Implementing Active Traffic Management Strategies in the U.S.

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16. Abstract

Limited public funding for roadway expansion and improvement projects, coupled with continued growth in travel along congested urban freeway corridors, creates a pressing need for innovative congestion management approaches. Strategies to address congestion have been implemented in many areas of this country and include such options as variable message signs, High Occupancy Vehicle (HOV) lanes, toll lanes, ramp metering, and network surveillance. These strategies, however, have largely been deployed so that they function independently and are often implemented only on preset schedules or manually in response to an incident. Active Traffic Management (ATM) utilizes many of these same strategies but does so in concert in order to maximize the efficiency of transportation facilities during all periods of the day and under both recurrent and non-recurrent congestion conditions. This approach stresses automation to dynamically deploy strategies to quickly optimize performance and enhance throughput and safety.

There are many opportunities and challenges associated with the implementation of ATM in the U.S. To gain a better understanding of the issues related to the potential deployment of ATM strategies, this study focuses on the following:

1. Assessment of the state of the practice for ATM strategies, such as speed harmonization, temporary shoulder lane use, and junction control, and
2. Analysis of potential operational benefits from implementing temporary shoulder lane use strategies on a segment of I-65 in the Birmingham, AL region.

The study uses microscopic simulation modeling to quantify the impacts of temporary shoulder lane use on traffic operations. Moreover, a detailed cost-benefit analysis was performed to analyze the economic feasibility and potential gains from deployment.

The analyses showed significant operational, environmental, and economic benefits from the potential temporary use of the left shoulder lane within an ATM environment. These results clearly indicate the excellent potential of temporary shoulder lane use as an ATM tool for addressing recurrent and non-recurrent congestion along I-65, in the Birmingham region. The study also summarizes best practices along with recommendations for advancing the research and implementation of active management strategies.

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Executive Summary

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There are many opportunities and challenges associated with the implementation of ATM in the U.S. To gain a better understanding of the issues related to the potential deployment of ATM strategies, this study focuses on the following:

- Assessment of the state of the practice for ATM strategies, such as speed harmonization, temporary shoulder lane use, and junction control, and
- Analysis of potential operational benefits from implementing temporary shoulder lane use strategies on a segment of I-65 in the Birmingham, AL region.

This study summarized best practices along with recommendations for advancing the research and implementation of active management strategies. Furthermore, this study used microscopic simulation modeling to quantify the impacts of temporary shoulder lane use on traffic operations. Moreover, a detailed cost-benefit analysis was performed to analyze the economic feasibility and potential gains from deployment.

The analyses showed significant operational, environmental, and economic benefits from the potential temporary use of the left shoulder lane for the relief of recurrent- and non-recurrent congestion. The results from this study clearly indicate the excellent potential of temporary shoulder lane use as an ATM tool for addressing recurrent and non-recurrent congestion along I-65, in the Birmingham region.

1 Introduction

1.1 Background

Traffic congestion is an increasing problem in the United States. Urban development patterns coupled with rapid growth in traffic demand without a matching growth in the transportation infrastructure causes congestion and increases the number of accidents. In *2007 Urban Mobility Report*, the Texas Transportation Institute points to a $78 billion congestion cost—and that is only the value of wasted time and fuel. Congestion causes the average peak-period traveler to spend an extra 38 hours of travel time and 26 gallons of fuel, amounting to a cost of $710 per traveler (19).

Urban areas in Alabama face similar challenges with respect to flow management and congestion mitigation as those identified nationwide. In 2003, for example, 9.7 million person-hours were wasted in Birmingham, AL alone due to congestion. This translates to a cost of congestion of $165 million, or three times the figure reported a decade ago ($53 million in 1993). The *2005 Urban Mobility Study* by the Texas Transportation Institute listed Birmingham as one of the medium-sized urban areas with higher congestion or a faster increase in urban congestion than their counterparts (18).

Addressing congestion problems can provide substantial benefits and provide improvements in many sectors of society and the economy. According to one study, eliminating serious congestion returns eight dollars for every one spent (19). The benefits range from less travel time and fuel consumed to faster and more reliable delivery times, expanded service regions and market areas, as well as improved safety and air quality. However, the costs involved in eliminating serious congestion problems are large and the projects, programs, and policies that are implemented often require the cooperation of the public, agencies at all levels of government and, in many states, the private sector.

In order to address congestion issues in a smart and cost-effective manner, transportation agencies in the U.S. and around the world have been looking at innovative ways to manage congestion and improve safety by making more efficient use of existing infrastructure. Having a cost-effective solution is essential due to the rise of financial constraints (24).

