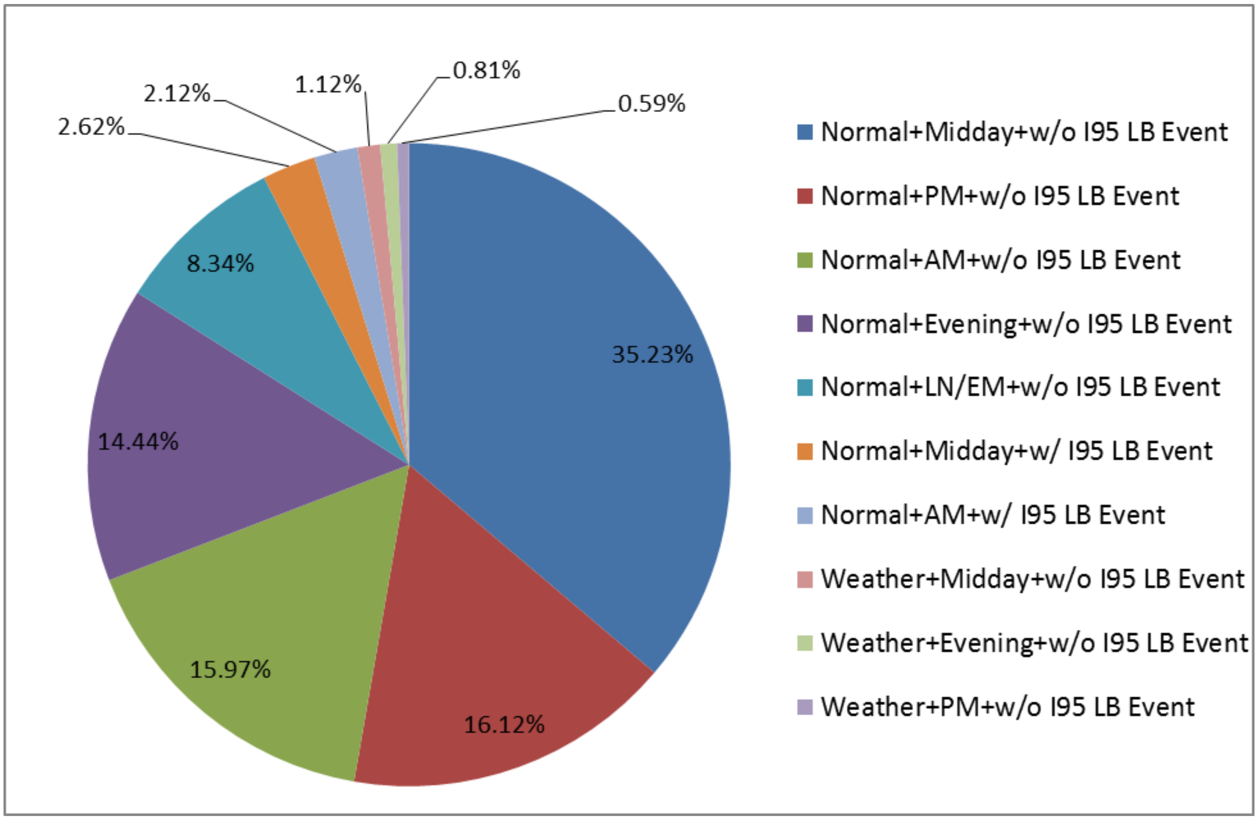


Figure F.20. Percentage of unreliability contribution for SR-7 SB.

APPENDIX G
L38C Updated Research Plan

G.1 Introduction

The SHRP 2 L38C research project is being conducted by a research team composed of members from FIU and AECOM Technical Services, Inc. in collaboration with Florida DOT District 6. AECOM is the consultant for the District 6 ITS operational support services and the ITS general consultant. The project activities will be based on substantial collaboration and coordination with project stakeholders, in accordance with the SHRP 2 L05 project guidance. The research team will work closely with the District 6 TSM&O program core group in Miami, which included representatives from various offices of the Florida DOT and regional partner agencies, and District 6 TMC staff. In addition, the researchers will coordinate efforts with the Florida DOT District 4 TSM&O program in the city of Fort Lauderdale and the town of Palm Beach. The project activities will also be coordinated with the central office reliability program and the Florida DOT central office TSM&O program. With the support of these programs, the results from this project will be shared with other agencies throughout Florida.

G.2 Goal and Objectives

The goal of this project is to conduct pilot testing of SHRP 2 Reliability data and analytical products from Projects L02, L05, L07, and L08. The proposed project will implement and clearly demonstrate how the SHRP 2 products can be incorporated into the business processes of the Florida DOT and its partner agencies in South Florida, one of the largest and most diverse regions in the country. The specific objectives of this project, as listed in the request for proposal), are to:

- Assist agencies in moving reliability into their business practices through testing of data integration and analytical tools developed by SHRP 2, and
- Provide feedback to SHRP 2 on the applicability and usefulness (benefits and value) of the products tested and suggest potential refinements.

G.3 Related Florida DOT Programs and Tools

Southeast Florida in general and the Miami area in particular have experienced an explosive population growth over the years, and together these areas are now one of the most congested traffic regions in the nation. South Florida has deployed advanced technologies and strategies to address the increasing congestion problems. The Florida DOT TSM&O program is one of the most advanced programs in the nation. In addition, the Florida DOT central office reliability program has been very active incorporating reliability in its planning and operations processes. The District 6 TSM&O program mission is to optimize the safety, mobility, and reliability performance outcomes of the South Florida transportation system through the timely implementation of TSM&O strategies. District 6 and its partner transportation organizations have engaged in many activities for years that fall under the umbrella of TSM&O. These activities include the I-95 Express dynamic-pricing managed lane (one of the most important managed lane projects in the nation, partially funded by the U.S. DOT as part of the Urban Partnership Agreement), a successful incident management program, traffic-adaptive ramp-metering operations, an extensive ITS infrastructure, one of the largest urban street advanced traffic management systems in the country (over 2,700 signals), operation of a state-of-the-art SunGuide TMC, implementation of advanced software supporting TMC operations, 511 traveler information, and data-archiving and performance measurement tools.

