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MEMORANDUM

DATE **March 15, 2012**

TO **Boston Region Metropolitan Planning Organization**

FROM **Chen-Yuan Wang, MPO Staff**

RE **Low-Cost Improvements to Bottleneck Locations, Phase II**

INTRODUCTION

According to the Federal Highway Administration, "Much of recurring congestion is due to physical bottlenecks – potentially correctible points on the highway system where traffic flow is restricted. While many of the nation's bottlenecks can only be addressed through costly major construction projects, there is a significant opportunity for the application of operational and low-cost infrastructure solutions to bring about relief at these chokepoints."[1] To be consistent with this guidance, the local office of the Federal Highway Administration (FHWA) has recommended, as part of its comments on the Unified Planning Work Program process, that the MPO identify the worst bottlenecks in the region that can be mitigated with low-cost countermeasures and develop recommendations for such countermeasures at these locations.

In the first bottleneck study, MPO staff identified six freeway mainline bottleneck locations and proposed low-cost improvements for three selected locations. In that study, staff realized that most of the freeway mainline bottleneck locations would require costly major construction fixes. MPO staff expanded the study in this phase to look at low-cost improvements to bottleneck locations at interchanges of state highways, in addition to interstate highways.

Usually, bottlenecks occur at a specific location and clear out downstream from that location. They have a traffic queue upstream and improved flow conditions downstream. There is an important distinction between "bottlenecks" and "congestion." Bottlenecks are congested highway segments with recurring operational problems (congestion that occurs at the same location and time daily and is predictable). It is generally considered the result of an imbalance between supply and demand. However, congestion can result from causes other than bottlenecks, such as incidents, work zones, and bad weather. Recurring bottlenecks, the subject of this study, are usually influenced by the highway design or operation at the point where the bottleneck begins, including:

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[1] U.S. Department of Transportation, Federal Highway Administration, *Recurring Traffic Bottlenecks: A Primer: Focus on Low-Cost Operations Improvements*, June 2009, p. 1.

- Merges, diverges, lane drops, and weaving sections
- Abrupt changes in highway alignment
- Short acceleration lanes and short ramp length
- Deficient ramp signal, poor signal coordination between ramp and the arterial connecting to the ramp, and exit ramp geometry

There are several options for addressing bottlenecks, including bringing supply and demand into alignment and investing in new highway capacity, but they are costly. Additional options include congestion mitigation strategies that provide alternative commute options, such as telecommuting; making transit easier and more attractive to use; and ridesharing. For low-cost operational and geometric improvement, the strategies include:

- Shoulder conversions to travel lanes
- Restriping merge and diverge to serve demand better
- Lane reallocation
- Modification of weaving areas and ramps
- Improved traffic signal timing
- Parking management
- Application of access management principles
- Provision of traveler information
- Construction of high-occupancy-vehicle (HOV) lanes
- Congestion pricing

The MPO agrees with FHWA that, if there are opportunities to implement low-cost bottleneck mitigation countermeasures in this region's highway and arterial system, those countermeasures should be identified, studied, implemented and designed. Benefits of localized low-cost bottleneck improvements include:

- They are less invasive to the physical and human travel environment.
- Lower costs allow more locations to be addressed.
- They are highly cost-effective.
- They can have significant safety benefits.
- They address existing problems and therefore have high visibility.
- They may actually end up being the long-term solution required.

This memorandum summarizes the identification of potential bottleneck locations, the analyses of available traffic and crash data, and proposed low-cost improvements of two selected locations in the region by MPO and MassDOT staff in response to the FHWA's recommendation.

PURPOSE OF STUDY

The purpose of this study is twofold:

1. To identify two bottleneck segments or points where low-cost mitigation improvements seem applicable. The identified bottlenecks may not be the worst in the region, as the worst may not be correctible with low-cost mitigation strategies.
2. To recommend low-cost mitigation improvements based on analysis of geometric design, traffic volumes and other data, and projected service performance associated with the improvements at each location.

SELECTION OF STUDY LOCATIONS

The selection of study locations was a two-stage process; it comprised inventorying and screening various candidate locations.

Inventorying of Candidate Locations

MPO staff developed an initial list of candidate locations in the MPO region based on the following sources:

- Staff knowledge of bottleneck locations in the Boston Region MPO area
- Review of congestion management process (CMP) monitoring data and recent MPO and other planning studies
- Consultations with MassDOT's Office of Transportation Planning and its Highway Division
- Input from MassDOT Highway Districts 3, 4, and 6
- Input from MPO members and private parties

The inventory process yielded seven bottleneck locations for screening. Figure 1 (all figures in this memorandum are placed after the text section) shows the seven locations, which are listed below.

Location 1: I-93 northbound, between Interchange 36 on-ramp in Woburn and Interchange 37A off-ramp in Stoneham

Location 2: I-95, between Interchange 28B in Waltham and Interchange 29A in Lexington

Location 3: I-95 southbound, at the off-ramp area of Interchange 32B in Burlington

Location 4: I-495 northbound, at the off-ramp area of Interchange 22 in Hopkinton

Location 5: I-495 southbound, at the off-ramp area of Interchange 22 in Hopkinton

Location 6: Route 9, at the intersection of Prospect Street/Main Street in Framingham

Location 7: Soldiers Field Road eastbound, adjacent to the Harvard University playing fields in Boston

Screening of Candidate Locations

MPO staff screened the seven candidate locations and selected two locations for analysis. The two bottlenecks selected for study were not the worst in the region, as the worst bottlenecks may not be correctible with low-cost mitigation strategies. MPO staff screened the bottleneck locations using the following criteria:

- Does the location qualify as a bottleneck?
- Does the location have a physical design constraint or operational conflict that causes the bottleneck?
- Can the bottleneck be fixed or relieved with low-cost operational and geometric improvements?

Based on the screening criteria and consultations with MassDOT's Office of Transportation Planning and Highway Division officials, MPO staff selected two locations for this study. They are Locations 2 and 3, described in the list above. MPO staff did not select Locations 1, 4, 5, 6, and 7. The reasons for not selecting these locations are summarized below.

Location 1: I-93 northbound, between Interchange 36 on-ramp in Woburn and Interchange 37A off-ramp in Stoneham

This section of highway is frequently congested due to intensive merging and diverging activities, especially during the PM peak period. During that period, the Exit 36 on-ramp carries about 800 to 900 vehicles per hour and the Exit 37A off-ramp carries about 1,300 vehicles per hour.[2] The merging and diverging activities of these vehicles slow down mainline traffic and seriously affect traffic on the upstream section on I-93. The distance between the two ramps is over a mile long. Adding an auxiliary lane between the two ramps would provide more room for the merging and diverging activities and reduce the disturbance to mainline traffic. The reasons for not selecting this location are:

- Adding an auxiliary lane can be expensive, as it may require expanding the Salem Street/William Street Bridge (located at the middle of the highway section) in order to provide sufficient space on I-93 under the bridge for the additional lane.
- Extending the acceleration length for the Exit 36 on-ramp and/or extending the deceleration length for the Exit 37A off-ramp could be a less expensive improvement alternative.[3]
- During the MPO staff' discussions with MassDOT engineers and planners, MassDOT staff pointed out that MassDOT is planning a study for the nearby I-95 and I-93 interchange and the I-95 section north of the interchange. They would propose to include this section of highway in that study.

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[2] I-93 northbound 2006 balanced traffic volumes estimated by CTPS.

[3] The Exit 37A off-ramp probably requires more attention than the Exit 36 on-ramp, as it carries a higher volume of traffic, which would seriously deter the mainline traffic if it does not operate sufficiently.

Location 4: I-495 northbound, at the off-ramp area of Interchange 22 in Hopkinton
Location 5: I-495 southbound, at the off-ramp area of Interchange 22 in Hopkinton

Both the northbound and southbound off-ramps provide a connection from I-495 to the Massachusetts Turnpike (I-90). MassDOT District 3 suggested these locations for lengthening the deceleration lanes of the off-ramps on I-495 northbound and southbound to provide sufficient queue storage for periods when queuing on these ramps backs onto the I-495 mainline. The congested conditions that frequently occur during the AM and PM peak periods sometimes last over three hours and seriously affect upstream sections of I-495. In addition to lengthening the deceleration lanes, District 3 also suggested adding an auxiliary lane on both sides of I-495 between I-90 and Route 9 in Westborough to mitigate the congested conditions. The reasons of not selecting these two locations are:

- Lengthening the I-495 northbound off-ramp could be expensive, as it might require expanding Fruit Street Bridge just south of the off-ramp in order to provide sufficient space on I-495 under the bridge.
- Lengthening the I-495 southbound off-ramp could be expensive, as it might require widening the bridge over I-90 just north of the off-ramp in order to provide sufficient space for the additional lane.
- Adding an auxiliary lane on both sides of I-495 between I-90 and Route 9 in Westborough could be expensive, as two bridges in this section of I-495 might need to be widened for the additional lanes.
- MassDOT had recently begun a study, *Interstate 495 and Route 9 Interchange Improvement Study*, which includes these two locations and other ramps connected to the I-495 and I-90 interchange in that study area. The study will examine potential short- and long-term improvement alternatives for the two major I-495 interchanges.

Location 6: Route 9, at the intersection of Prospect Street/Main Street in Framingham

This signalized intersection is located on Route 9 about a mile west of Shoppers World in Framingham. At this location, the Route 9 mainline traffic frequently endures delays due to traffic signal operations. The reasons of not selecting this location are:

- It is unlikely that any low-cost solutions at this location would be feasible, except for closing the intersection and allowing only right turns from Prospect Street and from Route 9 westbound (i.e. prohibiting left turns from Prospect Street and from Route 9 eastbound).
- The closure of the intersection could have a major impact on local traffic patterns and would necessitate using a transportation model to analyze the potential traffic demand and traffic pattern changes.
- Route 9 in Southborough and Framingham is a state-owned arterial highway with congestion at several signalized intersections. The corridor, including this location, could benefit from a broader study on improving traffic signal timing and coordination and providing traveler information.

Location 7: Soldiers Field Road eastbound, adjacent to the Harvard University playing fields in Boston

This bottleneck section is located on Soldiers Field Road eastbound adjacent to the Harvard University playing fields. The roadway segment from Elliot Bridge to the intersection of Soldiers Field Road westbound has three travel lanes, but it is wide enough for four lanes of traffic.[4] Past the intersection, the eastbound roadway narrows from three to two lanes in a short distance and in a section with a sharp curve. Essentially, traffic in this section (from Elliot Bridge eastbound to the two-lane-wide segment) has to squeeze from four to three and then from three to two lanes in a relatively short distance. The situation creates potential conflicts among vehicles, as they are forced to merge, slow down, or change lanes within limited space. The reasons of not selecting this location are:

- Reducing travel lanes from three to two before and after the intersection would remove the forced merging condition and improve traffic safety. However, it would reduce the intersection capacity and the traffic could potentially spill back onto the other side of the river and seriously affect the operations at the upstream intersection at Greenough Boulevard. This option would have to be carefully examined further by a traffic simulation model.
- Maintaining three travel lanes and decreasing the eastbound roadway to two lanes at a suitable downstream location before the North Harvard Street underpass would require some geometric modifications in the section between the intersection and North Harvard Street. Soldiers Field Road is owned and operated by the Department of Conservation and Recreation. The agency usually is very strict about widening roadways under their jurisdiction.

The following sections describe the existing conditions and proposed low-cost improvements at the two locations selected for study.

I-95 BETWEEN INTERCHANGE 28B IN WALTHAM AND INTERCHANGE 29A IN LEXINGTON

This bottleneck location is an eight-lane freeway section (four lanes in each direction) about half a mile long, located between Exit 28B in Waltham and Exit 29A in Lexington. The northbound section, from the Exit 28B on-ramp to the Exit 29A off-ramp, is congested in the PM peak period. The southbound section, from the Exit 29A on-ramp to the Exit 28 off-ramp, is congested in the AM peak period.

The northbound section contains four 12-foot travel lanes, a traffic-bearing right shoulder about 10 to 12 feet wide, and a left shoulder about four feet wide. The deceleration lane for the I-95

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[4] The rightmost lane of the eastbound segment that connects Eliot Bridge to Soldiers Field Road is about 20 feet wide. During peak periods, traffic usually forms two lanes in that lane in order to gain a beneficial position for passing through the intersection. After the roadway crosses Soldiers Field Road westbound, the rightmost lane is only about 12 feet wide. The four lanes of traffic essentially have to merge into three lanes in the middle of the intersection.

northbound traffic exiting to Route 2 eastbound is only about 250 feet long.[5] The acceleration lane for the ramp traffic entering I-95 northbound is about 550 feet long.

The southbound section contains four 12-foot-wide travel lanes, a right shoulder about 8 to 10 feet wide, and a left shoulder about two feet wide. The acceleration lane for traffic entering I-95 southbound from Route 2 eastbound is about 300 feet long. The deceleration lane for traffic exiting I-95 southbound to Trapelo Road is only about 150 feet long. There are wetlands on the west side of the southbound section. Figure 2 shows the location of the bottleneck and the ramp configuration near it.

Problem

In the northbound section, I-95 carries heavy traffic during the PM peak period. Traffic going through this section usually has to slow down due to the high volume of traffic exiting from I-95 northbound to Route 2 eastbound. The southbound section of I-95 is congested during the AM peak period, where the high volume of traffic from Route 2 eastbound enters the already congested I-95 southbound, causing further delays for mainline traffic.

Causes

Figure 3 shows the 2007 PM peak-period traffic volumes on I-95 northbound and the off- and on-ramps near the bottleneck location. The four-lane northbound section carries about 6,900 to 7,800 vehicles per hour, including about 1,000 to 1,400 seeking to exit onto Route 2 eastbound. There are intensive diverging maneuvers, accompanied by lane changing, decelerating, and accelerating activities, causing delays for the I-95 mainline traffic. In addition, the short deceleration lane (about 250 feet long) does not provide sufficient capacity in the diverging area for the intensive diverging maneuvers. Another safety concern is that drivers do not have a sufficient distance to slow down before reaching the curved area of the off-ramp. During the AM peak period, there is much less traffic in that section and the diverging maneuvers usually do not cause traffic congestion.

Figure 4 shows the 2007 AM peak-period traffic volumes on I-95 southbound and the off- and on-ramps near the bottleneck location. The four-lane section carries about 6,900 to 8,400 vehicles per hour, including about 800 to 1,000 coming from Route 2 eastbound. The intensive merging maneuvers, accompanied by lane changing, decelerating, and accelerating activities, cause delays for the I-95 mainline traffic. During the PM peak period, the problem is less severe near the bottleneck location due to lower traffic volumes, both on the mainlines and on the on-ramp.