Systems to address congestion have been implemented in many areas of this country and include such strategies as variable message signs, High Occupancy Vehicle (HOV) lanes, toll lanes, and network surveillance. These strategies, however, have largely been deployed so that they function independently and are often implemented only on preset schedules or manually in response to incidents. Active Traffic Management (ATM) is a new approach that utilizes many of these same strategies but does so in concert in order to maximize the efficiency of transportation facilities during all periods of the day and under both recurrent and non-recurrent congestion conditions. This approach stresses automation to dynamically deploy strategies to quickly optimize performance and enhance throughput and safety.

ATM includes the frequent adjustment or alteration of the traffic control and regulatory features of the road network in response to changing traffic conditions. ATM is the practice of dynamically managing both recurrent and non-recurrent congestion based on prevailing and future traffic conditions. In practice, ATM seeks to provide reliable travel times for all users, reduce both recurrent and non-recurrent congestion, and provide enhanced information to drivers.

Unlike many existing systems, which are deployed manually and only in response to incidents or non-recurrent congestion, ATM typically relies on comprehensive automated systems to continuously monitor and adjust roadway management strategies as traffic conditions change. ATM is composed of a set of different strategies that can work together or on an individual basis to achieve the common goal of congestion alleviation. Strategies considered under the ATM umbrella include temporary shoulder use, speed harmonization, dynamic intersection control, and dynamic signing and rerouting. Managed lanes, as applied in the United States, are an obvious addition to this collection.

ATM received attention in the U.S. in the recent years as an approach with great potential to address the ever-growing congestion problems in U.S. urban areas. In 2007, the Federal Highway Administration (FHWA) endorsed ATM in the United States as an approach to optimize existing infrastructure during recurrent and non-recurrent congestion and offered a number of recommendations for advancing research and implementation of active management strategies, including the following:

- Promote ATM to optimize existing infrastructure during recurrent and non-recurrent congestion.
- Emphasize customer orientation and focus on trip reliability.
- Integrate ATM into infrastructure planning, programming, and funding processes, and
- Develop tools to support ATM investment decisions.

1.2 Research Objectives

The objective of this research study is twofold:

- To develop a better understanding of ATM strategies and
- To examine the feasibility of one of these strategies, namely temporary shoulder use, in addressing congestion problems in the Birmingham area.

To reach the research objective, several tasks needed to be accomplished. These tasks are summarized as follows:

- Review the state of practice for ATM, with greater emphasis placed on the temporary use of shoulder lanes.
- Use a case study to evaluate potential impacts from implementation of temporary shoulder lane use in Birmingham.
- Compile basic practical guidelines for implementing temporary shoulder lanes in the U.S.

Overall, the research project is expected to increase awareness and understanding of the practice among transportation professionals in the U.S. and provide a practical set of guidelines for planning and implementation.

2 Literature Review

Increasing recurrent and non-recurrent congestion in urban areas of the United States is a reason for concern, as it leads to increased delays, higher fuel consumption and pollution, driver frustration, and compromised traffic safety. Figure 1 shows the typical causes of traffic congestion in the United States (16). Limited public funding for roadway expansion and improvement projects, coupled with continued growth in travel along congested urban freeway corridors, creates a pressing need for innovative congestion management approaches.

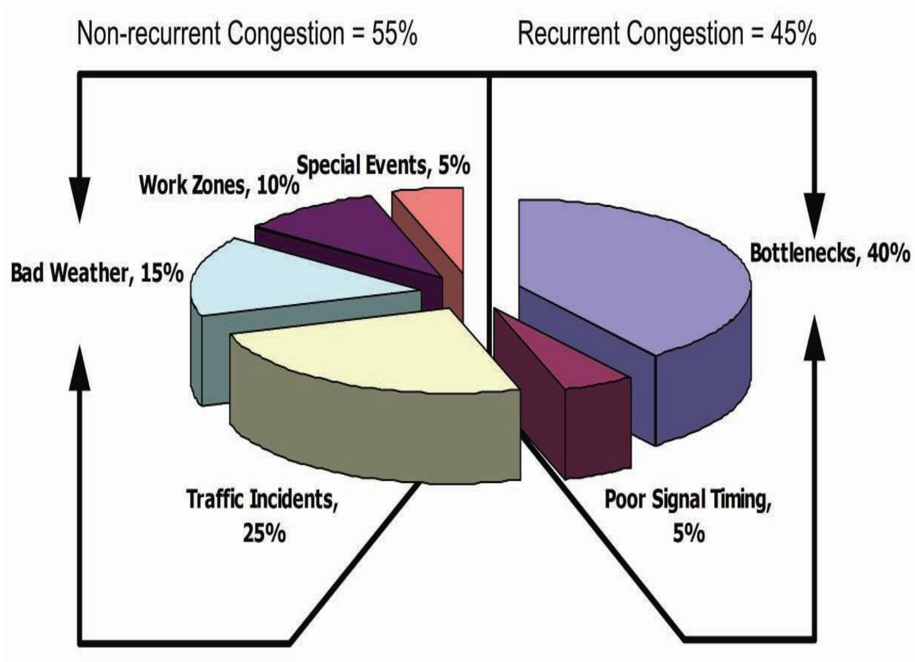

Figure 1. Causes of traffic congestion.