This research will use products, findings, and guidance from four SHRP 2 Reliability Program projects (L02, L05, L07, and L08) in conjunction with a data analysis tool (ITSDCAP) developed for the Florida DOT by FIU researchers. ITSDCAP can capture data from a number of sources: traffic detectors, automatic vehicle identification and automatic vehicle location systems at different aggregation levels, the SunGuide incident management database, the FHP incident database, INRIX (private-sector data provider), work zone (construction) databases, 511 calls and website hits, dynamic toll pricing data for managed lanes (I-95 Express), the Florida DOT crash database, Florida DOT planning statistics office data, and weather data. The tool filters, imputes, and fuses the data and calculates various mobility, reliability, safety, and environmental impacts. It also contains modules that support data mining, traffic modeling, and ITS benefit–cost analyses. Several recommendations of the L03 project are already incorporated in the calculation of reliability in ITSDCAP.

IRISDS is another tool developed by the research team that will be used to demonstrate a real-time application based on the L02 project recommendations. IRISDS is a web-based system for the provision of regionally shared information and decision support environment for use by transportation system management agencies in a region in real time. The web-based system receives information in XML data streams using center-to-center communication. Decision support systems were developed and integrated as part of the system.

G.4 Overview of the Research Approach

As stated above, the proposed project is to test products from four SHRP 2 projects: L02, L05, L07, and L08. This project will develop a concept of operation of how the products from the four SHRP 2 projects will be tested as tools to support business processes associated with the Florida DOT TSM&O programs and TMC operations. The concept of operation will be based on L05 project guidelines and will take into consideration stakeholder input and the Florida DOT central office reliability program approach to reliability evaluation. Stakeholder input will be gathered in a stakeholder workshop and face-to-face meetings with agencies throughout South Florida.

The concept of operation will identify the project stakeholders and the related business processes that will benefit from reliability estimation, the incorporation of reliability in policy statements, reliability performance measures, analysis scope, setting of reliability performance thresholds (thresholds beyond that which the system considers unreliable), the methods used for assessing reliability, and the selection between improvement alternatives based on trade-off analyses.

This research will use products, findings, and guidance from Reliability Projects L02, L05, L07, and L08 in conjunction with a data analysis environment developed for the Florida DOT. The SHRP 2 products will be used as a basis for assessing existing reliability deficiencies and improvement alternatives for three facilities in the Miami area. The research team will then evaluate the technical feasibility of the use of the SHRP 2 products to support agencies' business processes, the consideration of the results by the decision makers, and the usefulness of the results for the decision makers. Data will be collected from multiple sources to support the analysis conducted in this project, including reliability estimation based on monitoring and/or modeling. The data will include traffic parameter, geometry, event, traffic management, and pricing data.

The existing reliability of the tested facilities will be assessed based on real-world data obtained from monitoring systems by using the L02 project guidelines. The L02 procedures will be incorporated into ITSDCAP, allowing for the estimation of a variety of reliability metrics and distributions to be recommended and used by the L02 project and the other three tested SHRP 2 projects. This project will also test other procedures based on real-world data, including estimating the reliability of routes and route bundles based on segment reliability, using one of the approaches recommended in the L02 project.

L02 products can be used in data-rich environments with established monitoring systems. The limited-access facilities managed by the Florida DOT and toll authorities are instrumented with state-of-the-art ITS monitoring systems with associated data-archiving capabilities. However, urban streets, generally managed by counties and cities, have limited instrumentation, particularly when considering travel time measurement devices, although the Florida DOT has purchased private-sector travel time data from INRIX for a year for some of these facilities. The use of L07 and L08 project products to assess existing reliability conditions will be tested and compared with the analysis results obtained based on real-world monitoring systems and/or private-sector data. The testing and comparison of results of the L07 and L08 reliability tools are also important steps toward validating the quality of the estimates of the impact of improvement alternatives when using these tools for this purpose.

The reliability thresholds identified in the concept of operation will be used to determine the reliability deficiencies based on the results of the analyses. The reliability deficiencies will be entered in electronic maps, charts, and figures to allow spatial and temporal visualization of the reliability deficiencies and the impact of each influencing factor on the reliability for different times of day and locations. The produced visualization aids will be shared and discussed with the project stakeholders in TSM&O and TMC staff meetings to gain a better understanding of the reliability issues of the system. The reliability thresholds will be adjusted, considering the agency's perception of system reliability, based on L05 recommendations.

Segment and route reliability deficiencies will be highlighted based on the reliability analysis results, and potential improvement alternatives will be identified to address these deficiency issues. The identified set of alternatives and the justifications for these alternatives will be reviewed with TSM&O partners and TMC managers, and input from these stakeholders will be used in producing a refined list of improvement alternatives for evaluation. The assessment of the identified alternative strategies will require an estimation of the expected improvements in reliability due to the implementations of these strategies. This process will be performed by using the L08 and/or L07 project products.

The research team will present the results from the reliability and alternative analyses described above to project stakeholders. The L05 project recommendations will be used in the selection of improvement alternatives and the incorporation of reliability into the investment decision-making process and project prioritization.

At the end of the project, the research team will assess the technical feasibility of the tested products, the understandability and credibility of the results by the decision makers, and the acceptability and implementation potential of the recommendations resulting from applying the products. This assessment will be based on interviews with project stakeholders and the examination of actual decisions made by the involved agencies. Table G.1 presents the relation of project tasks to SHRP 2 products, coordination with the Florida DOT central office reliability program, and stakeholder involvement.

Table G.1. Relation of Project Tasks to SHRP 2 Products, Coordination with Florida DOT Reliability Program, and Stakeholder Involvement

Project Task	L02	L05	L07	L08	Coordination with Florida DOT Reliability Program	Stakeholder Involvement
Developed Concept of Operation	✓	✓	✓	✓	✓	✓
Monitoring of Data Compilation	✓				✓	✓
Analysis of Baseline Reliability and Improvements	✓	✓	✓	✓	✓	✓
Use of Reliability Analysis in the Decision-Making Process		✓			✓	✓
Evaluation of the Functionality and Outcomes of the Products	✓	✓	✓	✓	✓	✓

G.5 Project Tasks

The project tasks needed to accomplish the project objectives and the approach outlined in the previous sections are described below.

Task 1. Project Briefing

This task included attending a one-day briefing in Washington, D.C. This meeting allowed a deeper understanding of the SHRP 2 products. Additional documents were obtained and reviewed after the meeting. The collected information was used to develop this updated research plan.

Task 2. Development of Revised Research Plan and Concept of Operation

The updated research plan and concept of operation developed in this task will provide the foundation for the use of products from the L02, L05, L07, and L08 projects, combined with Florida DOT tools to meet the goal and objectives of this project.

Task 2.a. Development of Research Plan

This task includes producing an updated and amplified research plan based on the briefing in Task 1 and access to deliverables from SHRP 2 projects that were made available to the research team. This updated research plan is to be submitted by April 19, 2013.

