TRANSPORTATION

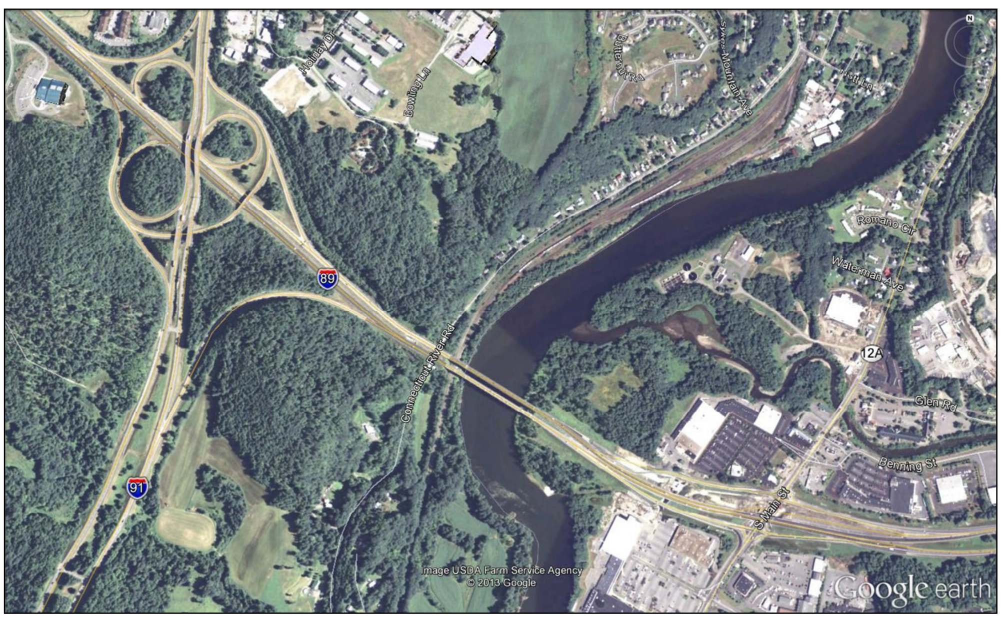
TECHNICAL MEMORANDUM

To: Gene McCarthy, McFarland Johnson
From: David Saladino, P.E.; Ivan Hooper, P.E.
Subject: I-89 Connecticut River Bridge Traffic Assessment
Date: 10 April 2013 *(updated 23 April 2013)*

Introduction

The New Hampshire Department of Transportation (NHDOT) is planning to rehabilitate the I-89 bridges over the Connecticut River on the New Hampshire/Vermont state line (bridge numbers 044/104 and 044/103). The Connecticut River bridges are located along I-89 between two interchanges approximately one mile apart. On the west side in Hartford, Vermont is the I-91 system interchange and on the east side, in Lebanon, New Hampshire, is the NH-12A (Exit 20) service interchange. Figure 1 is an aerial photo of the project study area.

Figure 1. Project Study Area



As part of this bridge rehabilitation project the NHDOT is considering whether bridge deck widening is needed in either or both directions. RSG was tasked with evaluating whether additional lanes on the bridge are justified or not based on an assessment of traffic and safety conditions. The primary reasons for considering bridge widening is the close proximity between the I-91 and Exit 20 ramps and the relatively steep grades on the Vermont side, which lead to sub-optimal merge and weaving areas.

RSG evaluated the bridge and adjacent area for conformity with design standards, existing and forecasted traffic performance, and crash history to develop our recommendation.

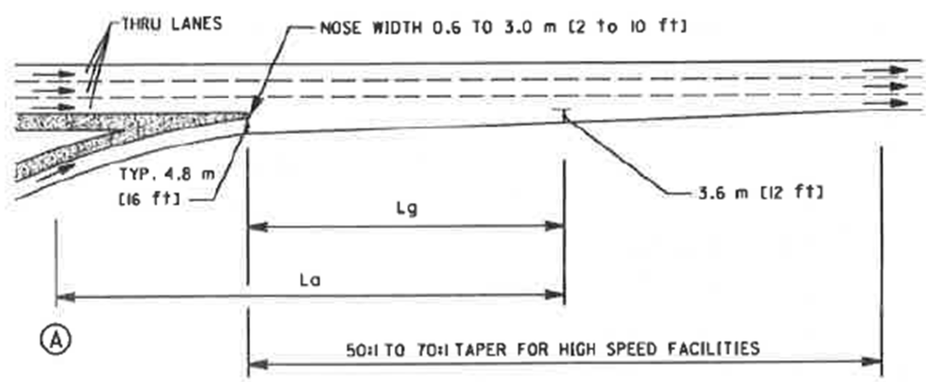
Design Standard Review

Because design standards change over time, a review was conducted of the existing interchanges to determine how well they comply with current design standards, which were taken from *A Policy on Geometric Design of Highways and Streets,*[1] which is commonly referred to as the "Green Book" and is the generally accepted national standard for highway design. The standards consulted in the *Green Book* related to the length of freeway ramp merges and the application of auxiliary lanes.

FREEWAY RAMP MERGES

There are two types of freeway ramp merges described in the *Green Book*. The first is the tapered design wherein the on-ramp gradually tapers into the mainline, typically over a distance of 700 to 1,300 feet depending on a variety of factors, including: the freeway grade, the width of the ramp, and the speed on the ramp. The second type is the parallel design which brings the on-ramp into a short new parallel lane on the freeway that runs for 300 to 800 feet before tapering into the adjacent through lane over an additional 300 or more feet. The same factors are utilized to determine the length of the parallel lane. The freeway on-ramps in the project area are of the tapered type. Figure 2 shows the portion of Figure 10-69 from the *Green Book* that illustrates the various components that go into calculating the required merge distance for a tapered design.

Figure 2. On-Ramp Merge Length Parameters



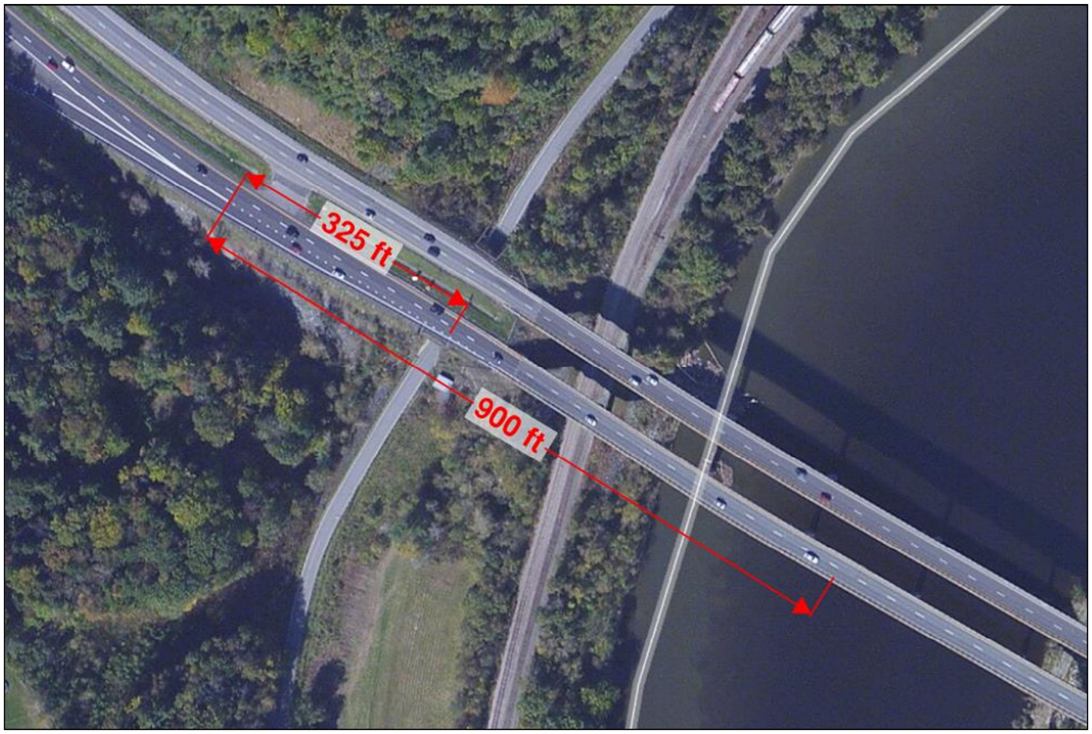
NOTES:

1. La IS THE REQUIRED ACCELERATION LENGTH AS SHOWN IN EXHIBIT 10-70 OR AS ADJUSTED BY EXHIBIT 10-71.
2. POINT (A) CONTROLS SPEED ON THE RAMP. La SHOULD NOT START BACK ON THE CURVATURE OF THE RAMP UNLESS THE RADIUS EQUALS 300 m [1000 ft] OR MORE.
3. Lg IS REQUIRED GAP ACCEPTANCE LENGTH. Lg SHOULD BE A MINIMUM OF 90 TO 150 m [300 to 500 ft] DEPENDING ON THE NOSE WIDTH.
4. THE VALUE OF La OR Lg, WHICHEVER PRODUCES THE GREATER DISTANCE DOWNSTREAM FROM WHERE THE NOSE EQUAL 0.6 m [2 ft], IS SUGGESTED FOR USE IN THE DESIGN OF THE RAMP ENTRANCE.

[1] American Association of State Highway and Transportation Officials (AASHTO), *A Policy on Geometric Design of Highways and Streets*, 6th Edition (Washington DC: AASHTO, 2011).

We performed an analysis on the on-ramp from northbound I-91 to southbound I-89 to compare the required merge distance (per *Green Book* standards) with the actual merge length provided. Assuming that the on-ramp is 16 feet wide with a two foot nose width and a 50:1 taper, then the on-ramp would require 900 feet to fully merge with the mainline. The existing northbound I-91 on-ramp has a merge distance of approximately 325 feet meaning that about 575 additional feet of merge distance are required to meet the current *Green Book* standard. Provision of this additional merge distance would necessitate widening of the I-89 southbound bridge as shown in the figure below.

Figure 3: Existing and Minimum Required Merge Distances (On-Ramp from I-91 Northbound)



Since the on-ramp from NH-12A at Exit 20 was just fully reconstructed, we have assumed that the ramp merge geometry complies with all appropriate design standards and as such did not perform a similar analysis for that ramp.

AUXILIARY LANES

Auxiliary lanes are continuous lanes that connect an on-ramp to an adjacent off-ramp. They are generally utilized when traffic volumes are high or when the distance between ramps is limited. The *Green Book* recommends that auxiliary lanes be utilized when the distance between the on- and off-ramps of adjacent interchange is 1,500 feet or less. The distance between the two study ramps on I-89 southbound is approximately 1,850 feet while the distance between the adjacent I-89 northbound ramps is about 3,000 feet. Per Figure 10-68 in the *Green Book*, the recommended spacing between adjacent on- and off-ramps when the on-ramp is from a system interchange is 2,000 feet. When the on-ramp is a service interchange the recommended spacing is 1,600 feet. Since the southbound on-ramp from I-91 is part of a system interchange the available spacing distance of 1,850 feet is less than the recommended 2,000 feet, which suggests that a southbound auxiliary lane may be applicable between the two interchanges in this direction.

Traffic Analysis

A micro-simulation traffic analysis was performed for the study area using VISSIM software, which is widely utilized to analyze complex roadway geometries. The VISSIM model geometry was developed using aerial photography and engineered drawings of the new Exit 20 interchange, which was obtained from NHDOT.[1] The analysis was performed for the weekday AM and PM peak hours and for the Saturday peak hour. The three analysis periods were analyzed for existing (2013) conditions, year of project opening (assumed to be 2019), and twenty years after opening (assumed to be 2039).The following sub-sections describe how the analysis was performed and the results of the analysis.

TRAFFIC DATA COLLECTION

To analyze traffic on I-89 between the I-91 and Exit interchanges, it was important to understand the traffic patterns among the various facilities. An origin-destination (O-D) study was performed using sensors to record the travel patterns of Bluetooth-enabled devices through the study area. Five sensors were deployed for a week in February 2013 at strategic locations on I-89 and I-91. Each sensor recorded a unique identifier of each Bluetooth-enabled device as it passed by. These unique identifiers were then matched up to determine the path that the vehicle took through the study area. By counting the number of times each of the possible routes through the study area occurred, an initial O-D table was developed for each time-of-day study periods. The O-D tables included I-89, I-91, and the Exit 20 ramps to/from the west. The three tables were then calibrated using a manual traffic count of the Exit 20 ramps conducted by RSG staff on 14 March 2013 and then scaled to match January 2013 traffic counts at the bridges from the NHDOT continuous traffic counter located immediately adjacent to the bridge (station # 253090). The resulting O-D tables were the basis for all of the subsequent traffic analyses. Appendix A contains a detailed description of the Bluetooth data collection process.

There was a desire for the analysis to reflect conditions during the peak time of the year, which is during the summer. However, the Bluetooth data was adjusted to January 2013 volumes. To get the O-D tables to represent summer 2013 conditions seasonal factors ranging from 1.08 to 1.16 were applied to the O-D tables. The seasonal factors were developed from NHDOT continuous traffic counters data in the general study area.

To represent the pulsing of traffic onto the freeway when the traffic lights turn green, the Exit 20 ramp terminals were included in the VISSIM model. Intersection turning movement counts from 2008 were utilized to determine the O-D patterns for the ramp terminals. These volumes were adjusted to match the Exit 20 ramp volumes in the summer 2013 O-D table. Appendix B contains figures showing the O-D tables, freeway volumes, and ramp terminal volumes.

Peak hour factors (PHF) for the analysis were obtained from the intersection turning movement counts and were 0.86 for the weekday AM peak hour, 0.93 for the weekday PM peak hour, and 0.95 for the Saturday peak hour. PHF values less than 0.95 were assumed to gradually increase over time as traffic volumes increase. In 2039 the assumed PHFs were 0.92 for the AM and 0.95 for the PM and Saturday.

Heavy vehicle percentages were primarily obtained from the *Vermont 2012 Automatic Vehicle Classification Report*[2] and were classified as single unit trucks and tractor-trailer trucks. Using data from the VTrans continuous traffic counter on I-89 north of the I-91 interchange and from the ramps comprising that interchange, an approximate heavy vehicle percentage was estimated for the I-89 Connecticut River bridges segment. Daily heavy vehicle data was used to estimate the AM percentages, peak hour data to estimate the PM percentages, and an average of the two to estimate Saturday

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[1] Lebanon 11700 – Project Specific Information, New Hampshire DOT, Accessed March 9, 2013, http://www.nh.gov/dot/projects/lebanon11700/index.htm.

[2] Vermont Agency of Transportation; Policy, Planning & Intermodal Development; Traffic Research Unit; *2012 Automatic Vehicle Classification Report* (March 2013).

percentages. Figure 4 shows the resulting heavy vehicle percentages utilized for the micro-simulation analysis.