Impacts

Figures 5 and 6 show AM and PM average travel speeds collected by MPO staff on I-95 near the bottleneck location in 2005. In the northbound section, Figure 5 shows no major traffic delays during the AM peak period, as the average travel speeds are over 55 mph near the bottleneck location. However, Figure 6 indicates that the northbound section endures some traffic delays in

[5] The acceleration and deceleration lengths referred in this study do not include the taper length.

the PM peak period, when the average travel speeds are less than 55 mph near the bottleneck location.

In the southbound section, Figure 5 shows significant traffic delays during the AM peak period, as the average travel speeds are less than 45 mph at the bottleneck and upstream locations. Figure 6 shows no major traffic delays during the PM peak period in that section, as the average travel speeds are over 55 mph near the bottleneck location.

Figure 7 shows crashes that happened near the bottleneck location on I-95 northbound. During the period 2007–09, there were 15 crashes near the Exit 28A off-ramp (Section 1) and 8 crashes near the Exit 28B on-ramp (Section 2). The high number of crashes in Section 1 is likely due to the intensive diverging maneuvers in the diverging area within a short deceleration distance. The crashes include about 53% rear-end crashes, 27% sideswipe crashes, and 20% other types of crashes. None of these crashes involved a fatality, and most of them involved property damage only. The number of crashes in Section 2 is relatively low and does not indicate a major safety concern.

Figure 8 shows the crashes near the bottleneck location on I-95 southbound. During the period 2007–09, there were 3 crashes near the Exit 29A on-ramp (Section 1) and 16 crashes near the Exit 28 off-ramp (Section 2). The number of crashes in Section 1 is relatively low and does not indicate a major safety concern. The high number of crashes in Section 2 is likely due to the diverging maneuvers in the diverging area within a very short deceleration distance. The crashes include about 50% rear-end crashes, 31% sideswipe or angle crashes, and 19% single vehicle crashes. None of these crashes involved a fatality, but about one-third of them involved personal injuries. The analysis indicates that the short deceleration distance (about only 150 feet) at the off-ramp may not be sufficient for safe diverging maneuvers.

Recommendations

The objective of the improvements proposed for addressing this bottleneck location was to reduce the impact of diverging and merging traffic on the through traffic on I-95 and to improve operational safety for the through, diverging, and merging traffic. To accomplish this objective, MPO staff reviewed the potential improvements for the major merging or diverging areas and recommended the following improvements at the diverging (the off-ramp) areas of I-95. Figure 9 shows the recommended improvements.

1. **Improvements for the I-95 northbound section:** Lengthen the deceleration lane at Exit 29A to a distance of at least 1,000 feet, by adding about 750 feet to the existing deceleration length (estimated as approximately 250 feet). The 1,000 feet would be in addition to the necessary taper length.

   A ramp junction analysis using Highway Capacity Software (HCS)[6] indicates that the diverging area currently operates at a level of service (LOS) E in the PM peak hour (see Appendix A for the detailed report). With the extension of the deceleration lane, the

[6] The Highway Capacity Software (HCS) is developed and maintained by McTrans as part of its user-supported software maintenance as a faithful implementation of the Highway Capacity Manual (HCM) procedures.

diverging area would operate at LOS D in the PM peak hour (see Appendix B). The existing conditions of the AM peak hour existing were evaluated as acceptable and therefore were not included in this report. A preliminary review of MassDOT's Road Inventory File and the MassGIS database indicates that the extension is feasible because this section of I-95 has a right-of-way width of 140 feet with no adjacent wetlands.[7]

No improvements are proposed for the merging area at Exit 28B, as the HCS ramp junction analysis for the on-ramp traffic operation indicates an acceptable LOS D. In addition, staff examined the possibility of adding an auxiliary lane from Exit 28B to Exit 29A. It would have capacity improvement similar to that of the proposed extension of the deceleration lane, but would be more costly to construct. Because of its cost, the auxiliary lane alternative was not considered for this location.

2. **Improvements for the I-95 southbound section:** Lengthen the deceleration lane at Exit 28 to a distance of at least 750 feet by adding about 600 feet to the existing deceleration length (which approximately 150 feet); this length does not include the necessary taper length (see Figure 9).

   The HCS ramp junction analysis indicates that the Exit 28 diverging area currently operates at LOS E in the AM peak hour (see Appendix C). With the extension, it would operate at LOS D in the AM peak hour (see Appendix D). The existing conditions of the PM peak hour were evaluated as acceptable and therefore were not included in this report. A preliminary review of the Road Inventory File and the MassGIS database indicates that the extension is feasible as this section of I-95 northbound has a right-of-width of 140 feet with no adjacent wetlands.

   No improvements are proposed for the merging area of Exit 29A, although the HCS ramp junction analyses indicate that the on-ramp traffic operation at the merging area would improve from LOS E to LOS D with an extension of the acceleration lane. The area adjacent to the acceleration lane is near the reservoir and is designated as "wooded swamp deciduous" wetlands in the MassGIS database. It appears that it might be possible to extend the 12-foot acceleration lane, with a 2-foot offset, for about 300 to 350 feet in length without encroaching on the wetlands. However, further investigation based on actual field surveys should be conducted if the extension at this location were to be considered.

These improvements would increase capacity for traffic exiting I-95 northbound and southbound, and as a result, they would reduce the duration and length of the bottleneck. More significantly, they would improve the traffic safety at the two off-ramp areas.

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[7] The Road Inventory File is created by MassDOT and contains the spatial linework for all public roadways and most of the private roadways in Massachusetts, along with roadway attributes covering the roadway classification, ownership, physical conditions, traffic volumes, pavement conditions, highway performance monitoring information, and more.

Benefits

The benefits of lengthening the deceleration lanes for the off-ramp on both the northbound and southbound sections of I-95 were assessed qualitatively in terms of traffic operations and safety and the costs and time frame for implementation. The benefits of the lengthening the two deceleration lanes are:

1. It would fit into the existing roadway layout.
2. It would reduce the impact of the bottleneck, especially the I-95 northbound section.
3. It would improve the operational safety for the mainline and diverging traffic.
4. It is a low-cost and short-term improvement; it can be implemented in a short time frame.
5. It would require only moderate widening

Cost

Implementing the improvements recommended for the extension of the deceleration lane at Exit 29A on I-95 northbound would cost between $1,000,000 and $1,300,000 and would require the following:

- Extending the deceleration lane adding a fifth lane on I-95 northbound for a distance of approximately 750 feet, which does not include the taper length
- Constructing a 10-foot shoulder alongside the extended deceleration lane
- Relocating and/or installing guardrails and catch basins
- Relocating the Exit 29A food/gas service sign and roadside traffic regulatory and guide signs

Implementing the improvements recommended for the extension of the deceleration lane at Exit 28 on I-95 southbound would cost between $800,000 and $1,000,000 and would require the following:

- Extending the deceleration lane on I-95 southbound for a distance of approximately 600 feet plus the necessary taper length
- Constructing a 10-foot shoulder alongside the extended deceleration lane
- Relocating and/or installing guardrails and catch basins
- Relocating the DeCordova Museum exit sign and roadside traffic regulatory and guide signs

I-95 SOUTHBOUND, AT THE OFF-RAMP AREA OF INTERCHANGE 32B IN BURLINGTON

This bottleneck is located on I-95 southbound at the off-ramp area of Interchange 32 in Burlington, where traffic exits onto Middlesex Turnpike and Route 3 northbound. There are four travel lanes, a 10- to-12-foot-wide traffic-bearing right shoulder, and a 4-foot-wide left shoulder on the I-95 southbound stretch passing through Interchange 32. The deceleration lane for traffic exiting onto Route 3 and Middlesex Turnpike is about 500 feet in length. Figure 10 shows the location of the bottleneck and the exit ramp configuration near it.

Problem

There is recurring congestion upstream of the bottleneck location during both AM and PM peak periods; the bottleneck backs up traffic and affects the traffic operations at the adjacent upstream interchange (Interchange 33). The high-volume exit traffic usually occupies the rightmost of the four travel lanes of I-95 southbound for an extensive distance. Meanwhile, traffic on the third travel lane also frequently backs up due to a few vehicles attempting to squeeze into the fourth lane and blocking the traffic behind them. These backups consequently affect mainline traffic operations and create serious traffic congestion on I-95 southbound. The queues often approach Interchange 33 (about one mile away) and affect its traffic operations. Once the traffic passes this off-ramp area, it usually flows freely on I-95 southbound for the short section before the Route 3 southbound on-ramp merging area.

Causes

The primary factor contributing to the formation of this bottleneck is the high volume of traffic on I-95 southbound that exits to the Middlesex Turnpike and Route 3 northbound during the peak periods. Figure 11 shows the 2007 AM peak-period traffic volumes on I-95 southbound and the off- and on-ramps near the bottleneck. According to the figure, about 2,150 to 2,600 vehicles per hour exit from I-95 southbound to Route 3 and the Middlesex Turnpike during the AM peak period, from 7:00 to 10:00. Similarly, Figure 12 shows the 2007 PM peak-period traffic volumes on I-95 southbound and the off- and on-ramps near the bottleneck. About 2,000 vehicles per hour exit from I-95 southbound to Route 3 and the Middlesex Turnpike during the PM peak period, from 4:00 to 6:00.

Field observations indicate that the fourth travel lane is usually jammed with vehicles exiting I-95 in the peak hours, and some motorists resort to using the lane next to it to exit I-95 as well. This occurrence leaves less than three full lanes on I-95 southbound for serving traffic heading straight on I-95, causing recurring congestion upstream from the diverge location. The existing single-lane exit ramp, with a relatively short deceleration length, is potentially insufficient to handle 2,000 to 2,600 vehicles per hour continuously for three hours. HCS ramp junction analyses indicate that the off-ramp operates at LOS F in both the AM and PM peak hours, as the volume of traffic exiting I-95 southbound exceeds the capacity of the single-lane exit ramp (see Appendix E).

Furthermore, the capacity of the off-ramp at Exit 32B is constrained and is further decreased during the peak periods when the Middlesex Turnpike traffic is heavy and the entry volume from Middlesex Turnpike to I-95 southbound is high. Once it diverges from the freeway, the I-95 southbound off-ramp splits into two lanes. The right lane, leading to Middlesex Turnpike, has a traffic signal at the end of the ramp. The left lane continues west for a short distance and proceeds to an entry ramp from Middlesex Turnpike to form a two-lane collector-distributor (C-D) road that shortly after splits into two single lanes connecting to Route 3 northbound and I-95 southbound. As almost all the traffic from I-95 in the C-D road section is heading to Route 3 northbound and about half of the traffic from Middlesex Turnpike in this section is heading to I-95 southbound, the short C-D road section experiences intensive weaving activities.

Field observations confirm that queuing vehicles frequently occupy the entire Middlesex Turnpike off-ramp section and the C-D section during the AM and PM peak periods. These conditions further reduce the capacity of the off-ramp and call for additional storage space at the off-ramp in order to reduce the disturbance of I-95 mainline operations.

Impacts

Figures 13 and 14 show AM and PM average travel speeds collected by MPO staff on I-95 near the bottleneck in 2005. It should be noted that the average travel speeds are estimated for each segment between interchanges. Field observations indicate that the fourth travel lane of I-95 southbound is congested during the AM peak period, although Figure 13 shows that the average travel speed is 55 mph or over upstream of the bottleneck location. The average speed on I-95 southbound downstream of the bottleneck is reduced to less than 45 mph because there are heavy volumes of traffic entering from Route 3 southbound.

However, Figure 14 clearly indicates that there is a traffic bottleneck at the off-ramp area during the PM peak period, as the average travel speed on I-95 southbound is less than 45 mph upstream of the off-ramp but increases to 55 mph or higher downstream of the bottleneck. The downstream segment maintains an average speed of 55 mph or higher because there is less heavy traffic entering from Route 3 southbound in the PM peak period than in the AM peak period.

Figure 15 shows the crashes near the bottleneck on I-95 southbound. During the period 2006–08, there were 34 crashes in the segment north of the off-ramp (Section 1), 146 crashes between the off-ramp and the on-ramp from Route 3 southbound, including the C-D road (Section 2), and 4 crashes in the Route 3 on-ramp area (Section 3). Section 2 has the highest number of crashes in the interchange area, as there are speed changes and speed differences among vehicles on the I-93 southbound mainline and intensive weaving activities on the short and narrow C-D road segment.

The resulting crash rate for the section of I-95 southbound near the bottleneck (Section 1) is 0.68 crashes per million vehicle miles traveled (MVMT), which is higher than the average of 0.58 crashes per MVMT for urban interstate highways in the commonwealth. About 74% of the crashes in the section were rear-end crashes, which are typically attributed to traffic congestion or queuing. None of these crashes involved a fatality; most of them (about 80% of the crashes) involved only property damage.

Recommendations

The objective of the proposed improvements for addressing this bottleneck location was to reduce the impacts of diverging traffic on the through traffic on I-95 southbound and to improve operational safety for the through and diverging traffic. MPO staff reviewed the existing conditions and determined that extending and expanding the off-ramp at this location would be an effective low-cost alternative for accomplishing the objective.

Figure 16 shows the location of the proposed improvement. The proposed off-ramp extension would contain two sections: a two-lane section of about 600 feet (estimated from the gore of the off-ramp) and a one-lane section of about 600 feet, with the necessary taper length for both sections of the off-ramp. The existing ramp and its taper area would be expanded to a two-lane section, and its upstream shoulder, about 600 feet long, would be converted to a one-lane off-ramp plus about a 150-foot-long taper. The geometric modification also includes a 10-foot-wide shoulder along the entire off-ramp.

HCS ramp junction analyses indicate that the off-ramp area currently operates at LOS F in both the AM and PM peak hours, because the volume of traffic exiting I-95 southbound exceeds the capacity of the single-lane exit ramp (see Appendix E). HCS analyses of the proposed improvement indicate that the off-ramp area would operate at acceptable LOS C in the AM peak hour and LOS B in the PM peak hour (see Appendix F). With the proposed improvement, the impact of the off-ramp queue to the mainlines would decrease significantly, and the operational safety for the through and diverging traffic would consequently be improved.

Benefits

The benefits of the proposed improvements were assessed qualitatively in terms of the costs and the time frame for implementation. The expected benefits are:

1. They would fit into the existing roadway layout, since the current right-of-way width for I-95 is about 300 feet.
2. They would reduce the impact of the bottleneck, especially in the I-95 southbound mainline section.
3. They would improve the operational safety for the I-95 southbound mainline and diverging traffic.
4. They are low-cost and short-term improvements, and could be implemented in a short time frame.

