VOLUME II

Modeling the Route-Level Reliability Impact of Operational Improvements

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LIST OF EXHIBITS

II-1. INTRODUCTION

This pilot study report volume covers various tools that were designed to predict the reliability impacts of operational improvements in the SHRP2 program. In general, those are tools that generate either the entire or at a minimum selected percentile values of the travel time (or travel time index) distribution. The executive summary provides the motivation for the pilot study work, of which this volume is one part. The focus here has been on pilot testing the L08 tool FREEVAL. In addition some comparison between the L07 segment based and L08 facility based tools are documented in this report.

It should be noted that since the completion of the SHRP2-L08 research project, the research team at ITRE has carried out significant improvements to that tool, some of which were done under the sponsorship of NCHRP 03-115, and through other funding from the state of North Carolina and University Transportation Centers. These enhancements include moving away from the limiting Excel platform to a Java based code; adding automatic facility segmentation feature through a graphical interface with Google Maps; developing manual and automated calibration methods to interact with the tool and with travel time data from third party providers (e.g. INRIX); and enabling the (indirect) generation of state of the art reliability metrics consistent with the latest FHWA rulemaking on mobility and reliability performance measures. The team is also currently testing new ways to input incident frequency and allocation data by segment or time period, to better match the temporal or spatial distribution of observed incidents on the modeled freeway facilities.

It is important to mention that many of the already implemented and some of the ongoing planned improvements in FREEVAL have addressed many of the shortcomings that were highlighted during the original L38 pilot testing of reliability tools that were carried out soon after the completion of the SHRP2 reliability program. Testers included organizations from California, Florida, Minnesota and Washington. It is also a testimony to the strength and robustness of the L08 tool that a statewide implementation called FREEVAL-NC is currently being developed with state funds to cover all interstate facilities in the state of North Carolina, and will be the tool of choice for the state to conduct core, reliability and work zone analyses on freeway sections statewide.

This document is organized as follows. Following the introduction we provide high level coverage of reliability tools generated in the SHRP2 program, including L03-based planning level tools such as L07 and C11 (these tools an there associated SHRP2 projects will be briefly reviewed in the discussion that follow). Because L07 is the closest in terms of functionality to L08 we present a case study comparing their results for a real world freeway facility. The remainder of the document is dedicated to the L08 tool, and its pilot testing on four routes in North Carolina that have different attributes. The results and findings are then reported, along with recommendations for tool enhancements. Detailed calibration and validation results are given in three appendices at the end of the document.

II-2. L03-BASED TOOLS

This section provides a summary of SHRP2 L07 (*1,2*) and C-11 (*3*) tools. These tools use the findings from SHRP2-L03 project (*4*) related to segment-level reliability MOE estimation. An overview is first presented to clarify the scope, capabilities and limitations of these tools. Next, other SHRP2-L38 contractors' findings that also relate to the L07 and C11 tools are summarized. Since NCDOT has pledged to pursue the use of the L08 products for reliability analysis, the research team contrasted the modeling of a real-world case study both in L07 (Single-Segment Based Analysis) and L08 (Facility Based Analysis) tools. The details of this modeling and comparison of the results are discussed later in this section.

II-2.1. Scope of L03-Based Tools

SHRP2 Project L07 has focused specifically on design treatments that can be used to reduce delays due to nonrecurrent congestion and improve travel-time reliability. The objectives of the L07 project were to (a) identify the full range of possible design treatments used by transportation agencies to improve travel-time reliability and reduce delays due to key causes of nonrecurrent congestion, (b) assess their costs and operational and safety effectiveness, and (c) provide recommendations for their use and eventual incorporation into appropriate design guides *(1, 2).*

The traffic operational analysis methodology developed in L07 tool is built from work completed in SHRP2 Project L03 *(1, 2).* L03 developed models for predicting the values of the travel time index (TTI) at five percentiles (10th, 50th, 80th, 95th, 99th) along the TTI distribution *(4).*

The L03 Project model focused primarily on estimating the TTI distributions during peak periods. L07 adapted the L03 models for use during one-hour time-slices, so that the TTI distribution could be predicted for each hour of the day. In addition, L07 improved upon the models in two important ways. First, the L03 models were found to be based on data from cities that did not experience significant snowfall, so this research incorporated a snowfall variable in addition to the rainfall variable already in the models. Second, the L03 models were designed to incorporate peak hours in large metropolitan areas. The L07 research developed additional models to be used for facilities and/or hours of the day with lower demand-to-capacity ratios *(1, 2).*

SHRP2 Project C11 provides spreadsheet tools to assist local agencies in examining the specific changes in transportation conditions associated with individual project proposals as well as their economic consequences *(3).* A reliability assessment spreadsheet was developed for this study. It takes information on the type of highway, projected traffic volume, speed, lanes and capacity and it then generates measures of a travel time index, average delay, buffer time and cost of delay *(3).* The tool calculates the travel time index and buffer time to provide a basis for further calculation of the direct economic value of improving reliability, in a separate accounting spreadsheet *(3).*

The Reliability Module is one of the economic analysis tools developed from SHRP2 Project C11. It is a sketch planning corridor spreadsheet tool based on SHRP2 Reliability Project L03 research that estimates the benefits of improving travel time reliability for use in benefit/cost analysis. Local travel time reliability data are not required because reliability measures are embedded in the L03 work *(3).* Agencies will typically have the required inputs (e.g., traffic volume, roadway capacity, AADT, percent trucks, number of lanes, and growth rate) *(3).*

II-2.2. Comparing SHRP2-L07 and SHRP2-L08 tools in a real-world case study context

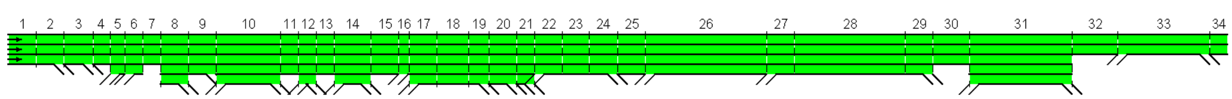
NCDOT has pledged to use FREEVAL for freeway analysis (including reliability analysis on freeway facilities). As such, in this section of the report, we compare the SHRP2-L07 tool with FREEVAL. As discussed earlier, L07 is a segment-based tool that only focuses on a freeway segment for any analysis derivations. On the other hand, FREEVAL considers a stretch of a freeway facility that includes bottlenecks and enough spatial extent to keep queues within analysis boundaries.

In order to compare the reliability predictions of these tools via a real-world facility, the research team modeled a stretch of I-40 facility in FREEVAL. All geometric details along with recurring and non-recurring sources of congestions are characterized. Within this 12.5-mile real world facility, the research team selected a one-mile long hypothetical segment. The hypothetical segment was assumed to carry the majority of the characteristics that the entire facility has, such as number of lanes and AADT. The hypothetical segment acted as a representative segment and was modeled in L07 tool. The reliability predictions of the L07 and FREEVAL tools yielded very different outcomes.

II-2.2.1. Geometric Characteristics

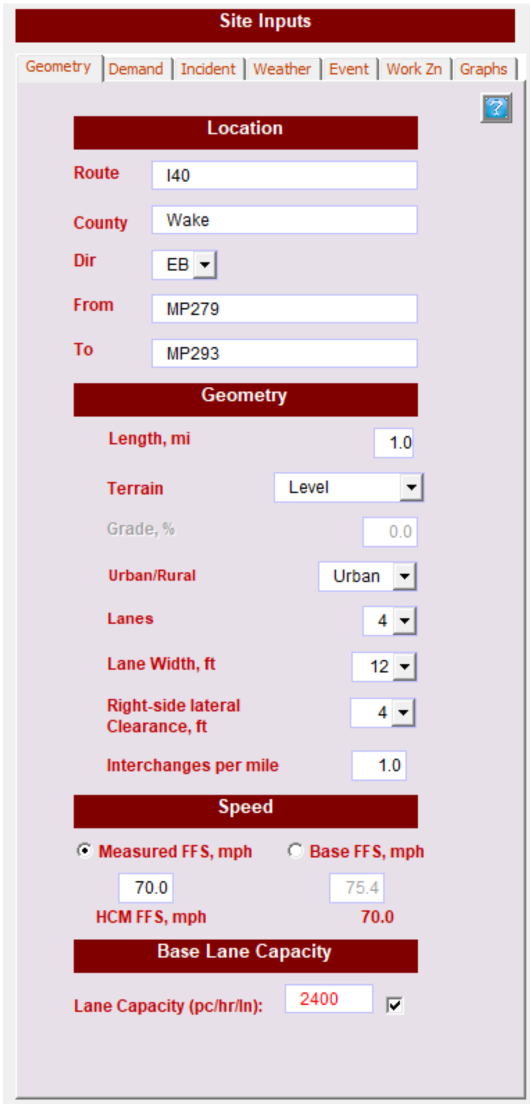
The facility under consideration is I-40 EB in RTP (Research Triangle Park) area from MM 293 to MM 281. The L08 analysis setup is from 2pm to 8pm.

Exhibit II - 1: HCM segmentation of I-40 Facility



This facility is 12.5 miles long and contains 34 HCM segments as shown in Exhibit II - 1. For L07 tool evaluation purposes. The average number of lanes on the I-40 facility is 3.9 and as such, this research assumed the representative segment to have 4 lanes, see Exhibit II - 2.

Exhibit II - 2: Geometric and Demand Configuration of I-40 EB Case Study in L07 Tool



II-2.2.1. Demand Flow Rates

The L07 tool requires 24 hours demand input for its analysis. Since FREEVAL's temporal analysis domain is only from 2pm to 8pm, the research team extrapolated FREEVAL demand to 24 hours. The 24 hourly demand profile is known to the research team at MM 284 via a count station. The research team used this hourly profile to extrapolate FREEVAL's results into 24 hours (Exhibit II - 3).

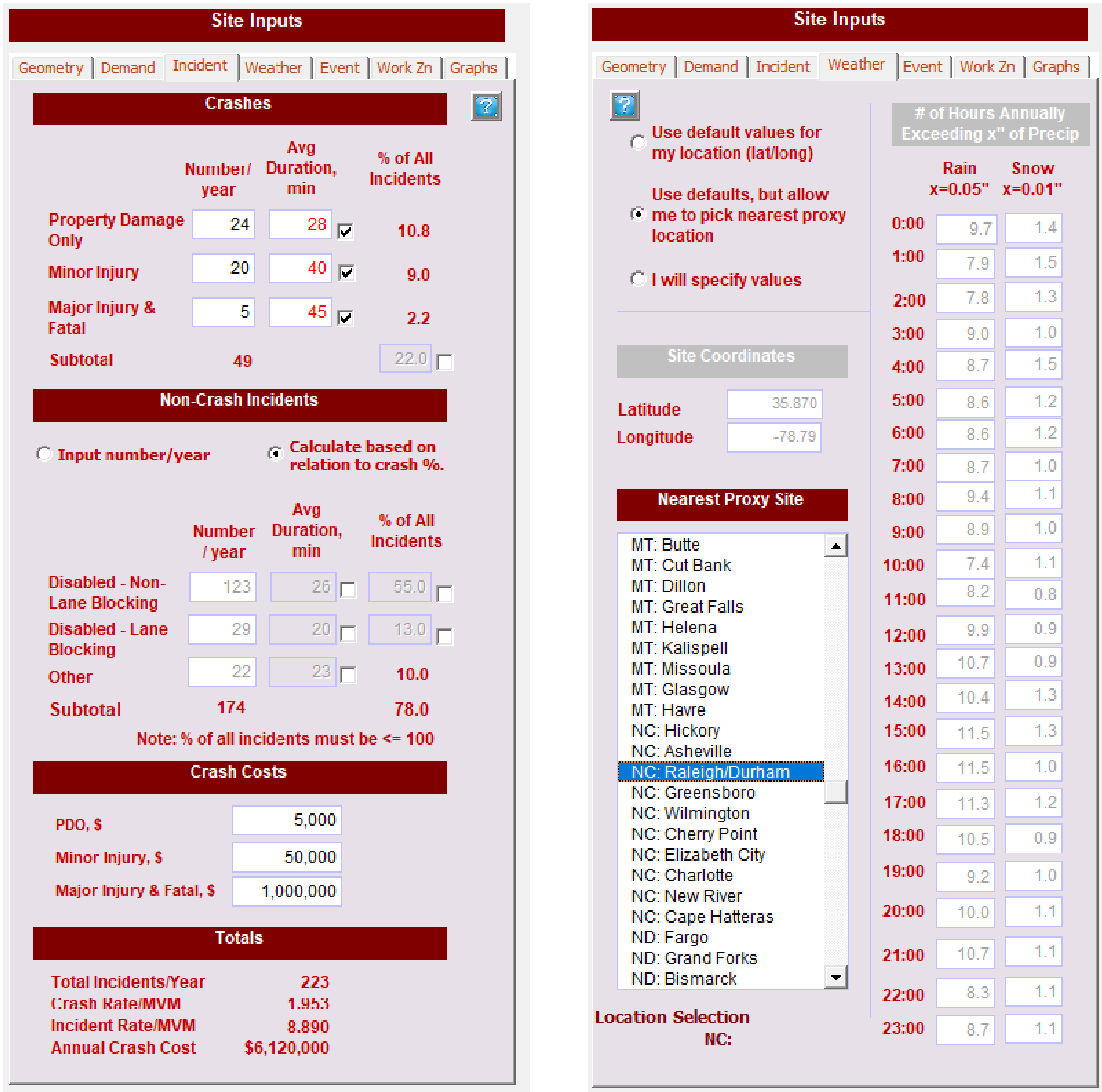
II-2.2.1. Non-Recurring Sources of Congestion Characterization