Figure 4: Assumed Freeway Heavy Vehicle Percentages

Analysis Period	Passenger Vehicles	Single Unit Trucks	Tractor-Trailer Trucks
Weekday AM Peak Hour	91.1%	5.6%	3.3%
Weekday PM Peak Hour	94.1%	3.5%	2.4%
Saturday Peak Hour	93.1%	4.5%	2.4%

Heavy vehicle percentages for NH-12A were taken from 2008 intersection turning movement volumes, which were 6% for the AM, 3% for the PM, and 4% for Saturday peak hours. The freeway proportions of single unit to tractor-trailer trucks were utilized for NH-12A.

TRAFFIC ANALYSIS METHODOLOGY

This section describes the process utilized to estimate the future year volumes, the measures of effectiveness used to compare scenarios, and how the VISSIM modeling was performed.

Future Year Volume Estimation

Future year volumes for 2019 and 2039 were estimated using interstate facility growth factors obtained from Vermont's *Continuous Traffic Counter Grouping Study and Regression Analysis Based on 2012 Traffic Data*[1] report.[2] The growth factors obtained from that report were 1.05 for adjusting from 2013 to 2019 and 1.21 for adjusting from 2013 to 2039. These factors were applied to the summer 2013 values to estimate the future year volumes for 2019 and 2039. Appendix B contains figures showing the 2019 and 2039 freeway and ramp terminal volumes.

VISSIM Modeling Approach and Calibration

The VISSIM micro-simulation software, developed by PTV was used for the traffic operations analysis. Version 5.4-07 of VISSIM was used to evaluate traffic operations in the study area. The model was run for an hour and ten minutes with no data being collected for the first ten minutes while the network was seeded. Data was then collected for the next four 15-minute intervals. The traffic volumes for the second 15-minute period were increased in accordance with the peak hour factor and the volumes for the other three 15-minute periods were correspondingly reduced so that the total hourly volume was unchanged.

Traffic signal timing data for the Exit 20 ramp terminals were developed for all scenarios using the Synchro software and a cycle length of 90 seconds. Because no evaluation was performed for the ramp terminals it was not necessary to match existing signal timing plans. The important thing was to have appropriate timing plans that fed vehicles onto the freeway in an appropriate manner.

The VISSIM model was calibrated to vehicle travel speeds measured by RSG personnel using the floating car method during peak- and off-peak periods. The average observed travel speeds were 63 mph in the southbound direction and 60 mph in the northbound direction. The January 2013 PM peak hour model was run five times and the speeds between I-91 and Exit 20 were averaged and compared to the target values. Adjustments were made to the desired vehicle speeds until the modeled speeds were within one

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[1] Vermont Agency of Transportation; Policy, Planning & Intermodal Development; Traffic Research Unit; *Continuous Traffic Counter Grouping Study and Regression Analysis Based on 2012 Traffic Data* (March 2013).

[2] We initially looked to conduct a trendline regression analysis on the historic AADT's reported at the NHDOT Continuous Count Station located on I-89 immediately east of the bridges. However, we found that the growth projections varied significantly depending on which year the regression analysis was started in and that the count station has not been functioning in recent years due to adjacent construction activities. We therefore, utilized the VTrans average interstate facility growth factors to grow traffic across the bridges.

mph of the observed speeds. The calibrated model that was used for all of the analyses had an average southbound speed of 63.3 mph and an average northbound speed of 59.3 mph.

The same desired vehicle speeds were assumed for both directions. The speed difference between the two directions was due primarily to the grades on the freeway. In the northbound direction the VISSIM analysis assumed a positive grade of 2% from Exit 20 to the Vermont side of the bridge at which point the grade increased to 5% until approximately the I-91 mainline overpasses. The same grades were assumed for the same locations in the southbound direction, only as negative instead of positive grades.

An important component of micro-simulation modeling is making sure that enough model runs are performed to ensure a statistically reliable result. Using the same speed data from the calibration model run, the following formula was used to calculate the minimum number of runs to achieve a 95% confidence interval.

$$N = \left(\frac{t_{0.05,N-1} * S_s}{Z}\right)^2$$

Where: t = t-test statistic for 95% confidence level with N-1 degrees of freedom
Z = number of standard deviations from the mean (1.96 for a 95% confidence level)
S_s = sample standard deviation
N = minimum number of runs (sample size)

Using data from the five model calibration runs, the standard deviation of the speed data was determined to be 0.29 mph in the southbound direction and 0.78 mph in the northbound direction. Using a t value of 2.78, the minimum number of runs was determined to be 0.2 runs in the southbound direction and 1.2 runs in the northbound direction; therefore 5 runs were adequate to provide satisfactory results. The VISSIM model was run five times for all of the scenario analyses and the results were averaged.

Measures of Effectiveness

The measures of effectiveness (MOEs) are the criteria used to compare the various scenarios. Two primary MOEs were utilized for the Connecticut River bridge analysis. The first was freeway level of service (LOS) and the second is a detailed examination of average speed along the length of the freeway segments.

Level-of-service (LOS) is a qualitative measure describing the operating conditions as perceived by motorists driving in a traffic stream. LOS is estimated using the procedures outlined in the *2010 Highway Capacity Manual (HCM).* [1] The HCM divides freeway facilities into three types of segments: (1) basic – sections with no ramps, (2) merge or diverge – 1,500 foot sections with either an on ramp or an off ramp, and (3) weaving – sections with an on-ramp followed within 2,500 feet or less by an off-ramp. Freeway LOS for all three segment types is based on vehicle density per lane, which is calculated by dividing the number of vehicles by the number of lanes and the average speed of those vehicles. Figure 5 shows the various LOS grades and descriptions for the three freeway segment types. New Hampshire and Vermont have a goal for freeway facilities to operate at LOS C within the general study area.

[1] Transportation Research Board, National Research Council, *Highway Capacity Manual* (Washington, DC: National Academy of Sciences, 2010).

Figure 5. Level-of-Service Criteria for Freeway Segments

LOS	Characteristics	Basic Segment Density (pc/hr/ln)	Merge/Diverge Density (pc/hr/ln)	Weaving Segment Density (pc/hr/ln)
A	Free flow operation	≤ 11.0	≤ 10.0	≤ 10.0
B	Reasonably free flow	11.1-18.0	10.1-20.0	10.1-20.0
C	Restricted freedom to maneuver	15.1-26.0	20.1-28.0	20.1-28.0
D	More restricted maneuverability	26.1-35.0	28.1-35.0	28.1-35.0
E	Closely spaced vehicles	35.1-45.0	> 35.0	35.1-43.0
F	Breakdowns in vehicular flow	> 45.0	Exceeds Capacity	> 43.0

Using the VISSIM software it is possible to estimate the freeway LOS for the various segments. In the southbound direction the section between the on-ramp from northbound I-91 and the Exit 20 off-ramp is considered a *weaving* segment since they are less than 2,500 feet apart. In the northbound direction, there is a *merge* segment at the Exit 20 on-ramp, followed by a short *basic* segment, and finally a *diverge* segment associated with the off-ramp to northbound I-91.

Some of the traffic issues in the study area are localized in nature occurring right at an on-ramp merge area, with the effects being diminished when looking at a 1,500 foot or longer segment over a 15 minute analysis period. To better understand traffic operations in these sections, the freeway section was divided into 100-foot segments and the average speed recorded in 60 second intervals. By having short segments and short time intervals it was possible to pick up on smaller disturbances in the traffic flow.

EXISTING CONDITIONS ANALYSIS

The existing conditions analysis was performed using the summer 2013 VISSIM models. Figure 6 shows the resulting volumes, speeds, and LOS for the weekday AM, weekday PM, and Saturday peak hours. The figure shows that all of the segments operate at LOS C or better. Appendix C contains some additional information regarding how well the simulation model volumes matched the target (input) volumes.

Figure 6. Existing Conditions Freeway LOS

Segment	AM Peak Hour			PM Peak Hour			Sat. Peak Hour		
	Vol.	Speed	LOS	Vol.	Speed	LOS	Vol.	Speed	LOS
I-89 Southbound									
Basic North of NB I-91 On Ramp	1,330	63	B	1,160	64	A	1,110	64	A
Weave NB I-91 On Ramp to Exit 20	1,680	59	B	1,360	62	B	1,460	60	B
Basic Between Exit 20 Ramps	920	64	A	820	65	A	600	65	A
I-89 Northbound									
Basic North of NB I-91 Off Ramp	640	61	A	1,370	53	B	930	61	A
Diverge at NB I-91 Off Ramp	1,070	61	A	2,110	57	C	1,350	61	B
Basic Exit 20 to NB I-91 Off Ramp	1,110	62	A	2,180	59	C	1,390	63	B
Merge at Exit 20 On Ramp	1,110	62	A	2,180	59	C	1,390	62	A
Between Exit 20 Ramps	850	65	A	1,220	65	A	950	65	A

Note: Speed and LOS results taken from peak 15-minute period.

Detailed speed data were extracted from the simulation models in the southbound direction from the weekday AM peak hour since that is when volumes are the highest. Figure 7 graphically illustrates the speeds along the freeway over time during 2013 AM peak conditions. The x-axis represents time and the y-axis distance. The green colors represent speeds of over 50 mph, while the orange is speeds of 40-50 mph. The figure shows consistent turbulence at the northbound I-91 on ramp merge with average speeds always below 60 mph and occasionally dropping below 40 mph. This turbulence generally dissipates over 500-700 feet, but occasionally continues all the way to Exit 20.

Figure 7. Existing Conditions AM Southbound Speed Details

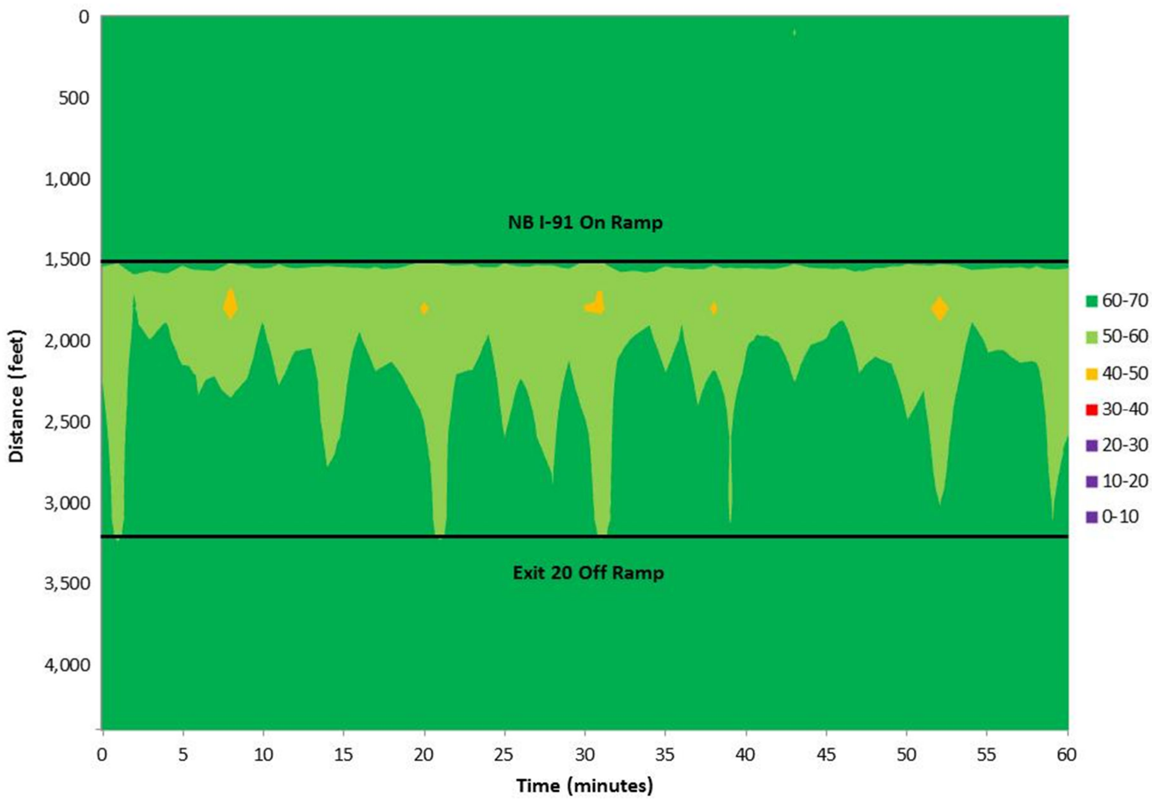
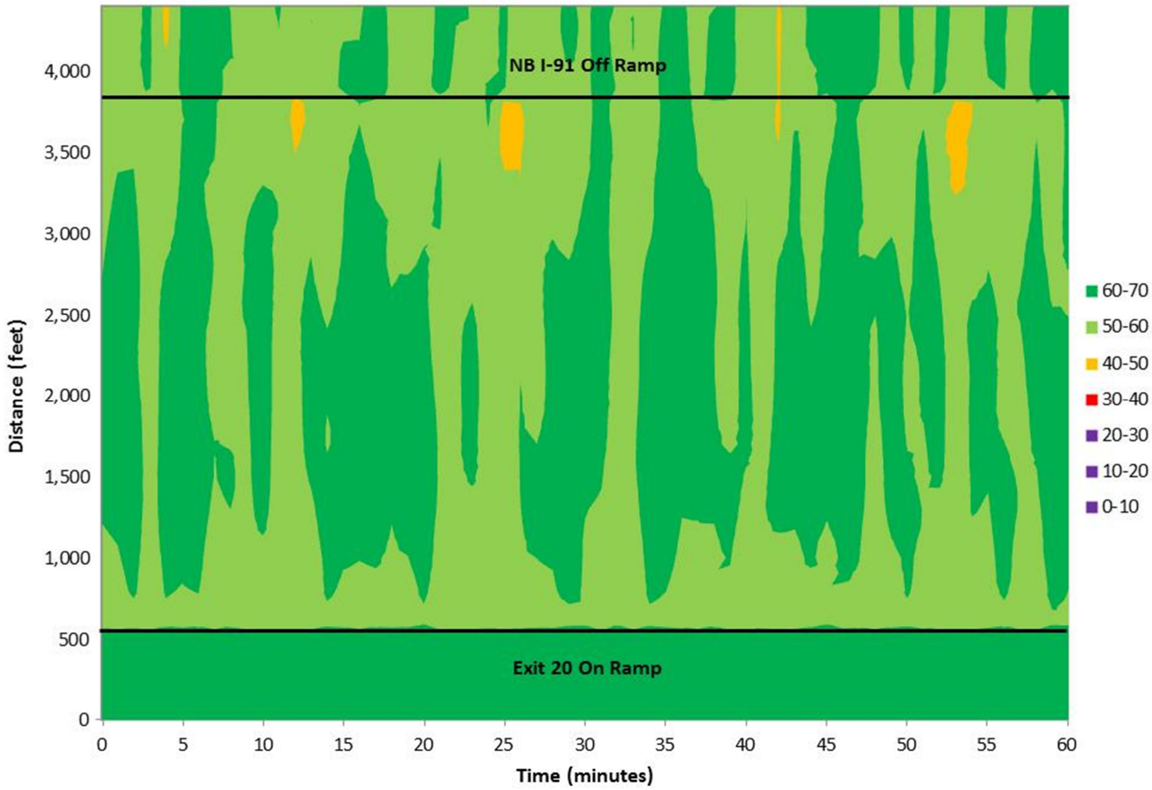


Figure 8 shows the same information for the northbound direction, which is much more turbulent than the southbound direction. This is due to the positive grades of 2 to 5% along these segments and the affect that they have on traffic, particularly heavy vehicles. However, one can see that the turbulence increases at the merge and diverge points where lane changing operations are occurring. The effect is noticeably pronounced at the northbound I-91 off ramp where there is a 5% grade and lane changing operations for vehicles desiring to take the off ramp to I-91.