Congestion management is certainly not a new concept. Many American cities employ congestion management practices on freeways and major arterials to reduce delays and improve the efficiency of existing facilities. Ramp metering and managed lanes (e.g., HOV lanes) are used in numerous cities to address recurrent congestion, which typically account for nearly 45% of all congestion the U.S. Many cities address non-recurrent congestion through the use of advanced surveillance to detect incidents and incident response plans to clear them quickly. ATM uses many of these same strategies but does so in a unified system that enhances the effectiveness of the individual strategies. By stressing continuous system monitoring, dynamic response, and coordination of systems, ATM provides a holistic approach to transportation system management (35).

2.1 Active Traffic Management Overview

ATM received attention in the U.S. in recent years as an approach with great potential to address the ever-growing congestion problems in urban areas. In 2007, FHWA endorsed ATM in the United States as an approach to optimize existing infrastructure during recurrent and non-recurrent congestion and offered a number of recommendations for advancing research and implementation of active management strategies, including the following:

- Promote ATM to optimize existing infrastructure during recurrent and non-recurrent congestion.
- Emphasize customer orientation and focus on trip reliability.
- Integrate ATM into infrastructure planning, programming, and funding processes.
- Develop tools to support ATM investment decisions.

While ATM is a new congestion management approach in the United States, there are numerous examples of overseas ATM systems deployments that provide useful information on implementation requirements and the potential for success. European studies from Denmark, England, Germany, and the Netherlands confirm that such strategies result in great benefits, including an increase in vehicle throughput, crash reduction, improvement in trip reliability, decreases in congestion and traffic delays, and an overall improvement in the driving experience. Depending on the location and the combination of strategies deployed, specific benefits measured in Europe as a result of this congestion management approach include the following (24).

- Increase in average throughput for congested periods of 3% to 7%
- Increase in overall capacity of 3% to 22%
- Decrease in primary incidents of 3% to 30%
- Decrease in secondary incidents of 40% to 50%
- Overall harmonization of speeds during congested periods
- Decreased headways and more uniform driver behavior
- Increase in trip reliability
- Ability to delay the onset of freeway breakdown

Strategies considered under the ATM umbrella include temporary shoulder use, speed harmonization, dynamic intersection control, and dynamic signing and rerouting. Managed lanes, as applied in the United States, are an obvious addition to this collection.

In brief, speed harmonization involves reducing speed limits in areas of congestion to maintain better traffic flow and reduce the risk of collisions. Queue warning warns motorists of downstream queues and directs traffic to alternate lanes, thereby reducing the likelihood of speed differentials and collisions due to queuing. Junction control directs traffic to specific lanes based on the traffic demand (e.g., utilizes mainline capacity by giving priority to higher ramp volumes). Temporary hard shoulder running utilizes the shoulder as a travel lane to allow traffic to move around an incident, which helps to minimize recurrent congestion and manage traffic during incidents. Dynamic rerouting involves changing the destination signing to account for current traffic conditions in order to redirect traffic to less congested facilities. Additional details on selected ATM strategies follow.

2.1.1 Speed Harmonization

Speed harmonization is a strategy widely employed in Europe to improve traffic flow. Speed harmonization systems use changeable speed limit signs posted over each freeway lane to constantly regulate freeway speeds based on prevailing traffic conditions. Speed limits can be reduced when freeway conditions are unsuitable for high speed operations, such as bad weather or during fog. Speed limits can also be lowered when there is an incident or congestion on specific segments in order to reduce the chances of secondary accidents and facilitate a smoother flow of traffic.

Advanced versions of the speed harmonization strategy include dynamic implementation (based on real-time travel demand, not simply time of day) along with dynamic speed controls to improve the overall safety and efficiency of freeway operations. Through speed harmonization, agencies make the most of existing capacity by delaying the point at which flow breaks down and stop-and-go conditions occur.

2.1.2 High Occupancy Vehicle Lanes

The HOV lanes are one of the managed lanes strategies that offer dedicated lanes for vehicles with two or more occupants. HOV lanes are restricted lanes for those vehicles that meet a minimum occupancy requirement. The main purpose of HOV facilities is to maximize the passenger-carrying capacity of the roadway, especially in peak periods. Entrance restrictions typically apply to passenger vehicles carrying less than two persons. Also, in many cases, the use of HOV lanes by transit buses, vanpools, and carpools is encouraged to further increase the carrying capacity of HOV lanes and lighten the traffic load of adjacent general use lanes.

The main benefits of HOV use are to reduce congestion and encourage people to carpool or vanpool, which reduces air pollution and saves money (26). HOV lanes can be open 24 hours a day, seven days a week, or managed dynamically, in which case they become part of ATM.