For FREEVAL analysis, the reliability reporting period was set to be from January 1 to December 31, including all weekdays in a year. Site specific I-40 EB demand fluctuation between weekdays and months in a year were used in the modeling. FREEVAL defaults were used for severe weather probabilities, and a rate of 1,150 crashes per 100 million VMT (vehicle mile travelled) based on local facility data was used for incidents modeling. HCM defaults were used for all other settings, such as the impacts of weather and incidents on freeway capacity and speeds. No work zones or special events were modeled in this comparison between the FREEVAL and L07 tools. See Exhibit II - 4 and Exhibit II - 5 for details.

Exhibit II - 3: Demand Flow Rate (pcph) for FREEVAL and L07 tools

Hour	From FREEVAL	Estimated Demand for 24 Hours via MM284 Hourly Profile
t=0		566
t=1		313
t=2		241
t=3		248
t=4		342
t=5		834
t=6		2,521
t=7		4,777
t=8		5,233
t=9		3,889
t=10		3,220
t=11		3,457
t=12		3,641
t=13		3,694
t=14	5,131	5,263
t=15	5,650	5,795
t=16	5,886	6,036
t=17	5,031	5,160
t=18	3,705	3,800
t=19	2,860	2,934
t=20		2,336
t=21		1,956
t=22		1,473
t=23		996

Exhibit II - 4: Weather and Incident Modeling in L07 Tool



As seen in , the L07 tool asks for incident information in terms of severity of crashes. However, FREEVAL requires users to specify the crash likelihoods in terms of lane closure severity. Therefore, the research team used information provided in Exhibit II - 5 to generate the required inputs for FREEVAL to render the L07 tool results as consistent with the FREEVAL results as possible.

Exhibit II - 5: Crash Severity Breakdown for L07 Tool

No. freeway lanes (one direction)	Crashes			Non-crash incidents (disabled vehicle)		
	PDO	Minor injury	Major injury & fatal	Non-lane-blocking	Lane-blocking	Other
2	0.67	0.58	0.16	0.95	0.34	0.83
3	0.73	0.64	0.29	0.99	0.48	0.87
4	0.77	0.69	0.38	0.99	0.57	0.89
5	0.80	0.74	0.48	0.99	0.64	0.90
6	0.84	0.78	0.56	0.99	0.70	0.92
7	0.86	0.81	0.62	0.99	0.74	0.93
8	0.89	0.84	0.66	0.99	0.77	0.94
Values above are adapted from HCM Exhibit 10-17, based on assumed conversions below from blockage type to incident type						
Shoulder Disablement	*0%*	*0%*	*0%*	*100%*	*0%*	*50%*
Shoulder Crash	*72%*	*59%*	*5%*	*0%*	*0%*	*39%*
1 Lane Blocked	*26%*	*28%*	*35%*	*0%*	*96%*	*10%*
2 Lanes Blocked	*2%*	*10%*	*45%*	*0%*	*3%*	*1%*
3 Lanes Blocked	*0%*	*3%*	*15%*	*0%*	*1%*	*0%*

II-2.2.2. Results and Comparisons

Both the FREEVAL and L07 tools are capable of reporting reliability level MOEs. The L07 tool reports the mean TTI and the 99th , 95th , 80th , 50th, and 10th percentile TTIs as shown in Exhibit II - 6. The FREEVAL tool is also capable of reporting reliability performance measures for the entire study period and entire facility. Note that FREEVAL does not breakdown the reliability performance measures by hour of the day. Exhibit II - 7 shows FREEVAL's output of I-40 EB case study.

Exhibit II - 6: Case Study Result (L07 Tool)

	Mean	99%	95%	80%	50%	10%
0:00	1.02	1.12	1.05	1.03	1.02	1.00
1:00	1.02	1.09	1.04	1.02	1.01	1.00
2:00	1.01	1.08	1.04	1.02	1.01	1.00
3:00	1.02	1.07	1.04	1.02	1.01	1.00
4:00	1.02	1.09	1.05	1.02	1.01	1.00
5:00	1.02	1.13	1.06	1.03	1.02	1.00
6:00	1.05	1.31	1.12	1.06	1.04	1.01
7:00	1.09	1.57	1.21	1.11	1.07	1.01
8:00	1.10	1.64	1.23	1.12	1.07	1.01
9:00	1.07	1.46	1.17	1.09	1.05	1.01
10:00	1.06	1.38	1.14	1.07	1.05	1.01
11:00	1.07	1.40	1.15	1.08	1.05	1.01
12:00	1.07	1.43	1.16	1.09	1.05	1.01
13:00	1.07	1.44	1.17	1.09	1.05	1.01
14:00	1.10	1.66	1.24	1.12	1.07	1.01
15:00	1.13	1.98	1.32	1.16	1.10	1.02
16:00	1.14	2.06	1.34	1.17	1.10	1.02
17:00	1.10	1.65	1.23	1.12	1.07	1.01
18:00	1.07	1.45	1.17	1.09	1.05	1.01
19:00	1.06	1.35	1.14	1.07	1.04	1.01
20:00	1.05	1.29	1.12	1.06	1.04	1.01
21:00	1.05	1.25	1.10	1.05	1.03	1.01
22:00	1.03	1.19	1.08	1.04	1.03	1.01
23:00	1.03	1.15	1.06	1.03	1.02	1.00

Exhibit II - 7: Case Study Results (FREEVAL Tool)

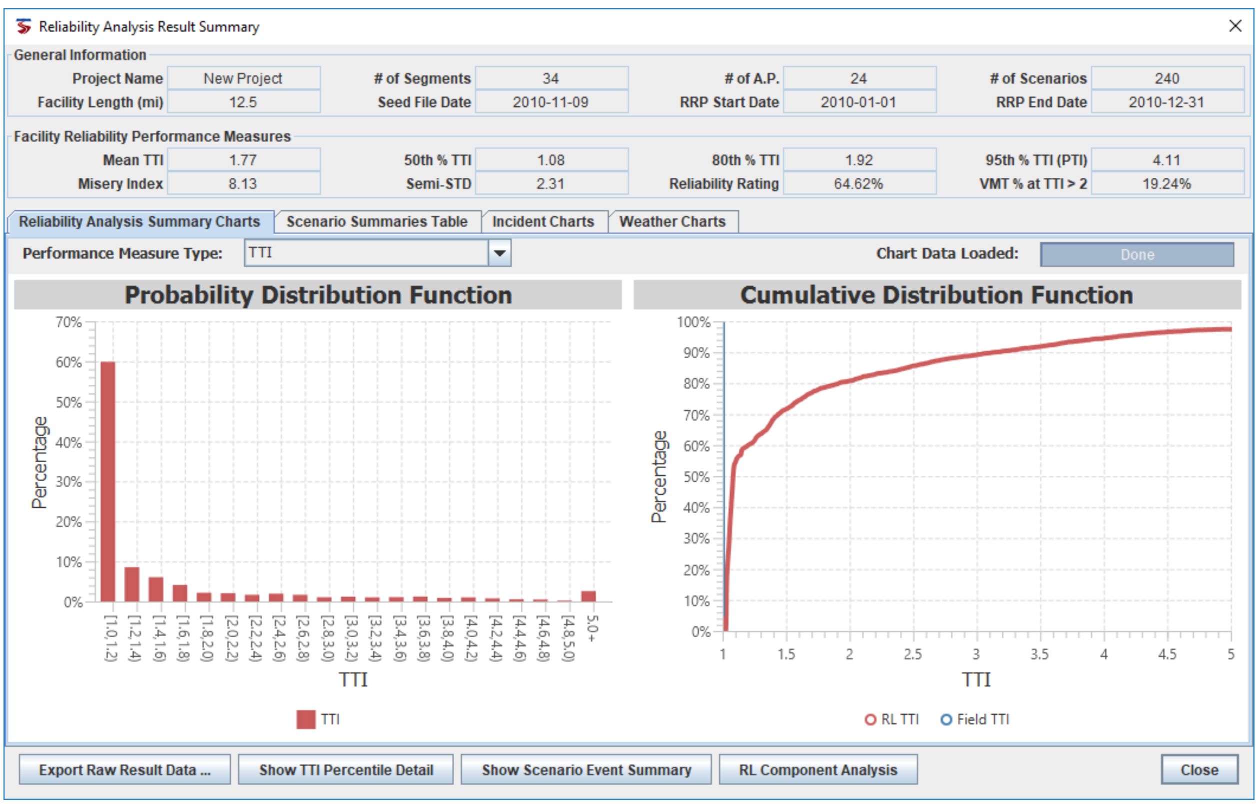


Exhibit II - 8 shows the comparison of common performance measures between these two tools. Since the L07 tool reports the performance measures on an hourly basis, we have reported all observations between 2pm and 8pm in the comparison table to match the temporal domain of the L07 tool results with the FREEVAL results.

Exhibit II - 8: Comparison of Key Reliability MOEs reported by FREEVAL and L07 Tool

Key Reliability MOE	FREEVAL	L07 Tool					
		2PM	3PM	4PM	5PM	6PM	7PM
Mean TTI	1.77	1.10	1.13	1.14	1.10	1.07	1.06
50th Percentile TTI	1.08	1.07	1.10	1.10	1.07	1.05	1.04
80th Percentile TTI	1.92	1.12	1.16	1.17	1.12	1.09	1.07
95th Percentile TTI (PTI)	4.11	1.24	1.32	1.34	1.23	1.17	1.14

The L07 tool tends to estimate less congestion and travel time degradation than does FREEVAL. This can be due to the fact that L07 and other segment-based tools cannot account for the queuing conditions occurring on freeways. Focusing on a single segment cannot provide accurate bottleneck modeling and analysis and cannot account for the subsequent queues. Another important issue is that the location of the segment in L07 analysis is important in determining the actual performance measure. For example, a segment located downstream of a bottleneck will tend to have a better performance due to traffic being metered at the bottleneck. The effects of segment location relative to active bottlenecks cannot be captured in tools that analyze a single segment.

On the other hand, FREEVAL (or Highway Capacity Manual) facilities methodology is designed to model traffic on longer stretches of freeway, including procedures for rigorous analysis of active and hidden bottlenecks. In FREEVAL, all queuing that occurs at active bottlenecks is explicitly modeled and associated delays are estimated.

II-3. L08-BASED TOOLS

II-3.1. Data Preparation

The types of data required for calibration of reliability analyses include demand or volume counts, weather event probabilities, and incident occurrence and duration distributions. Information related to work zones, if any is present in the study route during analysis period, should also be included.

II-3.1.1. Facility Geometry

In order to code the facility to be analyzed, geographic information such as type of HCM segments, length of segments, number of lanes, free-flow speed, etc. is required. Information regarding the number of lanes, posted speed limit and different types of segments are gathered from Google Earth *(5)*. The free-flow speed was selected at 5 mph above the posted speed limit for each freeway segment. The enhanced version of FREEVAL includes a Google Map interface, which makes creating facilities more user-friendly.