An initial meeting will be conducted in early May 2013 to review the produced research plan with the Florida DOT District 6 and District 4 TSM&O program managers, District 6 TMC managers, District 6 planning office, and the Florida DOT central office reliability program. In this meeting, the research team will present a detailed review of the L38C project research activities and why they are important to agency planning and operations. The Florida DOT central office reliability program management will provide an overview of the program, and a basis will be established for coordinating the project’s activities among the above-mentioned project partners. During the meeting, additional information will be collected as needed to conduct the project’s tasks.

Task 2.b. Development of Concept of Operation

This project will develop a concept of operation on how SHRP 2 reliability products could be used as tools to support business processes associated with the Florida DOT TSM&O programs and TMC operations. The concept of operation will be based on L05 project guidelines, taking into consideration stakeholder input and the Florida DOT central office reliability program approach to reliability evaluation. The stakeholder input will be gathered from a stakeholder workshop and face-to-face meetings with agencies in South Florida, including members of the core groups of the TSM&O programs and District 6 TMC personnel and planning office staff. The TSM&O core group includes representatives from various Florida DOT disciplines and their regional partners.

The concept of operation will address the following issues:

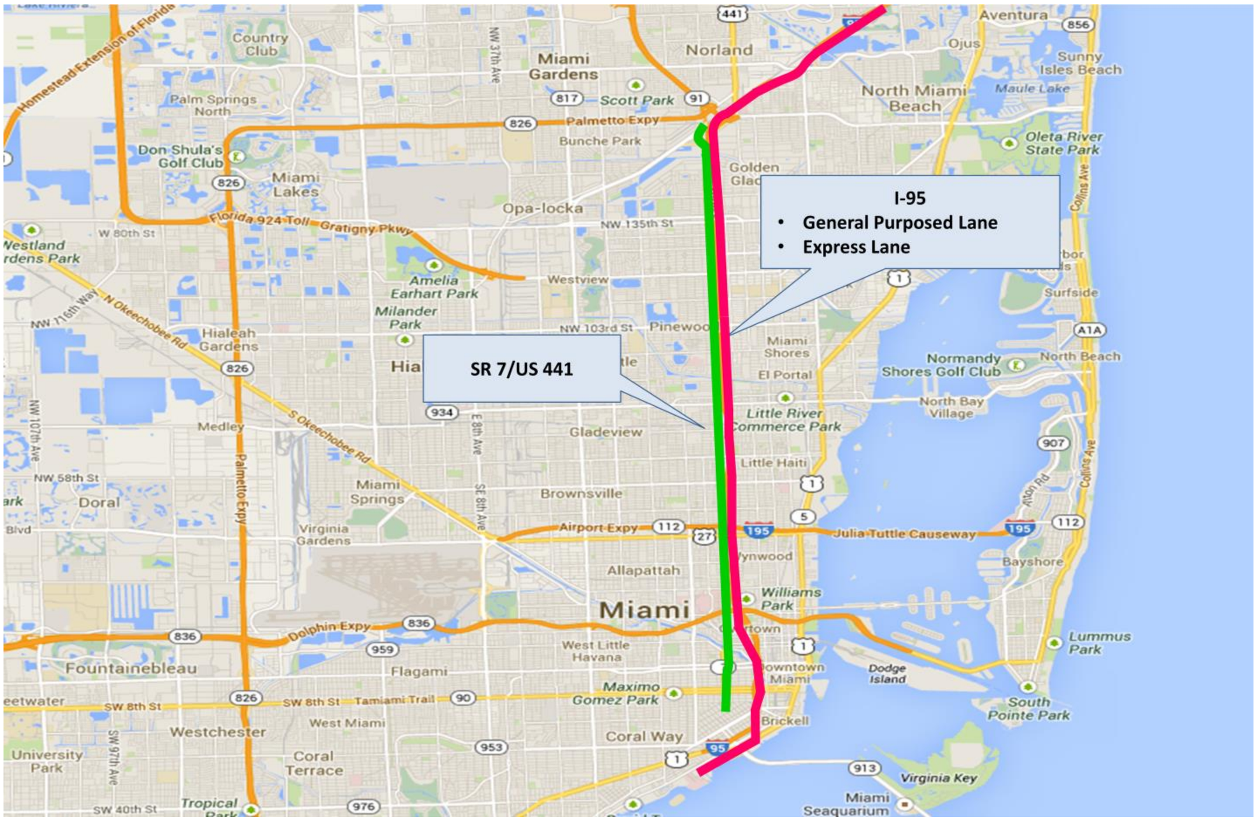
Project stakeholders and associated business processes. A list and descriptions of the project stakeholders and the Florida DOT programs and regional partners will be provided. Associated business processes to be addressed by the project activities will also be identified and described.

Incorporation of reliability in policy statement. The Florida DOT programs that will be involved in this study have already included the issue of reliability in their policy statements. For example, the District 6 TSM&O program mission is to “optimize the safety, mobility and reliability performance outcomes of South Florida’s transportation system through the timely implementation of TSM&O strategies.” This task will review how reliability is incorporated in the vision, mission, goals, and objectives of Florida DOT programs and partner agencies and will recommend revisions and/or additions to these statements, if needed.

Review and identification of performance measures. A review will be conducted on the current reliability and other performance measures used or planned for use by Florida DOT departments and partner agencies, as well as how these measures are currently used to monitor performance and select or prioritize improvement alternatives. The common measures reported in L05, in addition to those used in L02, L03, and L07 and those identified for the Florida DOT central office reliability program, will be highlighted as potential measures. This project will experiment with these measures to determine the best combinations of measures to facilitate monitoring system performance and evaluate strategies.

Development of performance thresholds. The identification of reliability thresholds is required to make the reliability measures meaningful to system stakeholders when trying to identify reliability issues with the transportation system. The performance measures obtained from the monitoring and modeling of system reliability will need to be converted into categories such as good, fair, and poor, as recommended by L05. The L08 project recommended thresholds for acceptable reliability LOS. The L02 project recommends comparing the actual versus desired travel time windows. These recommendations were tested in this study.