Figure 8. Existing Conditions PM Northbound Speed Details



A numerical analysis was performed on the "cells" that lie between the on- and off-ramps in both directions. Each cell is 100 feet by one minute. Figure 9 lists the number of cells in each direction and the percentage of those cells that fall within the various speed categories. The northbound direction has more cells because the distance between the ramps is longer than the southbound direction.

Figure 9. Existing Conditions Speed Detail Summary

	Southbound	Northbound
# of Cells	1,020	1,980
< 40 mph	0%	0%
40 - 50 mph	1%	1%
50 - 60 mph	42%	54%
> 60 mph	57%	44%

YEAR 2019 ANALYSIS

The year 2019 analysis was performed in the same manner as the existing conditions with a couple of differences in the MOEs that were reported and the scenarios that were evaluated. The detailed speed analysis was not performed for 2019 since it represents a mid-point between the existing conditions and the 2039 conditions and is therefore not as useful.

Because 2019 represents the opening year of the project, a build scenario was evaluated that added an auxiliary lane to I-89 in each direction between the ramps on either side of the bridges. For the purposes of the analysis, the auxiliary lane was assumed to come in at the on-ramp and drop as a single lane exit at the off-ramp. This configuration is not consistent with the principles of lane balance described in the

Green Book, which says that between the mainline and the ramp there should be one more lane exiting the diverge area than entered it. Lane balance is generally achieved by having two-lane off ramps or by continuing the auxiliary lane beyond the exit and then dropping it before the next ramp (or usually before the next structure to save money). This approach was chosen because it represents the lowest capacity weaving section where every weaving vehicle is required to make one lane change. As such, it provides a conservative estimate of traffic performance.

Figure 10 compares the build and no build 2019 scenarios for the key freeway segments. The freeway is expected to operate effectively at LOS C or better in both scenarios. In the peak direction of the peak hour, the build scenario improves freeway speeds between I-91 and Exit 20 by 4-7 miles per hour. Additional information on each scenario can be found in Appendix C.

Figure 10. 2019 Freeway Performance Comparison

Segment	No Build			Build (*auxiliary lane*)		
	Volume	Speed	LOS	Volume	Speed	LOS
Weekday AM Peak Hour						
I-89 SB - Basic North of NB I-91 On Ramp	1,390	62	B	1,390	62	B
I-89 SB - Weave NB I-91 On Ramp to Exit 20	1,760	58	B	1,820	63	A
I-89 SB - Basic Between Exit 20 Ramps	970	64	A	970	65	A
I-89 NB - Basic North of NB I-91 Off Ramp	670	61	A	670	62	A
I-89 NB - Diverge at NB I-91 Off Ramp	1,120	60	A	1,160	62	A
I-89 NB - Basic Exit 20 to NB I-91 Off Ramp	1,160	62	A	1,160	64	A
I-89 NB - Merge at Exit 20 On Ramp	1,160	62	A	1,160	64	A
I-89 NB - Between Exit 20 Ramps	890	65	A	890	65	A
Weekday PM Peak Hour						
I-89 SB - Basic North of NB I-91 On Ramp	1,220	64	A	1,220	64	A
I-89 SB - Weave NB I-91 On Ramp to Exit 20	1,430	62	B	1,470	64	A
I-89 SB - Basic Between Exit 20 Ramps	860	65	A	860	65	A
I-89 NB - Basic North of NB I-91 Off Ramp	1,440	53	B	1,440	60	B
I-89 NB - Diverge at NB I-91 Off Ramp	2,210	53	C	2,280	60	B
I-89 NB - Basic Exit 20 to NB I-91 Off Ramp	2,280	58	C	2,280	62	B
I-89 NB - Merge at Exit 20 On Ramp	2,280	58	C	2,280	62	B
I-89 NB - Between Exit 20 Ramps	1,280	64	A	1,280	64	A
Saturday Peak Hour						
I-89 SB - Basic North of NB I-91 On Ramp	1,160	64	A	1,160	64	A
I-89 SB - Weave NB I-91 On Ramp to Exit 20	1,530	59	B	1,610	63	A
I-89 SB - Basic Between Exit 20 Ramps	620	65	A	620	65	A
I-89 NB - Basic North of NB I-91 Off Ramp	970	60	A	970	62	A
I-89 NB - Diverge at NB I-91 Off Ramp	1,410	61	B	1,460	62	A
I-89 NB - Basic Exit 20 to NB I-91 Off Ramp	1,460	62	B	1,460	64	A
I-89 NB - Merge at Exit 20 On Ramp	1,450	62	B	1,460	63	A
I-89 NB - Between Exit 20 Ramps	990	65	A	990	65	A

Note: Speed and LOS results taken from peak 15-minute period.

2039 Conditions

The year 2039 analysis was performed in the same manner as the other years and all of the MOEs and scenarios were evaluated. The build scenario assumed the same lane configuration as described in the

2019 Conditions section. Figure 11 compares the build and no build 2039 scenarios for the key freeway segments. The freeway is expected to operate effectively at LOS C or better in both scenarios. In the peak direction of the peak hour the Build scenario improves freeway speeds between I-91 and Exit 20 by 4-6 miles per hour and improves the LOS from C to B. Additional information on each scenario can be found in Appendix C.

Figure 11. 2039 Freeway Performance Comparison

Segment	No Build			Build		
	Volume	Speed	LOS	Volume	Speed	LOS
Weekday AM Peak Hour						
I-89 SB - Basic North of NB I-91 On Ramp	1,610	62	B	1,610	62	B
I-89 SB - Weave NB I-91 On Ramp to Exit 20	2,040	56	C	2,110	63	B
I-89 SB - Basic Between Exit 20 Ramps	1,120	64	A	1,120	64	A
I-89 NB - Basic North of NB I-91 Off Ramp	770	59	A	770	62	A
I-89 NB - Diverge at NB I-91 Off Ramp	1,300	59	B	1,350	62	A
I-89 NB - Basic Exit 20 to NB I-91 Off Ramp	1,350	62	B	1,350	64	A
I-89 NB - Merge at Exit 20 On Ramp	1,350	62	A	1,340	64	A
I-89 NB - Between Exit 20 Ramps	1,030	65	A	1,030	65	A
Weekday PM Peak Hour						
I-89 SB - Basic North of NB I-91 On Ramp	1,400	64	B	1,400	64	B
I-89 SB - Weave NB I-91 On Ramp to Exit 20	1,640	62	B	1,690	64	A
I-89 SB - Basic Between Exit 20 Ramps	990	65	A	990	65	A
I-89 NB - Basic North of NB I-91 Off Ramp	1,660	52	B	1,660	57	B
I-89 NB - Diverge at NB I-91 Off Ramp	2,540	52	C	2,640	57	B
I-89 NB - Basic Exit 20 to NB I-91 Off Ramp	2,630	57	C	2,640	62	B
I-89 NB - Merge at Exit 20 On Ramp	2,630	57	C	2,630	62	B
I-89 NB - Between Exit 20 Ramps	1,480	64	B	1,480	64	B
Saturday Peak Hour						
I-89 SB - Basic North of NB I-91 On Ramp	1,350	64	B	1,350	64	B
I-89 SB - Weave NB I-91 On Ramp to Exit 20	1,780	57	B	1,860	63	A
I-89 SB - Basic Between Exit 20 Ramps	730	64	A	730	65	A
I-89 NB - Basic North of NB I-91 Off Ramp	1,120	56	A	1,120	61	A
I-89 NB - Diverge at NB I-91 Off Ramp	1,630	59	B	1,680	62	A
I-89 NB - Basic Exit 20 to NB I-91 Off Ramp	1,680	61	B	1,680	64	A
I-89 NB - Merge at Exit 20 On Ramp	1,680	61	B	1,680	63	A
I-89 NB - Between Exit 20 Ramps	1,150	65	A	1,150	65	A

Note: Speed and LOS results taken from peak 15-minute period.

As with the existing conditions analysis, detailed speed data were extracted from the simulation models in the southbound direction from the weekday AM peak hour and in the northbound direction from the weekday PM peak hour. Figure 12 graphically illustrates the speeds along the southbound freeway for the 2039 No Build scenario. The figure shows consistent turbulence at the northbound I-91 on ramp merge with average speeds always below 60 mph and regularly below 50 and occasionally even dropping below 30 mph. By 2039 it will be much more common for the slower speeds to continue all the way to Exit 20.

Figure 12. 2039 AM No Build Conditions Southbound Speed Details

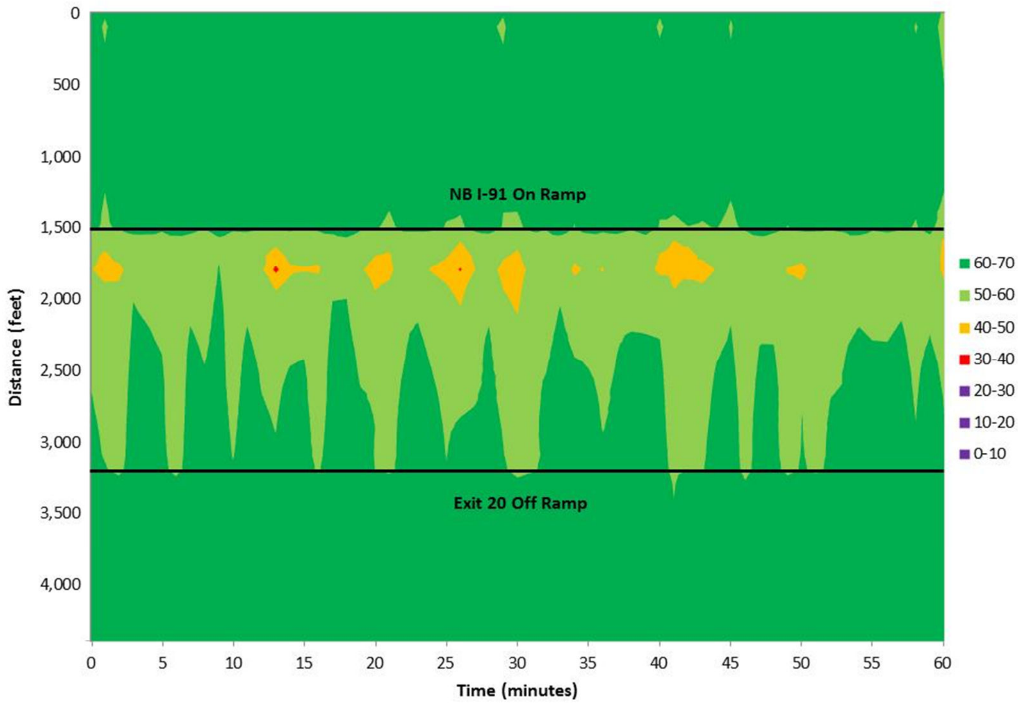


Figure 13 shows the same information for the 2039 Build scenario and clearly illustrates that adding a southbound auxiliary lane will eliminate virtually all of the areas of speeds below 60 mph.

Figure 13. 2039 AM Build Conditions Southbound Speed Details

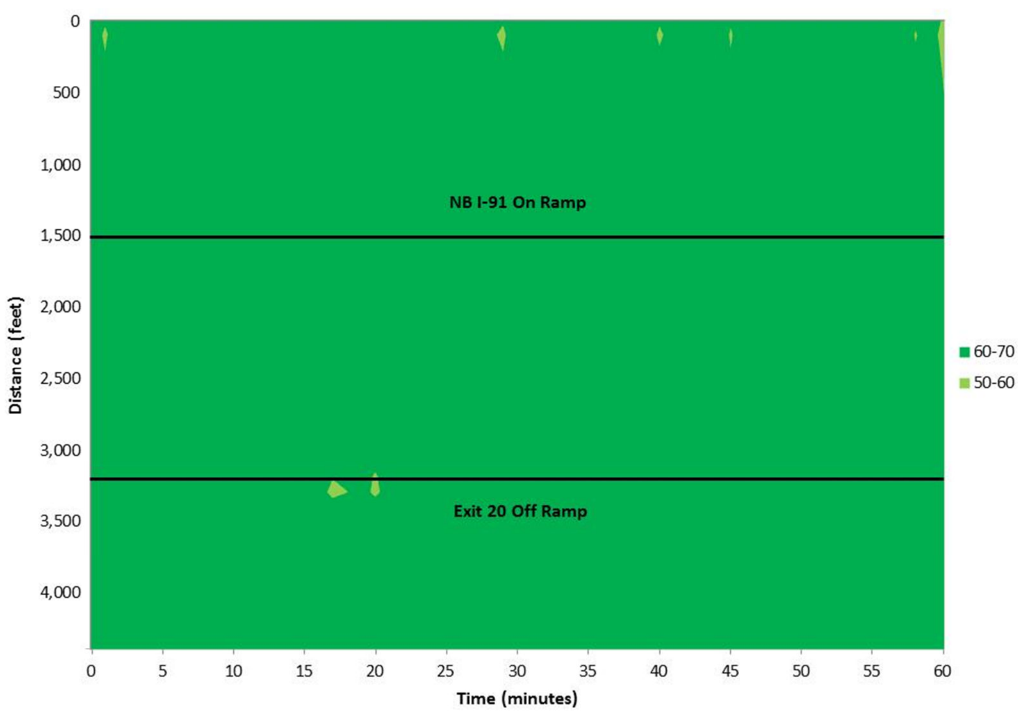


Figure 14 shows 2039 PM peak hour detailed speed information for the northbound direction, which, as seen in the existing conditions analysis, is much more turbulent than the southbound direction, again due to the positive grades. By 2039 nearly the entire section between ramps can be expected to operate at speeds less than 50 mph with substantial time at speeds less than 50 mph at the northbound I-91 off-ramp.