II-3.1.2. Demand Data

After gathering information about the different HCM segments making up a freeway facility, the mainline, on-ramp entry and off-ramp exit demands are required to be gathered. The new version of FREEVAL (FREEVAL-2015e) enables the user to input Average Annual Daily Traffic (AADT) values for different segments and select from a list of default time of day demand profiles to apply to these AADTs. The time of day profiles can also be a user input and is subsequently aggregated into 15-minute intervals. AADT information on different ramps and freeway segments are usually available on state DOT websites. For this study, we gathered this information from the Connect NCDOT Traffic Volume Maps website *(6)*. This data is required for single-day calibration of the facilities.

For the reliability analysis, it is required to calibrate the demand fluctuation across different day-of-week and month-of-year temporal dimensions. The user is required to input demand multipliers or demand adjustment factors by day of week and month of year. The best source of demand fluctuation data is permanent traffic recorders (PTR) located alongside the facility. Categorization of demand is done by assigning similar demand patterns to specific days with the same demand level in the reliability scenario generator. Demand patterns are defined along two dimensions to account for monthly and weekday variability. Monthly variability accounts for seasonal trends in travel, while the weekday dimension shows the effect of day-to day variation in demand. These demand multipliers give the ratio of demand for a day-month combination to the AADT, and are used to generate demand values while modeling different reliability scenarios.

II-3.1.3. Incident Data

For modeling the effect of incidents as part of the reliability analysis, one option is to gather detailed incident logs. This process generally requires a substantial amount of data cleaning, filtering and manipulation before they can be used in a reliability analysis. The input data required for the reliability analysis includes incident frequencies by month of year, and incident duration statistics categorized by severity. Characterizing incidents requires cleaning and processing of annual incident log datasets, typically maintained by state DOTs or other transportation agencies. Such databases usually contain incidents logs reported for different roads and includes attributes such as road name, direction, mile marker, start and end time, severity, and number of closed lanes. For the selected test routes, incident records were collected from NCDOT Travel Information Management Systems (TIMS) website *(7)*. All incident observations on I-40 for weekdays in calendar year 2015 were filtered by mile markers and direction of travel for each route.

The duration of an incident is calculated as the difference between its reported start and end time. Since incident logs are usually manually reported and, hence, susceptible to human error, outlier removal is a necessary step. Outlier observations for the test routes were removed using an Inter-Quartile Range check on incident duration grouped by severity type (shoulder closure, one lane closure, etc.). The records were then processed to calculate daily incident frequencies for each month of the year and incident duration statistics including the mean, standard deviation, min and max were computed and categorized by severity. These distributional characteristics of incident duration were input to FREEVAL, which randomly simulates incident occurrence and durations in an analysis period using Poisson and Log Normal distributions respectively fitted to these input parameters. The start time and location of these incidents are assigned using a weighted allocation based on the daily Vehicle Miles Traveled (VMT) profile for each segment.

II-3.1.4. Weather Data

Calibrating weather events require historical weather data, which is used to estimate the probability, average duration, and standard deviation of duration of different weather events. The HCM methodology requires the specification of the probability of up to 11 different weather events by calendar month as input. Calibrating weather events require historical weather data, which is used to estimate the probability, average duration, and standard deviation of duration of different weather events, as categorized in the HCM. In this project, the research team used regional default weather event probabilities and default impacts. FREEVAL has a database of 10 years' average of weather events probabilities for about a hundred largest metropolitan areas in the US, via the Weather Underground service *(8).* This study used the Raleigh-Durham Airport location to extract weather probabilities for the case studies.

II-3.1.5. ITS Probe Vehicle Data

ITS probe vehicle speed data is required for both the core facilities method and the reliability analysis. The core facility methodology in the HCM requires calibrating bottlenecks in the facility, to represent the traffic demand patterns that the facility experiences in a typical day. In order to do this, speed data aggregated for 15-minute time intervals for a normal or typical day of the year is gathered, for the TMC segments included in the facility. FREEVAL uses a genetic meta-heuristic algorithm to perform the bottleneck capacity calibration and estimate capacity adjustment factors.

The speed data ultimately forms the basis for the validation data set, used after the reliability analysis is done. The speed data is converted to simultaneous travel times by stitching across the different TMCs on the route and used to calculate Travel Time Index (TTI). This TTI is then used to validate the results provided by FREEVAL at the end of the reliability analysis.

II-3.2. Application to Pilot Test Routes in North Carolina

This section describes the procedure of application of the HCM reliability analysis using FREEVAL and discussed the results of the tests on four selected real-world case studies.

II-3.2.1. Scope of Study

Four routes on I-40 around the Raleigh-Durham metropolitan area were selected to implement the steps for the single-day and reliability methodology described in the HCM.

II-3.2.1.1. Spatial Boundaries of Analysis

Route 1 an urban interstate route, 15.63 miles long along I-40 in the eastbound direction, from NC-147 to US-1, and contains 27 TMC segments. This route experiences an evening or PM peak hour traffic, with most drivers commuting from the Research Triangle Park to Raleigh after a work day. The path is primarily a commuter route that connects Raleigh, NC to Durham, NC and serves and passes through the Research Triangle Park, a major employment center in the area. The speed limit is 65 mph along the entire path, and the travel time at the speed limit is 18.06 minutes.

Route 2 is the westbound directional stretch of I-40 spanning the same geographical extents as Route 1, between US-1 and NC-147. It contains about 27 TMC segments, and experiences a morning peak hour traffic, with most people commuting to Research Triangle Park in the morning to report to work. Due to the presence of the large-scale construction zone upstream of this route during the analysis timeframe, the peak period demand is metered and more spread out than was observed in previous year. The speed limit is 65 mph along the entire path.

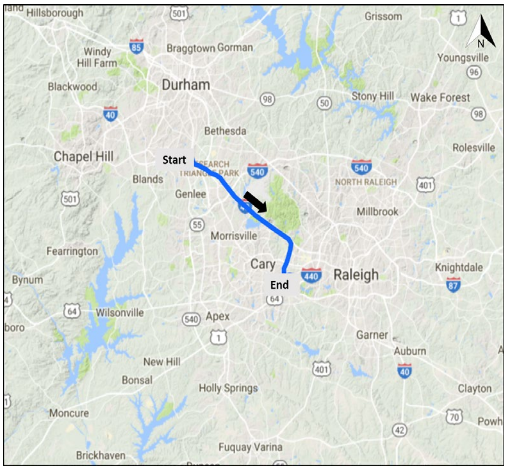
Route 3 is a rural part of I-40 in the westbound direction and is 38.19 miles long, running between NC-50/55 in Benson and I-440 near Raleigh and contains 22 TMC segments. The path crosses I-95 on the way to Raleigh, NC from southeastern North Carolina. The speed limit is 70 mph from the origin until approximately 30 miles into the path, where the speed limit is 65 mph for the remainder of the path, and the travel time at the speed limit is 34.53 minutes. This route also experiences a morning or AM peak travel with commuters driving in to the Triangle for work.

Route 4 is a mixture of urban and rural interstate, 48.69 miles long on I-40 westbound between the I-95 and NC-147 and contains 53 TMC segments. The path serves commuter traffic on interior sections, but typically only intercity traffic travels the entire path. The path encompasses all of Route 2 and part of Route 3, and includes the stretch of I-40 on the Raleigh beltline in between them. The speed limit is 70 mph from the origin until approximately 17 miles into the path, where the speed limit drops to 65 mph for the remainder of the path. The travel time for the entire path at the speed limit is 52.22 minutes. This route experiences a mixture of AM and PM peak traffic on different stretches. The travel time on this route also exceeds the 15-minute analysis period, which is why the 15-minute volume count inputs are averaged for 4 consecutive periods. Exhibit II - 9 contains the geographical information about the four selected routes and Exhibit II - 10 displays the maps of the four paths.

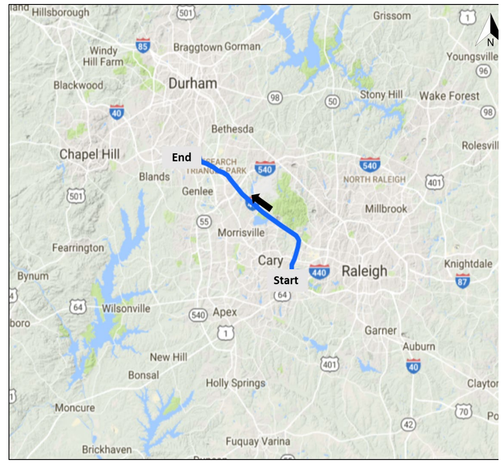
Exhibit II - 9: Geometric information for four selected routes

Facility Geometry	Route 1	Route 2	Route 3	Route 4
Number of TMC Segments	27	27	22	53
Number of HCM Segments	37	45	37	94
Length of Facility (mi)	15.63	15.69	38.19	48.97
Average Free Flow Speed (mph)	70	70	70	70
Free Flow Travel Time (min)	18.06	14.92	34.72	43.37
Start Lat/Long	35.906010, -78.888834	35.772844, -78.741697	35.253196, -78.378151	35.398602, -78.522559
End Lat/Long	35.772634, -78.742212	35.906216, -78.888743	35.746584, -78.593094	35.906216, -78.888743
Start Mile Marker	Exit 278	Exit 293	Exit 301	Exit 328
End Mile Marker	Exit 293	Exit 278	Exit 341	Exit 278
AADT	107,000 – 192,000	107,000 – 192,000	17,000 – 107,000	38,000 – 192,000

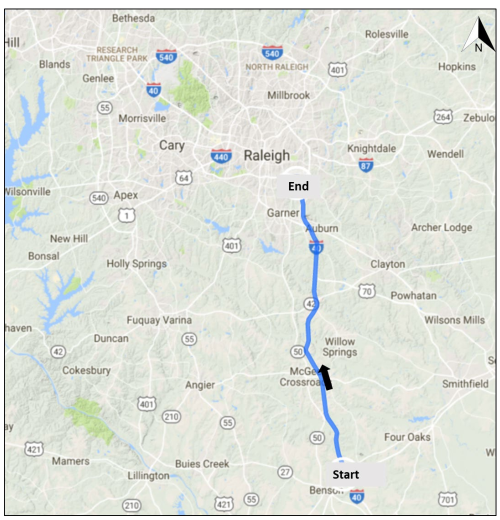
Exhibit II - 10: Map of Study Routes



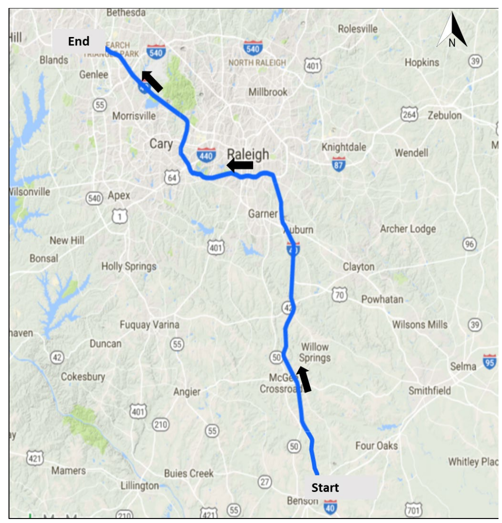
(a) Route 1



(b) Route 2



(c) Route 3



(d) Route 4

II-3.2.1.2. Temporal Boundaries of Analysis

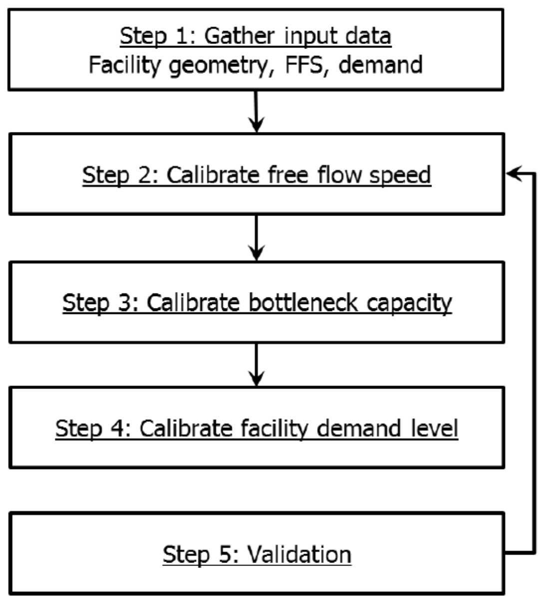
The analysis period, defined as the smallest time unit for which the HCM analysis procedure is applied, is 15 minutes. The study period is the sum of the sequential analysis periods for which the HCM facility analysis procedure is applied. For our case study, we selected a 24-hour study period, which adds up to 96 analysis periods in a day. We also defined a reliability reporting period, which specifies the number of days for which the reliability analysis is to be performed. For the analysis of the three routes described above, all weekdays for the year 2015 were selected as the temporal scope, which corresponds to 240 study periods and a total of 23,040 analysis periods.