Identification of the analysis scope. The development of this project will be tested for three of the most important facilities in the Miami area: I-95 (including the I-95 Express managed lanes) and SR-7/US-441, as shown in Figure G.1. The analysis will be conducted for AM, PM, and midday time periods. I-95 is a limited-access facility managed by Florida DOT and can be considered a data-rich environment. SR-7 is an urban arterial that is a state road managed by the Florida DOT, but the signal control is managed by Miami-Dade County; SR-7 can be considered a relatively data-poor environment. The selected I-95 segment is one of the most congested in Florida, with managed lane with dynamic pricing, an advanced incident management system, traffic-adaptive ramp-metering operations, and an extensive ITS infrastructure. SR-7 is parallel to I-95 and can be considered an alternate route in case of traffic incidents on I-95.


I-95
- General Purposed Lane
- Express Lane

SR 7/US 441

Figure G.1. Test facilities.

Methods used for assessing reliability. A review will be conducted of how partner agencies are currently assessing or planning to assess reliability. This project will assess reliability based on a combination of monitoring and modeling methods. Monitoring will be used for assessing existing reliability conditions and causes of system unreliability for data-rich environments based on L02 project products. Modeling will be applied, and will use L07 and L08 project products to assess reliability for corridors with limited traffic detection systems, as well as to assess reliability improvement alternatives. L05 guidance will be used to develop system-level measures based on segment- and/or corridor-level measures. This method will allow agencies to track overall system performance.

Defining reliability deficiencies. Reliability deficiencies will be assessed by comparing segment and facility reliability to threshold values and highlighting the segments and facilities with reliabilities that are worse than the actual threshold.

Selection between improvement alternatives. Methods will be identified for the selection of alternative strategies based on L05 project recommendations concerning the incorporation of reliability into the investment decision process and project prioritization.

Task 3. Data Compilation and Integration

This task will include the collection and fusion of data from multiple sources to support the reliability analyses of this project. For data-rich environments with monitoring systems, real-world travel time data will be used to estimate reliability for different periods under different regimes based on real-world travel time measurements. The collected data will also be used to support the reliability modeling of the L07 and L08 projects. Traffic parameter, geometry, event, traffic management, and pricing data will be included. The main data that will be collected are as follows:

- *SunGuide traffic sensor system and travel time data.* Traffic sensor system data are traffic measurements collected by the traffic sensor system of SunGuide. At the time of the study, the aggregated traffic sensor system data are stored in the Oracle database for report generation, and the raw data are saved in a text file in a comma-separated file format. The traffic sensor system file contains one record per lane for each detection station at a 20-second polling interval. Each traffic sensor system data record includes the following information: time stamp, detection station name, lane number, speed, occupancy, and raw count. The travel time data provides estimates of travel time for travel time links associated with DMSs calculated based on detector speed measurements.
- *Statewide ITS data warehouse data.* The Florida DOT statewide data warehouse retrieves point traffic detector data from district TMCs and processes and archives the data for users to download through a web link. The user can download traffic volumes, speeds, and occupancies at different aggregation levels. The data will be downloaded at the five-minute level and aggregated as necessary for the purpose of this study.
- *SunGuide incident management database.* At the time of the study, this database includes detailed incident information stored in the SunGuide Oracle database, including incident time stamps (such as detection, notification, arrivals, and departures), incident ID, responding agencies, event details, chronicles of the event, and environmental information. The detection time stamp is the time when an incident is reported to the TMC and input into the SunGuide system. The notification time stamps are recorded per responding agency and refer to the time when such responding agencies are notified. The arrival and departure time stamps are also recorded per responding agency and refer to the time when responding agencies arrive and depart from the incident site.
- *FHP incident database.* FHP incident data are stored through Signal Four Analytics, a traffic crash database environment developed for FHP. This program gathers information from FHP reports on a daily basis. Crash occurrence times and FHP response timelines are archived in the database. This database will provide incident information for SR-7 that is not available in the SunGuide incident management database.
- *INRIX data.* INRIX data is available for the investigated limited-access highways (I-95) for more than one year because these facilities are covered by the I-95 Corridor Coalition. INRIX data was also purchased by the Florida DOT system planning office for other facilities, including SR-7, for the period between July 2010 and June 2011.

- *Dynamic-pricing toll of managed lanes.* These data includes the dynamic toll rate information for the I-95 EL archived by Florida DOT District 6.
- *Florida DOT crash analysis reporting system.* Crash data from the Florida DOT crash analysis reporting system will provide additional incident information. This system is based on police reports; 38 data elements for crashes are recorded in the system, including crash location, time stamp, property damage dollar value, injury, fatality, pavement conditions, weather and lighting conditions, and crash cause.
- *Weather data*. Weather data will be retrieved from data downloaded from national weather agencies. The experience of the L02 and L08 projects in this regard will be examined when selecting the types of weather data and the data sources.
- *Florida DOT statistics database*. The Florida DOT transportation statistics office collects traffic data through various telemetered and portable traffic monitoring sites along all Florida state highways. It reports the data of annual average daily traffic, peak hour factors, directional distribution factors, and truck factors. Depending on location, it may also report the daily traffic count, speed, and vehicle classification at the 15-minute aggregation level. These data will be particularly important in obtaining the demands on freeway corridor ramps that do not have detectors, as well as on SR-7, as this arterial is not instrumented with ITS traffic detectors.
- *SR-7 intersection turning movement counts.* These counts will be obtained from previous studies that analyzed the corridor. Florida DOT departments will be contacted for this information.
- *Signal control data.* SR-7 signal control information will be downloaded from the Miami-Dade County signal control system website.
- *Geometry data.* Geometry data will be obtained from aerials, field observations, and Florida DOT databases.

The data in the list above will be imported to ITSDCAP as needed and preprocessed and fused for the analyses. Modification of the data capture and preprocessing modules of the ITSDCAP tool will be conducted to capture additional data items not captured by the tool, and will also to conduct additional preprocessing required for the analysis of this project.

Task 4. Analysis of Baseline Reliability Issues and Alternative Strategies

Task 4 will involve the analysis of existing reliability deficiencies, contributing factors to these deficiencies, and the ability of identified alternative improvements to resolve the reliability deficiencies.

Task 4.a. Assessment of Reliability Conditions Based on System Monitoring

This task will assess the existing segment and system reliability based on real-world speed and travel time data collected from infrastructure-based traffic detectors and/or INRIX combined with nonrecurrent event data (e.g., weather, incidents, construction, and special events). The reliability module of ITSDCAP will be used to estimate the various reliability measures recommended and/or used in the tested SHRP 2 products. The ITSDCAP tool allows the estimation of several reliability measures based on real-world data, including standard deviation/variance; buffer index; failure/on-time performance; TTI based on the 95th, 90th, or 80th percentile; skew statistics; and misery index. ITSDCAP will be modified for the calculation of additional reliability metrics and associated distributions. These additional metrics will include, for example, the semivariance measure used in L02; the proportion of travel with TTI above a given threshold as discussed in L08 and L05 project products; the TTI cumulative distribution function as used in L07; and the travel time rate PDFs and travel time rate CDF as used in L02.