At this planning stage of the project, no major issues related to potential environmental impacts are expected. The MassGIS database indicates a small area of “deep marsh” wetlands adjacent to the parking lot of Burlington Mall north of the existing off-ramp. The proposed improvements are not expected to infringe on these wetlands. However, this should be further examined in the design stage.

Cost

Implementing the improvements recommended for the two-lane exit ramp would cost about $2 million to $3 million (with no right-of-way costs). Major items in the cost estimation include the following:

- Constructing a new one-lane off-ramp farther upstream for a distance of about 600 feet, with a taper of about 150 feet
- Adding a second lane to the existing off-ramp for a distance of about 600 feet, connected by a taper to the new one-lane off-ramp
- Constructing a 10-foot -wide shoulder along the entire off-ramp
- Relocating and/or installing guardrails, catch basins, and overhead signs in the area
- Installing new signs to direct motorists to Route 3 and the Middlesex Turnpike

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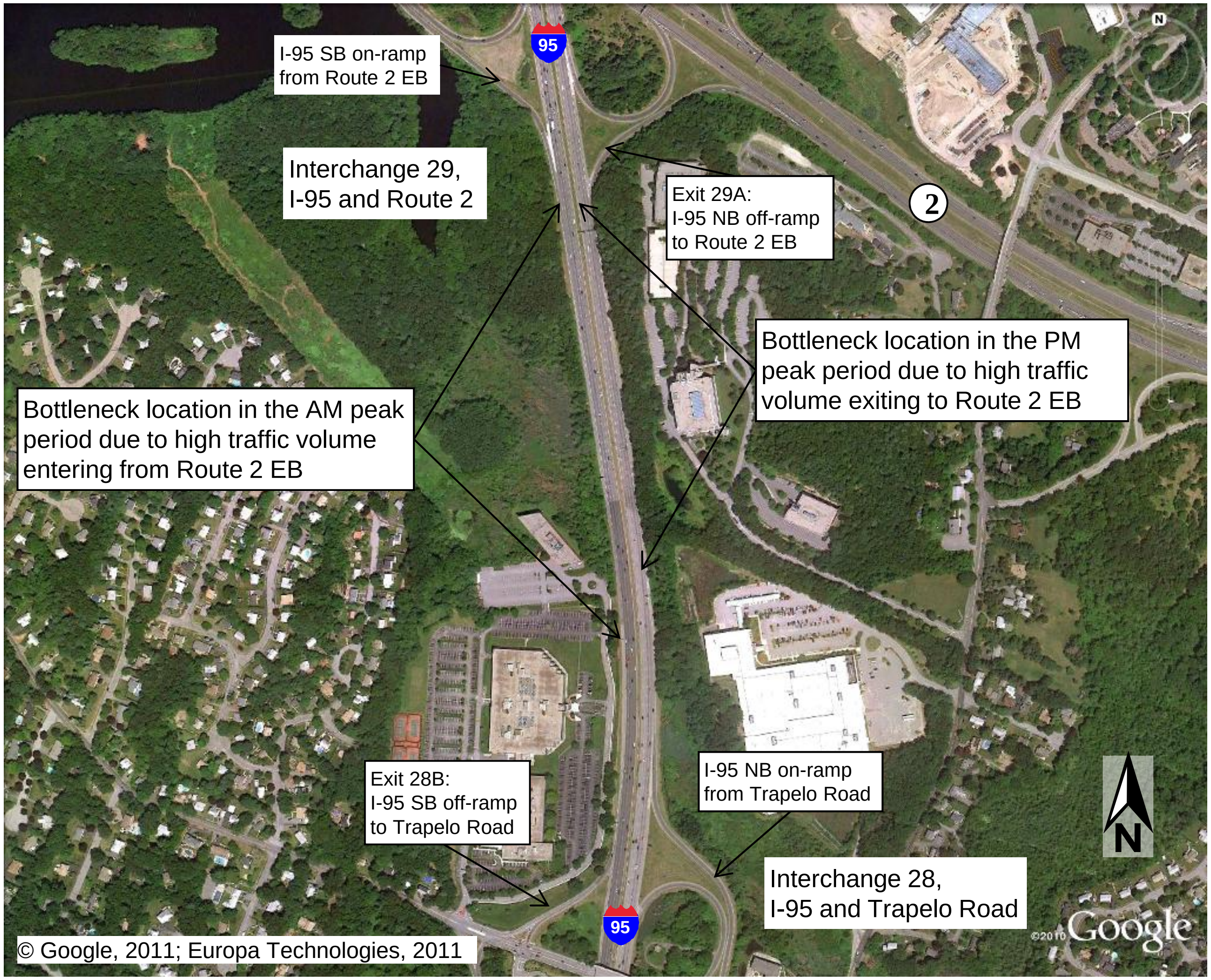
FIGURE 1
Candidate Bottleneck Locations

Low-Cost Bottleneck Improvements



BOSTON
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MPO

FIGURE 2
Location of Bottleneck on I-95
between Interchange 28B in Waltham and Interchange 29A in Lexington

Low-Cost Bottleneck Improvements

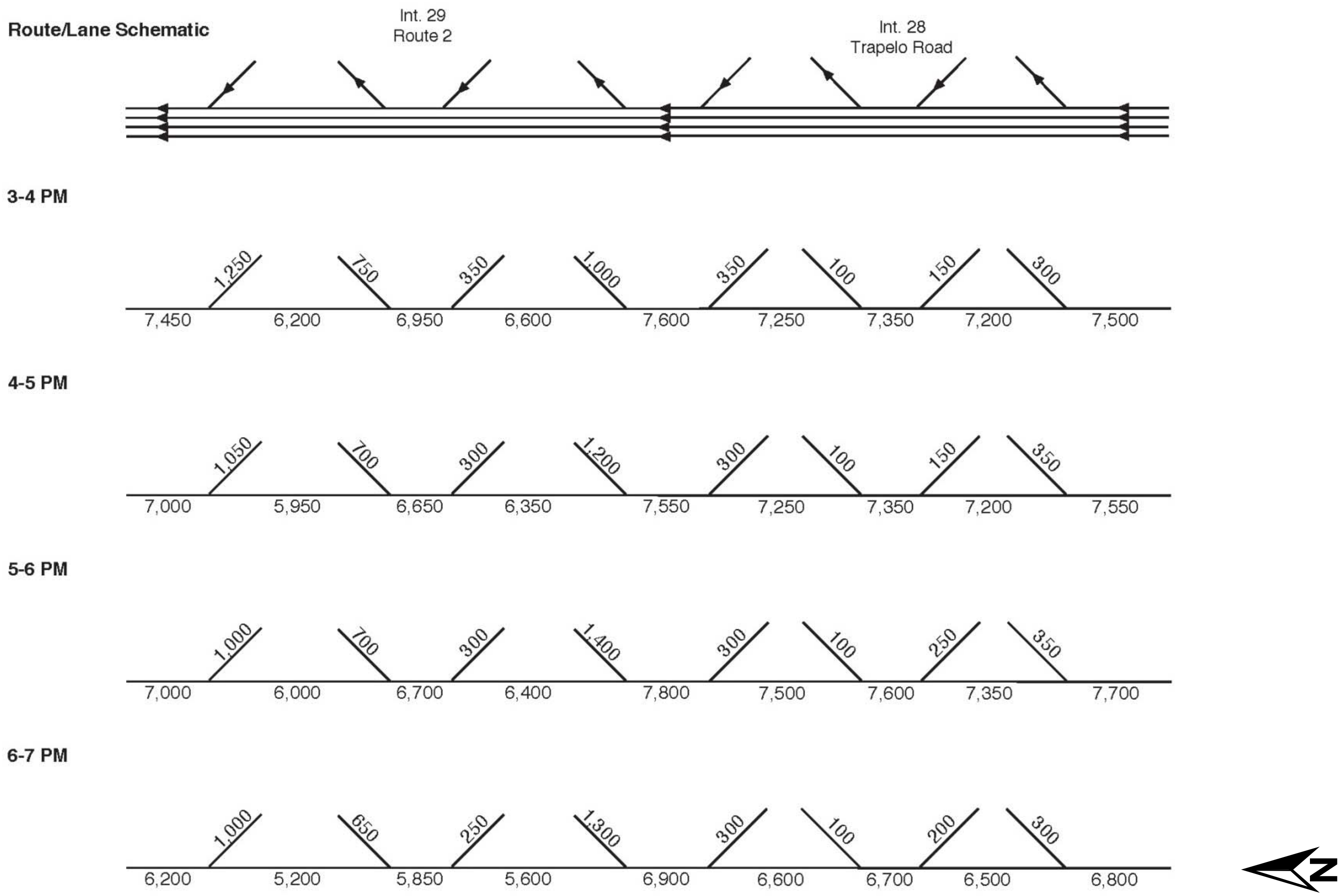

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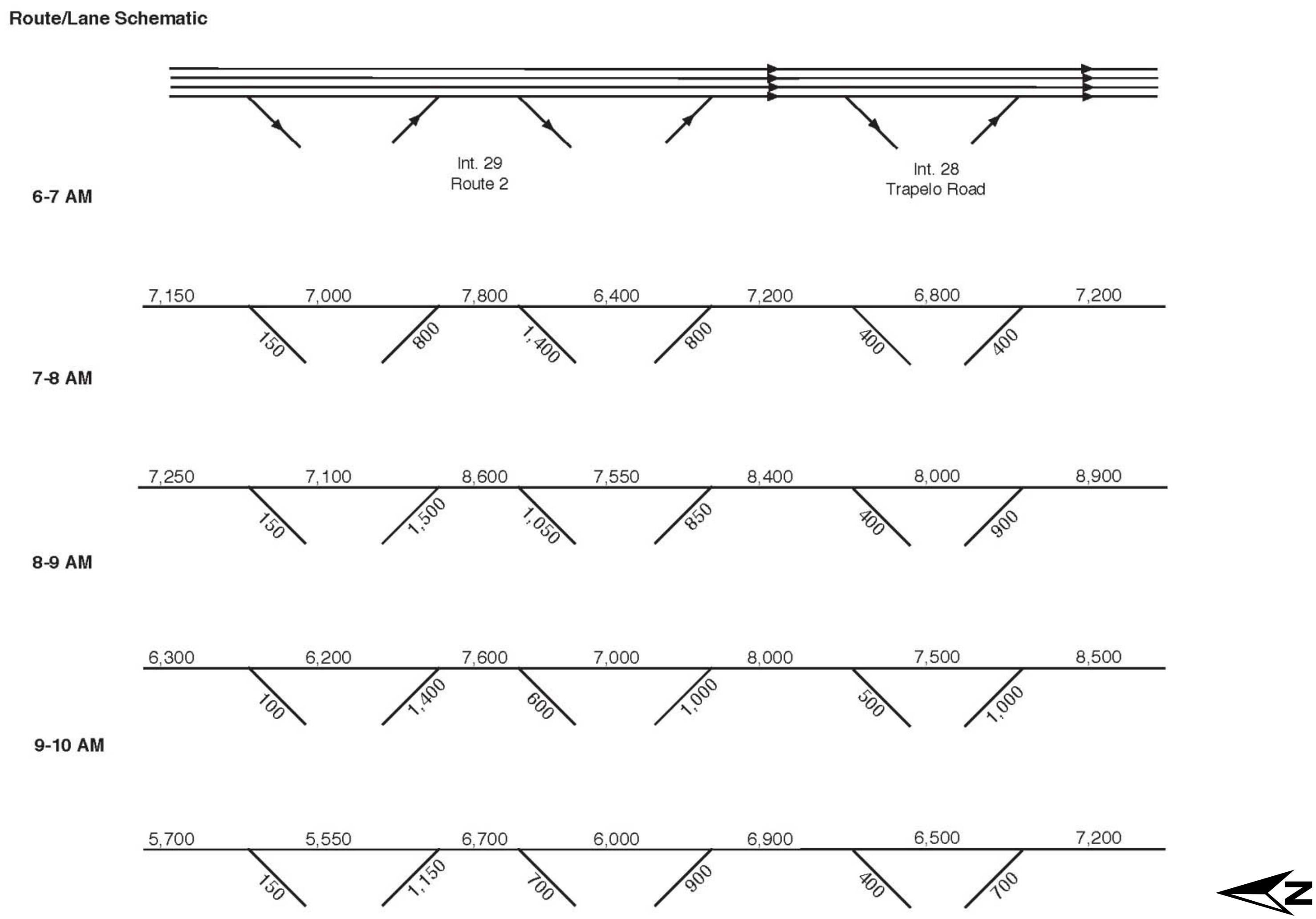
FIGURE 3
PM Peak-Period Traffic Volumes on I-95 Northbound near Interchanges 28 and 29, 2007

Low-Cost Bottleneck Improvements



BOSTON
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FIGURE 4
AM Peak-Period Traffic Volumes on I-95 Southbound near Interchanges 29 and 28, 2007