II-3.2.2. Core Methodology Calibration and Results

II-3.2.2.1. <u>Core Methodology Calibration</u>

This section discusses the steps to calibrate the core (single day) freeway facility, as shown in Exhibit II - 11. This calibrated core facility forms the basic model on top of which the reliability analysis is carried out.

Exhibit II - 11: HCM Exhibit 25-26 - Core Analysis Calibration Prcoedure



The first step involved defining the segments' geometry consistent with the requirements of performing the analysis method described in the HCM. In our study, routes 1, 2, 3 and 4 consist of 37, 45, 37 and 94 HCM segments respectively. This process followed the HCM guidelines on how to segment the subject freeway facility. Other inputs, such as segment length, number of lanes, and shoulder clearances were extracted directly from Google Maps.

Travel times at very low traffic demand conditions represent free flow travel times, which is a function of free flow speed. The estimated free flow travel times at low traffic demand flows were compared to the probe-based sensor data and necessary adjustments were made to calibrate the free-flow speed in the models.

Demand flow rates for the mainline, on-ramp entry and off-ramp exit were estimated based on AADTs and hourly demand profiles, and subsequently aggregated into 15-minute intervals. Collectively, this data forms the basis for all inputs and outputs of the model. However, Route 4 is a much longer section of I-40, with a free flow travel time longer than 15 minutes. Hence, the demand input for three subsequent time periods were averaged as an input into this model. Finally, to calibrate the single day facility, an automated approach for the

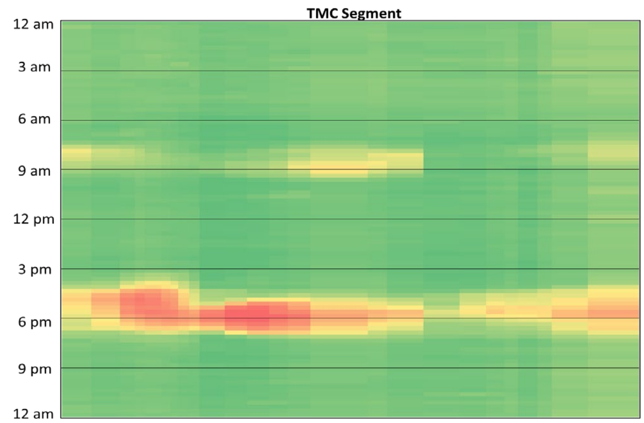
HCM bottleneck capacity calibration process was used for all routes, except for Route 4 *(9)*. It uses mathematical optimization techniques and employs a genetic algorithm (GA) to estimate capacity and demand adjustment factors. It optimizes the capacity and demand adjustments such that they result in predicted performance measures consistent with the empirical speed data and significantly helps reduce the time and effort needed for analysis. However, this algorithm makes use of a Google Maps API to allow users to download target probe speed data from data providers such as RITIS.org for calibration. Due to limitations on free Google Maps API download, the automated approach could not be extended to the larger Route 4. The research team was not able to use Google Maps to create the large Route 4 facility. Therefore, manual calibration based on the HCM6 guidance is used to calibrate Route 4. In other words, the calibration process for Route 4 was carried out manually, by tuning the Capacity Adjustment Factors (CAFs) and Demand Adjust Factors (DAFs), such that the resulting speed contour matches the speed contour from INRIX speed observations for a typical weekday.

II-3.2.2.2. Results of Core Methodology Calibration

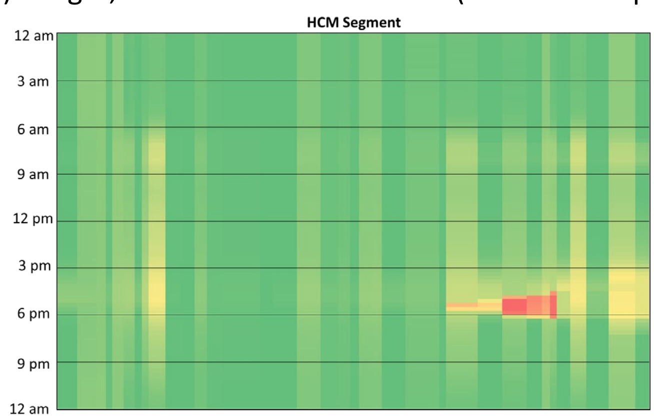
The primary data source for calibration was INRIX (extracted from RITIS.org), which provides probe-based travel time and speed data *(10)*. INRIX uses internal and external TMC codes as the smallest spatial unit for reporting freeway performance measures. This method reports traffic data between each break in access on any road (such as from one on-ramp to next off-ramp). It was observed that a single TMC segment usually covers two or more HCM segments. To perform validation via probe-based data sources, the actual facility as configured was converted into HCM segments. A length-based average of HCM segments' performance measures is used to match TMC segments. The speed contours before and after calibration using INRIX probe data, for Routes 1 and 4, respectively, can be seen in Exhibit II - 12 and Exhibit II - 13. Calibration contours for the remaining routes can be found in Appendix II - A.

In Exhibit II - 12, the results of demand/bottleneck calibration for Route 1, using the automated genetic algorithm are shown *(9)*. It is used to estimate and adjust demand profiles such that the predicted speed contours are consistent with provided real-world data. The HCM freeway facilities methodology includes a set of parameters called Demand Adjustment Factors (DAFs), that can be used to adjust input demand volumes. As can be seen, the calibrated facility is able to reproduce speed contours similar to real-world target speeds, by activating the bottleneck and increasing the duration of congested flow in the PM peak period.

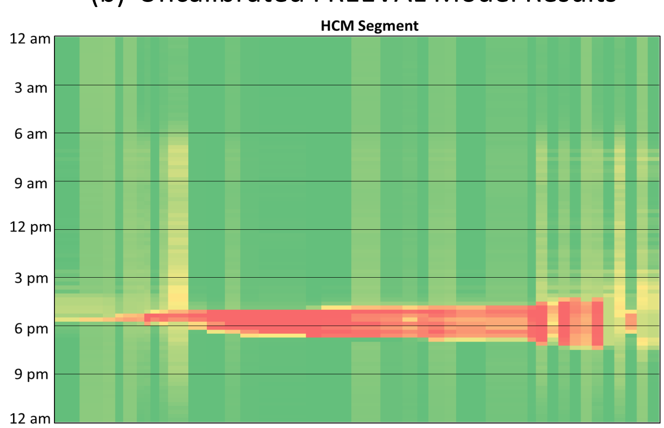
Exhibit II - 12: Automated Demand Calibration using Probe Data for Route 1



(a) Target, real - world observations (Probe Data Speeds)



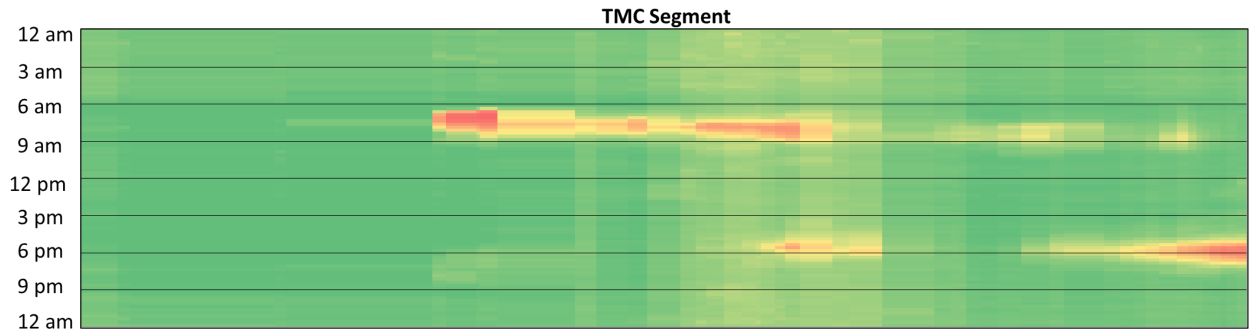
(b) Uncalibrated FREEVAL Model Results



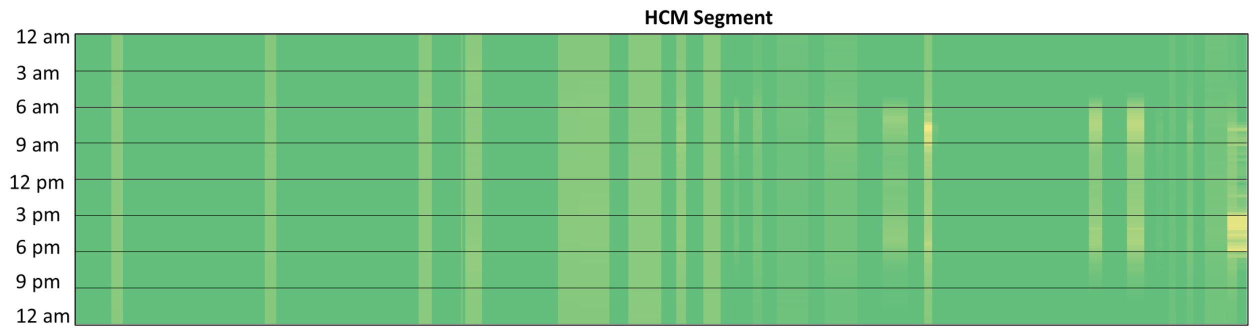
(c) FREEVAL Model after Automated Calibration

For Route 4, the core facility calibration was carried out by changing the DAFs and CAFs. The effect of this, as shown in Exhibit II - 13 (c), is to create congestion a pattern more consistent with the real-world data than was the pattern created by the uncalibrated model.

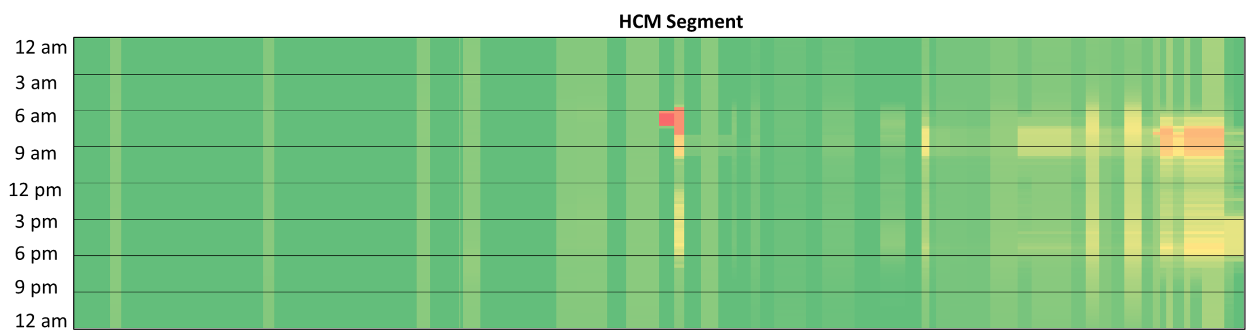
Exhibit II - 13: Manual Demand and Capacity Calibration using Probe Data for Route 4



(a) Target real - world observations (Probe Data Speeds)



(b) Uncalibrated FREEVAL Model Results



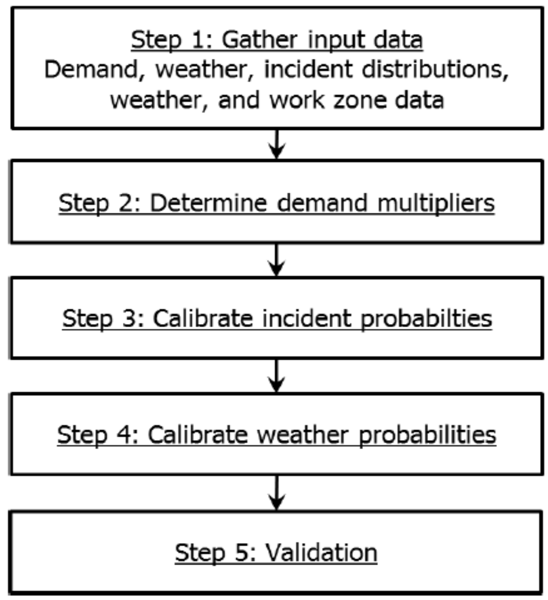
(c) FREEVAL Model after Manual Calibration

II-3.2.3. Reliability Analysis and Results

II-3.2.3.1. Reliability Methodology Calibration

After the single day calibration of the four selected facilities, calibration for the reliability scenarios was performed. The HCM requires characterization of the demand fluctuation across days of the week and months of the year. Also, non-recurring congestion sources, i.e., incidents, weather, work zones, etc. need to be calibrated. The steps involved in the calibration of the reliability scenario generator in FREEVAL are shown in Exhibit II - 14 and the input data in each step is also displayed.