Often HOV lanes are utilized as High Occupancy Toll Lanes (HOT), allowing single-occupant vehicles to use HOV lanes during peak hours in return for a toll that varies based on demand. The tolls change throughout the day according to real-time traffic conditions to manage the number of cars in the lanes and keep them free of congestion, even during rush hour. States with proven applications of HOT lanes include California, Colorado, Florida, Minnesota, Texas, Utah, and Washington.

2.1.3 Junction Control

The junction control strategy is a combination of ramp metering and lane control at on-ramps (5). Typically, junction control is applied at entrance ramps or merge points where the number of downstream lanes is fewer than that of upstream lanes. In Germany this is done dynamically by installing lane control signals over both upstream approaches before the merge, as depicted in Figure 2 and Figure 3. This strategy provides priority to the facility with the higher volume and gives a lane drop to the lesser volume approach (24).

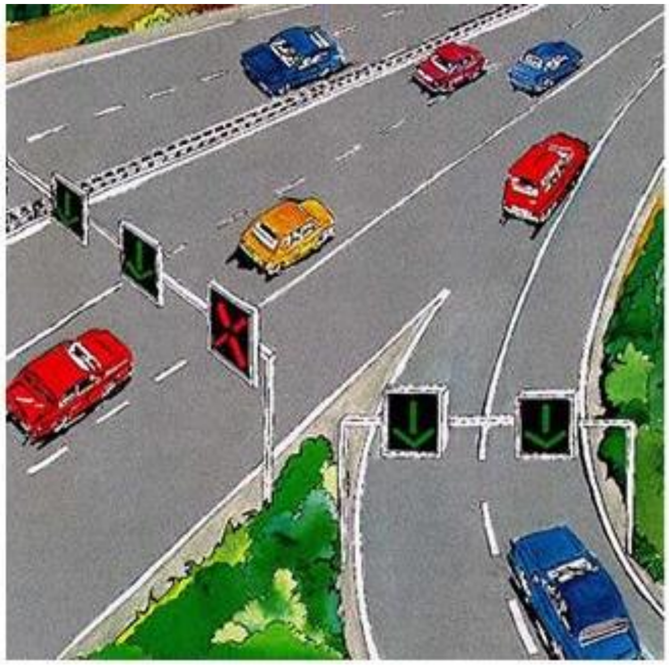

Figure 2. Junction control schematic in Germany (24).

Figure 3. Junction control at an exit with hard shoulder running (40).

In the U.S., a similar strategy in applied statically by dropping one lane from the outside lanes or merging the two inside lanes (40). The objective of junction control through either static or real-time means is better management of recurrent congestion by making traffic flow more uniform, effective utilization of existing roadway capacity, and improved safety. The literature reports decreases in primary collisions by 15% to 25% through implementation of junction control strategies (37).

2.1.4 Temporary Shoulder Lane Use

Temporary use of shoulder lanes as a travel lane began in many cities in the late 1960s; this was usually done during peak periods and in the peak direction. Temporary shoulder lane use provides additional lane(s) within the existing pavement, without the need to widen the freeway (7). Temporary shoulder lane use gives permission to vehicles to use either the right or left shoulder lanes in specific conditions. The use of shoulder lanes is done by using dynamically variable signs to let drivers know that the shoulder lane is open in a certain segment. The purpose of temporary shoulder use is to improve the performance of freeway facility by providing additional capacity in case of congestion which, decreases travel time and provides safety.

Temporary use of shoulder lanes on freeways is a strategy currently employed in several U.S. cities (Washington, D.C., Boston, Minneapolis, and Southern California, among others) to increase peak period capacity on congested freeway facilities. In a typical application, motorists are allowed to use shoulders as an extra driving lane during the AM and PM peak periods. In other cases, as in Minneapolis, freeway shoulder lanes are used by transit buses during certain periods of the day. In both cases, the use of shoulder lanes provides a temporary capacity increase for congested freeways during the times when demand is greatest.

Temporary use of shoulder lanes is also employed as an active congestion management strategy in Europe. In several countries, it is coupled with speed harmonization to enhance its effectiveness. Speed harmonization systems allow freeway operators to reduce freeway speeds during times of shoulder lane usage, resulting in an increase in the capacity gained by the use of shoulder lanes even further while simultaneously reducing the chances and severity of crashes. As this study investigates shoulder lane implementation potential in detail, some details on implementation requirement are presented next.