Low-Cost Bottleneck Improvements

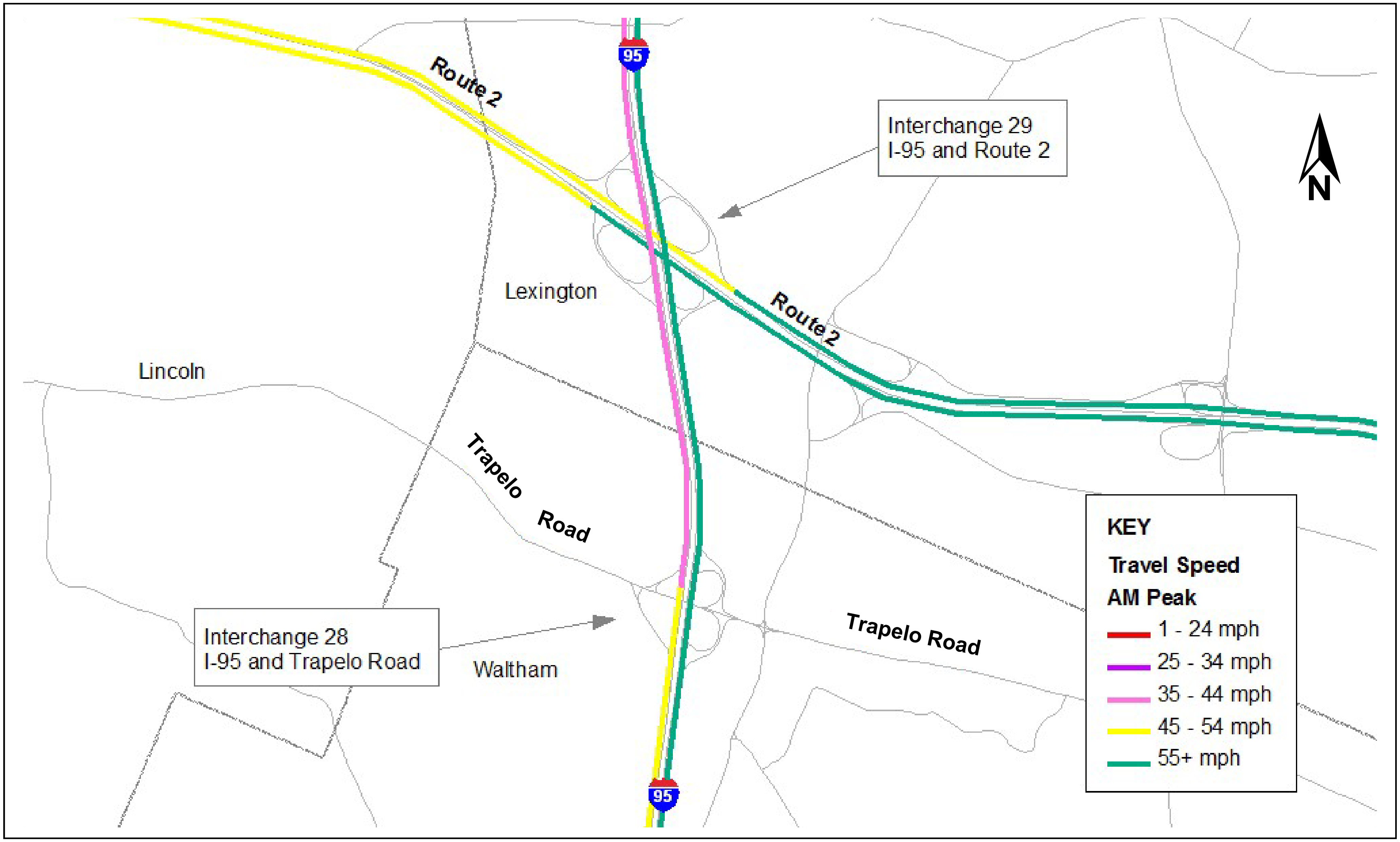

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FIGURE 5
AM Peak-Period Travel Speeds on I-95 near Interchanges 28 and 29, 2005

Low-Cost Bottleneck Improvements

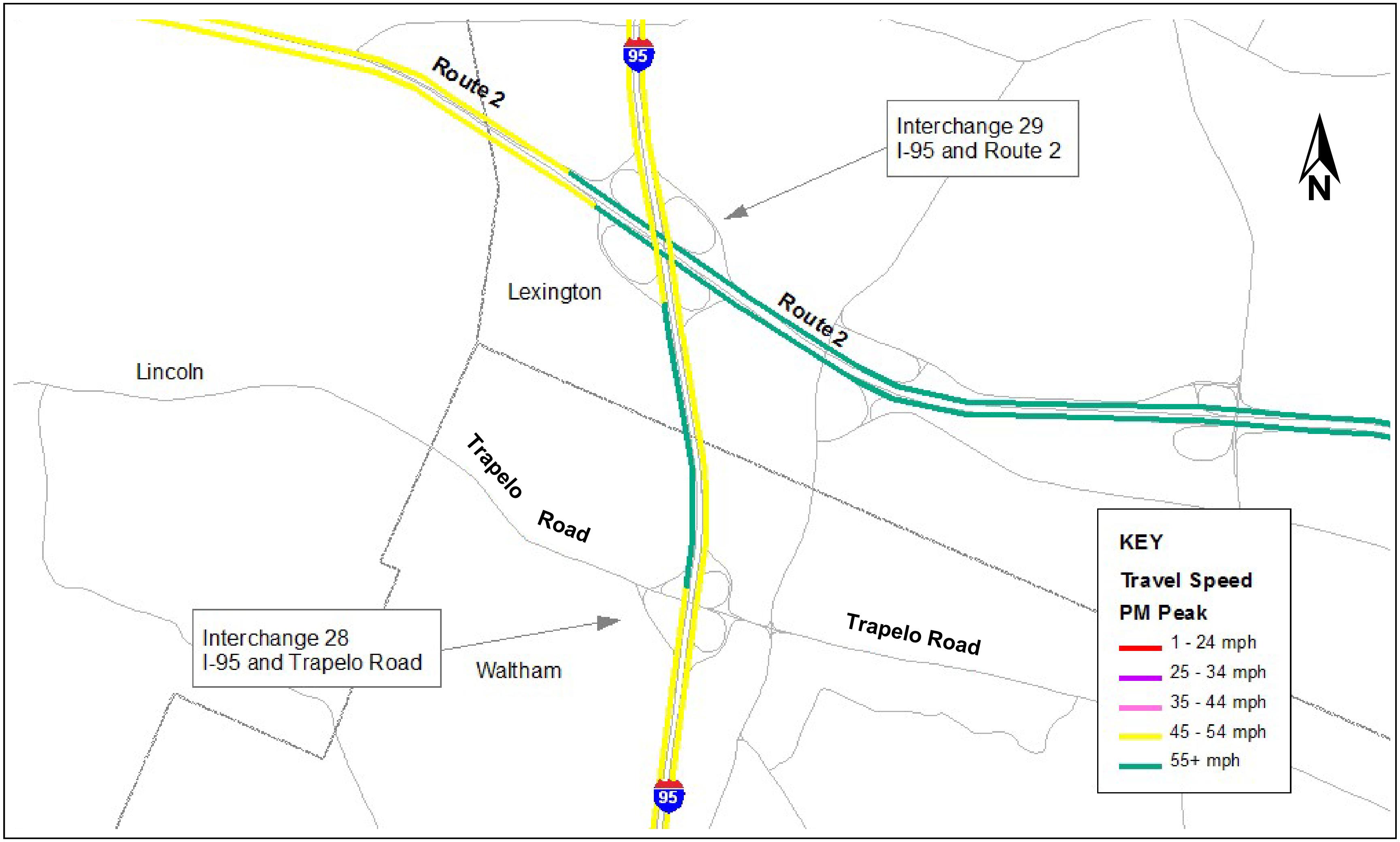

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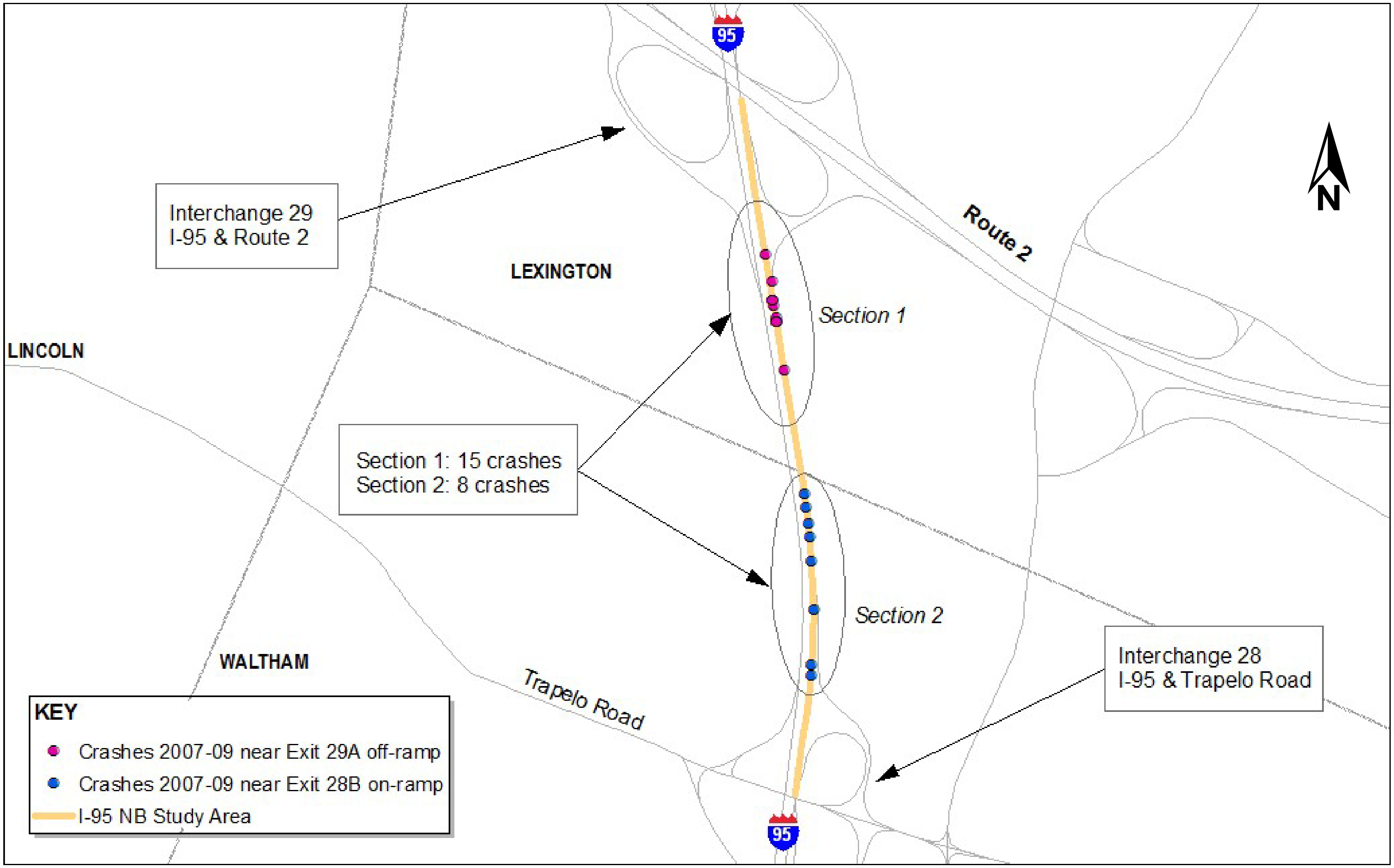
FIGURE 6
PM Peak-Period Travel Speeds on I-95
near Interchanges 28 and 29, 2005

Low-Cost
Bottleneck
Improvements



BOSTON REGION MPO

FIGURE 7
Crashes on I-95 Northbound between Exit 28B and Exit 29A, 2007–09

Low-Cost Bottleneck Improvements

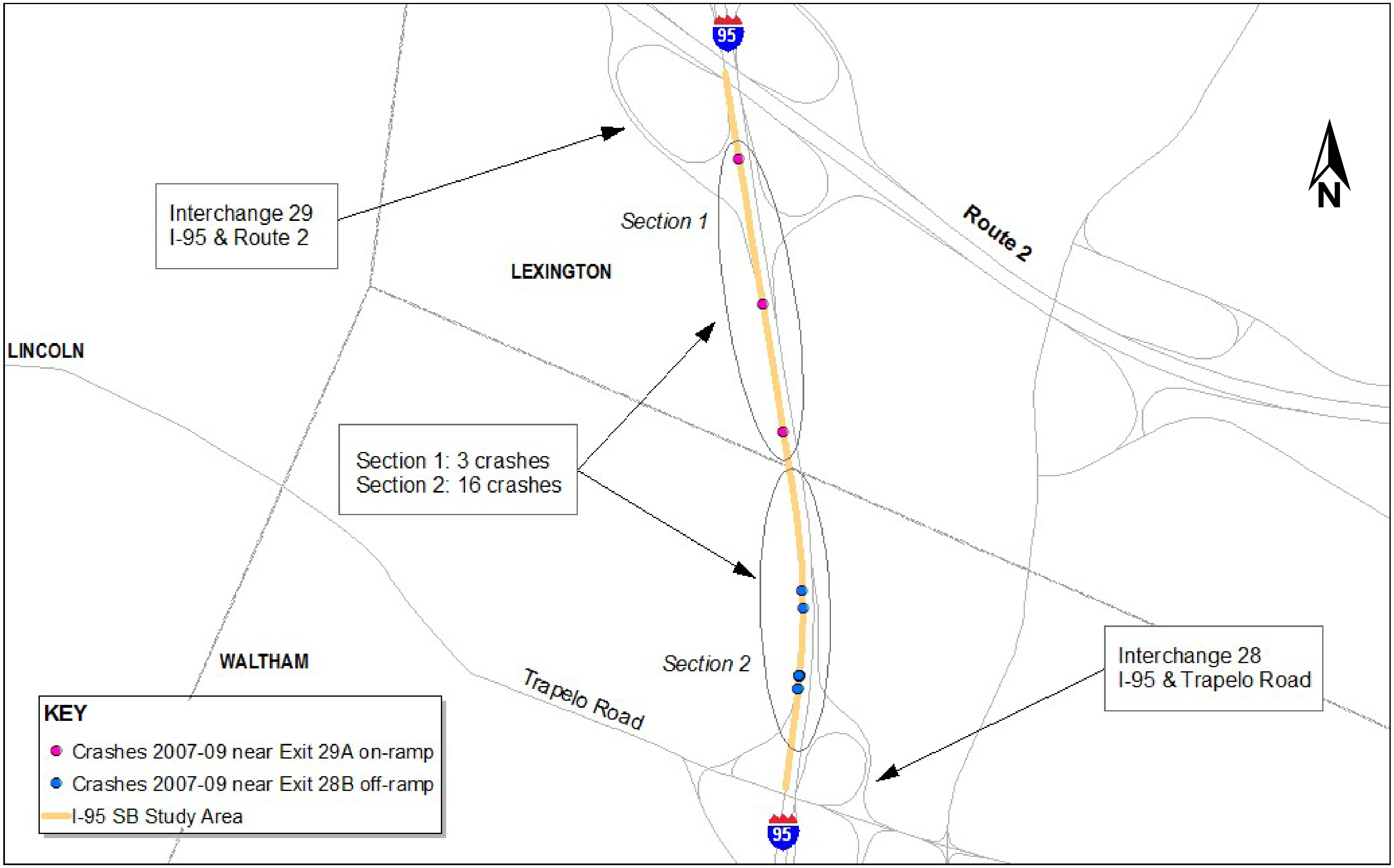


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FIGURE 8
Crashes on I-95 Southbound
between Exit 29A and Exit 28, 2007–09