Exhibit II - 14: HCM Exhibit 25-32 Reliability Calibration Procedure



For estimating the demand multipliers, the permanent counts station data was aggregated and divided by the AADT on different sections of I-40 to construct Exhibit II - 15, since the subject facilities are quite close to each other.

Exhibit II - 15: Demand Multipliers for I-40

Demand Multiplier		Day of Week				
		Monday	Tuesday	Wednesday	Thursday	Friday
Month of Year	January	0.99662	1.02778	1.04039	1.0526	1.08161
	February	0.93925	1.01073	1.03921	1.09203	1.14007
	March	1.04331	1.06934	1.06352	1.11092	1.17112
	April	1.07358	1.08746	1.09824	1.16197	1.215
	May	1.07633	1.10618	1.11396	1.15772	1.21043
	June	1.07804	1.08585	1.06747	1.13872	1.18033
	July	1.08258	1.07099	1.10251	1.14728	1.18498
	August	1.04605	1.05215	1.06037	1.09324	1.1649
	September	1.01602	1.02405	1.02363	1.07478	1.15295
	October	1.04898	1.04572	1.06699	1.10704	1.16095
	November	0.97404	0.99995	1.04121	1.08154	1.07035
	December	0.97479	0.95648	0.98702	0.91611	1.0077

Exhibit II - 16 and Exhibit II - 17 show the daily incident frequencies, incident duration statistics and distribution between different lane closure types on the four study facilities, which serve as a user-defined input to the reliability scenario generator in FREEVAL.

Exhibit II - 16: Daily Incident Frequencies for each month of 2015 for each Route

Month	Number of Incidents	Number of days	Incident Frequencies
January	29	22	1.32
February	38	20	1.90
March	26	22	1.18
April	28	22	1.27
May	23	21	1.10
June	25	22	1.14
July	22	23	0.96
August	38	21	1.81
September	27	22	1.23
October	30	22	1.36
November	37	21	1.76
December	26	23	1.13

(a) Route 1

Month	Number of Incidents	Number of days	Incident Frequencies
January	28	22	1.27
February	40	20	2.00
March	31	22	1.41
April	32	22	1.45
May	22	21	1.05
June	26	22	1.18
July	24	23	1.04
August	37	21	1.76
September	30	22	1.36
October	42	22	1.91
November	34	21	1.62
December	32	23	1.39

(b) Route 2

Month	Number of Incidents	Number of days	Incident Frequencies
January	11	22	0.50
February	20	20	1.00
March	7	22	0.32
April	7	22	0.32
May	9	21	0.43
June	12	22	0.55
July	1	23	0.04
August	3	21	0.14
September	8	22	0.36
October	10	22	0.45
November	11	21	0.52
December	7	23	0.30

(c) Route 3

Month	Number of Incidents	Number of days	Incident Frequencies
January	52	22	2.36
February	69	20	3.45
March	50	22	2.27
April	54	22	2.45
May	50	21	2.38
June	61	22	2.77
July	48	23	2.09
August	64	21	3.05
September	73	22	3.32
October	86	22	3.91
November	74	21	3.52
December	74	23	3.22

(d) Route 4

Exhibit II - 17: Incident Duration Statistics by Incident Type for the year 2015 for each Route

Incident Type	Count	Average duration (min)	Std dev duration (min)	Max duration (min)	Min duration (min)	Percentage Distribution (%)
1 Lane Closed	105	39.90	32.46	136.33	2.77	30.09
2 Lane Closed	8	39.29	25.90	89.00	8.72	2.29
3 Lane Closed	2	32.56	30.18	53.90	11.22	0.57
Shoulder Closed	234	60.47	31.74	147.53	3.97	67.05

(a) Route 1

Incident Type	Count	Average duration (min)	Std dev duration (min)	Max duration (min)	Min duration (min)	Percentage Distribution (%)
1 Lane Closed	120	33.29	23.32	104.55	4.53	31.75
2 Lane Closed	11	42.93	31.05	92.18	4.53	2.91
3 Lane Closed	2	99.53	23.23	115.95	83.10	0.53
Shoulder Closed	245	55.30	29.05	134.62	3.52	64.81

(b) Route 2

Incident Type	Count	Average duration (min)	Std dev duration (min)	Max duration (min)	Min duration (min)	Percentage Distribution (%)
1 Lane Closed	25.00	69.11	61.87	230.10	5.48	23.58
2 Lane Closed	2.00	57.40	16.07	68.77	46.03	1.89
Shoulder Closed	79.00	52.67	26.35	118.12	4.65	74.53

(c) Route 3

Incident Type	Count	Average duration (min)	Std dev duration (min)	Max duration (min)	Min duration (min)	Percentage Distribution (%)
1 Lane Closed	236	35.80	24.81	120.00	4.53	31.26
2 Lane Closed	30	42.70	25.36	95.38	4.53	3.97
3 Lane Closed	6	54.06	38.39	115.95	12.65	0.79
Shoulder Closed	483	52.43	28.43	140.42	2.68	63.97

(d) Route 4

II-3.2.3.2. Results of Reliability Analysis

The results of the model were validated against travel times collected for the corresponding TMC segments on each route. Since the HCM method uses 15-minute intervals as the basic temporal unit of analysis, 15-minute average reported TMC travel times were gathered from INRIX. These travel times were converted to a route Travel Time Index using a simultaneous path travel time estimation method. The TTI distribution of the HCM method was then validated against that counted from probe data speeds. Additional results of the reliability analysis are reported in Appendix II - B.

Travel Time Index Comparison

Exhibit II - 18 through Exhibit II - 21 show the various distribution statistics, alongside the Cumulative Distribution Functions (CDFs) of the emerging Travel Time Index distribution estimated using FREEVAL for the four study sites compared to that reported by INRIX for the corresponding set of TMC segments. The average, 50th and 80th percentile TTIs computed using the HCM method for all three routes were all within 15% of those reported by INRIX. The new reliability performance measures, such as Level of Travel Time Reliability (LOTTR), proposed by the Federal Highways Administration (FHWA) as part of the Moving Ahead for Progress in the 21st Century Act (MAP-21) were also calculated. It is the ratio of the 80th percentile travel time to 50th percentile travel time, for three time windows in a day (6 am to 10 am, 10 am to 4 pm, and 4 pm to 8 pm). The travel time observations for the year 2015, from the FREEVAL output and reported probe speeds, were filtered for each of the three time windows and the corresponding percentiles and hence, LOTTRs were calculated. These metrics calculated from the FREEVAL output for each of the four study routes were found to be within 15% of INRIX observations.

However, for Route 1, the evening peak LOTTR value from the FREEVAL output is significantly higher than that calculated from INRIX data. The same comments apply to the higher region of the distribution at or above the 90% TTI, where significant differences between the two CDF's are noted. For routes 2 and 3, the overall CDFs and performance statistics were very consistent between the FREEVAL output and empirical data from INRIX. In Appendix II - C, we take a closer look at the incident scenario generation technique to investigate possible contributions to the large discrepancy in the upper regions of the TTI distribution for Route 1.

Another discrepancy in the results is seen in the LOTTR calculation for the evening peak period for the manually calibrated Route 4. The evening LOTTR calculated from the probe vehicle data is higher than what is modeled by FREEVAL. One reason may be attributed to using simultaneous (as opposed to stitched) travel times from probe data speeds to compare the results of FREEVAL against. For a long route, this produces a larger impact on accuracy and results in higher route travel times than is actually experienced. This MOE in the probe context is derived from instantaneous speed observations, which is not the case in FREEVAL. FREEVAL simulates traffic conditions at the time of congestion and due to the large length of facility, MOEs are correlated between time periods. This may insert some bias into the reliability performance measures estimated by FREEVAL with respect to real world conditions. Another issue related to the length of the facility includes the presence of multiple bottlenecks that activate at different times of day, while the current CAF-based approach is confined to applying a single CAF per segment for the entire analysis period. Finally, the use of fixed demand for 4 consecutive analysis periods to accommodate the travel time constraint (i.e., demand cannot change while other vehicles from previous periods are traveling on the facility) could also have impacted the results for Route 4.

Exhibit II - 18: Reliability Statistics and CDF from FREEVAL and Probe Data for Route 1

TTI Metrics	FREEVAL	Probe Data
Average	1.31	1.13
Min	1.02	0.95
Max	22.79	6.79
Std Dev	0.77	0.34
50th Percentile	1.06	1.03
80th Percentile	1.12	1.06
95th Percentile	3.04	1.29
LOTTR (6 am to 10 am)	1.02	1.10
LOTTR (10 am to 4 pm)	1.03	1.02
LOTTR (4 pm to 8 pm)	1.65	1.19

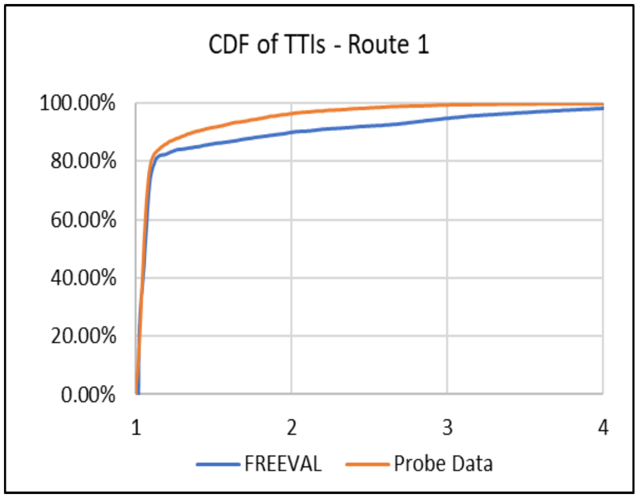


Exhibit II - 19: Reliability Statistics and CDF from FREEVAL and Probe Data for Route 2

TTI Metrics	FREEVAL	Probe Data
Average	1.11	1.09
Min	1.02	0.95
Max	8.39	5.72
Std Dev	0.24	0.22
50th Percentile	1.06	1.03
80th Percentile	1.09	1.06
95th Percentile	1.46	1.29
LOTTR (6 am to 10 am)	1.05	1.01
LOTTR (10 am to 4 pm)	1.02	1.01
LOTTR (4 pm to 8 pm)	1.54	1.39

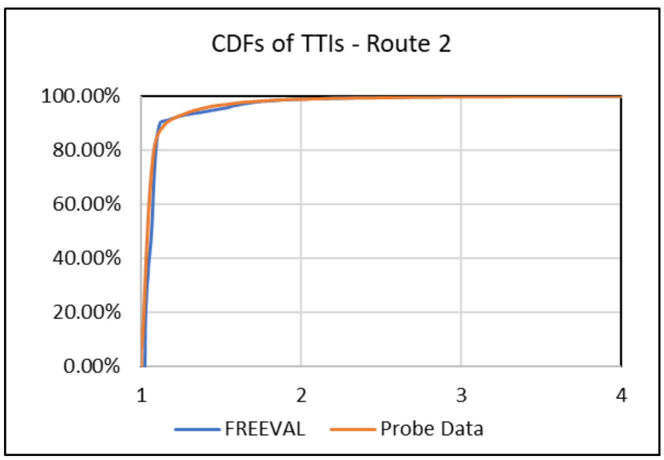


Exhibit II - 20: Reliability Statistics and CDF from FREEVAL and Probe Data for Route 3