Figure 14. 2039 PM No Build Conditions Northbound Speed Details

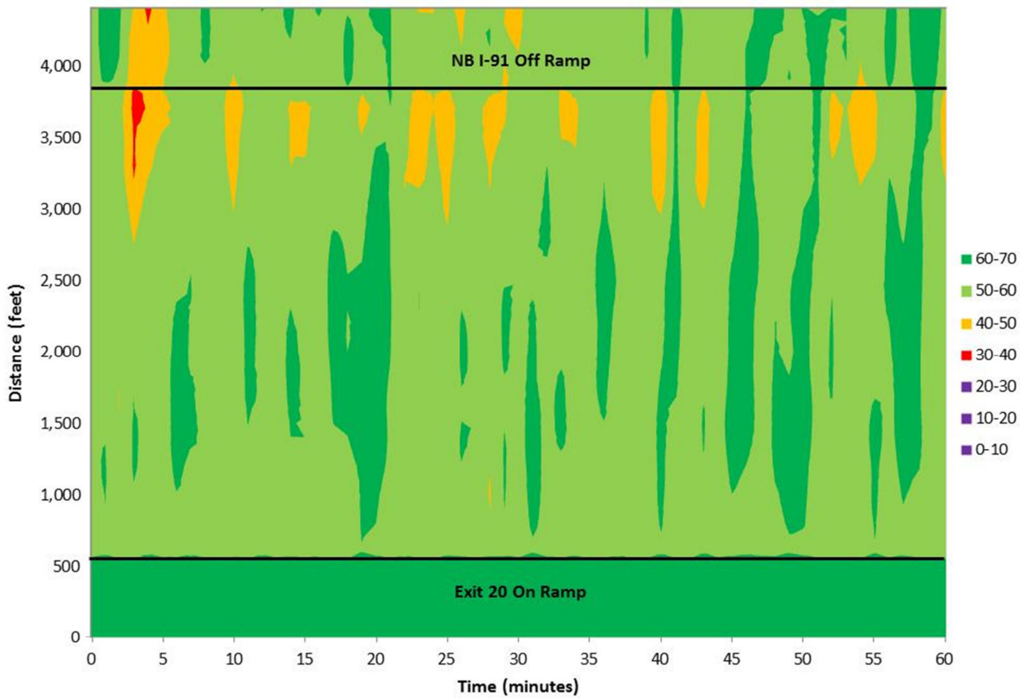
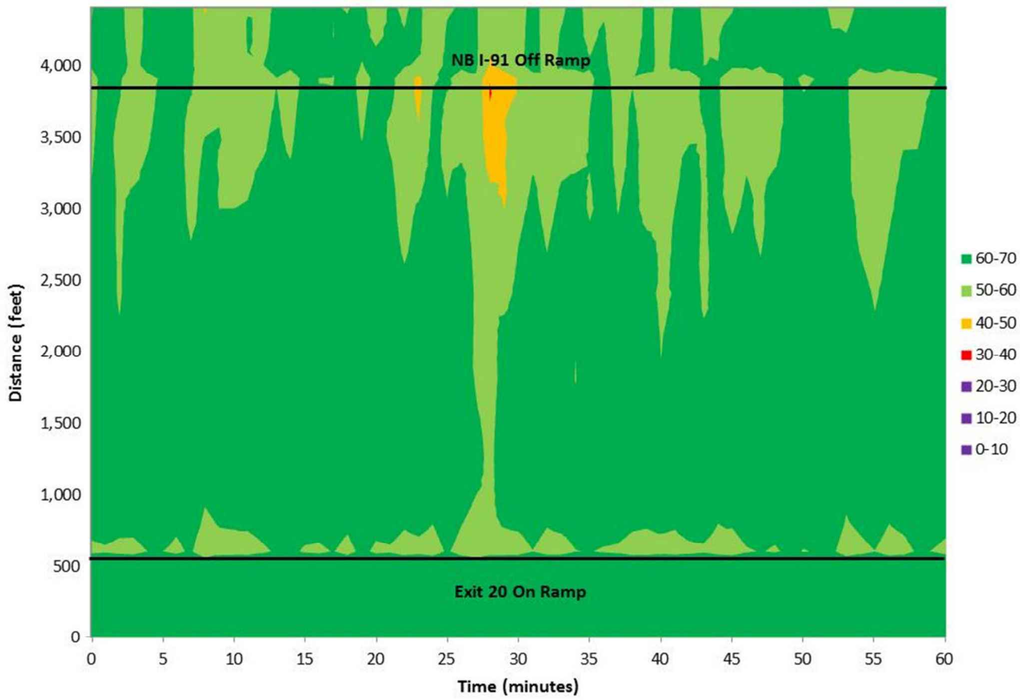


Figure 15 shows that the 2039 PM Build scenario dramatically improves the average vehicle speeds in the northbound direction, although not to the same level as previously shown for the southbound direction. Most of the section would operate at speeds over 60 mph, but there would still be occasional pockets of lower speeds.

Figure 15. 2039 PM Build Conditions Northbound Speed Details



As with the existing conditions, a numerical analysis was performed on the "cells" that lie between the on- and off-ramps. Figure 16 lists the number of cells in each direction and the percentage of those cells that fall within the various speed categories. As shown in the previous figures and quantified here, the Build scenario does a good job of increasing I-89 speeds between I-91 and Exit 20, particularly in the southbound direction.

Figure 16. Speed Detail Summary Comparison

	Existing Conditions		2039 No Build Conditions		2039 Build Conditions	
	Southbound	**Northbound**	**Southbound**	**Northbound**	**Southbound**	**Northbound**
# of Cells	1,020	1,980	1,020	1,980	1,020	1,980
< 40 mph	0%	0%	0%	0%	0%	0%
40 - 50 mph	1%	1%	4%	6%	0%	1%
50 - 60 mph	42%	54%	59%	73%	0%	22%
> 60 mph	57%	44%	37%	21%	100%	77%

Safety Analysis

A safety analysis was performed for the study area to better understand the crashes that have taken place and to determine if high crash rates might provide justification for widening the I-89 bridges across the Connecticut River.

CRASH HISTORIES

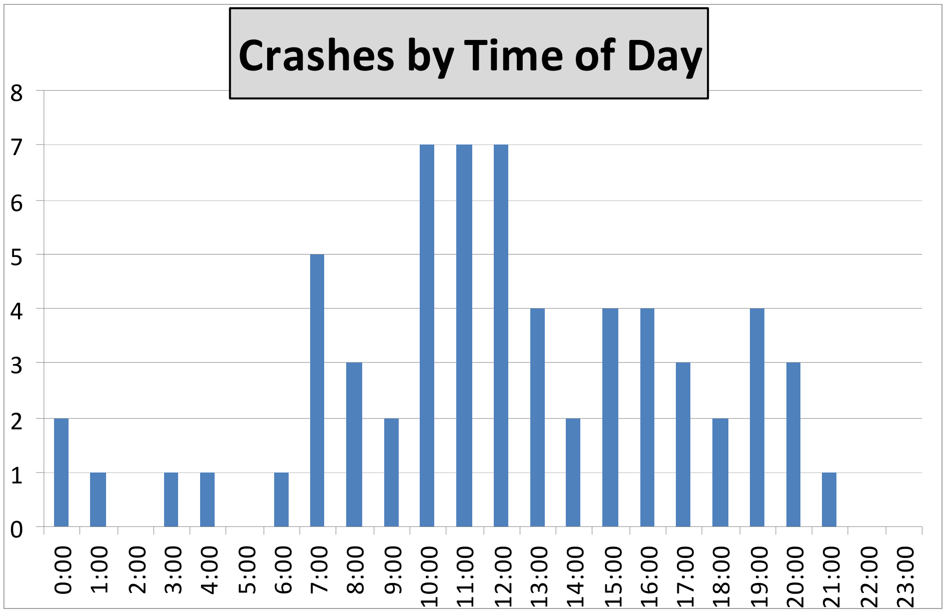
Five year crash histories for the study area on and around the Connecticut River bridges were collected from NHDOT and VTrans. The total number of crashes based on both NHDOT and VTrans data that occurred in the five year period between 2007 and 2011 is shown in Figure 17. There are several locations that jump out as high crash locations, although they are all outside of the study area defined by the red rectangle. The highest concentrations of crashes (~120) occur at the Exit 20 ramp terminals, which isn't too surprising given that intersections typically have the highest crash rates largely due to all of the conflicting turning movements made there. The other location that stands out is at the merge of the southbound and northbound I-89 ramps to northbound I-91, which had 41 crashes during this time period.

Figure 17. Study Area Crash Locations

Study Area Crashes

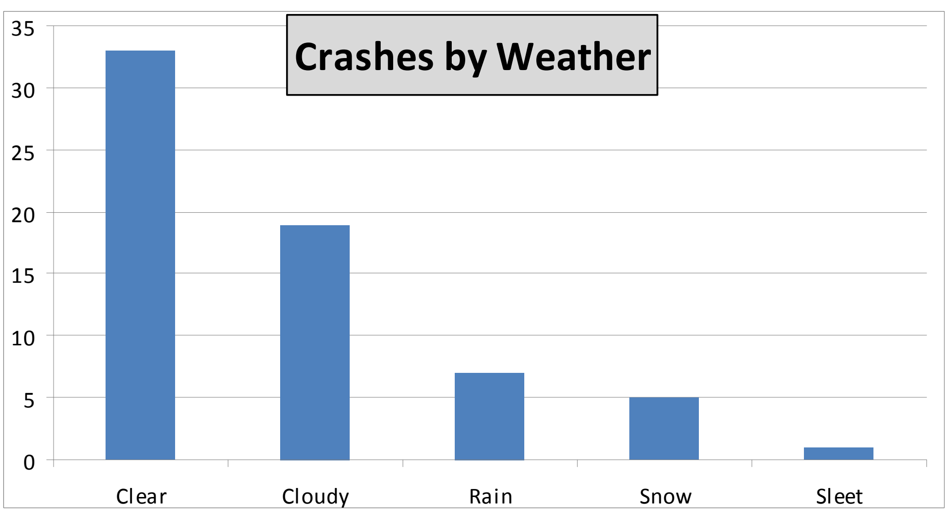
Within the study area (ie. red rectangle shown in the figure above) there were a total of 65 reported crashes with 18 injuries and no fatalities in the period between 2007 and 2011. As illustrated in Figure 18, the peak crash period occurs between 10am and 1pm, with 21 (32%) accidents occurring in this span. Nearly half (48%) of all crashes occur between the hours of 7:00 am and 1:00 pm.

Figure 18. Study Area Crashes by Time of Day



The three highest crash months are: July (10), January (8) and October (8). Crashes appear to be declining during the interval examined, with 17 in 2007, 15 in 2008 and 2009, 13 in 2010, and 5 in 2011. Adverse weather conditions do not seem to be a major factor in causing crashes. Figure 19 shows that 33 occurred while conditions were clear, 19 while conditions were cloudy, 7 while it was raining, 5 while it was snowing, and 1 during sleet conditions. Forty-eight (74%) crashes involved multiple vehicles while 17 involved only a single vehicle.

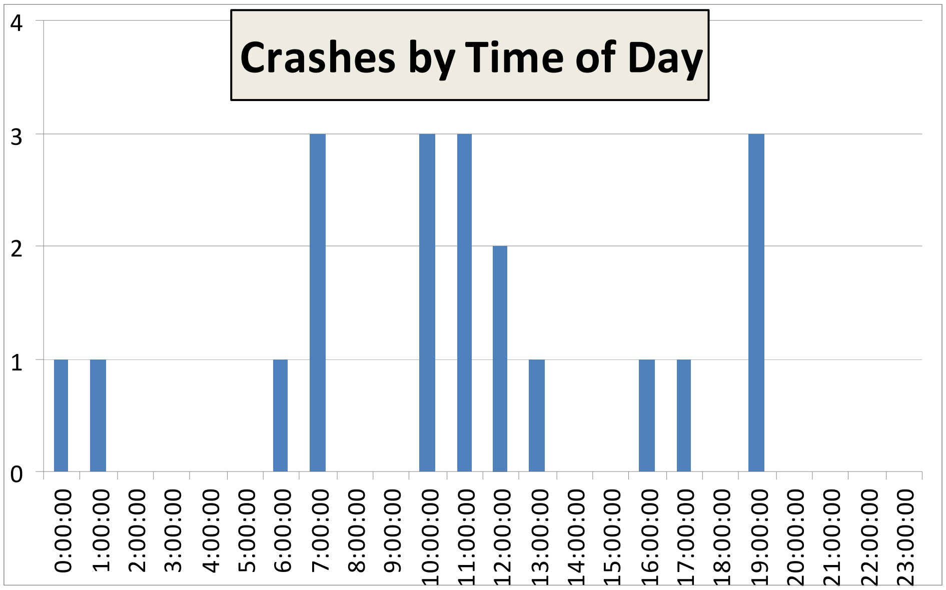
Figure 19. Study Area Crashes by Weather



Crashes on the Bridge

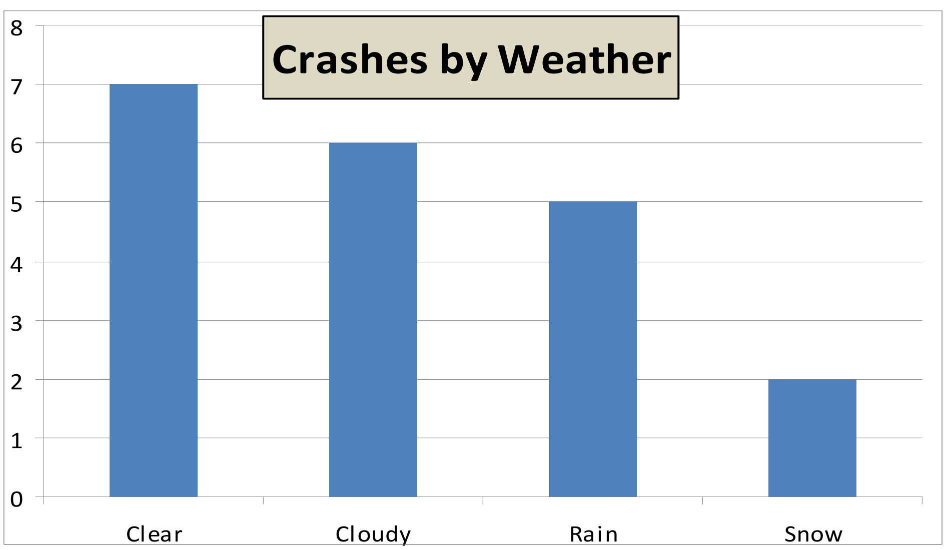
Looking specifically at crashes that occurred on the bridge itself, there were a total of 20 crashes in the five year span with 6 injuries and 0 deaths. Figure 20 shows that the peak crash time on the bridge is between 7am and 1pm, with 6 accidents (30%) occurring in this time period. The peak crash months are: October (4), December (4), January (3), and July (3). Crashes appear to be declining, with 8 in 2007, 7 in 2008, 2 in 2009 and 2010, and 1 in 2011.

Figure 20. Bridge Crashes by Time of Day



Weather does not seem to play a significant factor in causing crashes on the bridge, with 7 occurring while it was clear, 6 while cloudy, 5 during rain, and 2 during snow, as shown in Figure 21. However, of the 7 accidents in the study area that happened during rainy conditions, 5 of them occurred on the bridge. Twelve accidents on the bridge involved multiple cars while 8 involved only one car.

Figure 21. Bridge Crashes by Weather



Crashes at Northbound I-91 to Southbound I-89 Merge

Of particular relevance to the question of whether to widen the bridges or not are those crashes that occurred at the merge of the on-ramp from northbound I-91 to southbound I-89. In this area there were a total of 9 reported crashes comprising 14% of the total study area crashes with two injuries and no fatalities. Weather does not seem to play a significant factor as 6 accidents (67%) occurred while conditions were clear. However, 89% of the crashes involved multiple vehicles, with 7 cases or 78% of the crashes citing "followed too closely" as the principle reason for the accident. It is likely that the majority of these crashes are occurring as vehicles attempt to merge onto the I-89 mainline. It is not unreasonable to think that the presence of a longer acceleration lane or a continuous auxiliary lane would reduce the accident rate in this location.