Observation of the travel time rate PDFs for a given period and segment will reveal the identification of important operational characteristics, such as the multimodal distributions of the rates. The travel time rate CDF shape under different regimes or combinations of regimes will help identify the levels of reliability and the impacts of various influencing factors.

Reliability will be estimated based on at least one year’s worth of point detector data (true-presence microwave detectors) located at one-third- to one-half-mile intervals along the facilities and/or based on INRIX data. Reliability will be calculated based on both detector and INRIX data at locations where traffic detectors are available (I-95). On SR-7, reliability will be calculated based on INRIX data.

The reliability measures and distributions will be examined to determine the segments and time periods with unacceptable reliability and the contributing factors to these unreliable conditions. The L02 recommendations of establishing “reliability regimes” will be used to categorize the impacts of various contributing factors on the reliability of the system. By examining the results under different regimes, it will be possible to identify the external and internal contributing factors to the unreliability of these segments. The internal and external factors include the previously identified seven sources of congestion: inadequate base capacity, traffic control devices, incidents, weather, work zones, special events, and fluctuations in demand. Observation of the travel time rate PDFs for a given period will result in the identification of important operational characteristics, such as multimodality or the existence of multiple operating conditions within the data being examined. The travel time rate CDF shape under different regimes or combinations of regimes will help visualize the levels of reliability and the impacts of various influencing factors.

This project will also examine other approaches to bin data by regime. For example, instead of having only one incident category in this process as is done in L02, the incidents could be further subcategorized by duration and/or number of lanes blocked. Further examination will be done of other analysis parameters identified in the L02 project, such as the use of instantaneous versus experienced travel times in reliability estimation. The inconsistency in the recommended segment definition in the L02 project (monument to monument) compared to what is used in the L07 and L08 projects (junction to junction) will also have to be considered.

The thresholds identified in Task 2 will be used to determine the level of reliability performance of each of the tested segments relative to each other and to national experience with similar facilities, as discussed in the L05 project guidelines. The thresholds could be based on the percentage of travel with certain TTI, as used in L08. Further analysis of the reliability will be made based on the comparison of desired travel rate window with actual travel rate, as recommended in L02.

The reliability performance and deficiencies will be used as output in electronic maps, charts, and figures to allow spatial and temporal visualization of the reliability performance and to reveal the impact of each influencing factor on reliability for different times of day and locations. The factors affecting reliability will be investigated based on the examination of videos, maps, and aerials of the unreliable sites.

The resulting visual aids will be shared and discussed with the project stakeholders in TSM&O core group meetings and TMC staff meetings for a better understanding of the reliability issues of the system. The L05 project recommended considering the perception of system users when setting reliability performance thresholds, because this perception varies significantly across locations, roadway types, users, times of day, and days of the week. Thus, the L05 project guidelines suggest that the setting of the thresholds requires an iterative approach to adjust the threshold up and down, based on agency and stakeholder understanding of reliability deficiencies. In accordance with the L05 recommendations, this project will adjust the thresholds based on meetings with the project stakeholders.

Task 4.b. Assessment of the Ability of L07 and L08 Products to Assess Existing Reliability

L02 products can be used in data-rich environments with established monitoring systems. The limited-access facilities managed by the Florida DOT and toll authorities are instrumented with state-of-the-art ITS monitoring systems with associated data-archiving capabilities. However, urban streets, generally managed by counties and cities, have limited instrumentation, particularly with regard to travel time measurements, although Florida DOT has purchased private-sector travel time data for one year from INRIX for some of these facilities. The L03, L07, and L08 project products, when incorporated within ITSDCAP, provided a unique opportunity to estimate the travel time reliability of these data-poor data environments based on limited traffic and network data captured. However, it will be useful to further validate the results from these tools.

The reliability measures estimated using the L08 and L07 project tools for selected segments of the facilities will be compared with those estimated based on system monitoring in Task 4.a. In addition, a comparison will be made of the results when using the default values incorporated in these tools versus using detailed real-world data provided by ITSDCAP. ITSDCAP contains a modeling support module that collects data from different sources to support the development and calibration of analytical and simulation models. This module will be modified to provide the required data for L07 and L08 products for use in the assessment of reliability and alternative strategies. In addition, the module will be modified to allow ITSDCAP to obtain the output from these products for reporting and visualization of the results. Further examination will be made of the sensitivity of the analysis results to varying input parameters to the models, such as capacities, free-flow speeds, and demands. An important investigation in this project is to examine the L07 project recommendations regarding the estimation of input demands to the model. The L07 procedure tool uses estimates of the highest 30 hours in the year for each hour to represent the demands. This issue was discussed in the L38 project briefing meeting, and further investigation appears to be warranted based on that discussion.

An investigation will also be conducted to determine the impact of varying the value of the minimum inclusion threshold in FREEVAL-RL, which is used to exclude very low probability scenarios from the analysis. The impacts of varying this threshold on the analysis results and efficiency of the program will be assessed. Another interesting sensitivity analysis that will be conducted is to verify the adequacy of using a crash rate multiplication factor to obtain incident rates and probabilities in L08 product procedures.

Task 4.c. Assessment of the Impacts of Existing Strategies Based on System Monitoring Data

Additional analyses of interest to the project stakeholders based on real-world data will be conducted to further demonstrate the utility of SHRP 2 products. The reliability of the managed lanes will be compared with the reliability of I-95 GPLs. The reliability for the I-95 facility with and without the activation of ramp metering will also be examined. L02 recommendations, along with the measures of reliability recommended in other SHRP 2 projects, will be used in this comparison.

Task 4.d. Assessment of the Identified Strategies Using L07 and L08 Products

The research team will examine the results from the reliability analysis in the previous tasks and identify alternative strategies to address reliability issues. Team members with experience in the planning, operation, and design of transportation facilities will examine the highlighted reliability problems to identify combinations of feasible alternative strategies to address various external and internal contributing factors to unreliability. The design features addressed in the L07 project will only include a subset of the considered alternatives. Additional capacity and operational improvements will be identified and tested, including modifications to existing ramp metering, managed lane dynamic pricing, TMC and incident management operations, work zone management strategies, and signal control. Improvements that are already planned or programmed will also be included in the reliability impact testing. The identified set of strategies and the justifications for these strategies will be reviewed with the TSM&O core group and TMC managers, and input from stakeholders will be used in producing a refined list of improvement alternatives for evaluation.