TTI Metrics	FREEVAL	Probe Data
Average	1.04	1.02
Min	1.02	0.95
Max	13.63	2.41
Std Dev	0.18	0.09
50th Percentile	1.02	1.00
80th Percentile	1.02	1.02
95th Percentile	1.20	1.12
LOTTR (6 am to 10 am)	1.09	1.11
LOTTR (10 am to 4 pm)	1.00	1.02
LOTTR (4 pm to 8 pm)	1.00	1.02

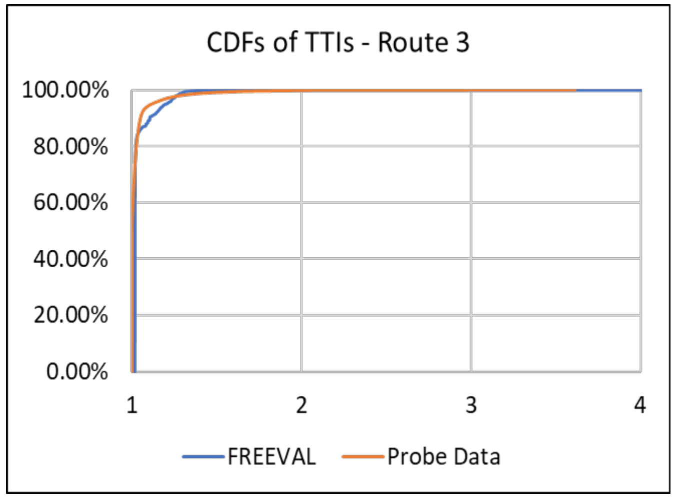
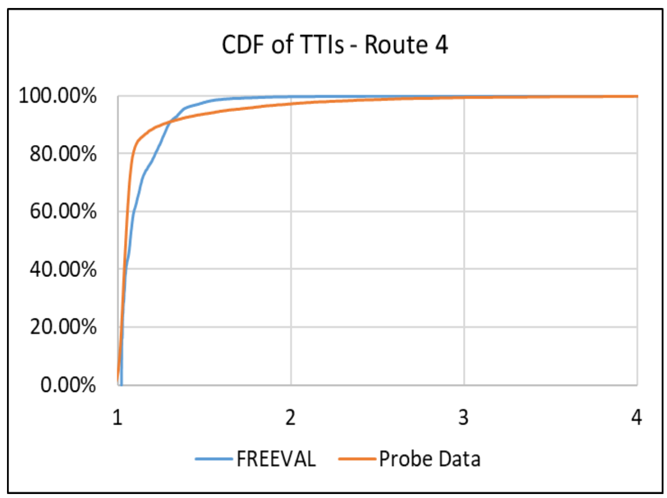


Exhibit II - 21: Reliability Statistics and CDF from FREEVAL and Probe Data for Route 4

TTI Metrics	FREEVAL	Probe Data
Average	1.13	1.13
Min	1.02	0.95
Max	13.06	6.79
Std Dev	0.25	0.34
50th Percentile	1.07	1.05
80th Percentile	1.22	1.09
95th Percentile	1.37	1.64
LOTTR (6 am to 10 am)	1.05	1.05
LOTTR (10 am to 4 pm)	1.10	1.02
LOTTR (4 pm to 8 pm)	1.10	1.52



II-3.3. Findings and Conclusions

The following discussion of the results focuses on the major findings and guidance in the use of the L08 tool. Those are summarized in the next few sections.

- <u>Data collection experience</u>

This section summarizes the overall procedure and experience related to carrying out the travel time reliability analysis methodology described in the 6th edition of the Highway Capacity Manual (HCM6). As described in the previous sections, the data requirement for carrying out both the core calibration and the reliability methodology is detailed. However, there are default parameters (national and regional) that can be used by agencies lacking ready access to more detailed data to carry out the analysis. The built-in AADT profiles in the later versions of the FREEVAL computational engine makes for a much easier input requirement than 15-minute demand volume counts. For the reliability analysis, to model variation in travel demand between days of week and months of the year, demand multipliers are required to be established. This process can become very time-consuming and expensive since it involves collecting volume counts for a few years across months and days of week. The HCM provides some default demand multiplier values for urban and rural facilities. In the case studies described herein, the team used demand multipliers calculated for I-40 in North Carolina. However, these values pertain to the entire stretch of I-40 in general and do not represent the traffic conditions for rural and urban areas separately. This can cause some discrepancies in the results of the reliability analysis.

Other data requirements of the reliability analysis methodology include gathering information about weather and incident occurrence. FREEVAL has an imbedded database of 10 years' average of weather events probabilities for the approximately one hundred largest metropolitan areas in the US. For incidents, national default values are provided for duration of different severity of incidents. Incident frequencies for each month of the year are required to be provided by the user. This information needs to be mined from incident management logs maintained by most DOTs or public transportation agencies. The efforts required for this data manipulation can be time-consuming and requires a moderate to high level of expertise. However, this type of data is highly susceptible to human errors in data entry, which can affect the reliability analysis considerably. Hence, there is need to understand the possible sources of errors and develop a sound methodology for outlier removal. In this project, the research team performed an Inter-Quartile Range outlier check on the incident duration statistics.

- <u>Calibration – automated vs manual</u>

It is advisable to calibrate the core facility to represent the travel conditions on a typical weekday. The automated bottleneck calibration methods provided in the later versions of FREEVAL uses a genetic algorithm to vary the Demand Adjustment Factors (DAFs) and match the core facility's condition to that represented by real-world probe speed data. However, the implementation of this method in FREEVAL makes use of a Google Maps API to allow users to download target probe speed data from data providers such as RITIS.org for calibration. Due to limitations on the free Google Maps API download, the research team was not able to extend this method to the longer Route 4. The bottleneck calibration process for Route 4 was carried out manually, by tuning the Capacity Adjustment Factors (CAFs) and Demand Adjustment Factors (DAFs), such that the resulting speed contour matches the speed contour from INRIX speed observations for a typical weekday. The results from the manual and automated processes show that they both can be beneficial to calibrate the core facility, so that the results of the reliability analysis may be more accurate.

- Reliability analysis – incident modeling

The results of the reliability analysis of the study sites were validated, and the TTI distribution up to the 80th percentile value for each route were found to match closely those observed from probe-based travel times. However, the upper tail of the distribution from FREEVAL for Route 1 yielded travel times that were generally higher than those reported by INRIX. The incidents modeled in the HCM method follow the distribution of the vehicle miles traveled (VMT) in a 24-hour period. However, for urban road segments, during peak periods, incidents can have a cascading effect as traffic demands increase when approaching the peak periods. The effect of one incident in a particular segment could lead to later secondary incidents on upstream segments. The HCM methodology also models incidents with higher average duration since it discretizes every incident duration to the nearest 15-minutes, which is the temporal basis of the HCM methodology. This exacerbates the poor travel conditions along the facility, especially when there are multiple incidents. Finally, FREEVAL does not model any changes in traffic demand (i.e., due to diversions) in response to major incidents, which may also result in inflating their travel time effect when generating the TTI distribution.

- Modeling longer routes vs shorter routes

The case studies carried out in this research also validated the HCM reliability methodology for longer real-world freeway facilities, with a wider variation in mainline AADT. In the case studies discussed above, Route 4 makes up a longer route, as a mixture of urban and rural interstate, 48.69 miles long on I-40 westbound. This route experiences a mixture of AM and PM peak traffic on different stretches, which makes it a challenge to calibrate. Due to limitations on free Google Maps API download, the automated bottleneck calibration method could not be used for this route. Manual calibration had to be done on this route to make the demand patterns similar to that observed from INRIX speed data, which proved to be a challenge. The travel time on this route also exceeds the 15-minute analysis period, which is why the 15-minute volume count inputs are averaged for 4 consecutive time periods. This makes modeling longer routes a time-consuming process.

While validating the reliability results for the longer route, it was observed that the PM peak period TTI's modeled by FREEVAL were consistently lower than those calculated from INRIX speed data. Since INRIX speeds are reported at a TMC segment level, the route travel times for each observation period were calculated by simultaneously adding the observed travel times in each TMC segment. This approach is not a true representation of the real world and can cause inflations in the ultimate calculated route travel times. Especially on a longer route such as Route 4 in this study, this artificial effect of simultaneous travel times can become quite significant. It is recommended to stitch these travel times across the different segments, but the current version of FREEVAL does not have the capacity to do so. Another reason for the lower PM peak travel times in FREEVAL could be the variation in AADT across the long route (38,000 – 192,000), whose impact is not being captured in the HCM methodology.

II-3.4. Recommendations for L08 Product Enhancement

- Because incidents are primarily responsible for the high region in the TTI distribution, it is recommended that users be able to input the diurnal (or spatial-by segment) pattern of their occurrence directly into the L08 tool. Only in cases where such data are not available, should the default distribution by VMT in time and space be used. Please see Appendix C for a screenshot of the proposed new incident input data option.

- The team recommends that the FHWA rulemaking metrics on travel time reliability be directly generated by the L08 tool, based on user specified time periods (which would default to LOTTR specifications).

- In a similar manner, and in order to generate network wide reliability per the FHWA final rulemaking, individual segment-based reliability measures should also be reported as part of the L08 tool output. This is important since each segment receives a 0/1 reliability rating based on the its LOTTR threshold value.

- A more realistic estimation of facility travel time is to replace the current simultaneous travel time calculation carried out each 15 minutes with a stitched or "walking the travel time" approach. In essence, vehicles entering a segment in the L08 tool will be assigned the travel time for the link at the time of entry, as opposed to the time entered the facility. While conceptually simple to understand, this may require some major restructuring of the current code.

- Another algorithmic improvement which will enable the consideration of multiple interacting bottlenecks in the L08 tool is to move from a quasi to a formal cell transmission approach in the oversaturated flow regime. This is an important and long overdue improvement, which can hopefully be attended to in the upcoming NCHRP 03-96A project on the enhancement to the oversaturated procedure in HCM 6th edition.

- We recommend that some of the proposed and short term improvements identified in this study be implemented in the FREEVAL-NC version currently being developed for all interstate facilities in North Carolina. It is a testament to the quality of the L08 tool that NCDOT has decided to use it statewide as the tool for both core facility, work zone and reliability analyses.

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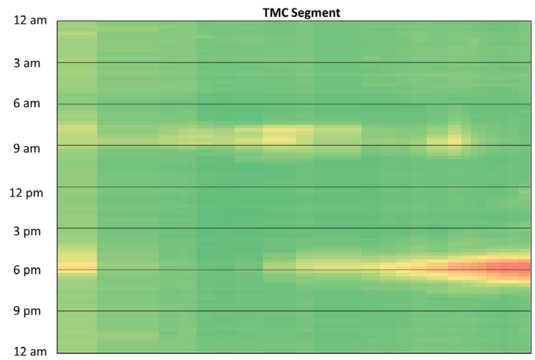
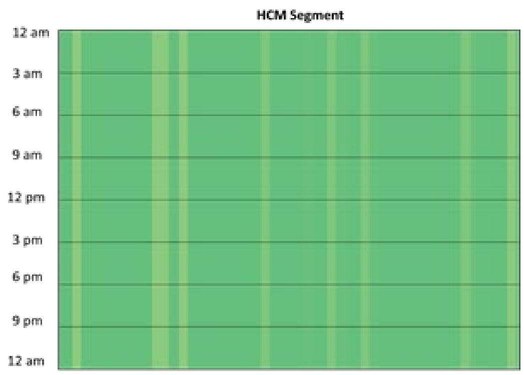
APPENDIX II - A – CORE CALIBRATION RESULTS

Exhibit II A - 1 below shows that the automated calibration approach activated the PM peak bottleneck, consistent with the real-world speed data for Route 2.