Conclusions

The preceding analyses were performed to determine whether there is a reasonable rationale to widen the I-89 bridges over the Connecticut River as part of a current bridge rehabilitation project. This analysis considered the study area's compatibility with current design standards, future traffic performance, and crash history. Based on the results of this analysis, it is recommended that a continuous auxiliary lane be added to southbound I-89 between the on-ramp from northbound I-91 and the Exit 20 off ramp for the following reasons:

1. The review of geometric design standards found that the on-ramp merge distance is currently insufficient, suggesting that either the acceleration lane should be extended or an auxiliary lane should be built.
2. The review of geometric design standards also found that there would ideally be 2,000 feet between the two ramps; since the distance between ramps is virtually unchangeable, having an auxiliary lane would help mitigate this issue.
3. The traffic operations analysis found that vehicle speeds on southbound I-89 between the two ramps will continue to fall as traffic volumes increase. Adding an auxiliary lane is estimated to eliminate nearly all of the delay.
4. The crash analysis showed that there are several crashes where the on-ramp from northbound I-91 merges with southbound I-89. Many of these crashes are likely due to the sub-standard merge distance and if an auxiliary lane were provided the crash rate would be expected to decrease in this area.

The case for a northbound auxiliary lane is not nearly so compelling. The recently reconstructed Exit 20 interchange provides sufficient merge length and many of the vehicle speed issues are related to the high positive grade on the Vermont side of the river. There is a noticeable decrease in vehicle speeds at the exit to northbound I-91. While an auxiliary lane would certainly provide improvements, it is also possible that lengthening the deceleration lane would also be beneficial and would certainly be much more beneficial.

Overall, it is our recommendation to pursue further consideration of an auxiliary lane on southbound I-89 between the on-ramp from northbound I-91 and not additional auxiliary lane or widening on the northbound section of I-89.

APPENDIX A – BLUETOOTH DATA COLLECTION PROCESS

BLUETOOTH DATA COLLECTION OVERVIEW

Bluetooth Technology

Bluetooth technology is a wireless communications system that is used in mobile phones, computers, personal digital assistants, car radios, and other short range wireless communications devices. Bluetooth technology operates by proximity – Bluetooth-enabled devices that are close to one another can connect to allow transmission of voice and/or data. In order for a connection to occur, each device needs to be in "discoverable" mode, with the Bluetooth enabled.

Bluetooth devices are rated as Type I (100 meter detection zone); Type II (10 meter detection zone); or Type III (1 meter detection zone). The Bluetooth detectors used to record data in this project were Type I detectors which can detect any other Bluetooth device within its range. All Bluetooth-enabled devices operate within a globally available frequency band of 2.45 GHz.

Each device emits a unique, 48-bit electronic identifier known as a Media Access Control (MAC) address, or MAC ID. The MAC ID is generated in two parts: the first half of the MAC ID is assigned to the device manufacturer, while the second half of the MAC ID is assigned to the specific device. While the MAC ID is unique to each Bluetooth device, it is not linked to an individual person.

Bluetooth for Traffic Data Collection

Traffax, Inc., a company based in Maryland, has developed a Bluetooth system that can be used for traffic data collection. Traffax's technology consists of a series of Bluetooth devices, named BlueFax sensors, which are placed on or near a roadway to capture the signals of other Bluetooth-enabled devices as they travel through the corridor. The BlueFax sensors are self-contained, discrete units that contain a Bluetooth device set to "discovery" mode, a GPS system, a small computer to record the data, and a battery to power the unit (Figure 1).

Figure 1: BlueFax Device (left) and Typical Post-Mounted Deployment on SR-826 (right)

When a Bluetooth-enabled device passes by a BlueFax sensor, the unique MAC ID of the device and the date and time are captured and stored in the on-board computer. As vehicles with Bluetooth-enabled devices travel through the corridor, they will pass other BlueFax sensors, where the MAC ID and timestamp will be recorded again. At the end of the study period, the data from each BlueFax device can be downloaded and aggregated into a database for analysis. By searching for the common MAC IDs recorded across pairs of BlueFax sensors, it is possible to identify origin-destination and travel time information for each vehicle.

DATA ANALYSIS

At the end of the deployment period, the data from the BlueFax sensors were downloaded and aggregated into a single dataset. For developing OD estimates, custom code using Python was written to process the raw Bluetooth data. OD tables were estimated for week day AM, week day PM, and Saturday peak hours. To develop the OD tables, the following steps were used.

Step 1. Establish Bluetooth Detector Locations

Each Bluetooth detector is outfitted with a GPS unit which records its latitude and longitude. Each detector location was buffered with a 100 meter radius (approximately 325 feet) to establish the detector area. This is the approximate range of Bluetooth devices. The broader detector area is used to determine whether other surface street traffic might be included in the raw data.

Step 2. Get all Plausible Paths through and around the Study Area, Assign Detector Sequences

Step two started by getting the set of all *plausible paths* through the study area. The study area has several entry points and exit points, most of which constitute “plausible paths” (i.e. paths, or trips, that make sense given the network).

Once we had generated a list of plausible paths, we determined the *actual detector sequence* (ADS) for each path, where an ADS is the sequence of detectors areas that the path passes through on its way from origin to destination.

Step 3. Process the Bluetooth Data to Get Observed Detector Sequence (ODS) Frequencies

To make the raw Bluetooth data useful we follow three sub-steps:

- assemble the Bluetooth data into trajectories
- remove redundant detections
- divide trajectories into trips

The first sub-step, to assemble the Bluetooth data into trajectories, is straightforward. We group the data from all detectors by device ID, then and sort by date and time, all while retaining the ID for the detector where each detection occurred. The result is a collection of trajectories, where each trajectory is a sequence of places and times where a particular Bluetooth device was detected.

Trip trajectories were formed using the following criteria:

1. *Trips were formed using a single MAC ID. Consecutive reads of the same MAC ID at the same detector, as would occur if a vehicle were idling in place, were clustered into one unique read using a 5 minute rule: if consecutive reads of the same ID were recorded within 5 minutes, they were considered as one read occurring at an averaged time point. Consecutive reads of the same MAC ID that occurred more than 5 minutes apart were considered as the end and/or beginning of different trips.*

2. *Within each MAC ID, links of consecutive sensor pairs were joined together in chronological order to form complete trips linking each sensor in sequence.*

3. *To determine whether any specific trip segment was an outlier, the zone-to-zone travel times of any specific trip were compared to the 30 travel times closest by time of day (e.g. if the trip occurred at 9:00, the 30 trips closest to 9:00 AM over the entire week were used to determine the mean travel speed for OD pair). The Blustats software uses this rule for determining segment speed, which is based on a statistical rule of thumb for a normal distribution with a 90% confidence. The travel times of these 30 trips were used to develop a normal distribution. Any trip length that is outside of +/- 3 standard deviations from the mean was determined to be an outlier, indicating a break in the trip sequence.*

4. *Any given trip could not pass the same sensor twice.*

The unique combination of MAC ID, sensor location, and timestamp were only included in a single trip.
To illustrate the trip itinerary concept, a subset of the data for a sample MAC ID is shown below. Based on the timestamps for this MAC ID and the trip linking criteria, two trips were generated as shown in

Figure 2. These two records would enter the OD matrix as one vehicle trip in two cells: the 15 → 8 cell and the 8 → 15 cells. The intermediate station information is retained to validate the estimates in a later stage of the analysis.

Figure 2: Example of Two Unique Trip Trajectories

Raw Data

MAC ID	Location	Date	Time
00:24:9F:D8:F9:E3	15	9/18/2011	1:09:23 PM
00:24:9F:D8:F9:E3	14	9/18/2011	1:12:57 PM
00:24:9F:D8:F9:E3	12	9/18/2011	1:16:12 PM
00:24:9F:D8:F9:E3	12	9/18/2011	1:16:17 PM
00:24:9F:D8:F9:E3	10	9/18/2011	1:19:54 PM
00:24:9F:D8:F9:E3	10	9/18/2011	1:19:59 PM
00:24:9F:D8:F9:E3	8	9/18/2011	1:24:48 PM
00:24:9F:D8:F9:E3	8	9/18/2011	11:47:28 PM
00:24:9F:D8:F9:E3	10	9/18/2011	11:51:02 PM
00:24:9F:D8:F9:E3	12	9/18/2011	11:54:05 PM
00:24:9F:D8:F9:E3	14	9/18/2011	11:56:38 PM
00:24:9F:D8:F9:E3	14	9/18/2011	11:56:43 PM
00:24:9F:D8:F9:E3	15	9/18/2011	11:59:36 PM
00:24:9F:D8:F9:E3	15	9/18/2011	11:59:42 PM
00:24:9F:D8:F9:E3	15	9/18/2011	11:59:47 PM

Clustered Data

MAC ID	Location	Date	Time
00:24:9F:D8:F9:E3	15	9/18/2011	1:09:23 PM
00:24:9F:D8:F9:E3	14	9/18/2011	1:12:57 PM
00:24:9F:D8:F9:E3	12	9/18/2011	1:16:17 PM
00:24:9F:D8:F9:E3	10	9/18/2011	1:19:59 PM
00:24:9F:D8:F9:E3	8	9/18/2011	1:24:48 PM
00:24:9F:D8:F9:E3	8	9/18/2011	11:47:28 PM
00:24:9F:D8:F9:E3	10	9/18/2011	11:51:02 PM
00:24:9F:D8:F9:E3	12	9/18/2011	11:54:05 PM
00:24:9F:D8:F9:E3	14	9/18/2011	11:56:43 PM
00:24:9F:D8:F9:E3	15	9/18/2011	11:59:42 PM

Trip 1

MAC ID	Location	Date	Time
00:24:9F:D8:F9:E3	15	9/18/2011	1:09:23 PM
00:24:9F:D8:F9:E3	14	9/18/2011	1:12:57 PM
00:24:9F:D8:F9:E3	12	9/18/2011	1:16:17 PM
00:24:9F:D8:F9:E3	10	9/18/2011	1:19:59 PM
00:24:9F:D8:F9:E3	8	9/18/2011	1:24:48 PM

Trip 2

MAC ID	Location	Date	Time
00:24:9F:D8:F9:E3	8	9/18/2011	11:47:28 PM
00:24:9F:D8:F9:E3	10	9/18/2011	11:51:02 PM
00:24:9F:D8:F9:E3	12	9/18/2011	11:54:05 PM
00:24:9F:D8:F9:E3	14	9/18/2011	11:56:43 PM
00:24:9F:D8:F9:E3	15	9/18/2011	11:59:42 PM

The second sub-step is to remove redundant detections, which can occur because the detectors record new detections every five seconds. If a Bluetooth device is within range of a detector for more than five seconds, it can result in multiple recorded detections. To correct this problem we group redundant detections into clusters, and then choose the middle detection of each cluster to represent that cluster in a new, shorter version of the trajectory. Clusters consist of adjacent detections that are not more than 5 minutes apart. This rule ensures that a cluster really represents just one visit to a detector, rather than a visit and return visit to a detector.

The final sub-step is to divide the trajectories into sub-trajectories, since each trajectory could contain data from more than one trip. We divide the trajectories where the time difference between two adjacent detectors is too large, where we define "too large" to be greater than the free flow travel time between the two detectors plus 30 minutes. This rule separates trajectories at the point where one trip has ended and another begins, since diverting a trip to a particular destination plus participating in the activity at that destination usually takes longer than 30 minutes. At the same time the rule allows trips subject to congestion to remain intact.

We aggregate by time of day, then we drop the time stamps from the sub-trajectories so that only the sequence of detectors remains. We call this sequence the *observed detector sequence* (ODS), and group together sub-trajectories that have identical ODSs. The result of aggregating these two ways is a data set which contains the number of sub-trajectories that fall into each unique combination of time-of-day group and ODS group. We average these frequencies to represent one average weekday, and call the result the *ODS frequencies* dataset.

Comparing the ODSs to the ADSs shows that most ODSs do not perfectly match any ADS. In some cases, the ODSs would match the ADSs if you allow for "missed" detections, or detections that appear in the ADS but not in the ODS. The ODS data indicate that Bluetooth devices can be missed at intermediate detector stations.

Step 4. Distribute the ODS Frequencies to the Plausible Paths to Get Path Volumes

The task in step five is to apportion the counts from the ODS frequencies dataset to the plausible paths as *path volumes*. We do this in two sub-steps. First we apportion the ODS frequencies to the ADSs to form an ADS frequencies database, then we apportion the ADS frequencies to the paths to create the path volumes.

Once we have an ADS frequencies dataset, we can apportion the ADS counts to the associated paths.

Step 5. Summarize the Path Volumes in an Aggregated OD Table

The last step is to summarize the path volumes. We do this by tabulating the path volumes by first and last detector to form an OD table

Appendix B – Traffic Volume Data

CT River Bridge Analysis Intersection Volumes

Exit 20 Ramp Intersections

April 3, 2013

#	Intersection	Northbound			Southbound			Eastbound			Westbound			Total	PHF
		Left	Thru	Right	Left	Thru	Right	Left	Thru	Right	Left	Thru	Right		
2008 Traffic Counts															
1	SB Ramps - AM	0	426	238	44	601	0	210	0	418	0	0	0	1,937	0.86
2	NB Ramps - AM	191	445	0	0	292	120	0	0	0	353	0	148	1,549	
1	SB Ramps - PM	0	1,006	317	68	1,000	0	200	0	358	0	0	0	2,949	0.93
2	NB Ramps - PM	492	714	0	0	643	403	0	0	0	425	1	195	2,873	
1	SB Ramps - Sat	0	1,069	464	95	1,240	0	198	0	495	0	0	0	3,561	0.95
2	NB Ramps - Sat	401	866	0	0	891	229	0	0	0	444	1	186	3,018	
Adjusted to January 2013															
1	SB Ramps - AM	0	485	271	50	684	0	239	0	476	0	0	0	2,204	0.86
2	NB Ramps - AM	142	582	0	0	472	89	0	0	0	262	0	110	1,657	
1	SB Ramps - PM	0	942	295	63	935	0	186	0	334	0	0	0	2,756	0.93
2	NB Ramps - PM	460	668	0	0	601	377	0	0	0	397	1	182	2,687	
1	SB Ramps - Sat	0	952	580	119	1,145	0	248	0	619	0	0	0	3,662	0.95
2	NB Ramps - Sat	258	942	0	0	979	147	0	0	0	285	1	120	2,731	
Adjusted to Summer 2013															
1	SB Ramps - AM	0	560	310	60	790	0	280	0	550	0	0	0	2,550	0.86
2	NB Ramps - AM	160	680	0	0	550	100	0	0	0	300	0	130	1,920	
1	SB Ramps - PM	0	1,070	330	70	1,060	0	210	0	380	0	0	0	3,120	0.93
2	NB Ramps - PM	520	760	0	0	680	430	0	0	0	450	0	210	3,050	
1	SB Ramps - Sat	0	1,030	630	130	1,250	0	270	0	670	0	0	0	3,980	0.95
2	NB Ramps - Sat	280	1,020	0	0	1,070	160	0	0	0	310	0	130	2,970	
Adjusted to Summer 2019															
1	SB Ramps - AM	0	590	330	60	830	0	290	0	580	0	0	0	2,680	0.88
2	NB Ramps - AM	170	710	0	0	580	110	0	0	0	320	0	140	2,030	
1	SB Ramps - PM	0	1,120	350	70	1,110	0	220	0	400	0	0	0	3,270	0.94
2	NB Ramps - PM	550	800	0	0	710	450	0	0	0	470	0	220	3,200	
1	SB Ramps - Sat	0	1,080	660	140	1,310	0	280	0	700	0	0	0	4,170	0.95
2	NB Ramps - Sat	290	1,070	0	0	1,120	170	0	0	0	330	0	140	3,120	
Adjusted to Summer 2039															
1	SB Ramps - AM	0	680	380	70	960	0	340	0	670	0	0	0	3,100	0.92
2	NB Ramps - AM	190	820	0	0	670	120	0	0	0	360	0	160	2,320	
1	SB Ramps - PM	0	1,290	400	80	1,280	0	250	0	460	0	0	0	3,760	0.95
2	NB Ramps - PM	630	920	0	0	820	520	0	0	0	540	0	250	3,680	
1	SB Ramps - Sat	0	1,250	760	160	1,510	0	330	0	810	0	0	0	4,820	0.95
2	NB Ramps - Sat	340	1,230	0	0	1,290	190	0	0	0	380	0	160	3,590	