2.1.4.1 Temporary shoulder lanes design characteristics and requirements

In order to have the shoulder lane operate as a safe travel lane, some geometric requirements must be satisfied. First, it should be a full-width hard shoulder, with no adverse superelevation, and should satisfy design requirements similar to general purpose traffic lanes. Additionally, the shoulder lane should be continuous. The shoulder must also be designed to withstand repeated traffic loading and potential heavy vehicle traffic loading. Designers should ensure that a “roll-over rate” (algebraic difference between the shoulder cross slope and the traveled way cross slope) does not exceed 8%. Finally, the pavement material should be the same as the whole lanes.

2.1.4.2 Temporary shoulder lane traffic control devices requirements

The control of the use of the shoulder lanes requires the presence of traffic control devices in order to inform the users whether the shoulder lane is open or not. As an example, Figure 4 shows three stages of dynamic variable signs that are used in the implementation of temporary shoulder lanes in Germany (24).

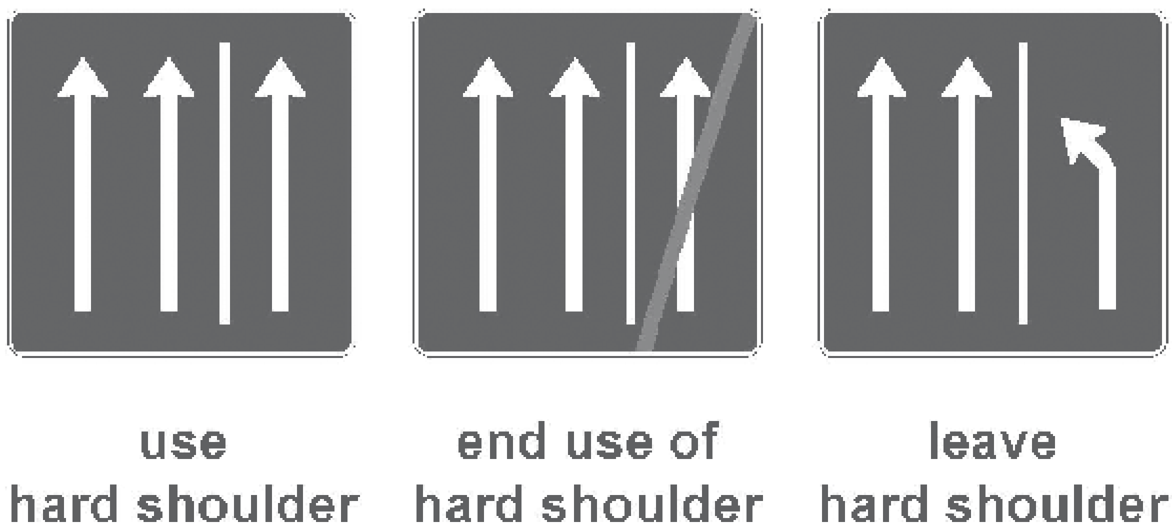

Figure 4. Dynamic variable sign for temporary shoulder lanes (24).

A variety of traffic devices and other pertinent technologies should be utilized to ensure driver safety when opening the shoulder lane, including the following (24):

- Lane control signals
- Dynamic speed limit signals
- Dynamic message signs
- Closed-circuit television cameras
- Roadway sensors
- Emergency roadside telephones

An example of a system in operation utilizing several of the above mentioned technologies is depicted in Figure 5.

The Manual of Uniform Traffic Control Devices (25) contains guidance on the placement and visibility of lane control signals that are applied when the travel on the shoulder lane is allowed, including details for the placement and use of overhead signals indicating whether the shoulder lane is opened or closed (17).

Based on some research, a large number of drivers have a good response to the red X and green arrow lane control signal symbols (43). Furthermore, based on an FHWA report, the lane control signal may be better understood if preceeded by another advanced sign that states "LANE CONTROL SIGNALS AHEAD" (28).