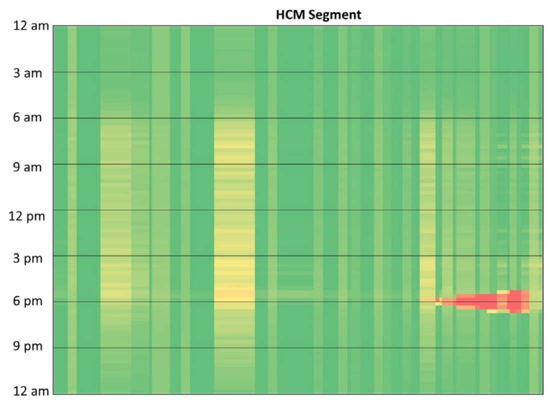
Exhibit II A - 1: Automated Demand Calibration using Probe Data for Route 2



(a) Target real - world observations (Probe Data Speeds)



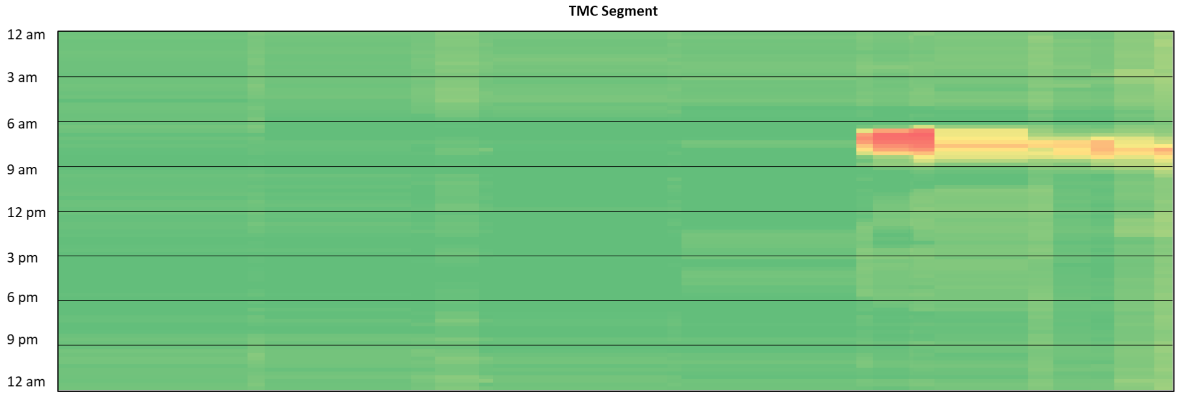
(b) Uncalibrated FREEVAL Model Results



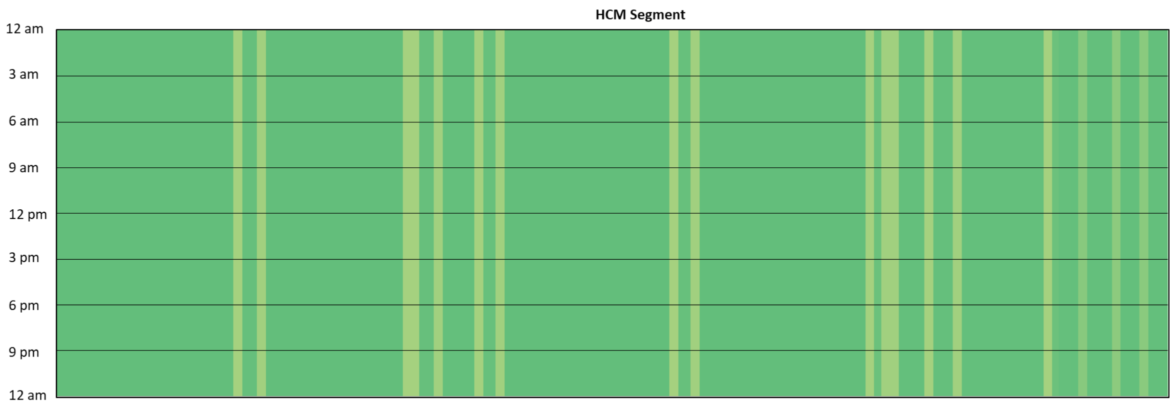
(c) FREEVAL Model after Automated Calibration

Exhibit II A - 2 below shows that the automated calibration approach activated the AM peak bottleneck, consistent with the real-world speed data for Route 3.

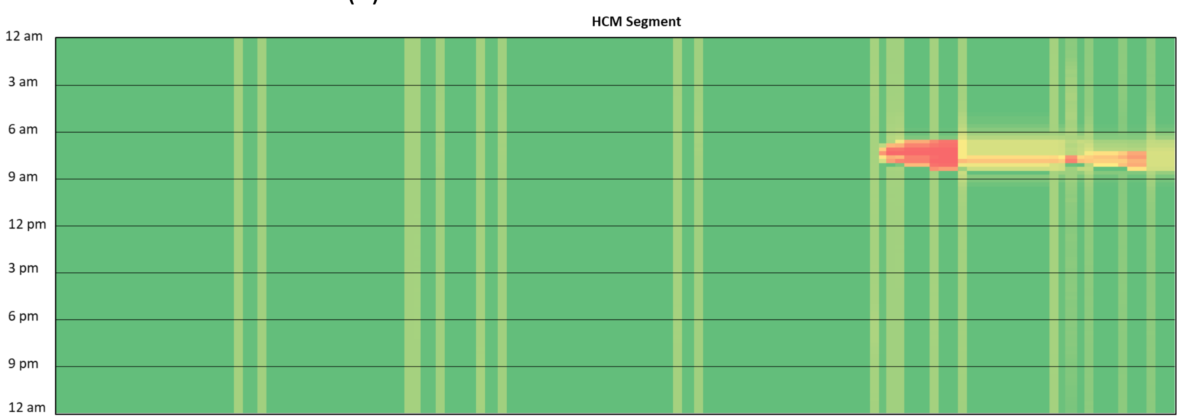
Exhibit II A - 2: Automated Demand Calibration using Probe Data for Route 3



(a) Target real - world observations (Probe Data Speeds)



(a) Uncalibrated FREEVAL Model Results



(a) FREEVAL Model after Automated Calibration

APPENDIX II - B – ADDITIONAL RELIABILITY ANALYSIS RESULTS

In this section, the TTI as calculated by the HCM reliability method is compared against that reported by the probe data, by averaging and grouping them by time of day.

In Exhibit II B - 1, it can be seen that the average TTI as modeled by FREEVAL is consistently higher on average for the evening peak hours between 4 pm and 8 pm. This also provides more insight into the discrepancies in the CDF shown earlier in Exhibit II - 18 through Exhibit II - 21.

Exhibit II B - 1: FREEVAL and Probe Data TTI Distribution over time of day for Route 1

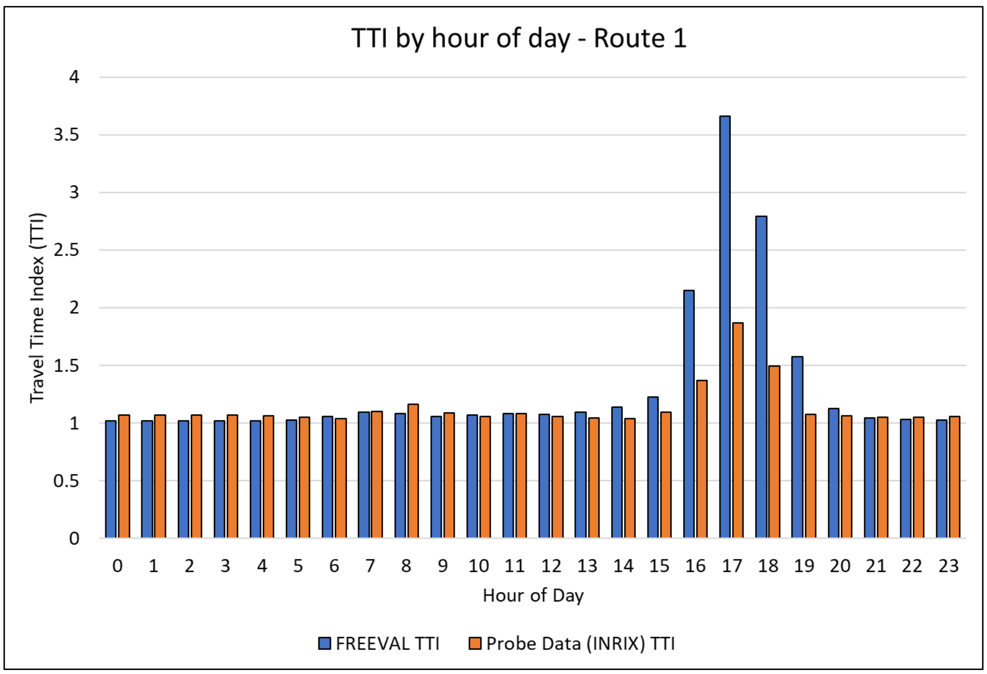


Exhibit II B - 2 and Exhibit II B - 3 below show that for Route 2 and Route 3, the distribution of the average TTI over time of day, as generated by the FREEVAL reliability analysis closely follows that reported by the probe data.

Exhibit II B - 2: FREEVAL and Probe Data TTI Distribution over time of day for Route 2

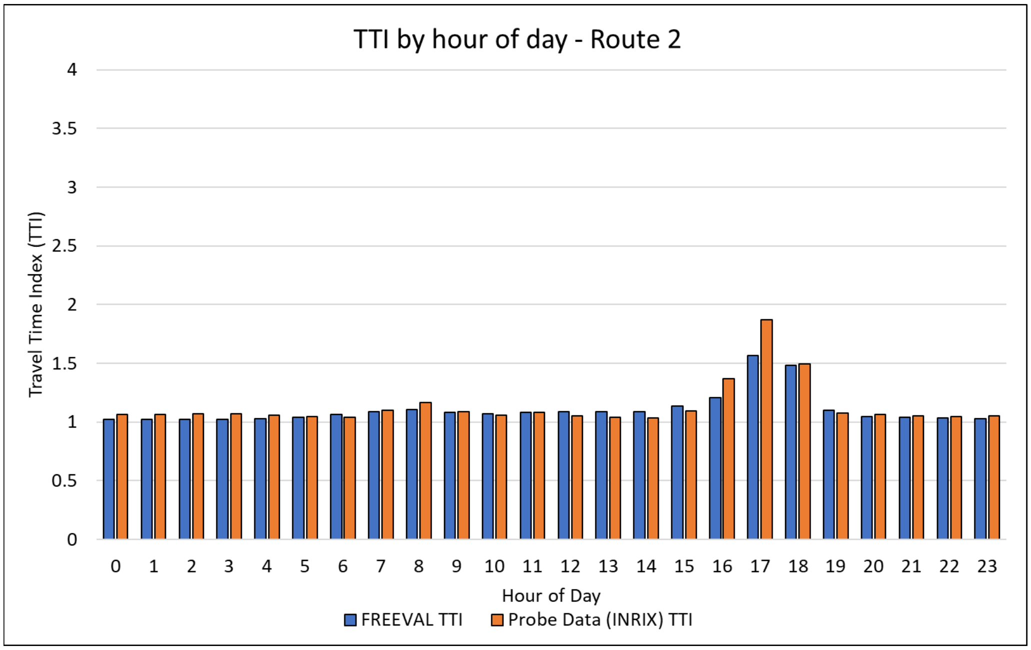
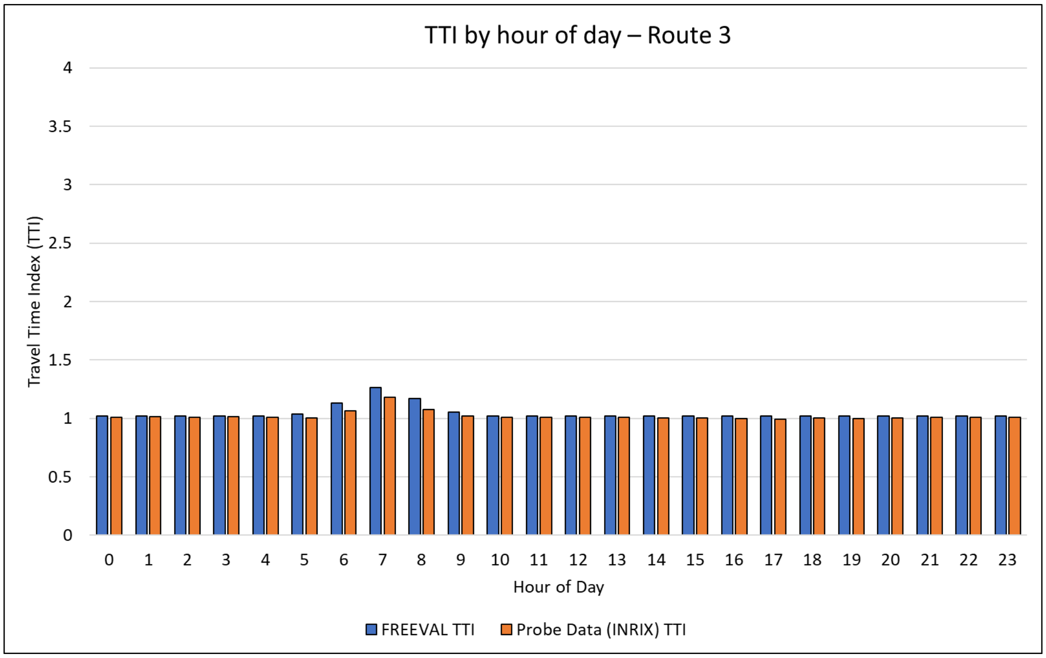
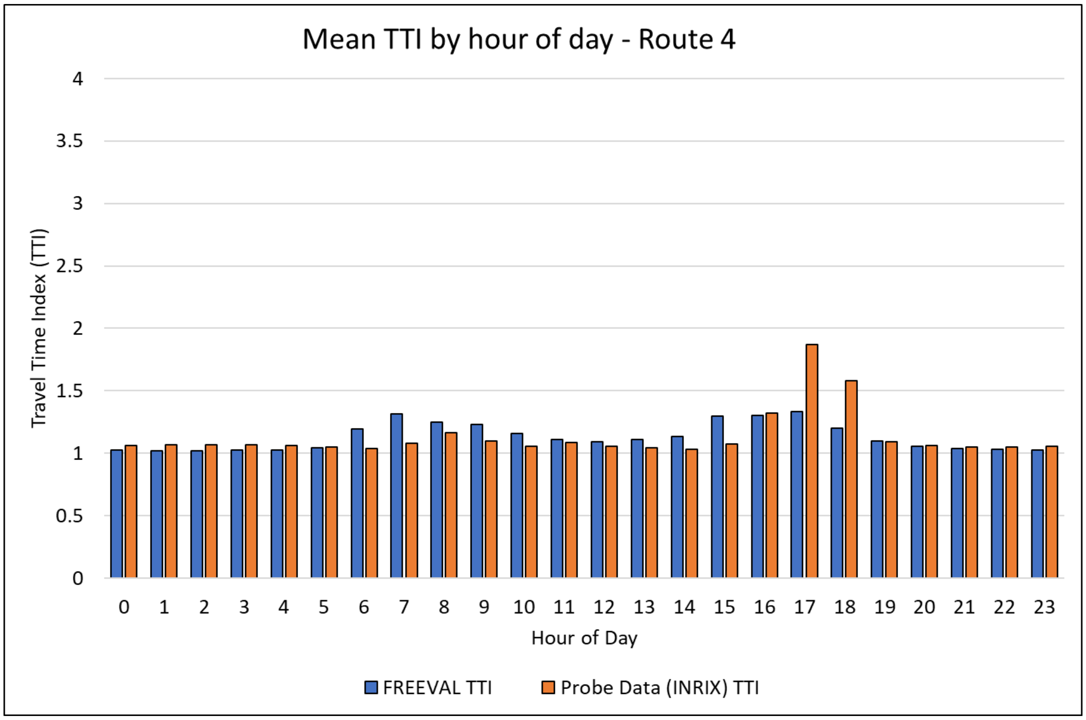