The selection of the identified alternative strategies will require an assessment of the expected improvements due to the implementation of the identified alternative strategies. Depending on the selected strategy, this assessment will be performed using the L08 and L07 products, as described in the following section.

The L08 project developed procedures and tools to include travel time reliability and nonrecurring congestion factors into the Highway Capacity Manual. The L08 freeway procedure uses the FREEVAL tool and a scenario generator to evaluate the change in travel time reliability performance measures associated with variations in freeway traffic, capacity, weather, and incident characteristics. The urban street L08 procedure uses the STREETVAL tool combined with a scenario generator to evaluate the change in travel time reliability on signalized arterial streets. By varying input parameters such as capacity increase and incident duration reduction to both tools, it will be possible to identify the benefits of the suggested improvements. Local data required by the scenario generators will be provided by ITSDCAP, and the results of the analyses when using these data will be compared with the results when using the default values.

Task 5. Preparation of Interim Report

This task will include preparing an interim report summarizing the activities and findings from Tasks 3 and 4. The research team will participate in an interim expert task group meeting in Washington, D.C., prepared the required materials for the meeting, and make presentations as required by the SHRP 2 project management. Comments on the interim report will be received and addressed by the research team. This task will also include participation in an interim expert task group meeting in Washington, D.C., with all the pilot site contractors and representatives of FHWA and AASHTO.

Task 6. Use of Reliability Analysis in the Decision-Making Process

The research team will present the results from the reliability and alternative analyses produced in Task 4 to the TSM&O core groups and TMC staff. Discussions with the agencies will address the identified reliability problems, the recommended countermeasures, and the results from the analyses.

This task will use the L05 guidelines to select improvement alternatives and the incorporation of reliability into trade-off analyses and project prioritization. A number of L05-recommended approaches for this purpose will be considered, including identifying solutions at the facility or segment level, using a performance-based approach to select strategies, and using incremental benefit–cost analysis to select strategies. The benefits of improvement alternatives in terms of other measures such as mobility and safety improvements will be assessed and used in the project prioritization. The alternative selection results will be compared with and without the consideration of reliability.

Task 7. Evaluation of the Functionality and Outcomes of the Products

This task will be conducted with active participation of AECOM research team members and will include the evaluation of the technical feasibility of the products, the understandability and credibility of the results by decision makers, and the acceptability and implementation potential of the recommendations resulting from the products. This assessment will be based on interviews with project stakeholders and examination of actual decisions made by the involved agencies.

Task 8. Preparation of Draft Final Report

The research team will prepare a draft report covering the activities, findings, and conclusions from project tasks. Materials from the interim report produced in Task 5 will be incorporated in the final report. The draft will be submitted to the SHRP 2 program for review and comments. The proposed outline of the final report is presented below.

1. Introduction
    - 1.1 Background
    - 1.2 Review of SHRP 2 Products
    - 1.3 Document Organization

2. Concept of Operation
    - 2.1 Goal and Objectives
    - 2.2 Review of Florida DOT Programs
    - 2.3 Existing Florida DOT Processes in Relation to Project Activities
    - 2.4 Review of Florida DOT Tools
    - 2.5 Project Stakeholders and Related Business Processes
    - 2.6 Reliability Incorporation in Policy Statements
    - 2.7 Reliability Performance Measures
    - 2.8 Analysis Scope
    - 2.9 Methods Used for Assessing Reliability
    - 2.10 Setting Reliability Performance Thresholds
    - 2.11 Use of Results in Improvement Trade-off Analysis

3. Data Compilation and Preprocessing
    - 3.1 Additional Data Collection Effort
    - 3.2 Data Postprocessing and Fusion
    - 3.3 Categorization into Different Regimes

4. Assessment of Reliability Conditions Based on System Monitoring Data
    - 4.1 Application of L02 Project Analysis Methods to Estimate Reliability
    - 4.2 Influencing Factor Analysis
    - 4.3 Identification of Reliability Deficiencies
    - 4.4 Assessing the Impacts of Existing Strategies
    - 4.5 Sensitivity Analysis

5. Assessment of Modeling Ability to Assess Existing Reliability
    - 5.1 Assessment of L08 Freeway Methodology
    - 5.2 Assessment of L08 Arterial Street Methodology
    - 5.3 Assessment of L07 Methodology
    - 5.4 Sensitivity Analysis

6. Assessment of Alternative Strategies
    - 6.1 Identification of Alternative Strategies
    - 6.2 Evaluation of Alternative Strategies Using L07 and L08 Products
    - 6.3 Applying L05 Methodology in the Decision-Making Process
    - 6.4 Comparison of Results With and Without Considering Reliability

7. Using Reliability for Real-Time Monitoring
    7.1 Incorporating Real-Time Reliability in IRISDS
    7.2 Use in TMC Operations

8. Evaluation of the Functionality and Outcomes of the Products
    8.1 Use of Results in the Decision-Making Process
    8.2 Technical Feasibility of the Products
    8.3 Understanding and Views of Stakeholders Toward the Products
    8.4 Acceptance of the Products by Stakeholders

9. Conclusions and Recommendations

Task 9. Preparation of Final Report

The research team will revise the draft of the final report in accordance with review comments and resubmit according to SHRP 2 guidelines. The research team will address any issues and concerns and refine the contents and format of the report to ensure that it meets the highest standards of the SHRP 2 products.

G.6 Project Schedule

The project timeline and related milestones are shown in Table G.2.