Low-Cost
Bottleneck
Improvements

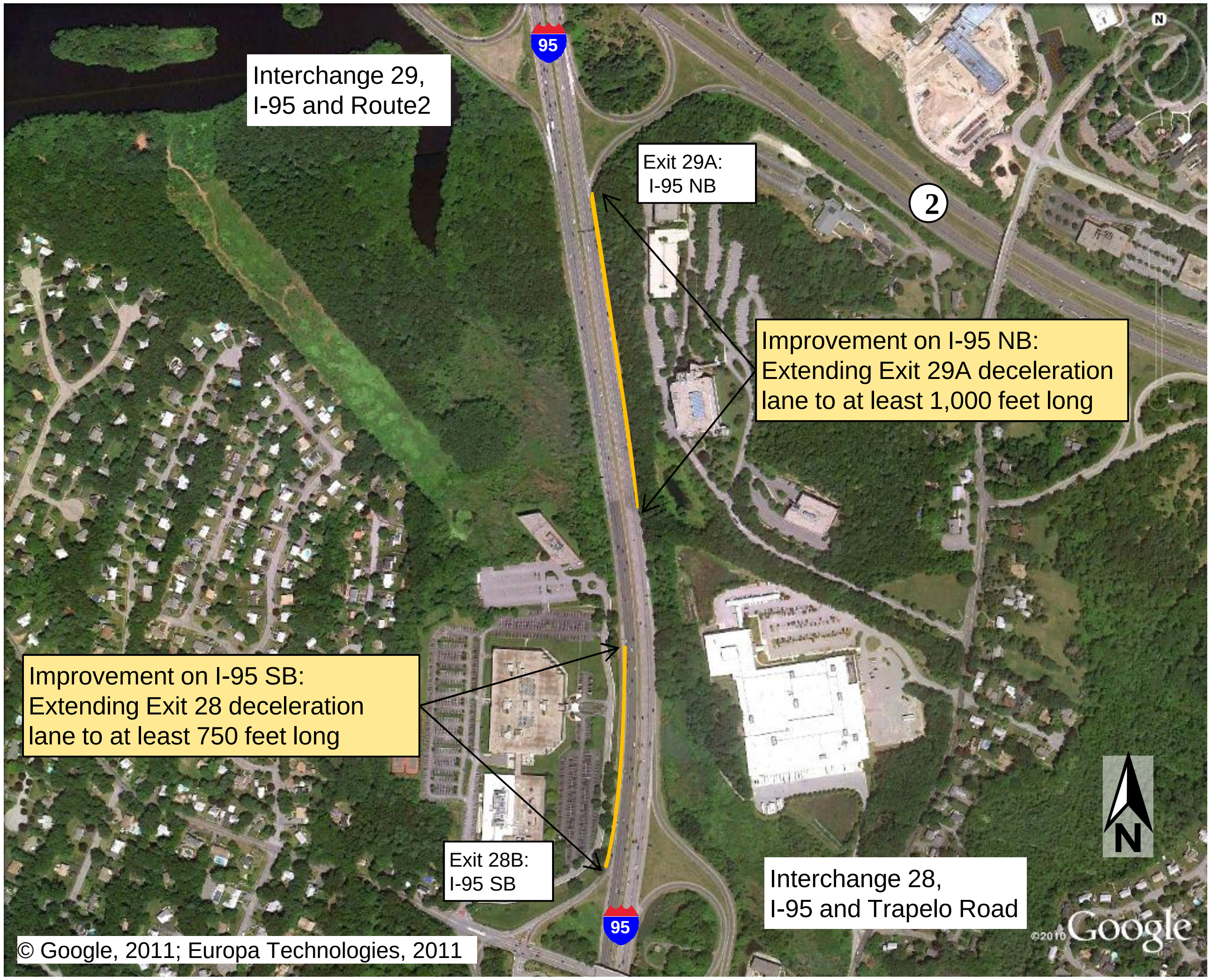

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FIGURE 9
Proposed Low-Cost Improvements on I-95
between Interchange 28B in Waltham and Interchange 29A in Lexington

Low-Cost Bottleneck Improvements

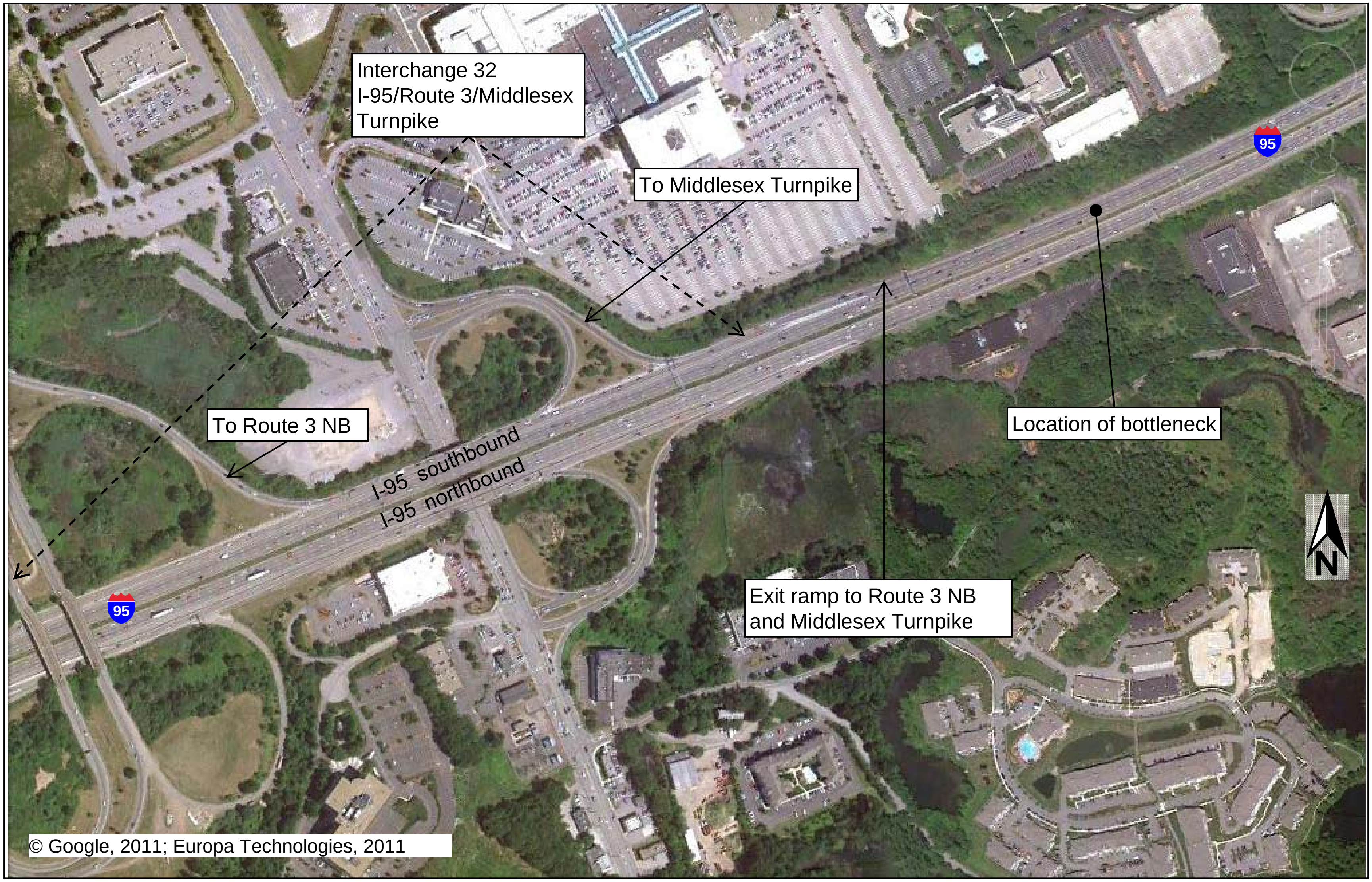

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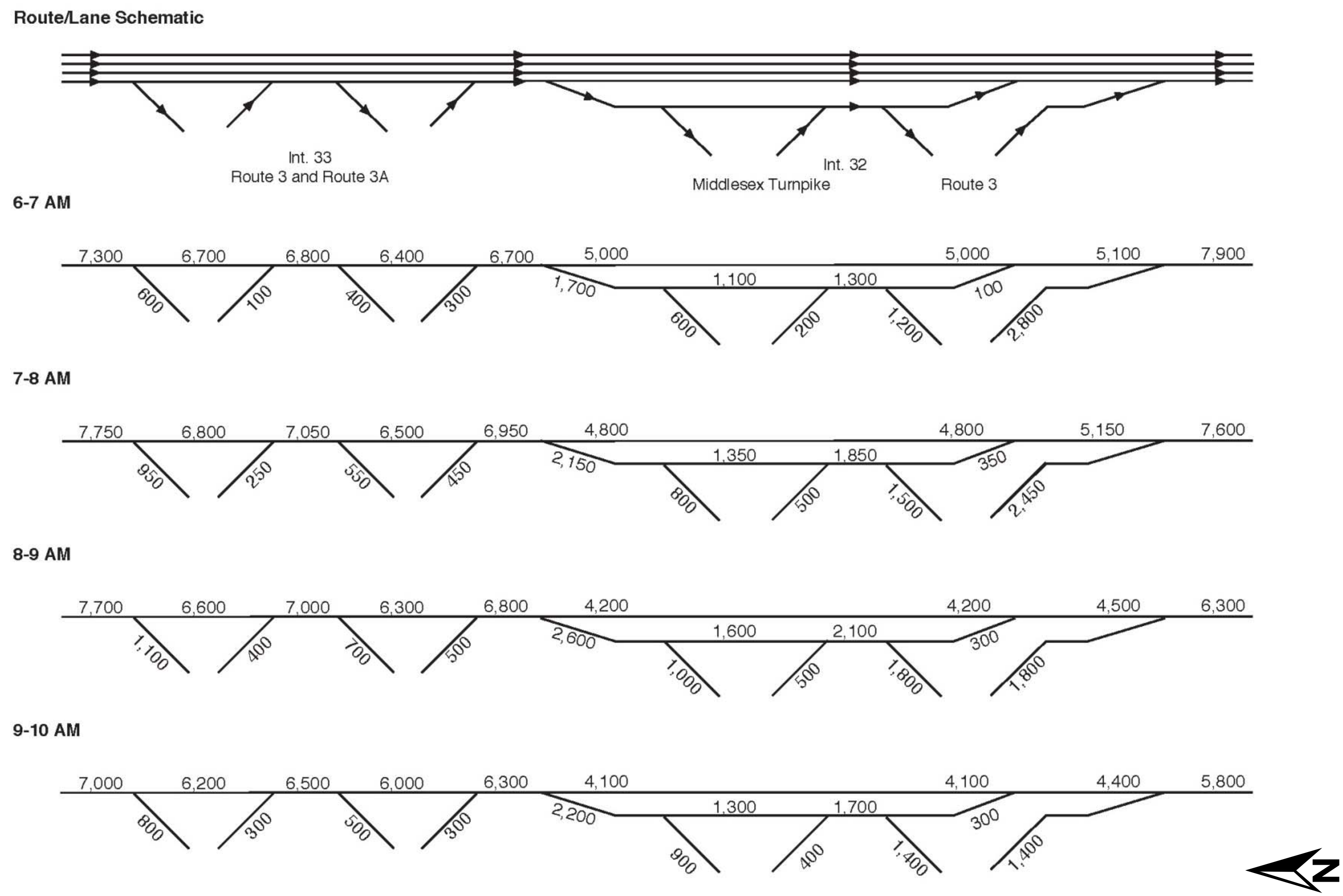
FIGURE 10
Location of Bottleneck and Configuration of Ramps at I-95 Interchange 32B in Burlington

Low-Cost Bottleneck Improvements



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REGION
MPO

FIGURE 11
AM Peak-Period Traffic Volumes on I-95 Southbound near the Bottleneck at Interchange 32 in Burlington, 2007