Exhibit II B - 3: FREEVAL and Probe Data TTI Distribution over time of day for Route 3



For Route 4, we can see from Exhibit II B - 4 that FREEVAL underestimated the PM peak period TTIs, between 5 pm and 6 pm, as compared to the real-world TTI distribution, calculated from probe data.

Exhibit II B - 4: FREEVAL and Probe Data TTI Distribution over time of day for Route 4

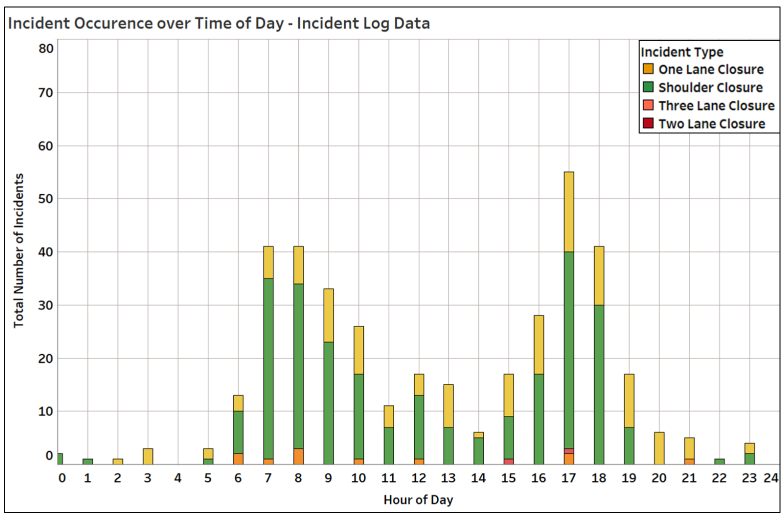


APPENDIX II - C – INCIDENT SCENARIO GENERATION

II-C-1. Comparison to Real-world Incident Occurrence and Duration

Exhibit II C - 1 shows the number of incidents generated over time of day, as calculated from the incident log data and as modeled by FREEVAL while generating the diiferent scenarios. It is clear that FREEVAL does not adequately capture the temporal incident trends found in the actual data, mainly as a result of the assumption in the HCM to use VMT distribution to spread incidents start times and location in the reliability scenarios. This pattern actually generated higher values of the 95th percentile TTI in the FREEVAL ouput, possibly because the accumulation of incidents starting in the early afternoon may have initiated congestion earlier, which was exacerbated as traffic demands kept increasing during the PM peak period.

Exhibit II C - 1: Incident occurrence for Time of Day from Incident Log Data (TIMS) and FREEVAL incident scenario generation



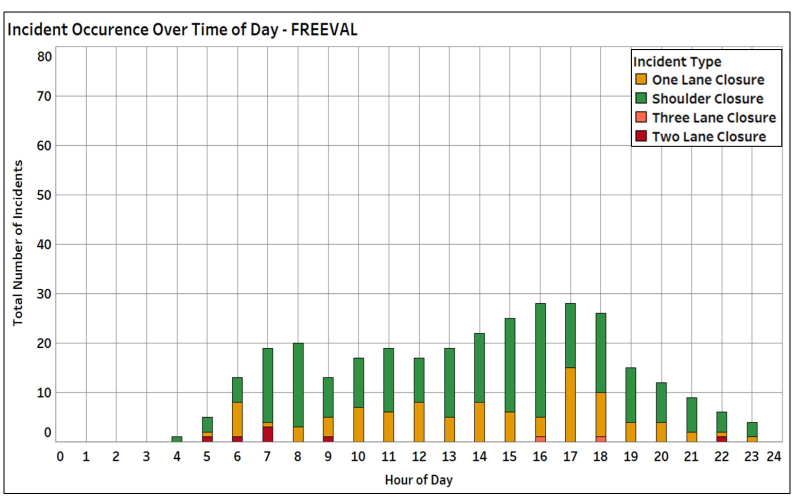
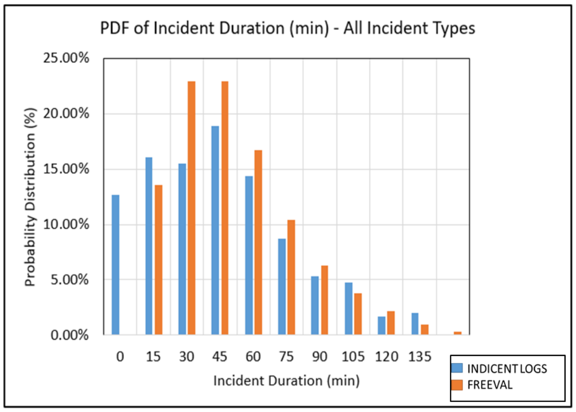
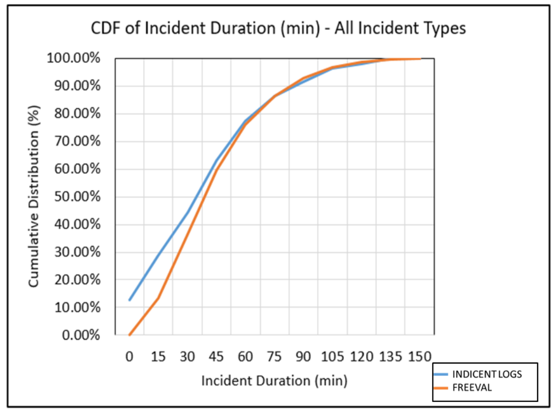


Exhibit II C - 2 below shows the incident duration distributions in both FREEVAL and in TIMS or incident logs. It depicts the discretization of all incident durations in the HCM model to the nearest 15-minutes. Hence, all actual incidents that clear in fewer than 15 minutes are not considered in the HCM approach. In effect, the method will tend to consistently model incidents with duration higher than empirical observations indicate.

Exhibit II C - 2: Distributions of Incident Duration: Incident Logs vs. FREEVAL

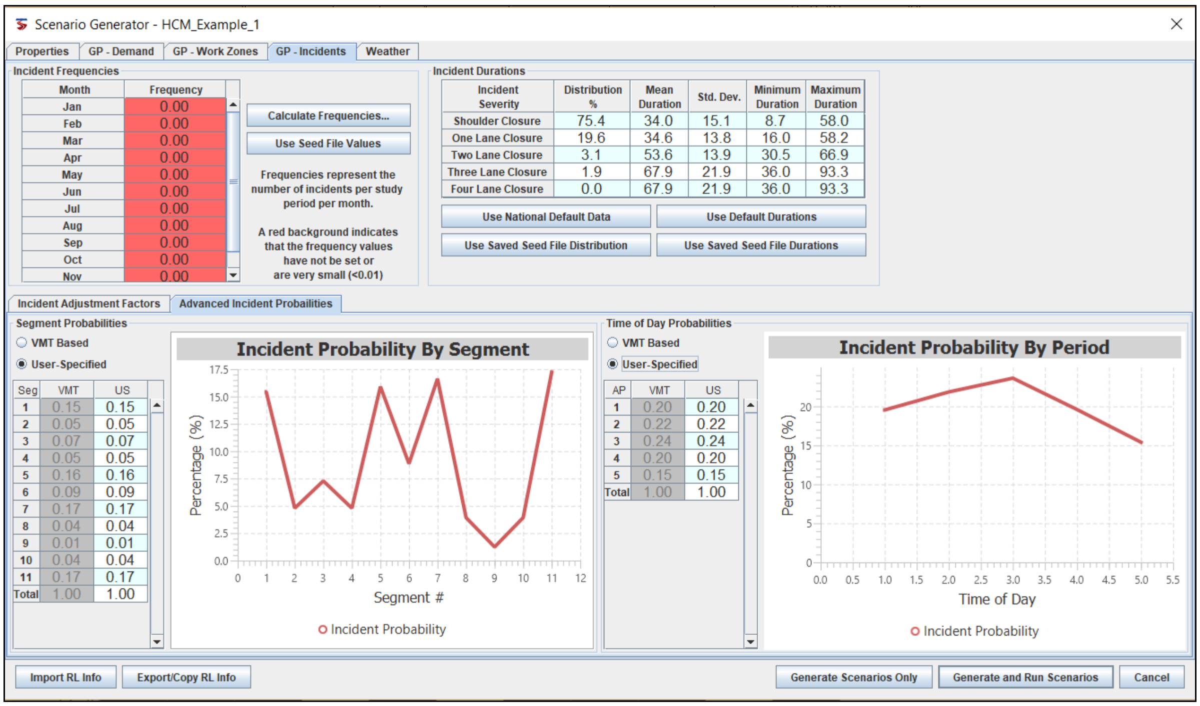




II-C-2. Enhanced FREEVAL Interface for Incident Distribution Input

The current versions of FREEVAL have incorporated the ability to allow users to provide as input the percentage distribution of incidents along each segment and across each analysis period. This is shown in Exhibit II C - 3. On the bottom left corner of the screen, the user can input the percentage distribution of incidents across each segment, while on the bottom right corner, the percentage distribution of incident occurence across each analysis period can be entered.

Exhibit II C - 3: Enhanced FREEVAL Interface for Incident Distribution Input



II-C-3. Enhanced FREEVAL Interface for Visulaizing Incident Generation

The current versions of FREEVAL also enable the user to visualize the different types of incidents generated by time of day, as shown in Exhibit II C - 4.

Exhibit II C - 4: Enhanced FREEVAL Interface for Visualizing Incident Generation