Table G.2. Project Timeline and Related Milestones

	Month													
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
TASK	Apr. 2013	May 2013	Jun. 2013	Jul. 2013	Aug. 2013	Sept. 2013	Oct. 2013	Nov. 2013	Dec. 2013	Jan. 2014	Feb. 2014	Mar. 2014	Apr. 2014	May 2014
Task 1.	▨													
Task 2.	▨	▨	▨	▨										
Task 3.	▨	▨	▨	▨	▨									
Task 4.		▨	▨	▨	▨	▨	▨	▨	▨	▨				
Task 5.									▨	▨				
Task 6.									▨	▨	▨			
Task 7.											▨	▨		
Task 8.												▨	▨	
Task 9.														▨
Monthly Reports	✧	✧	✧	✧	✧	✧	✧	✧	✧	✧	✧	✧	✧	✧
Quarterly Reports			★			★			★			★		
Deliverables	●							●				●		●

Project tasks are listed as follows:

Task 1. Attending Project Briefing
Task 2. Development of Revised Research Plan and Concept of Operation
Task 3. Data Compilation and Integration
Task 4. Analysis of Baseline Reliability Issues and Alternative Strategies
Task 5. Preparation of Interim Report
Task 6. Use of Reliability Analysis in the Decision-Making Process
Task 7. Evaluation of the Functionality and Outcomes of the Products
Task 8. Draft Final Report
Task 9. Final report

APPENDIX H
Second Stakeholder Workshop Meeting Minutes

Time and Place: May 21, 2014 (9:00 a.m. – 12:30 p.m.) at FIU Engineering Center
Attendees: See attendance list at end of meeting minutes

The purpose of the workshop was to provide a summary of the results of *Pilot Testing of SHRP 2 Reliability Data and Analytical Products* to project stakeholders. Reena Mathew provided an overview of the SHRP 2 Reliability Program, followed by Drs. Hadi and Edelstein, who provided a summary of the research results. The project stakeholders participated in a before and after survey of eight questions related to their understanding of reliability, as well as a series of questions toward the end of the workshop that generated an interactive discussion on how the reliability data and analytical products may begin to be integrated into transportation planning and operations business processes. Summary highlights of the meeting are presented below:

- What are the applicability and usefulness (value) of the products tested?

SHRP 2 products can be used for a diverse range of planning and operations applications. The planning applications include development of TIPs, LRTPs, TSM&O plans, corridor studies, and PD&E studies. The operations applications include arterial operations, freeway and toll road operations, transit operations, and freight operations. Specifically,

- ITSDCAP may be useful to help understand reliability as additional input to the development of LRTPs and evaluating component projects.
- It may be useful to incorporate travel time reliability into the planning process to better understand capacity improvements versus reliability improvements.
- In response to questions concerning the benefits of incorporating FHWA tools into systems planning and how these tools could be used to evaluate specific projects as part of LRTPs, participants learned that high-level tools can be incorporated to evaluate reliability as these tools are easy to use. L07 and L08 modeling tools can also be used.

- Do you plan to include travel time reliability as a performance measure as part of your weekly, monthly, and/or annual reporting, and if so how?

Travel time reliability performance reports are already being generated by Florida DOT District 6 for all Interstate facilities within Miami-Dade County by direction and by hourly time frames. These monthly reliability reports are archived on their website. District 4 generates monthly reports for the arterial and freeway system, but does not include travel time reliability reports. Specifically,

  - Activity-based regional demand models already include some reliability metrics in developing the 2040 LRTP Updates for Miami-Dade, Broward, and Palm Beach Counties.
  - The Florida Turnpike has already developed a reliability report card.
  - Reliability reporting should be coordinated with statewide efforts for planning and operations.
  - Reliability can be incorporated into corridor study scope of services and for alternatives analysis.

- Do you plan to apply travel time reliability as a real-time performance measure to adjust operation, and if so, how?

District 6 reported being interested in applying travel time reliability as input to developing predictive models and decision support systems to be more proactive in addressing both recurring and nonrecurring congestion. Miami-Dade County was also interested in applying these tools; however, they were concerned about the required resources and maintenance of these tools, as staff resources are constrained. Specifically,

  - There is no known effort for applying reliability to transit, pedestrian, and bike modes.
  - Miami-Dade Transit is applying travel time reliability as a performance measure for transit along Kendall Drive.
  - Reliability may be used to compare measures of effectiveness for multimodal alternatives.
  - Reliability may be included as part of the SR-7 study to compare multimodal alternatives (e.g., exclusive bus lanes).
  - Reliability for transit applications may be defined in terms of schedule adherence or point-to-point travel time reliability for transit users.
  - Travel time reliability should also be considered for freight traffic.
  - Freight carriers can use reliability as part of dynamic routing and dispatching of their truck fleets.
  - Reliability is being used on transit studies to help prioritize improvement strategies (e.g., queue jumps to improve schedule adherence). Reliability performance is estimated based on the top five origin–destination trip pairs generated by the demand model using travel time and speed information. Similar procedures may be applied to freight traffic.
  - Reliability metrics are soft measures compared to needs and costs, which are hard measures in developing short- and long-range transportation plans.

- What are the main analysis and visualization elements from this project that you consider powerful and plan to implement?

Although CDF and PDF curves are valuable analytical tools, they may be too difficult to apply for nontechnical audiences. Perhaps animated or video tools would be useful, as well as methods to convey the same message to nontechnical audiences (e.g., policy makers). Specifically,

- The reliability tools require a good understanding of data as they use an extensive amount of data for reliability calculations.
- Reliability may be a factor to consider for traffic-adaptive signal control.
- For LRTPs, the CDF and PDF graphs are too detailed and too technical. Simple graphics indicating reliability performance levels are preferred.
- The more technical outputs of the reliability tools may be more applicable to corridor planning studies versus LRTPs.
- It was suggested that the reliability tools begin to be applied to corridor studies, then evolve into regional planning applications.

- How can travel time reliability be included as part of your public outreach program?

Travel time reliability may be used by the media as part of traffic reports to supplement the real-time camera images they use, as well as travel time information that they report along selected links within the regional highway network. This information may also be used by the private sector in developing smartphone apps to report real-time travel time reliability to supplement congestion-level information currently being displayed. Specifically,

- FHWA will have a pilot project that helps the public to understand reliability terms.
- The public may have a different understanding of reliability (e.g., leave early or arrive on time) than traffic analysts and will find PDFs difficult to understand.
- It would be helpful if the benefits of using reliability can be better understood, possibly beginning with corridor study applications.

- What are the challenges in applying travel time reliability as part of TMC operations?

The challenges are applying travel time reliability to develop predictive models that can provide input to decision support systems. This process may begin with selected applications, such as applying this information to make decisions about activating ramp signals earlier than peak periods or adjusting ramp signal release rates. The Miami-Dade County Traffic Signal Control Center recognized that the reliability products could help develop and implement better signal timing plans; however, their constrained staff resources were a concern in applying travel time reliability in their operations. Therefore, automated tools would be needed to make them more useful without creating a burden on their staff.

- Do you plan to apply travel time reliability as a tool to support the development of short- and long-range transportation plans, and if so, how?

Travel time reliability can be used in qualitatively developing TIP and LRTP goals and objectives, as well as quantitatively as a measure of effectiveness in evaluating improvement projects. The MPO will need to assess these issues in developing future plans.