Low-Cost Bottleneck Improvements

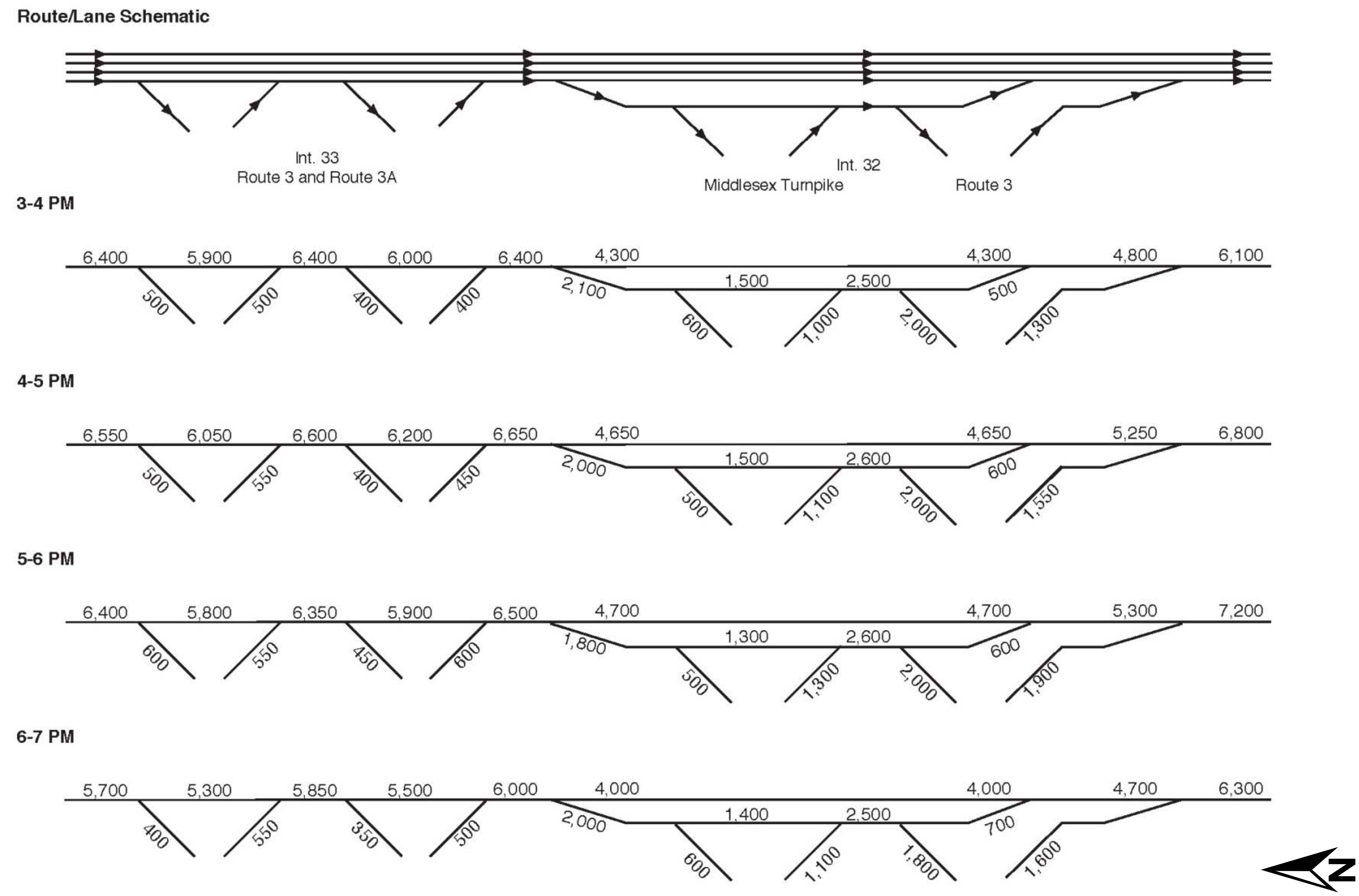

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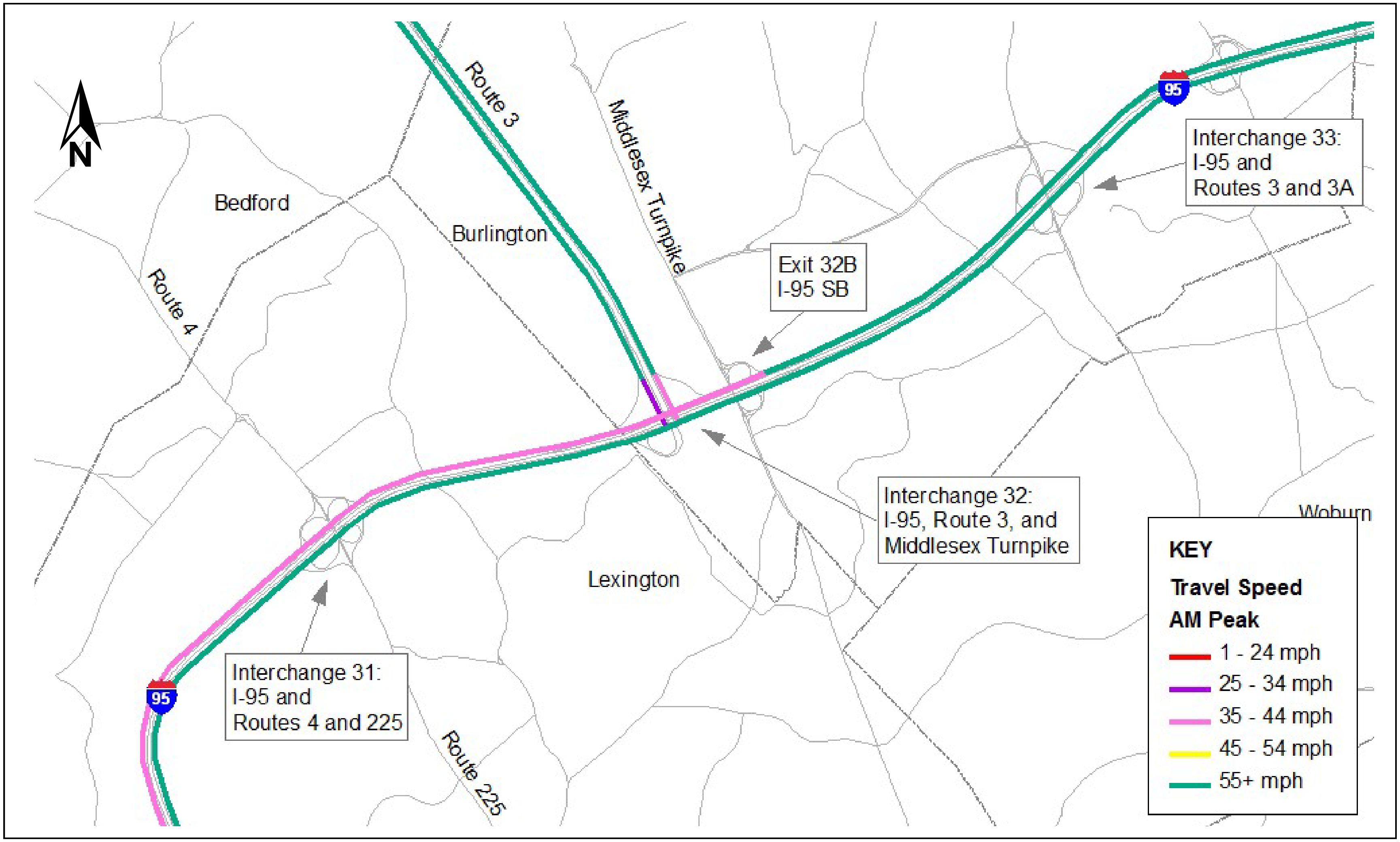
FIGURE 12
PM Peak-Period Traffic Volumes on I-95 Southbound near the Bottleneck at Interchange 32 in Burlington, 2007

Low-Cost Bottleneck Improvements



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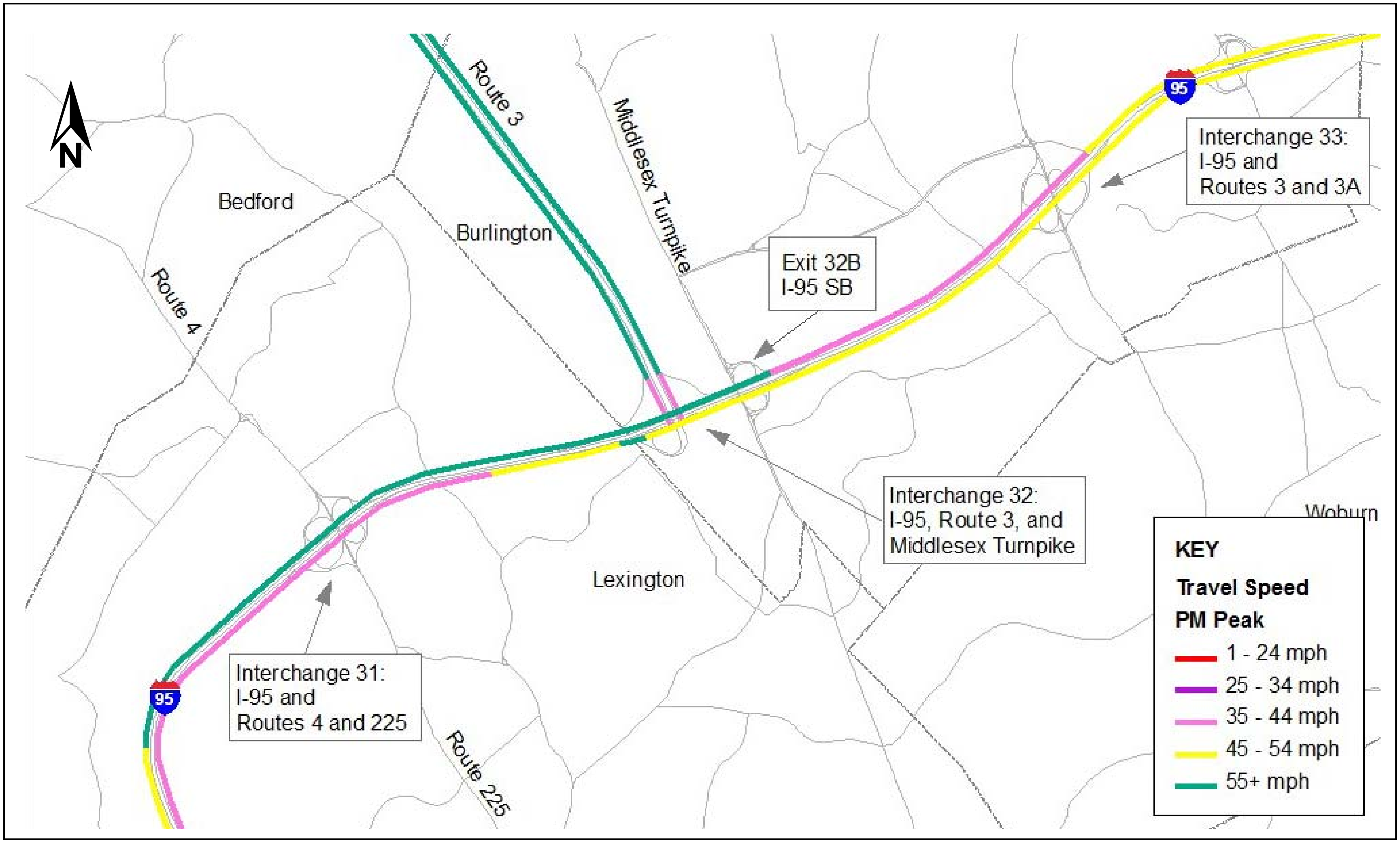
REGION
MPO

FIGURE 13
AM Peak-Period Travel Speeds on I-95 Southbound
near the Bottleneck at Interchange 32 in Burlington, 2005

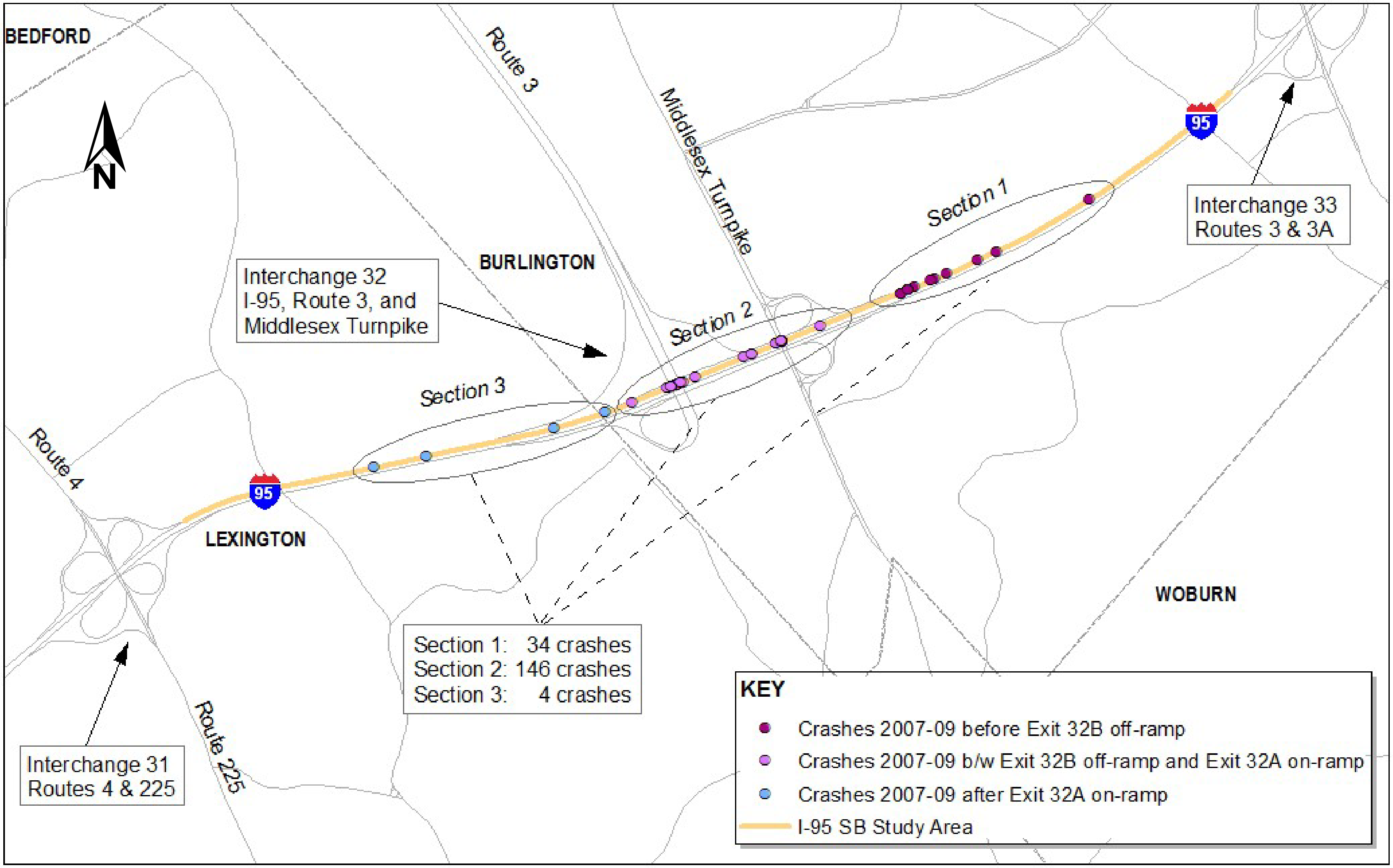
Low-Cost
Bottleneck
Improvements



BOSTON
REGION
MPO

FIGURE 14
PM Peak-Period Travel Speeds on I-95 Southbound near the Bottleneck at Interchange 32 in Burlington, 2005

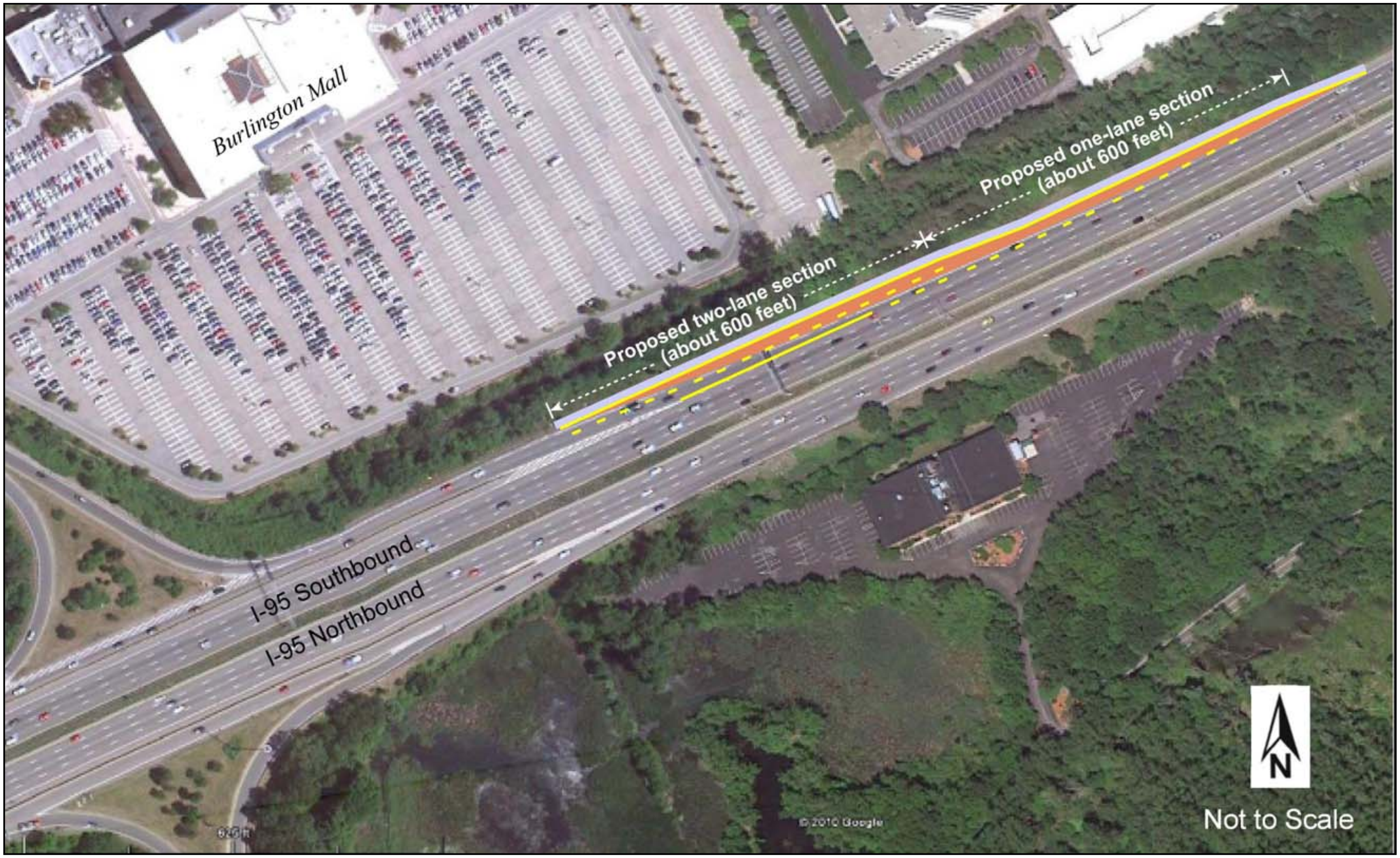
Low-Cost Bottleneck Improvements



BOSTON
REGION
MPO

FIGURE 15
Crashes on I-95 Southbound near the Bottleneck at Interchange 32 in Burlington, 2007–09