January 2013 OD Table

AM Peak		4	5	7	8	9	
		Exit 20 SB	I-89 SB-South	Exit 20 NB	I-89 NB to I-91 NB	I-89 NB-North	
1	I-89 SB-North	196	367				**563**
2	I-91 SB to I-89 SB	333	254				**587**
3	I-91 NB to I-89 SB	185	176				**361**
4	Exit 20 SB		321				**321**
6	I-89 NB-South			372	248	475	**1,095**
7	Exit 20 NB				158	73	**231**
		714	**1,117**	**372**	**406**	**548**	**3,158**

PM Peak		4	5	7	8	9	
1	I-89 SB-North	186	375				**561**
2	I-91 SB to I-89 SB	264	201				**465**
3	I-91 NB to I-89 SB	70	155				**225**
4	Exit 20 SB		359				**359**
6	I-89 NB-South			581	231	843	**1,655**
7	Exit 20 NB				465	372	**837**
		520	**1,090**	**581**	**696**	**1,215**	**4,102**

Sat. Peak		4	5	7	8	9	
1	I-89 SB-North	278	322				**600**
2	I-91 SB to I-89 SB	300	122				**422**
3	I-91 NB to I-89 SB	289	111				**400**
4	Exit 20 SB		699				**699**
6	I-89 NB-South			406	167	709	**1,282**
7	Exit 20 NB				251	154	**405**
		867	**1,254**	**406**	**419**	**862**	**3,808**

	AM	PM	Sat
I-89 SB - North End	**563**	**561**	**600**
I-89 SB - SB I-91 On Ramp	587	465	422
I-89 SB - SB I-91 On to NB I-91 On	**1,150**	**1,026**	**1,022**
I-89 SB - NB I-91 On Ramp	361	225	400
I-89 SB - NB I-91 On to Exit 20	**1,511**	**1,251**	**1,422**
I-89 SB - Exit 20 Off Ramp	714	520	867
I-89 SB - Between Exit 20 Ramps	**797**	**731**	**555**
I-89 SB - Exit 20 On Ramp	321	359	699
I-89 SB - South End	**1,117**	**1,090**	**1,254**
I-89 NB - North End	**548**	**1,215**	**862**
I-89 NB - NB I-91 Off Ramp	406	696	419
I-89 NB - Exit 20 to NB I-91 Off Ramp	**954**	**1,911**	**1,281**
I-89 NB - Exit 20 On Ramp	231	837	405
I-89 NB - Between Exit 20 Ramps	**723**	**1,074**	**876**
I-89 NB - Exit 20 Off Ramp	372	581	406
I-89 NB - South End	**1,095**	**1,655**	**1,282**

Summer 2013 OD tables

Adjustment Factors:	AM	PM	Sat.
	1.16	1.13	1.08

		4	5	7	8	9	
		Exit 20 SB	I-89 SB-South	Exit 20 NB	I-89 NB to I-91 NB	I-89 NB-North	
1	I-89 SB-North	227	423				**650**
2	I-91 SB to I-89 SB	386	294				**680**
3	I-91 NB to I-89 SB	215	205				**420**
4	Exit 20 SB		370				**370**
6	I-89 NB-South			430	288	552	**1,270**
7	Exit 20 NB				185	85	**270**
		828	**1,292**	**430**	**473**	**637**	**3,660**

		4	5	7	8	9	
1	I-89 SB-North	209	421				**630**
2	I-91 SB to I-89 SB	301	229				**530**
3	I-91 NB to I-89 SB	77	173				**250**
4	Exit 20 SB		400				**400**
6	I-89 NB-South			660	260	950	**1,870**
7	Exit 20 NB				528	422	**950**
		587	**1,223**	**660**	**788**	**1,372**	**4,630**

		4	5	7	8	9	
1	I-89 SB-North	301	349				**650**
2	I-91 SB to I-89 SB	327	133				**460**
3	I-91 NB to I-89 SB	311	119				**430**
4	Exit 20 SB		760				**760**
6	I-89 NB-South			440	180	760	**1,380**
7	Exit 20 NB				273	167	**440**
		938	**1,362**	**440**	**453**	**927**	**4,120**

	AM	PM	Sat
I-89 SB - North End	**650**	**630**	**650**
I-89 SB - SB I-91 On Ramp	680	530	460
I-89 SB - SB I-91 On to NB I-91 On	**1,330**	**1,160**	**1,110**
I-89 SB - NB I-91 On Ramp	420	250	430
I-89 SB - NB I-91 On to Exit 20	**1,750**	**1,410**	**1,540**
I-89 SB - Exit 20 Off Ramp	830	590	940
I-89 SB - Between Exit 20 Ramps	**920**	**820**	**600**
I-89 SB - Exit 20 On Ramp	370	400	760
I-89 SB - South End	**1,290**	**1,220**	**1,360**
I-89 NB - North End	**640**	**1,370**	**930**
I-89 NB - NB I-91 Off Ramp	470	790	450
I-89 NB - Exit 20 to NB I-91 Off Ramp	**1,110**	**2,160**	**1,380**
I-89 NB - Exit 20 On Ramp	270	950	440
I-89 NB - Between Exit 20 Ramps	**840**	**1,210**	**940**
I-89 NB - Exit 20 Off Ramp	430	660	440
I-89 NB - South End	**1,270**	**1,870**	**1,380**

Summer 2019 OD tables

Adjustment Factor: 1.05

		4 Exit 20 SB	5 I-89 SB-South	7 Exit 20 NB	8 I-89 NB to I-91 NB	9 I-89 NB-North	
1	I-89 SB-North	237	443				**680**
2	I-91 SB to I-89 SB	403	307				**710**
3	I-91 NB to I-89 SB	226	214				**440**
4	Exit 20 SB		390				**390**
6	I-89 NB-South			460	299	571	**1,330**
7	Exit 20 NB				191	89	**280**
		865	**1,355**	**460**	**490**	**660**	**3,830**

		4	5	7	8	9	
1	I-89 SB-North	219	441				**660**
2	I-91 SB to I-89 SB	318	242				**560**
3	I-91 NB to I-89 SB	81	179				**260**
4	Exit 20 SB		420				**420**
6	I-89 NB-South			690	273	997	**1,960**
7	Exit 20 NB				556	444	**1,000**
		618	**1,282**	**690**	**829**	**1,441**	**4,860**

		4	5	7	8	9	
1	I-89 SB-North	315	365				**680**
2	I-91 SB to I-89 SB	341	139				**480**
3	I-91 NB to I-89 SB	325	125				**450**
4	Exit 20 SB		800				**800**
6	I-89 NB-South			470	187	793	**1,450**
7	Exit 20 NB				285	175	**460**
		981	**1,429**	**470**	**473**	**967**	**4,320**

	AM	PM	Sat
I-89 SB - North End	**680**	**660**	**680**
I-89 SB - SB I-91 On Ramp	710	560	480
I-89 SB - SB I-91 On to NB I-91 On	**1,390**	**1,220**	**1,160**
I-89 SB - NB I-91 On Ramp	440	260	450
I-89 SB - NB I-91 On to Exit 20	**1,830**	**1,480**	**1,610**
I-89 SB - Exit 20 Off Ramp	870	620	990
I-89 SB - Between Exit 20 Ramps	**960**	**860**	**620**
I-89 SB - Exit 20 On Ramp	390	420	800
I-89 SB - South End	**1,350**	**1,280**	**1,420**
I-89 NB - North End	**660**	**1,440**	**970**
I-89 NB - NB I-91 Off Ramp	490	830	470
I-89 NB - Exit 20 to NB I-91 Off Ramp	**1,150**	**2,270**	**1,440**
I-89 NB - Exit 20 On Ramp	280	1,000	460
I-89 NB - Between Exit 20 Ramps	**870**	**1,270**	**980**
I-89 NB - Exit 20 Off Ramp	460	690	470
I-89 NB - South End	**1,330**	**1,960**	**1,450**

Summer 2039 OD tables

Adjustment Factor: 1.21

		4	5	7	8	9	
		Exit 20 SB	I-89 SB-South	Exit 20 NB	I-89 NB to I-91 NB	I-89 NB-North	
1	I-89 SB-North	276	514				**790**
2	I-91 SB to I-89 SB	465	355				**820**
3	I-91 NB to I-89 SB	261	249				**510**
4	Exit 20 SB		450				**450**
6	I-89 NB-South			520	350	670	**1,540**
7	Exit 20 NB				226	104	**330**
		1,002	**1,568**	**520**	**576**	**774**	**4,440**

		4	5	7	8	9	
1	I-89 SB-North	252	508				**760**
2	I-91 SB to I-89 SB	364	276				**640**
3	I-91 NB to I-89 SB	93	207				**300**
4	Exit 20 SB		480				**480**
6	I-89 NB-South			790	316	1,154	**2,260**
7	Exit 20 NB				639	511	**1,150**
		709	**1,471**	**790**	**955**	**1,665**	**5,590**

		4	5	7	8	9	
1	I-89 SB-North	366	424				**790**
2	I-91 SB to I-89 SB	398	162				**560**
3	I-91 NB to I-89 SB	376	144				**520**
4	Exit 20 SB		920				**920**
6	I-89 NB-South			540	216	914	**1,670**
7	Exit 20 NB				329	201	**530**
		1,139	**1,651**	**540**	**545**	**1,115**	**4,990**

	AM	PM	Sat
I-89 SB - North End	**790**	**760**	**790**
I-89 SB - SB I-91 On Ramp	820	640	560
I-89 SB - SB I-91 On to NB I-91 On	**1,610**	**1,400**	**1,350**
I-89 SB - NB I-91 On Ramp	510	300	520
I-89 SB - NB I-91 On to Exit 20	**2,120**	**1,700**	**1,870**
I-89 SB - Exit 20 Off Ramp	1,000	710	1,140
I-89 SB - Between Exit 20 Ramps	**1,120**	**990**	**730**
I-89 SB - Exit 20 On Ramp	450	480	920
I-89 SB - South End	**1,570**	**1,470**	**1,650**
I-89 NB - North End	**780**	**1,660**	**1,120**
I-89 NB - NB I-91 Off Ramp	570	960	540
I-89 NB - Exit 20 to NB I-91 Off Ramp	**1,350**	**2,620**	**1,660**
I-89 NB - Exit 20 On Ramp	330	1,150	530
I-89 NB - Between Exit 20 Ramps	**1,020**	**1,470**	**1,130**
I-89 NB - Exit 20 Off Ramp	520	790	540
I-89 NB - South End	**1,540**	**2,260**	**1,670**

APPENDIX C – SCENARIO SPECIFIC SIMULATION RESULTS

CT River Bridge Traffic Analysis

Summer 2013 AM No Build Freeway Operations

Segment	Length (ft)	Volume (vph)	Volume Target	% Served	Speed (mph)	Density	LOS
Southbound							
I-89 SB - Basic North of NB I-91 On Ramp	1,500	1,330	1,330	100%	63	12	B
I-89 SB - Weave NB I-91 On Ramp to Exit 20	1,800	1,680	1,750	96%	59	15	B
I-89 SB - Basic Between Exit 20 Ramps	1,100	920	920	100%	64	8	A
Northbound							
I-89 NB - Basic North of NB I-91 Off Ramp	500	640	640	100%	61	6	A
I-89 NB - Diverge at NB I-91 Off Ramp	1,500	1,070	1,110	96%	61	10	A
I-89 NB - Basic Exit 20 to NB I-91 Off Ramp	300	1,110	1,110	100%	62	10	A
I-89 NB - Merge at Exit 20 On Ramp	1,500	1,110	1,110	100%	62	10	A
I-89 NB - Between Exit 20 Ramps	500	850	840	101%	65	8	A

Note: Speed and LOS results taken from peak 15-minute period.

CT River Bridge Traffic Analysis
Summer 2013 PM No Build Freeway Operations

Segment	Length (ft)	Volume (vph)	Volume Target	% Served	Speed (mph)	Density	LOS
Southbound							
I-89 SB - Basic North of NB I-91 On Ramp	1,500	1,160	1,160	100%	64	10	A
I-89 SB - Weave NB I-91 On Ramp to Exit 20	1,800	1,360	1,410	97%	62	11	B
I-89 SB - Basic Between Exit 20 Ramps	1,100	820	820	100%	65	7	A
Northbound							
I-89 NB - Basic North of NB I-91 Off Ramp	500	1,370	1,370	100%	53	13	B
I-89 NB - Diverge at NB I-91 Off Ramp	1,500	2,110	2,160	98%	57	20	C
I-89 NB - Basic Exit 20 to NB I-91 Off Ramp	300	2,180	2,160	101%	59	20	C
I-89 NB - Merge at Exit 20 On Ramp	1,500	2,180	2,160	101%	59	18	C
I-89 NB - Between Exit 20 Ramps	500	1,220	1,210	101%	65	10	A

Note: Speed and LOS results taken from peak 15-minute period.

CT River Bridge Traffic Analysis

Summer 2013 Sat No Build Freeway Operations

Segment	Length (ft)	Volume (vph)	Volume Target	% Served	Speed (mph)	Density	LOS
Southbound							
I-89 SB - Basic North of NB I-91 On Ramp	1,500	1,110	1,110	100%	64	9	A
I-89 SB - Weave NB I-91 On Ramp to Exit 20	1,800	1,460	1,540	95%	60	12	B
I-89 SB - Basic Between Exit 20 Ramps	1,100	600	600	100%	65	5	A
Northbound							
I-89 NB - Basic North of NB I-91 Off Ramp	500	930	930	100%	61	8	A
I-89 NB - Diverge at NB I-91 Off Ramp	1,500	1,350	1,380	98%	61	12	B
I-89 NB - Basic Exit 20 to NB I-91 Off Ramp	300	1,390	1,380	101%	63	12	B
I-89 NB - Merge at Exit 20 On Ramp	1,500	1,390	1,380	101%	62	11	A
I-89 NB - Between Exit 20 Ramps	500	950	940	101%	65	8	A

Note: Speed and LOS results taken from peak 15-minute period.