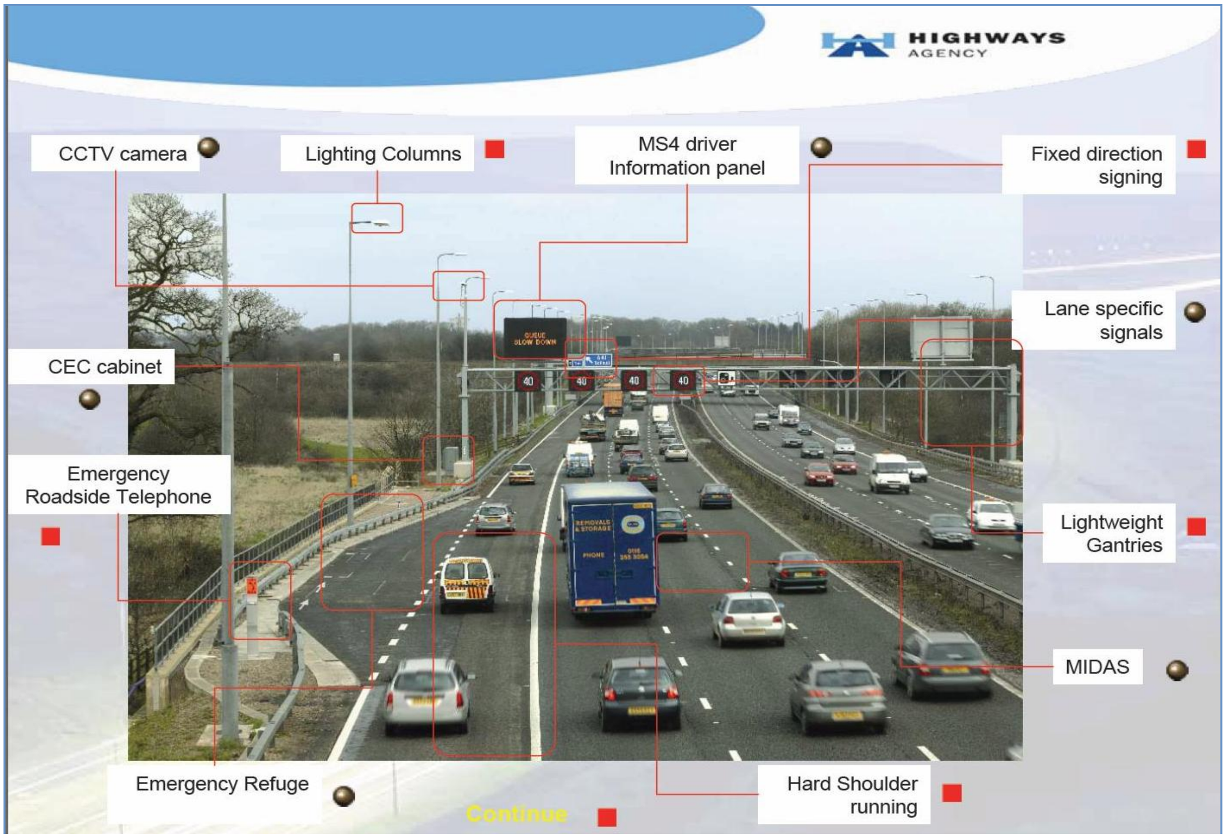

Figure 5. Traffic devices and strategies in M24 UK (37).

2.1.5 Implementation of Temporary Shoulder Lanes Facilities

As mentioned previously, temporary use of shoulder lanes on freeways is a strategy currently employed in several U.S. cities such as Washington, D.C., Boston, and Minneapolis to increase peak period capacity on congested freeway facilities. In a typical application, motorists are allowed to use shoulders as an extra driving lane during the AM and PM peak periods. In other cases, as in Minneapolis, freeway shoulder lanes are used by transit buses during certain periods of the day. The use of shoulder lanes provides a temporary capacity increase for congested freeways during the times when demand is greatest.

Temporary use of shoulder lanes is also employed as an active congestion management strategy in Europe, and in several countries is it combined with speed harmonization to enhance its effectiveness. Speed harmonization systems allow freeway operators to reduce freeway speeds during times of shoulder lane usage, resulting in an increase in the capacity gained by the use of shoulder lanes even further while simultaneously reducing the chances and severity of crashes. The following sections present implementation cases for the use of shoulder lane in Europe as well as the U.S.

2.2 Active Traffic Management Case Studies

2.2.1 Speed Harmonization

The primary impact of speed harmonization or variable speed limit (VSL) systems in congestion reduction is through delaying the onset of congestion and smoothing traffic flows. Further, such systems are beneficial at eliminating dangerous speed differentials and subsequently smoothing vehicle speeds through bottlenecks. Speed harmonization does not operate well after heavy congestion forms, but it provides relief before this state is reached and delays its occurrence (21).

Germany has used speed harmonization on roadways with high traffic volumes since the 1970s with a focus on improving traffic flow based on prevailing conditions. In Denmark, speed harmonization is referred to as variable speed limits and is used to manage congestion during construction projects. An example is the successful deployment of speed harmonization as part of work zone traffic management strategies for the multiyear widening of the M3. As a result of speed harmonization, incidents on the motorway have not increased during the reconstruction project, while the existing two lanes have been maintained at a narrower-than-normal width, and no entrance ramps, exit ramps, or bridges have been closed (45).

Used for many years in the Netherlands, speed harmonization has often been implemented during adverse weather conditions (e.g., fog), and as a traffic management strategy to create more uniform travel speeds. The Netherlands' Motorway Control System provides lane control and speed limit signs generally every 500 meters, and the lane control displays are used for incidents, maintenance, and construction. In 2001, England introduced a pilot program in response to motorists’ demands for better service within the realistic limitations of widening and expanding the roadway network.Table 1 provides a summary of variable speed limits implementation sites and associated benefits (21).