Low-Cost Bottleneck Improvements



BOSTON
REGION
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FIGURE 16
Proposed Improvement at the Off-ramp Area of I-95 Southbound Exit 32B in Burlington

Low-Cost Bottleneck Improvements

APPENDIX A

Existing Conditions Analysis (PM Peak Hour)

HCS 2010: Freeway Merge and Diverge Segments

I-95 Northbound Exit 29A, Lexington

Phone: Fax:
E-mail:

Diverge Analysis

Analyst:	Chen-Yuan Wang
Agency/Co.:	Boston Region MPO
Date performed:	9/29/2011
Analysis time period:	PM peak Hour
Freeway/Dir of Travel:	I-95 NB
Junction:	Exit 29A
Jurisdiction:	MassDOT
Analysis Year:	Existing Conditions Analysis

Description: Low-Cost Bottlenecks Improvements

Freeway Data

Type of analysis	Diverge	
Number of lanes in freeway	4	
Free-flow speed on freeway	60.0	mph
Volume on freeway	7800	vph

Off Ramp Data

Side of freeway	Right	
Number of lanes in ramp	1	
Free-Flow speed on ramp	30.0	mph
Volume on ramp	1400	vph
Length of first accel/decel lane	250	ft
Length of second accel/decel lane		ft

Adjacent Ramp Data (if one exists)

Does adjacent ramp exist?	Yes	
Volume on adjacent ramp	300	vph
Position of adjacent ramp	Upstream	
Type of adjacent ramp	On	
Distance to adjacent ramp	1500	ft

Conversion to pc/h Under Base Conditions

Junction Components	Freeway		Ramp		Adjacent Ramp	
Volume, V (vph)	7800		1400		300	vph
Peak-hour factor, PHF	0.92		0.92		0.92	
Peak 15-min volume, v15	2120		380		82	v
Trucks and buses	2		2		2	%
Recreational vehicles	0		0		0	%
Terrain type:	Level		Level		Level	
Grade	0.00	%	0.00	%	0.00	%
Length	0.00	mi	0.00	mi	0.00	mi
Trucks and buses PCE, ET	1.5		1.5		1.5	
Recreational vehicle PCE, ER	1.2		1.2		1.2	

Heavy vehicle adjustment, fHV	0.990	0.990	0.990	
Driver population factor, fP	1.00	1.00	1.00	
Flow rate, vp	8563	1537	329	pcph

Estimation of V12 Diverge Areas

L_{EQ} = (Equation 13-12 or 13-13)

P_{FD} = 0.436 Using Equation 8

$v_{12} = v_R + (v_F - v_R) P_{FD}$ = 4600 pc/h

Capacity Checks

	Actual	Maximum	LOS F?
$v_{Fi} = v_F$	8563	9200	No
$v_{FO} = v_F - v_R$	7026	9200	No
v_R	1537	2000	No
v_3 or v_{av34}	1981 pc/h	(Equation 13-14 or 13-17)	

Is v_3 or v_{av34} > 2700 pc/h? No

Is v_3 or v_{av34} > 1.5 v_{12}/2 No

If yes, v_{12A} = 4600 (Equation 13-15, 13-16, 13-18, or 13-19)

Flow Entering Diverge Influence Area

	Actual	Max Desirable	Violation?
v_{12}	4600	4400	Yes

Level of Service Determination (if not F)

Density, $D_R = 4.252 + 0.0086\, v_{12} - 0.009\, L_D$ = 41.6 pc/mi/ln

Level of service for ramp-freeway junction areas of influence E

Speed Estimation

Intermediate speed variable,	D_S = 0.631	
Space mean speed in ramp influence area,	S_R = 48.6	mph
Space mean speed in outer lanes,	S_0 = 62.0	mph
Space mean speed for all vehicles,	S = 54.0	mph

APPENDIX B

Improvement Alternative Analysis (PM Peak Hour)

HCS 2010: Freeway Merge and Diverge Segments

I-95 Northbound Exit 29A, Lexington

Phone: Fax:
E-mail:

Diverge Analysis

Analyst:	Chen-Yuan Wang
Agency/Co.:	Boston Region MPO
Date performed:	9/29/2011
Analysis time period:	PM peak Hour
Freeway/Dir of Travel:	I-95 NB
Junction:	Exit 29A
Jurisdiction:	MassDOT
Analysis Year:	Improvement Alternative

Description: Low-Cost Bottlenecks Improvements

Freeway Data

Type of analysis	Diverge	
Number of lanes in freeway	4	
Free-flow speed on freeway	60.0	mph
Volume on freeway	7800	vph

Off Ramp Data

Side of freeway	Right	
Number of lanes in ramp	1	
Free-Flow speed on ramp	30.0	mph
Volume on ramp	1400	vph
Length of first accel/decel lane	1000	ft
Length of second accel/decel lane		ft

Adjacent Ramp Data (if one exists)

Does adjacent ramp exist?	Yes	
Volume on adjacent ramp	300	vph
Position of adjacent ramp	Upstream	
Type of adjacent ramp	Off	
Distance to adjacent ramp	750	ft

Conversion to pc/h Under Base Conditions

Junction Components	Freeway		Ramp		Adjacent Ramp	
Volume, V (vph)	7800		1400		300	vph
Peak-hour factor, PHF	0.92		0.92		0.92	
Peak 15-min volume, v15	2120		380		82	v
Trucks and buses	2		2		2	%
Recreational vehicles	0		0		0	%
Terrain type:	Level		Level		Level	
Grade	0.00	%	0.00	%	0.00	%
Length	0.00	mi	0.00	mi	0.00	mi
Trucks and buses PCE, ET	1.5		1.5		1.5	
Recreational vehicle PCE, ER	1.2		1.2		1.2	

Heavy vehicle adjustment, fHV	0.990	0.990	0.990	
Driver population factor, fP	1.00	1.00	1.00	
Flow rate, vp	8563	1537	329	pcph

Estimation of V12 Diverge Areas

L_{EQ} = (Equation 13-12 or 13-13)

P_{FD} = 0.436 Using Equation 8

$v_{12} = v_R + (v_F - v_R) P_{FD}$ = 4600 pc/h

Capacity Checks

	Actual	Maximum	LOS F?
$v_{Fi} = v_F$	8563	9200	No
$v_{FO} = v_F - v_R$	7026	9200	No
v_R	1537	2000	No
v_3 or v_{av34}	1981 pc/h	(Equation 13-14 or 13-17)	
Is v_3 or v_{av34} > 2700 pc/h?		No	
Is v_3 or v_{av34} > 1.5 v_{12}/2		No	

If yes, v_{12A} = 4600 (Equation 13-15, 13-16, 13-18, or 13-19)

Flow Entering Diverge Influence Area

	Actual	Max Desirable	Violation?
v_{12}	4600	4400	Yes

Level of Service Determination (if not F)

Density, $D = 4.252 + 0.0086\, v_{12} - 0.009\, L_D$ = 34.8 pc/mi/ln

Level of service for ramp-freeway junction areas of influence D

Speed Estimation

Intermediate speed variable,	D_S = 0.631	
Space mean speed in ramp influence area,	S_R = 48.6	mph
Space mean speed in outer lanes,	S_0 = 62.0	mph
Space mean speed for all vehicles,	S = 54.0	mph

APPENDIX C

Existing Conditions Analysis (AM Peak Hour)

HCS 2010: Freeway Merge and Diverge Segments

I-95 Southbound Exit 28B, Waltham

HCS 2010: Freeway Merge and Diverge Segments Release 6.2

Phone: Fax:
E-mail:

Diverge Analysis

Analyst: Chen-Yuan Wang
Agency/Co.: Boston Region MPO
Date performed: 9/29/2011
Analysis time period: AM peak Hour
Freeway/Dir of Travel: I-95 SB
Junction: Exit 28B
Jurisdiction: MassDOT
Analysis Year: Existing Conditions Analysis
Description: Low-Cost Bottlenecks Improvements

Freeway Data

Type of analysis	Diverge	
Number of lanes in freeway	4	
Free-flow speed on freeway	60.0	mph
Volume on freeway	8400	vph

Off Ramp Data

Side of freeway	Right	
Number of lanes in ramp	1	
Free-Flow speed on ramp	30.0	mph
Volume on ramp	400	vph
Length of first accel/decel lane	150	ft
Length of second accel/decel lane		ft

Adjacent Ramp Data (if one exists)

Does adjacent ramp exist?	Yes	
Volume on adjacent ramp	1000	vph
Position of adjacent ramp	Upstream	
Type of adjacent ramp	On	
Distance to adjacent ramp	1500	ft

Conversion to pc/h Under Base Conditions

Junction Components	Freeway		Ramp		Adjacent Ramp	
Volume, V (vph)	8400		400		1000	vph
Peak-hour factor, PHF	0.95		0.95		0.95	
Peak 15-min volume, v15	2211		105		263	v
Trucks and buses	2		2		2	%
Recreational vehicles	0		0		0	%
Terrain type:	Level		Level		Level	
Grade	0.00	%	0.00	%	0.00	%
Length	0.00	mi	0.00	mi	0.00	mi
Trucks and buses PCE, ET	1.5		1.5		1.5	
Recreational vehicle PCE, ER	1.2		1.2		1.2	

```
Heavy vehicle adjustment, fHV          0.990       0.990       0.990
Driver population factor, fP           1.00        1.00        1.00
Flow rate, vp                          8931        425         1063      pcph

_________________________Estimation of V12 Diverge Areas_________________________

                  L  =            (Equation 13-12 or 13-13)
                   EQ
                  P  =    0.436   Using Equation  8
                   FD
                  v  = v  + (v - v ) P  =  4134   pc/h
                   12   R     F   R   FD

_______________________________Capacity Checks_________________________________

                             Actual        Maximum         LOS F?
     v  = v                  8931          9200            No
      Fi   F
     v  = v - v              8506          9200            No
      FO   F   R
     v                       425           2000            No
      R
     v  or v                 2398 pc/h     (Equation 13-14 or 13-17)
      3     av34
Is   v  or v      > 2700 pc/h?             No
      3     av34
Is   v  or v      > 1.5 v  /2              No
      3     av34         12
If yes, v    = 4134                     (Equation 13-15, 13-16, 13-18, or 13-19)
         12A

______________________Flow Entering Diverge Influence Area______________________
                        Actual        Max Desirable         Violation?
     v                  4134          4400                  No
      12
_________________Level of Service Determination (if not F)______________________

Density,                 D = 4.252 + 0.0086 v  - 0.009  L   =   38.5    pc/mi/ln
                          R                   12         D
Level of service for ramp-freeway junction areas of influence E

_____________________________Speed Estimation___________________________________

Intermediate speed variable,                 D  = 0.531
                                              S
Space mean speed in ramp influence area,     S  = 50.4    mph
                                              R
Space mean speed in outer lanes,             S  = 60.4    mph
                                              0
Space mean speed for all vehicles,           S  = 55.3    mph
________________________________________________________________________________
```

APPENDIX D

Improvement Alternative Analysis (AM Peak Hour)

HCS 2010: Freeway Merge and Diverge Segments

I-95 Southbound Exit 28B, Waltham

HCS 2010: Freeway Merge and Diverge Segments Release 6.2

Phone: Fax:
E-mail:

Diverge Analysis

Analyst:	Chen-Yuan Wang
Agency/Co.:	Boston Region MPO
Date performed:	9/29/2011
Analysis time period:	AM peak Hour
Freeway/Dir of Travel:	I-95 SB
Junction:	Exit 28B
Jurisdiction:	MassDOT
Analysis Year:	Improvement Alternative

Description: Low-Cost Bottlenecks Improvements

Freeway Data

Type of analysis	Diverge	
Number of lanes in freeway	4	
Free-flow speed on freeway	60.0	mph
Volume on freeway	8400	vph

Off Ramp Data

Side of freeway	Right	
Number of lanes in ramp	1	
Free-Flow speed on ramp	30.0	mph
Volume on ramp	400	vph
Length of first accel/decel lane	750	ft
Length of second accel/decel lane		ft

Adjacent Ramp Data (if one exists)

Does adjacent ramp exist?	Yes	
Volume on adjacent ramp	1000	vph
Position of adjacent ramp	Upstream	
Type of adjacent ramp	On	
Distance to adjacent ramp	900	ft

Conversion to pc/h Under Base Conditions

Junction Components	Freeway		Ramp		Adjacent Ramp	
Volume, V (vph)	8400		400		1000	vph
Peak-hour factor, PHF	0.95		0.95		0.95	
Peak 15-min volume, v15	2211		105		263	v
Trucks and buses	2		2		2	%
Recreational vehicles	0		0		0	%
Terrain type:	Level		Level		Level	
Grade	0.00	%	0.00	%	0.00	%
Length	0.00	mi	0.00	mi	0.00	mi
Trucks and buses PCE, ET	1.5		1.5		1.5	
Recreational vehicle PCE, ER	1.2		1.2		1.2	

Heavy vehicle adjustment, fHV	0.990	0.990	0.990	
Driver population factor, fP	1.00	1.00	1.00	
Flow rate, vp	8931	425	1063	pcph