CT River Bridge Traffic Analysis

Summer 2019 AM No Build Freeway Operations

Segment	Length (ft)	Volume (vph)	Volume Target	% Served	Speed (mph)	Density	LOS
Southbound							
I-89 SB - Basic North of NB I-91 On Ramp	1,500	1,390	1,390	100%	62	12	B
I-89 SB - Weave NB I-91 On Ramp to Exit 20	1,800	1,760	1,830	96%	58	16	B
I-89 SB - Basic Between Exit 20 Ramps	1,100	970	960	101%	64	8	A
Northbound							
I-89 NB - Basic North of NB I-91 Off Ramp	500	670	660	101%	61	6	A
I-89 NB - Diverge at NB I-91 Off Ramp	1,500	1,120	1,150	97%	60	11	A
I-89 NB - Basic Exit 20 to NB I-91 Off Ramp	300	1,160	1,150	101%	62	11	A
I-89 NB - Merge at Exit 20 On Ramp	1,500	1,160	1,150	101%	62	10	A
I-89 NB - Between Exit 20 Ramps	500	890	870	102%	65	8	A

Note: Speed and LOS results taken from peak 15-minute period.

CT River Bridge Traffic Analysis

Summer 2019 PM No Build Freeway Operations

Segment	Length (ft)	Volume (vph)	Volume Target	% Served	Speed (mph)	Density	LOS
Southbound							
I-89 SB - Basic North of NB I-91 On Ramp	1,500	1,220	1,220	100%	64	10	A
I-89 SB - Weave NB I-91 On Ramp to Exit 20	1,800	1,430	1,480	96%	62	11	B
I-89 SB - Basic Between Exit 20 Ramps	1,100	860	860	100%	65	7	A
Northbound							
I-89 NB - Basic North of NB I-91 Off Ramp	500	1,440	1,440	100%	53	14	B
I-89 NB - Diverge at NB I-91 Off Ramp	1,500	2,210	2,270	97%	53	22	C
I-89 NB - Basic Exit 20 to NB I-91 Off Ramp	300	2,280	2,270	101%	58	21	C
I-89 NB - Merge at Exit 20 On Ramp	1,500	2,280	2,270	100%	58	19	C
I-89 NB - Between Exit 20 Ramps	500	1,280	1,270	101%	64	11	A

Note: Speed and LOS results taken from peak 15-minute period.

CT River Bridge Traffic Analysis

Summer 2019 Sat No Build Freeway Operations

Segment	Length (ft)	Volume (vph)	Volume Target	% Served	Speed (mph)	Density	LOS
Southbound							
I-89 SB - Basic North of NB I-91 On Ramp	1,500	1,160	1,160	100%	64	10	A
I-89 SB - Weave NB I-91 On Ramp to Exit 20	1,800	1,530	1,610	95%	59	13	B
I-89 SB - Basic Between Exit 20 Ramps	1,100	620	620	100%	65	5	A
Northbound							
I-89 NB - Basic North of NB I-91 Off Ramp	500	970	970	100%	60	8	A
I-89 NB - Diverge at NB I-91 Off Ramp	1,500	1,410	1,440	98%	61	12	B
I-89 NB - Basic Exit 20 to NB I-91 Off Ramp	300	1,460	1,440	101%	62	12	B
I-89 NB - Merge at Exit 20 On Ramp	1,500	1,450	1,440	101%	62	11	B
I-89 NB - Between Exit 20 Ramps	500	990	980	101%	65	8	A

Note: Speed and LOS results taken from peak 15-minute period.

CT River Bridge Traffic Analysis

Summer 2019 AM Build Freeway Operations

Segment	Length (ft)	Volume (vph)	Volume Target	% Served	Speed (mph)	Density	LOS
Southbound							
I-89 SB - Basic North of NB I-91 On Ramp	1,500	1,390	1,390	100%	62	12	B
I-89 SB - Weave NB I-91 On Ramp to Exit 20	1,800	1,820	1,830	100%	63	11	A
I-89 SB - Basic Between Exit 20 Ramps	1,100	970	960	101%	65	8	A
Northbound							
I-89 NB - Basic North of NB I-91 Off Ramp	500	670	660	101%	62	6	A
I-89 NB - Diverge at NB I-91 Off Ramp	1,500	1,160	1,150	101%	62	7	A
I-89 NB - Basic Exit 20 to NB I-91 Off Ramp	300	1,160	1,150	101%	64	7	A
I-89 NB - Merge at Exit 20 On Ramp	1,500	1,160	1,150	101%	64	7	A
I-89 NB - Between Exit 20 Ramps	500	890	870	102%	65	8	A

Note: Speed and LOS results taken from peak 15-minute period.

CT River Bridge Traffic Analysis
Summer 2019 PM Build Freeway Operations

Segment	Length (ft)	Volume (vph)	Volume Target	% Served	Speed (mph)	Density	LOS
Southbound							
I-89 SB - Basic North of NB I-91 On Ramp	1,500	1,220	1,220	100%	64	10	A
I-89 SB - Weave NB I-91 On Ramp to Exit 20	1,800	1,470	1,480	100%	64	8	A
I-89 SB - Basic Between Exit 20 Ramps	1,100	860	860	100%	65	7	A
Northbound							
I-89 NB - Basic North of NB I-91 Off Ramp	500	1,440	1,440	100%	60	13	B
I-89 NB - Diverge at NB I-91 Off Ramp	1,500	2,280	2,270	101%	60	13	B
I-89 NB - Basic Exit 20 to NB I-91 Off Ramp	300	2,280	2,270	101%	62	13	B
I-89 NB - Merge at Exit 20 On Ramp	1,500	2,280	2,270	100%	62	13	B
I-89 NB - Between Exit 20 Ramps	500	1,280	1,270	101%	64	11	A

Note: Speed and LOS results taken from peak 15-minute period.

CT River Bridge Traffic Analysis

Summer 2019 Sat Build Freeway Operations

Segment	Length (ft)	Volume (vph)	Volume Target	% Served	Speed (mph)	Density	LOS
Southbound							
I-89 SB - Basic North of NB I-91 On Ramp	1,500	1,160	1,160	100%	64	10	A
I-89 SB - Weave NB I-91 On Ramp to Exit 20	1,800	1,610	1,610	100%	63	9	A
I-89 SB - Basic Between Exit 20 Ramps	1,100	620	620	100%	65	5	A
Northbound							
I-89 NB - Basic North of NB I-91 Off Ramp	500	970	970	100%	62	8	A
I-89 NB - Diverge at NB I-91 Off Ramp	1,500	1,460	1,440	101%	62	8	A
I-89 NB - Basic Exit 20 to NB I-91 Off Ramp	300	1,460	1,440	101%	64	8	A
I-89 NB - Merge at Exit 20 On Ramp	1,500	1,460	1,440	101%	63	8	A
I-89 NB - Between Exit 20 Ramps	500	990	980	101%	65	8	A

Note: Speed and LOS results taken from peak 15-minute period.

CT River Bridge Traffic Analysis

Summer 2039 AM No Build Freeway Operations

Segment	Length (ft)	Volume (vph)	Volume Target	% Served	Speed (mph)	Density	LOS
Southbound							
I-89 SB - Basic North of NB I-91 On Ramp	1,500	1,610	1,610	100%	62	14	B
I-89 SB - Weave NB I-91 On Ramp to Exit 20	1,800	2,040	2,120	96%	56	18	C
I-89 SB - Basic Between Exit 20 Ramps	1,100	1,120	1,120	100%	64	9	A
Northbound							
I-89 NB - Basic North of NB I-91 Off Ramp	500	770	780	98%	59	7	A
I-89 NB - Diverge at NB I-91 Off Ramp	1,500	1,300	1,350	96%	59	12	B
I-89 NB - Basic Exit 20 to NB I-91 Off Ramp	300	1,350	1,350	100%	62	12	B
I-89 NB - Merge at Exit 20 On Ramp	1,500	1,350	1,350	100%	62	11	A
I-89 NB - Between Exit 20 Ramps	500	1,030	1,020	101%	65	9	A

Note: Speed and LOS results taken from peak 15-minute period.

CT River Bridge Traffic Analysis

Summer 2039 PM No Build Freeway Operations

Segment	Length (ft)	Volume (vph)	Volume Target	% Served	Speed (mph)	Density	LOS
Southbound							
I-89 SB - Basic North of NB I-91 On Ramp	1,500	1,400	1,400	100%	64	11	B
I-89 SB - Weave NB I-91 On Ramp to Exit 20	1,800	1,640	1,700	96%	62	13	B
I-89 SB - Basic Between Exit 20 Ramps	1,100	990	990	100%	65	8	A
Northbound							
I-89 NB - Basic North of NB I-91 Off Ramp	500	1,660	1,660	100%	52	17	B
I-89 NB - Diverge at NB I-91 Off Ramp	1,500	2,540	2,620	97%	52	25	C
I-89 NB - Basic Exit 20 to NB I-91 Off Ramp	300	2,630	2,620	101%	57	24	C
I-89 NB - Merge at Exit 20 On Ramp	1,500	2,630	2,620	100%	57	22	C
I-89 NB - Between Exit 20 Ramps	500	1,480	1,470	101%	64	12	B

Note: Speed and LOS results taken from peak 15-minute period.

CT River Bridge Traffic Analysis
Summer 2039 Sat No Build Freeway Operations

Segment	Length (ft)	Volume (vph)	Volume Target	% Served	Speed (mph)	Density	LOS
Southbound							
I-89 SB - Basic North of NB I-91 On Ramp	1,500	1,350	1,350	100%	64	11	B
I-89 SB - Weave NB I-91 On Ramp to Exit 20	1,800	1,780	1,870	95%	57	15	B
I-89 SB - Basic Between Exit 20 Ramps	1,100	730	730	101%	64	6	A
Northbound							
I-89 NB - Basic North of NB I-91 Off Ramp	500	1,120	1,120	100%	56	10	A
I-89 NB - Diverge at NB I-91 Off Ramp	1,500	1,630	1,660	98%	59	15	B
I-89 NB - Basic Exit 20 to NB I-91 Off Ramp	300	1,680	1,660	101%	61	14	B
I-89 NB - Merge at Exit 20 On Ramp	1,500	1,680	1,660	101%	61	13	B
I-89 NB - Between Exit 20 Ramps	500	1,150	1,130	101%	65	9	A

Note: Speed and LOS results taken from peak 15-minute period.

CT River Bridge Traffic Analysis

Summer 2039 AM Build Freeway Operations

Segment	Length (ft)	Volume (vph)	Volume Target	% Served	Speed (mph)	Density	LOS
Southbound							
I-89 SB - Basic North of NB I-91 On Ramp	1,500	1,610	1,610	100%	62	14	B
I-89 SB - Weave NB I-91 On Ramp to Exit 20	1,800	2,110	2,120	100%	63	12	B
I-89 SB - Basic Between Exit 20 Ramps	1,100	1,120	1,120	100%	64	9	A
Northbound							
I-89 NB - Basic North of NB I-91 Off Ramp	500	770	780	98%	62	7	A
I-89 NB - Diverge at NB I-91 Off Ramp	1,500	1,350	1,350	100%	62	8	A
I-89 NB - Basic Exit 20 to NB I-91 Off Ramp	300	1,350	1,350	100%	64	8	A
I-89 NB - Merge at Exit 20 On Ramp	1,500	1,340	1,350	100%	64	8	A
I-89 NB - Between Exit 20 Ramps	500	1,030	1,020	101%	65	9	A

Note: Speed and LOS results taken from peak 15-minute period.

CT River Bridge Traffic Analysis

Summer 2039 PM Build Freeway Operations

Segment	Length (ft)	Volume (vph)	Volume Target	% Served	Speed (mph)	Density	LOS
Southbound							
I-89 SB - Basic North of NB I-91 On Ramp	1,500	1,400	1,400	100%	64	11	B
I-89 SB - Weave NB I-91 On Ramp to Exit 20	1,800	1,690	1,700	100%	64	9	A
I-89 SB - Basic Between Exit 20 Ramps	1,100	990	990	100%	65	8	A
Northbound							
I-89 NB - Basic North of NB I-91 Off Ramp	500	1,660	1,660	100%	57	15	B
I-89 NB - Diverge at NB I-91 Off Ramp	1,500	2,640	2,620	101%	57	16	B
I-89 NB - Basic Exit 20 to NB I-91 Off Ramp	300	2,640	2,620	101%	62	15	B
I-89 NB - Merge at Exit 20 On Ramp	1,500	2,630	2,620	100%	62	15	B
I-89 NB - Between Exit 20 Ramps	500	1,480	1,470	101%	64	12	B

Note: Speed and LOS results taken from peak 15-minute period.

CT River Bridge Traffic Analysis

Summer 2039 Sat Build Freeway Operations

Segment	Length (ft)	Volume (vph)	Volume Target	% Served	Speed (mph)	Density	LOS
Southbound							
I-89 SB - Basic North of NB I-91 On Ramp	1,500	1,350	1,350	100%	64	11	B
I-89 SB - Weave NB I-91 On Ramp to Exit 20	1,800	1,860	1,870	100%	63	10	A
I-89 SB - Basic Between Exit 20 Ramps	1,100	730	730	101%	65	6	A
Northbound							
I-89 NB - Basic North of NB I-91 Off Ramp	500	1,120	1,120	100%	61	10	A
I-89 NB - Diverge at NB I-91 Off Ramp	1,500	1,680	1,660	101%	62	9	A
I-89 NB - Basic Exit 20 to NB I-91 Off Ramp	300	1,680	1,660	101%	64	9	A
I-89 NB - Merge at Exit 20 On Ramp	1,500	1,680	1,660	101%	63	9	A
I-89 NB - Between Exit 20 Ramps	500	1,150	1,130	101%	65	9	A

Note: Speed and LOS results taken from peak 15-minute period.