2.2.2 HOV Lanes

HOV lanes have been used widely in the United States since the 1970s. Today there are over 125 HOV lane projects in 30 cities operating over 2,500 lane-miles of HOV facilities and carrying more than 3 million passengers every day.

Several states have implemented or are currently in the process of introducing HOV lane strategies to combat urban congestion. Major HOV systems operate in Houston and Dallas, TX; Seattle, WA; the Los Angeles, Orange County, and San Francisco Bay regions in California; the Newark, NJ, and New York City areas; the Northern Virginia, Washington, D.C., and Maryland regions; and Atlanta, GA. Other facilities are in various stages of planning, design, and construction. A review of case studies is available in “Implementation of High Occupancy Vehicle Lanes” (33).

Table 1. Variable Speed Limits Applications and Benefits (21)

Association/ Project Name	Technologies	Benefits	Reference
Amsterdam's Lane Management System (The Netherlands)	Lane control signs, VSL, dynamic message signs	23% decrease in accidents, high compliance rate	a.
Make Better Use, The Highways Agency (U.K.)	Tidal flow, dedicated lanes, ramp metering, VSL, HS running, dynamic lanes	5% to 10% increase in freeway throughput	b.
London's Ring Road (U.K.)	VSL, managed lanes	10% to 15% reduction in accidents, high driver approval rating	b.
Optimal Coordination of VSL to Suppress Shockwaves (The Netherlands)	VSL	Minimized total time vehicle spends in network	c.
University of Maryland	VSL	Reduced queue lengths, increased vehicle throughput	d.
University of Virginia	VSL	Reduced speed variances	e.
University of Waterloo (Canada)	VSL	Significantly reduced total potential for crash	f.
A9 Outside Munich (Germany)	VSL	Dissipated upstream forming shockwaves, reduced intensity of shockwaves	g.
Delaware DOT	VSL	Reduced pollution on ozone-alert days, lowered speed limits during adverse weather and construction	h.

a. Federal Highway Administration, Office of Operations. *Congestion Mitigation.* FHWA-OP-04-047. Washington, D.C., 2004.
b. Yadlapati, S., and Park, B. *Development and Testing of Variable Speed Limit Control Logics for Work Zones Using Simulation*. Center for Transportation Studies, University of Virginia, Charlottesville, 2004.
c. Tignor, S.C. *Innovative Traffic Control Technology and Practice in Europe.* Federal Highway Administration, Office of International Programs, Washington, D.C., 1999.
d. Hegvi, A., De Schutter, B., and Hellendoorn, J. Optimal Coordination of Variable Speed Limits to Suppress Shock Waves. In *Transportation Research Record, Journal of the Transportation Research Board, No. 1852. T*ransportation Research Board, Washington, D.C., 2003, pp. 167-174.
e. Fontaine, M.D., and Edara, P.K. *Assessing the Benefits of Smart Work Zone Systems. In TRB 86th Annual Meeting Compendium of Papers CD-ROM.* Transportation Research Board, Washington, D.C., 2007.
f. Lee, C., Saccomanno, F., and Hellinga, B. Assessing Safety Benefits of Variable Speed Limits. In *Transportation Research Record, Journal of the Transportation Research Board, No. 1897.* Transportation Research Board, Washington, D.C., 2004, pp. 183-190.
g. HNTB. *Task 1 Report: I-66 Next Generation Shoulder Lane Control System Feasibility Review and Alternative Analysis.* ITS/Systems Operations On-Call Contract (Northern Virginia 105-CS), Task Order 10. Prepared for [Virginia Department of Transportation] Northern Region Operations Planning and Programming. Unpublished Report. May 6, 2008.
h. Lin, P.-W., Kang, K.-P., and Chang, G.-L. *Exploring the Effectiveness of Variable Speed Limit Controls on Highway Work-Zone Operations*. University of Maryland, Department of Civil Engineering, College Park, 2004. http://www.informaworld.com/smpp/content?content=10.1080/15472450490492851.

Many studies in the literature confirm that the implementation of HOV lanes resulted in travel time savings and more predictable travel times. For example, in the Washington D.C. region, there were three interstate HOV lane corridors in operation (42). One of them was the I-395 corridor, a 28-mile-long reversible HOV lane with an average of 10,400 person trips per day and a carrying capacity of 2,800 vehicles during the morning peak. Reported travel time savings on the facility due to HOV operation are approximately 31 minutes for morning peak periods and 36 minutes for evening peak (9). The other HOV facilities in the region are on the I-66 and I-270 corridors. Travel time savings for these facilities range from 5 to 12 minutes on I-270 and from 17 to 28 minutes on I-66 (42).