Estimation of V12 Diverge Areas

L_{EQ} = (Equation 13-12 or 13-13)

P_{FD} = 0.436 Using Equation 8

$v_{12} = v_R + (v_F - v_R) P_{FD}$ = 4134 pc/h

Capacity Checks

	Actual	Maximum	LOS F?
$v_{Fi} = v_F$	8931	9200	No
$v_{FO} = v_F - v_R$	8506	9200	No
v_R	425	2000	No
v_3 or v_{av34}	2398 pc/h	(Equation 13-14 or 13-17)	

Is v_3 or v_{av34} > 2700 pc/h? No

Is v_3 or v_{av34} > 1.5 v_{12}/2 No

If yes, v_{12A} = 4134 (Equation 13-15, 13-16, 13-18, or 13-19)

Flow Entering Diverge Influence Area

	Actual	Max Desirable	Violation?
v_{12}	4134	4400	No

Level of Service Determination (if not F)

Density, $D_R = 4.252 + 0.0086\, v_{12} - 0.009\, L_D$ = 33.1 pc/mi/ln

Level of service for ramp-freeway junction areas of influence D

Speed Estimation

Intermediate speed variable, D_S = 0.531

Space mean speed in ramp influence area, S_R = 50.4 mph

Space mean speed in outer lanes, S_0 = 60.4 mph

Space mean speed for all vehicles, S = 55.3 mph

APPENDIX E

Existing Conditions Analysis (AM/PM Peak Hour)

HCS 2010: Freeway Merge and Diverge Segments

I-95 Southbound Exit 32B, Burlington

Phone: Fax:
E-mail:

Diverge Analysis

Analyst: Chen-Yuan Wang
Agency/Co.: Boston Region MPO
Date performed: 9/30/2011
Analysis time period: AM peak Hour
Freeway/Dir of Travel: I-95 SB
Junction: Exit 32B
Jurisdiction: MassDOT
Analysis Year: Existing Conditions
Description: Low-Cost Bottlenecks Improvements

Freeway Data

Type of analysis	Diverge	
Number of lanes in freeway	4	
Free-flow speed on freeway	65.0	mph
Volume on freeway	6800	vph

Off Ramp Data

Side of freeway	Right	
Number of lanes in ramp	1	
Free-Flow speed on ramp	30.0	mph
Volume on ramp	2600	vph
Length of first accel/decel lane	500	ft
Length of second accel/decel lane		ft

Adjacent Ramp Data (if one exists)

Does adjacent ramp exist?	No	
Volume on adjacent ramp		vph
Position of adjacent ramp		
Type of adjacent ramp		
Distance to adjacent ramp		ft

Conversion to pc/h Under Base Conditions

Junction Components	Freeway		Ramp		Adjacent Ramp	
Volume, V (vph)	6800		2600			vph
Peak-hour factor, PHF	0.92		0.92			
Peak 15-min volume, v15	1848		707			v
Trucks and buses	2		2			%
Recreational vehicles	0		0			%
Terrain type:	Level		Level			
Grade	0.00	%	0.00	%		%
Length	0.00	mi	0.00	mi		mi
Trucks and buses PCE, ET	1.5		1.5			
Recreational vehicle PCE, ER	1.2		1.2			

Heavy vehicle adjustment, fHV	0.990	0.990	
Driver population factor, fP	1.00	1.00	
Flow rate, vp	7465	2854	pcph

Estimation of V12 Diverge Areas

L_{EQ} = (Equation 13-12 or 13-13)

P_{FD} = 0.436 Using Equation 8

$v_{12} = v_R + (v_F - v_R) P_{FD}$ = 4864 pc/h

Capacity Checks

	Actual	Maximum	LOS F?
$v_{Fi} = v_F$	7465	9400	No
$v_{FO} = v_F - v_R$	4611	9400	No
v_R	2854	2000	Yes
v_3 or v_{av34}	1300 pc/h	(Equation 13-14 or 13-17)	
Is v_3 or v_{av34} > 2700 pc/h?		No	
Is v_3 or v_{av34} > 1.5 v_{12} /2		No	
If yes, v_{12A} = 4864		(Equation 13-15, 13-16, 13-18, or 13-19)	

Flow Entering Diverge Influence Area

	Actual	Max Desirable	Violation?
v_{12}	4864	4400	Yes

Level of Service Determination (if not F)

Density, $D_R = 4.252 + 0.0086\, v_{12} - 0.009\, L_D$ = 41.6 pc/mi/ln

Level of service for ramp-freeway junction areas of influence F

Speed Estimation

Intermediate speed variable,	D_S = 0.750	
Space mean speed in ramp influence area,	S_R = 47.8	mph
Space mean speed in outer lanes,	S_0 = 70.1	mph
Space mean speed for all vehicles,	S = 53.7	mph

HCS 2010: Freeway Merge and Diverge Segments Release 6.2

Phone: Fax:
E-mail:

Diverge Analysis

Analyst:	Chen-Yuan Wang
Agency/Co.:	Boston Region MPO
Date performed:	9/30/2011
Analysis time period:	PM peak Hour
Freeway/Dir of Travel:	I-95 SB
Junction:	Exit 32B
Jurisdiction:	MassDOT
Analysis Year:	Existing Conditions

Description: Low-Cost Bottlenecks Improvements

Freeway Data

Type of analysis	Diverge	
Number of lanes in freeway	4	
Free-flow speed on freeway	65.0	mph
Volume on freeway	6650	vph

Off Ramp Data

Side of freeway	Right	
Number of lanes in ramp	1	
Free-Flow speed on ramp	30.0	mph
Volume on ramp	2000	vph
Length of first accel/decel lane	500	ft
Length of second accel/decel lane		ft

Adjacent Ramp Data (if one exists)

Does adjacent ramp exist?	No	
Volume on adjacent ramp		vph
Position of adjacent ramp		
Type of adjacent ramp		
Distance to adjacent ramp		ft

Conversion to pc/h Under Base Conditions

Junction Components	Freeway		Ramp		Adjacent Ramp	
Volume, V (vph)	6650		2000			vph
Peak-hour factor, PHF	0.92		0.92			
Peak 15-min volume, v15	1807		543			v
Trucks and buses	2		2			%
Recreational vehicles	0		0			%
Terrain type:	Level		Level			
Grade	0.00	%	0.00	%		%
Length	0.00	mi	0.00	mi		mi
Trucks and buses PCE, ET	1.5		1.5			
Recreational vehicle PCE, ER	1.2		1.2			

```
Heavy vehicle adjustment, fHV          0.990       0.990
Driver population factor, fP           1.00        1.00
Flow rate, vp                          7301        2196                     pcph

_________________________Estimation of V12 Diverge Areas______________________

                  L  =            (Equation 13-12 or 13-13)
                   EQ
                  P  =    0.436   Using Equation  8
                   FD
                  v  = v  + (v - v ) P  =  4422   pc/h
                   12   R     F   R   FD

_______________________________Capacity Checks_________________________________

                             Actual        Maximum         LOS F?
     v  = v                  7301          9400            No
      Fi   F
     v  = v - v              5105          9400            No
      FO   F   R
     v                       2196          2000            Yes
      R
     v  or v                 1439 pc/h     (Equation 13-14 or 13-17)
      3     av34
Is   v  or v      > 2700 pc/h?             No
      3     av34
Is   v  or v      > 1.5 v  /2              No
      3     av34         12
If yes, v    = 4422                     (Equation 13-15, 13-16, 13-18, or 13-19)
         12A

______________________Flow Entering Diverge Influence Area_____________________
                        Actual        Max Desirable        Violation?
     v                  4422          4400                 Yes
      12
_________________Level of Service Determination (if not F)____________________

Density,                 D = 4.252 + 0.0086 v  - 0.009  L   =   37.8    pc/mi/ln
                          R                  12          D
Level of service for ramp-freeway junction areas of influence F

_____________________________Speed Estimation__________________________________

Intermediate speed variable,                 D  = 0.691
                                              S
Space mean speed in ramp influence area,     S  = 49.1    mph
                                              R
Space mean speed in outer lanes,             S  = 69.6    mph
                                              0
Space mean speed for all vehicles,           S  = 55.6    mph
_______________________________________________________________________________
```

APPENDIX F

Improvement Alternative Analysis (AM/PM Peak Hour)

HCS 2010: Freeway Merge and Diverge Segments

I-95 Southbound Exit 32B, Burlington

Phone: Fax:
E-mail:

Diverge Analysis

Analyst:	Chen-Yuan Wang
Agency/Co.:	Boston Region MPO
Date performed:	9/30/2011
Analysis time period:	AM peak Hour
Freeway/Dir of Travel:	I-95 SB
Junction:	Exit 32B
Jurisdiction:	MassDOT
Analysis Year:	Improvement Alternative

Description: Low-Cost Bottlenecks Improvements

Freeway Data

Type of analysis	Diverge	
Number of lanes in freeway	4	
Free-flow speed on freeway	65.0	mph
Volume on freeway	6800	vph

Off Ramp Data

Side of freeway	Right	
Number of lanes in ramp	2	
Free-Flow speed on ramp	30.0	mph
Volume on ramp	2600	vph
Length of first accel/decel lane	600	ft
Length of second accel/decel lane	600	ft

Adjacent Ramp Data (if one exists)

Does adjacent ramp exist?	No	
Volume on adjacent ramp		vph
Position of adjacent ramp		
Type of adjacent ramp		
Distance to adjacent ramp		ft

Conversion to pc/h Under Base Conditions

Junction Components	Freeway		Ramp		Adjacent Ramp	
Volume, V (vph)	6800		2600			vph
Peak-hour factor, PHF	0.92		0.92			
Peak 15-min volume, v15	1848		707			v
Trucks and buses	2		2			%
Recreational vehicles	0		0			%
Terrain type:	Level		Level			
Grade	0.00	%	0.00	%		%
Length	0.00	mi	0.00	mi		mi
Trucks and buses PCE, ET	1.5		1.5			
Recreational vehicle PCE, ER	1.2		1.2			

Heavy vehicle adjustment, fHV	0.990	0.990	
Driver population factor, fP	1.00	1.00	
Flow rate, vp	7465	2854	pcph

Estimation of V12 Diverge Areas

L_{EQ} = (Equation 13-12 or 13-13)

P_{FD} = 0.260 Using Equation 0

$v_{12} = v_R + (v_F - v_R) P_{FD}$ = 4053 pc/h

Capacity Checks

	Actual	Maximum	LOS F?
$v_{Fi} = v_F$	7465	9400	No
$v_{FO} = v_F - v_R$	4611	9400	No
v_R	2854	4000	No
v_3 or v_{av34}	1706 pc/h	(Equation 13-14 or 13-17)	
Is v_3 or v_{av34} > 2700 pc/h?		No	
Is v_3 or v_{av34} > 1.5 v_{12}/2		No	

If yes, v_{12A} = 4053 (Equation 13-15, 13-16, 13-18, or 13-19)

Flow Entering Diverge Influence Area

	Actual	Max Desirable	Violation?
v_{12}	4053	4400	No

Level of Service Determination (if not F)

Density, $D_R = 4.252 + 0.0086\, v_{12} - 0.009\, L_D$ = 22.9 pc/mi/ln

Level of service for ramp-freeway junction areas of influence C

Speed Estimation

Intermediate speed variable,	D_S = 0.750	
Space mean speed in ramp influence area,	S_R = 47.8	mph
Space mean speed in outer lanes,	S_0 = 68.6	mph
Space mean speed for all vehicles,	S = 55.4	mph

HCS 2010: Freeway Merge and Diverge Segments Release 6.2

Phone: Fax:
E-mail:

Diverge Analysis

Analyst:	Chen-Yuan Wang
Agency/Co.:	Boston Region MPO
Date performed:	9/30/2011
Analysis time period:	PM peak Hour
Freeway/Dir of Travel:	I-95 SB
Junction:	Exit 32B
Jurisdiction:	MassDOT
Analysis Year:	Improvement Alternative

Description: Low-Cost Bottlenecks Improvements

Freeway Data

Type of analysis	Diverge	
Number of lanes in freeway	4	
Free-flow speed on freeway	65.0	mph
Volume on freeway	6650	vph

Off Ramp Data

Side of freeway	Right	
Number of lanes in ramp	2	
Free-Flow speed on ramp	30.0	mph
Volume on ramp	2000	vph
Length of first accel/decel lane	600	ft
Length of second accel/decel lane	600	ft

Adjacent Ramp Data (if one exists)

Does adjacent ramp exist?	No	
Volume on adjacent ramp		vph
Position of adjacent ramp		
Type of adjacent ramp		
Distance to adjacent ramp		ft

Conversion to pc/h Under Base Conditions

Junction Components	Freeway		Ramp		Adjacent Ramp	
Volume, V (vph)	6650		2000			vph
Peak-hour factor, PHF	0.92		0.92			
Peak 15-min volume, v15	1807		543			v
Trucks and buses	2		2			%
Recreational vehicles	0		0			%
Terrain type:	Level		Level			
Grade	0.00	%	0.00	%		%
Length	0.00	mi	0.00	mi		mi
Trucks and buses PCE, ET	1.5		1.5			
Recreational vehicle PCE, ER	1.2		1.2			

Heavy vehicle adjustment, fHV	0.990	0.990	
Driver population factor, fP	1.00	1.00	
Flow rate, vp	7301	2196	pcph

Estimation of V12 Diverge Areas

L_{EQ} = (Equation 13-12 or 13-13)

P_{FD} = 0.260 Using Equation 0

$v_{12} = v_R + (v_F - v_R) P_{FD}$ = 3523 pc/h

Capacity Checks

	Actual	Maximum	LOS F?
$v_{Fi} = v_F$	7301	9400	No
$v_{FO} = v_F - v_R$	5105	9400	No
v_R	2196	4000	No
v_3 or v_{av34}	1889 pc/h	(Equation 13-14 or 13-17)	
Is v_3 or v_{av34} > 2700 pc/h?		No	
Is v_3 or v_{av34} > 1.5 v_{12}/2		No	

If yes, v_{12A} = 3523 (Equation 13-15, 13-16, 13-18, or 13-19)

Flow Entering Diverge Influence Area

	Actual	Max Desirable	Violation?
v_{12}	3523	4400	No

Level of Service Determination (if not F)

Density, $D_R = 4.252 + 0.0086\, v_{12} - 0.009\, L_D$ = 18.3 pc/mi/ln

Level of service for ramp-freeway junction areas of influence B

Speed Estimation

Intermediate speed variable,	D_S = 0.691	
Space mean speed in ramp influence area,	S_R = 49.1	mph
Space mean speed in outer lanes,	S_0 = 67.8	mph
Space mean speed for all vehicles,	S = 57.3	mph