- Do you plan to apply travel time reliability as part of PD&E studies and alternatives analyses, and if so, how?

In future studies, travel time reliability will be considered as a possible measure of effectiveness in comparing project alternatives in addition to other traditionally used measures of effectiveness (e.g., costs, right-of-way impacts, delay savings, crash reduction, emission savings, and benefit–cost ratio).

- What are the challenges in conveying the meaning and importance of travel time reliability to nontechnical audiences (e.g., political leaders, executive management)?

The challenges in conveying the meaning and importance of travel time reliability to nontechnical audiences are presenting the information in simple visual graphics or video animations. It was suggested that a common definition be selected from the many possible definitions of travel time reliability (e.g., TTI, buffer index, misery index) and used consistently in presentations to nontechnical audiences. Specifically,

- It is important to demonstrate the applicability of reliability in the real world.
- It is important to provide reliability information, as well as speed and travel time information, to travelers.
- Reliability can be used for prioritization. The importance of reliability needs to be emphasized.
- Although visualization tools (e.g., heat maps) are useful to technical staff, relating reliability data to geography is more important for the public. A time variation of data using video would be useful.
- Reliability data need to be marketed to help the public understand the concept (e.g., simple color-coded maps indicating the level of travel time reliability).
- More funding is needed to support the integration of reliability as part of the planning and operations processes.

A survey was conducted at the beginning and end of the workshop to gauge the level of understanding that the stakeholders had regarding the research. The results were based on a show of hands for those in attendance (not on the phone line) and are presented in Table H.1.

Table H.1. Stakeholder Survey

Question	Beginning		End	
	No.	%	No.	%
1. How familiar are you with the concept of travel time reliability?				
Very Familiar	1	9%	1	11%
Familiar	10	91%	8	89%
Unfamiliar	0	0%	0	0%
Very Unfamiliar	0	0%	0	0%
2. Describe the extent to which you believe travel time reliability can be quantified.				
Highly	6	50%	8	57%
Moderately	4	34%	6	43%
Limited	1	8%	0	0%
Qualitatively Only	1	8%	0	0%
3. How often have you seen travel time reliability used in project evaluations previously?				
Frequently	0	0%	0	0%
Sometimes	8	80%	4	40%
Once	1	10%	3	30%
Never	1	10%	3	30%
4. How often has your agency used travel time reliability in a program or planning application?				
Frequently	0	0%	0	0%
Sometimes	5	56%	3	30%
Once	2	22%	4	40%
Never	2	22%	3	30%
5. How likely are you to consider the evaluation of travel time reliability in the future?				
Very Likely	7	78%	10	71%
Likely	2	22%	4	29%
Unlikely	0	0%	0	0%
Very Unlikely	0	0%	0	0%
6. What planning and study applications of travel time reliability do you find most promising? (select all that apply)				
MPO LRTP / TIP / CMP	1	6%	2	8%

Corridor / Multimodal Studies	12	71%	14	61%
PD&E Studies	4	23%	5	22%
Interchange Modification Reports	0	0%	2	9%
7. What operation applications of travel time reliability do you find most promising? (select all that apply)				
Freeway Real-Time TMC Operations	11	23%	9	19%
Signal Agency Center Operations	11	23%	9	19%
TSM&O Applications	11	23%	10	21%
Planning for Operations	5	10%	11	22%
Transit and Freight Operations	10	21%	9	19%
8. What barrier is most likely to impede your agency's ability to evaluate travel time reliability?				
Data Availability	9	43%	10	29%
Staff Expertise	2	9%	5	15%
Staff and Time Resources	4	19%	11	32%
Existing Methods Are Adequate	2	10%	2	6%
Resistance to Change	4	19%	6	18%

Although the survey reported in Table H.1 was not conducted to provide statistically accurate conclusions, the following inferences may be drawn:

- All participants were familiar with the concept of travel time reliability.
- All participants believed, particularly after the completion of the workshop, that travel time reliability can be quantified.
- The participants had not seen travel time reliability used frequently as part of project evaluations.
- The participants had not seen their agencies frequently use travel time reliability in a program or planning application.
- All participants believed that the evaluation of travel time reliability will likely or very likely be used in the future.
- The participants believed that the following planning and study applications of travel time reliability are the most promising in order of importance: corridor and multimodal studies; followed by PD&E studies; followed by interchange modification reports and MPO LRTP, TIP, and CMP studies.
- The participants believed that the following operations applications of travel time reliability are equally promising: freeway real-time TMC operations, signal agency center

operations, TSM&O applications, planning for operations, and transit and freight operations.

- The participants believed that the following barriers, in order of importance, are most likely to impede an agency's ability to evaluate travel time reliability: staff and time resources, followed by data availability, followed by resistance to change, followed by staff expertise, followed by believing that existing methods are adequate.

In summary, the workshop was successful in presenting the results of the research, providing high-level training, and introducing how the reliability data and analytical products may begin to be integrated within transportation planning and operations business processes. Positive feedback was provided by the stakeholders.

Table H.2 lists the participants in the second stakeholder workshop meeting.

Table H.2. Attendance List

Name	Agency
In Room (27)	
Reena Mathew	SHRP 2 Reliability Program
Rory Santana	Florida DOT District 6 TMC
Javier Rodriguez	Florida DOT District 6 TMC
Neil Lyn	Florida DOT District 6 Planning
Phil Steinmiller	Florida DOT District 6 Planning
Ivan DeCampo	Miami-Dade Expressway Authority
Hiram Hernandez	Miami-Dade Public Works
Peng Zhu	Cambridge Systematics
Leigh Ann White	Jacobs
Christine Springer	Jacobs
Jessica Josselyn	Kittelson & Associates
Mohammed Hadi	FIU
Bob Edelstein	AECOM
Yan Xiao	FIU
Tao Wang	FIU
Jianmin Jia	FIU
Shahadat Iqbal	FIU
Samaneh Khazraeian	FIU
Somaye Fakharian Qom	FIU
Others from Florida DOT District 6, Miami-Dade County, Miami-Dade MPO, and Florida Turnpike did not sign in.	
Online (26)	
Giri Jeedigunta	Palm Beach County Traffic
Melissa Ackert	Florida DOT District 4 Traffic Operations
Daniel Smith	Florida DOT District 4 TMC
Emmanuel Posadas	City of Boca Raton, Florida
Vladimir Majano	Florida DOT System Planning Office
Cesar Segovia	URS
Rich Taylor	FHWA
Jim Hunt	FHWA
Kris Milster	FHWA
Others did not identify themselves.	