APPENDIX D - HIGHWAY CAPACITY SOFTWARE RESULTS

CT River Bridge Traffic Analysis

HCS Analysis Summary

AM Peak Hour

Southbound	2013			2019 No Build			2019 Build			2039 No Build			2039 Build		
	Speed	Density	LOS	Speed	Density	LOS	Speed	Density	LOS	Speed	Density	LOS	Speed	Density	LOS
I-89 SB - SB I-91 On to NB I-91 On	63.0	13.4	B	63.0	13.7	B	63.0	13.7	B	63.0	15.1	B	63.0	15.1	B
I-89 SB - NB I-91 On to Exit 20 Weave (A)	50.4	17.4	B	49.8	18.4	B	50.0	12.2	B	47.9	22.1	C	48.4	14.6	B
I-89 SB - Between Exit 20 Ramps	61.8	9.0	A	61.7	9.2	A	61.8	9.2	A	61.6	10.3	A	61.6	10.3	A
Northbound	**Speed**	**Density**	**LOS**	**Speed**	**Density**	**LOS**	**Speed**	**Density**	**LOS**	**Speed**	**Density**	**LOS**	**Speed**	**Density**	**LOS**
I-89 NB - North End	61.5	8.1	A	61.5	8.2	A	63.0	8.0	A	61.5	9.2	A	63.0	9.0	A
I-89 NB - I-91 Off Ramp Diverge	55.7	13.3	B	55.6	13.5	B				55.5	14.9	B			
I-89 NB - Exit 20 to NB I-91 Off Ramp	61.7	10.9	A	61.7	11.1	B	63.0	6.0	A	61.7	12.4	B	63.0	7.1	A
I-89 NB - Exit 20 Merge	57.5	12.0	B	57.5	12.2	B		(Weaving Section)		57.4	13.7	B		(Weaving Section)	
I-89 NB - Between Exit 20 Ramps	63.0	8.1	A	63.0	8.2	A	63.0	8.2	A	63.0	9.2	A	63.0	9.2	A

PM Peak Hour

Southbound	2013			2019 No Build			2019 Build			2039 No Build			2039 Build		
	Speed	Density	LOS	Speed	Density	LOS	Speed	Density	LOS	Speed	Density	LOS	Speed	Density	LOS
I-89 SB - SB I-91 On to NB I-91 On	63.0	10.5	A	63.0	10.9	A	63.0	10.9	A	63.0	12.4	B	63.0	12.4	B
I-89 SB - NB I-91 On to Exit 20 Weave (A)	52.6	13.4	B	52.1	14.2	B	51.7	9.5	A	50.3	16.9	B	50.2	11.3	B
I-89 SB - Between Exit 20 Ramps	62.0	7.3	A	62.0	7.6	A	61.9	7.6	A	61.8	8.7	A	61.8	8.7	A
Northbound	**Speed**	**Density**	**LOS**	**Speed**	**Density**	**LOS**	**Speed**	**Density**	**LOS**	**Speed**	**Density**	**LOS**	**Speed**	**Density**	**LOS**
I-89 NB - North End	61.4	15.6	B	61.4	15.8	B	62.9	15.5	B	61.4	18.1	C	62.8	17.7	B
I-89 NB - I-91 Off Ramp Diverge	55.1	22.3	C	55.0	23.1	C				54.8	26.1	C			
I-89 NB - Exit 20 to NB I-91 Off Ramp	61.5	19.5	C	61.5	20.2	C	60.2	12.6	B	61.4	23.1	C	59.0	14.8	B
I-89 NB - Exit 20 Merge	56.7	20.3	C	56.6	20.8	C		(Weaving Section)		56.0	23.8	C		(Weaving Section)	
I-89 NB - Between Exit 20 Ramps	63.0	10.7	A	63.0	11.0	B	63.0	11.0	B	63.0	12.6	B	63.0	12.6	B

Saturday Peak Hour

Southbound	2013			2019 No Build			2019 Build			2039 No Build			2039 Build		
	Speed	Density	LOS	Speed	Density	LOS	Speed	Density	LOS	Speed	Density	LOS	Speed	Density	LOS
I-89 SB - SB I-91 On to NB I-91 On	63.0	9.9	A	63.0	10.4	A	63.0	10.4	A	63.0	12.1	B	63.0	12.1	B
I-89 SB - NB I-91 On to Exit 20 Weave (A)	51.5	14.9	B	50.8	15.8	B	50.6	10.6	B	49.0	19.1	B	49.1	12.7	B
I-89 SB - Between Exit 20 Ramps	61.9	5.3	A	61.8	5.5	A	61.8	5.5	A	61.7	6.4	A	61.7	6.4	A
Northbound	**Speed**	**Density**	**LOS**	**Speed**	**Density**	**LOS**	**Speed**	**Density**	**LOS**	**Speed**	**Density**	**LOS**	**Speed**	**Density**	**LOS**
I-89 NB - North End	61.6	10.3	A	61.6	10.8	A	62.6	8.4	A	61.6	12.4	B	63.0	12.1	B
I-89 NB - I-91 Off Ramp Diverge	55.8	14.8	B	55.8	15.3	B				55.8	17.3	B			
I-89 NB - Exit 20 to NB I-91 Off Ramp	61.7	12.2	B	61.7	12.7	B	61.1	7.9	A	61.7	14.7	B	63.0	8.7	A
I-89 NB - Exit 20 Merge	57.5	13.1	B	57.4	13.6	B		(Weaving Section)		57.3	15.7	B		(Weaving Section)	
I-89 NB - Between Exit 20 Ramps	63.0	8.1	A	63.0	8.5	A	63.0	8.5	A	63.0	9.8	A	63.0	9.8	A

APPENDIX E - TRAFFIC ADJUSTMENTS

Continuous Traffic Counter Grouping Study and Regression Analysis Based on 2012 Traffic Data

Vermont Agency of Transportation
Policy, Planning, & Intermodal Development Division
Traffic Research Unit
March 2013

A: Interstate Highways

					Short Term Growth				**2007**	**to**	**2012**	**1.03**
					20 Year Growth				**2012**	**to**	**2032**	**1.16**
	2007	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
2007	1.00											
2008	1.01	1.00										
2009	1.01	1.01	1.00									
2010	1.02	1.01	1.01	1.00								
2011	1.02	1.02	1.01	1.01	1.00							
2012	1.03	1.02	1.02	1.01	1.01	1.00						
2013						1.01	1.00					
2014						1.02	1.01	1.00				
2015						1.02	1.02	1.01	1.00			
2016						1.03	1.02	1.02	1.01	1.00		
2017						1.04	1.03	1.02	1.02	1.01	1.00	
2018						1.05	1.04	1.03	1.02	1.02	1.01	1.00
2019						1.06	1.05	1.04	1.03	1.02	1.02	1.01
2020						1.06	1.06	1.05	1.04	1.03	1.02	1.02
2021						1.07	1.06	1.06	1.05	1.04	1.03	1.02
2022						1.08	1.07	1.06	1.05	1.05	1.04	1.03
2023						1.09	1.08	1.07	1.06	1.05	1.05	1.04
2024						1.10	1.09	1.08	1.07	1.06	1.05	1.05
2025						1.10	1.10	1.09	1.08	1.07	1.06	1.05
2026						1.11	1.10	1.09	1.09	1.08	1.07	1.06
2027						1.12	1.11	1.10	1.09	1.09	1.08	1.07
2028						1.13	1.12	1.11	1.10	1.09	1.08	1.08
2029						1.14	1.13	1.12	1.11	1.10	1.09	1.08
2030						1.14	1.13	1.13	1.12	1.11	1.10	1.09
2031						1.15	1.14	1.13	1.13	1.12	1.11	1.10
2032						1.16	1.15	1.14	1.13	1.12	1.12	1.11
2033						1.17	1.16	1.15	1.14	1.13	1.12	1.11
2034						1.18	1.17	1.16	1.15	1.14	1.13	1.12
2035						1.18	1.17	1.17	1.16	1.15	1.14	1.13
2036						1.19	1.18	1.17	1.16	1.16	1.15	1.14
2037						1.20	1.19	1.18	1.17	1.16	1.15	1.15
2038						1.21	1.20	1.19	1.18	1.17	1.16	1.15
2039						1.22	1.21	1.20	1.19	1.18	1.17	1.16
2040						1.22	1.21	1.20	1.20	1.19	1.18	1.17
2041						1.23	1.22	1.21	1.20	1.19	1.18	1.18
2042						1.24	1.23	1.22	1.21	1.20	1.19	1.18
2043						1.25	1.24	1.23	1.22	1.21	1.20	1.19
2044						1.26	1.25	1.24	1.23	1.22	1.21	1.20
2045						1.26	1.25	1.24	1.23	1.22	1.22	1.21
2046						1.27	1.26	1.25	1.24	1.23	1.22	1.21
2047						1.28	1.27	1.26	1.25	1.24	1.23	1.22
2048						1.29	1.28	1.27	1.26	1.25	1.24	1.23
2049						1.30	1.29	1.28	1.27	1.26	1.25	1.24
2050						1.30	1.29	1.28	1.27	1.26	1.25	1.24
2051						1.31	1.30	1.29	1.28	1.27	1.26	1.25
2052						1.32	1.31	1.30	1.29	1.28	1.27	1.26
2053						1.33	1.32	1.31	1.30	1.29	1.28	1.27
2054						1.34	1.33	1.31	1.30	1.29	1.28	1.27
2055						1.34	1.33	1.32	1.31	1.30	1.29	1.28
2056						1.35	1.34	1.33	1.32	1.31	1.30	1.29
2057						1.36	1.35	1.34	1.33	1.32	1.31	1.30

STATE OF NEW HAMPSHIRE, DEPARTMENT OF TRANSPORTATION - BUREAU OF TRAFFIC
IN COOPERATION WITH U.S. DEPARTMENT OF TRANSPORTATION FEDERAL HIGHWAY ADMINISTRATION
AUTOMATIC TRAFFIC RECORDER DATA FOR THE MONTH OF JANUARY 2013

02 253090 LEBANON- I-89 AT CROSSOVER SOUTH OF VERMONT SL (SB-NB) (01253001-01253002)

MON	DATE	DAY	12 AM	1 AM	2 AM	3 AM	4 AM	5 AM	6 AM	7 AM	8 AM	9 AM	10 AM	11 AM	12 PM	1 PM	2 PM	3 PM	4 PM	5 PM	6 PM	7 PM	8 PM	9 PM	10 PM	11 PM	Total
1	1	3	279	183	59	54	109	274	442	523	813	1540	2378	2950	3130	3064	2756	2494	1986	1469	1072	684	437	293	160	79	27228
1	2	4	74	86	117	227	512	1376	2559	2239	1873	2090	2278	2495	2532	2661	2957	3445	3137	1868	1153	813	564	335	296	135	35822
1	3	5	110	106	116	181	518	1343	2434	2313	1919	1922	2056	2332	2428	2725	2913	3356	3254	1990	1272	952	712	391	311	166	35820
1	4	6	107	131	124	212	488	1266	2409	2240	1902	2019	2325	2493	2585	2880	3336	3615	3676	2347	1878	1673	1162	681	413	232	40194
1	5	7	135	111	120	165	198	550	860	1399	1716	2293	2631	2710	2703	2543	2507	2455	2131	1658	1165	937	737	481	283	199	30687
1	6	1	111	76	52	80	108	293	555	809	1292	1720	2233	2571	2561	2733	2765	2679	2217	1645	1092	767	495	320	151	101	27426
1	7	2	72	97	113	202	537	1449	2635	2296	1883	2046	1944	2087	2301	2317	2445	2833	3170	3030	1806	1220	718	544	326	296	36367
1	8	3	131	97	105	120	230	537	1402	2583	2362	1889	1989	2013	2195	2258	2469	2960	3289	3068	1908	1251	779	601	410	270	34916
1	9	4	141	82	92	112	219	519	1465	2662	2314	1872	1927	2052	2162	2264	2525	2978	3293	3110	1849	1243	839	577	382	276	34955
1	10	5	114	128	111	130	236	508	1374	2726	2375	1911	1832	2147	2313	2356	2526	2948	3383	3219	2026	1351	996	764	434	283	36191
1	11	6	146	121	131	116	223	474	1375	2433	2197	1950	2042	2220	2455	2675	2920	3488	3672	3416	2359	1565	1348	1151	747	377	39601
1	12	7	163	134	102	87	128	228	486	856	1354	1719	2196	2655	2560	2444	2541	2594	2439	2016	1601	1181	864	766	497	319	29930
1	13	1	188	119	77	50	67	113	351	482	866	1355	2049	2693	2939	3015	3128	3014	2583	1929	1440	1003	843	574	343	205	29426
1	14	2	131	92	89	102	233	565	1408	2679	2334	1952	1902	2101	2312	2303	2542	2734	3177	2904	1726	1009	751	534	366	248	34194
1	15	3	136	81	111	110	236	541	1440	2571	2262	1775	1839	2007	2169	2162	2396	2808	3098	2987	1820	1119	776	590	349	290	33673
1	16	4	163	93	104	134	202	477	1238	2145	2030	1499	1408	1407	1675	1678	1836	2171	2552	2369	1462	932	715	472	357	270	27389
1	17	5	122	103	105	129	216	487	1399	2547	2238	1920	1867	2043	2182	2265	2484	3008	3302	3170	1992	1263	961	783	414	315	35315
1	18	6	156	115	116	163	219	476	1338	2420	2174	1933	2220	2406	2660	2679	3070	3745	3968	3780	2909	2133	1936	1841	960	481	43898
1	19	7	246	171	110	104	135	203	522	983	1489	1870	2362	2821	2883	2771	2586	2637	2520	2301	1685	1281	894	753	510	316	32153
1	20	1	196	107	77	56	89	120	312	507	874	1394	1907	2309	2564	2537	2510	2432	2291	1855	1315	841	595	479	388	205	25960
1	21	2	108	90	91	113	214	514	1282	2205	2001	1983	2507	2898	3226	3186	3481	3459	3543	3072	1784	1083	663	456	316	233	38508
1	22	3	124	83	121	123	257	479	1287	2514	2166	1723	1716	1967	2005	2050	2270	2625	2966	2811	1627	1037	728	460	316	270	31725
1	23	4	118	92	92	110	192	454	1390	2492	2147	1749	1777	1882	2081	2074	2305	2615	3010	3077	1659	1042	731	589	336	274	32288
1	24	5	118	91	100	132	208	489	1353	2481	2177	1759	1776	1985	2130	2171	2364	2812	3180	3072	1899	1238	933	725	372	305	33870
1	25	6	149	130	111	132	227	488	1311	2417	2071	1954	2040	2239	2476	2555	3062	3362	3729	3584	2549	1897	1536	1239	633	434	40325
1	26	7	233	141	96	109	187	161	495	837	1311	1784	2295	2624	2488	2461	2330	2366	2335	1957	1552	1058	907	717	420	295	29159
1	27	1	184	135	80	56	85	103	360	536	837	1272	1759	2393	2689	2848	2903	2832	2799	2306	1726	1158	699	464	311	177	28712
1	28	2	104	79	80	111	230	546	1443	2691	2284	1848	1922	2018	1949	1752	1756	1925	2222	2019	1095	722	452	413	296	201	28158
1	29	3	103	94	105	121	235	475	1214	2462	2061	1666	1708	1722	1972	2002	2235	2588	2970	2765	1602	1017	579	423	322	222	30663
1	30	4	126	117	102	101	179	454	1262	2221	2070	1834	1867	1902	1999	2062	2398	2718	3058	2899	1738	1135	776	552	521	301	32392
1	31	5	134	91	92	137	227	485	1396	2577	2194	1791	1897	1963	2203	2221	2432	2719	3102	3055	1954	1237	883	699	384	330	34203

	12 AM	1 AM	2 AM	3 AM	4 AM	5 AM	6 AM	7 AM	8 AM	9 AM	10 AM	11 AM	12 PM	1 PM	2 PM	3 PM	4 PM	5 PM	6 PM	7 PM	8 PM	9 PM	10 PM	11 PM	Total
al average weekday	**127**	**99**	**104**	**127**	**239**	**550**	**1429**	**2495**	**2186**	**1837**	**1871**	**2009**	**2180**	**2214**	**2446**	**2835**	**3175**	**3019**	**1888**	**1245**	**913**	**720**	**440**	**302**	