Studies also show an increase in the person-carrying ability of HOV lanes. For example, according to a study done by the Texas Transportation Institute at the Texas A&M University, by implementing a barrier-separated contra flow HOV lane on I-30 and buffer-separated concurrent flow HOV lanes on I-35E North and I-635 freeways, in the Dallas area, person trips were increased by 14% in these corridors. The HOV lane also carried twice the number of people compared to an adjacent general-purpose lane during the peak period, partly due to the fact that several bus routes utilize the I-30 HOV lane. Automobile occupancy was also increased from % to 12% while the average automobile occupancy on that route, without an HOV lane, has decreased by 2% (36).

Another example of successful use of HOV lanes comes from Boston, MA which implemented a reversible, barrier-separated HOV lane on the I-93/Southeast Expressway and a southbound, buffer-separated lane on I-93 North. Before 1999, an average daily traffic of 3,500 HOVs per lane was carried on lanes in the Boston Metropolitan region. This volume increased to a daily average of 8,700 high-occupancy vehicles per lane between 2001 and 2003. According to an occupancy count survey conducted by the Central Transportation Planning staff in 2003, 21,142 vehicles traveled northbound on the I-93/Southeast Expressway in the four general-purpose lanes with an average of 1.11 occupants per vehicle, while 4,193 vehicles traveled in the HOV lane with an average of 2.97 occupants per vehicle, between 6:00 AM and 10:00 AM (41).

A 1994 study in Minneapolis, MN, found that the HOV lanes average vehicle occupancy for AM peak period carpool, vanpool, and bus use lanes along I-394 was 3.28, more than triple that of the general purpose lanes (average vehicle occupancy of 1.01) (15). The facility is an 11-mile-long corridor with two general purpose lanes in each direction, three miles of two-lane, reversible, barrier-separated HOV lanes, eight miles of concurrent flow HOV lanes, park-and-ride lots, expanded bus service, and three parking garages on the edge of downtown Minneapolis.

Other successful HOV implementation projects are found in Atlanta, GA, Los Angeles, CA, and Seattle, WA. HOV lanes in the metro Atlanta were opened in 1994 along an 18-mile section of I-20, east of I-75/85. In 1996, 60 lane miles were added on 75/85 inside I-285 to reduce air-pollution and traffic congestion, and to provide time savings (10). Another addition was made on I-85 in 2004. According to a Fact Sheet prepared by the Atlanta Regional Commission in November 2006, the Atlanta region currently has over 90 miles of HOV lanes on I-20, I-75, and I-85. In 2005, HOV lanes were used by more than 28,000 commuters, 8% greater than the 2004 usage. Plans are currently in place to expand the HOV lane system over the next 20 years (2).

Los Angeles County has an impressive system of HOV facilities, with 14 HOV corridors covering over 425 HOV lane-miles and serving an average of 1,200 vehicles or 3,100 people per hour during peak periods, or approximately 233,000 vehicle trips and 529,000 person trips per day. It is predicted that the Los Angeles County HOV system will serve more than one million person-trips each day by the year 2015 (39).

Washington State has implemented approximately 200 lane-miles of a planned 300 miles of freeway HOV lanes and ramps since 1970. Today, HOV facilities in Seattle, WA, move more than 100,000 persons per day (9). HOV facilities are on I-5, I-90 (east of I-405), I-90 (west of I-405), I-405, SR 167, SR 520 (east of I-405), and SR 520 (west of I-405) corridors. All corridors have direct access ramps 24 hours a day. With respect to operations, the I-5, I-90 (west of I-405), and SR 520 (west of I-405) corridors operate 24 hours a day, while the rest operate 5 AM - 7 PM. The HOV facility on SR 520 (west of I-405) requires 3+ persons per vehicle (20). Among the concurrent flow HOV lanes throughout the U.S., the I-5 facility carries the second largest number of bus riders in the AM peak period (15).

2.2.3 Temporary Shoulder Lanes

2.2.3.1 Implementation in Germany

Germany's temporary hard shoulder use strategy was introduced during the 1990s. The first deployment was in December 1996 on the A4 near Cologne, which is the fourth largest city in Germany (3). Temporary hard shoulder use was permitted only when speed harmonization was active and speed limits were reduced. In 2007 about 200 km of temporary shoulder was developed by the German Federal Ministry of Transport and operated in various locations (40). Figure 6 shows a German site where temporary shoulder lane use is implemented. The signs indicate that travel on the shoulder is permitted and that travel speed is reduced during the operation.

When overhead gantries are not present, the sign shown in Figure 7 is used. The sign indicates that travel on the shoulder is permitted and that the travel speed is 120 km/h. This sign remains blank when travel on the shoulder is not permitted (24).

Additional technologies deployed with temporary shoulders help mitigate adverse safety consequences. At the German implementation sites, these include overhead gantries with speed limit displays, dynamic direction signing, video cameras, and CCTVs to make sure that the shoulder is not blocked by any vehicles. A traffic management center is of vital importance for deployment and monitoring of temporary shoulder use.

Studies confirm that the implementation of temporary shoulder lanes when speed harmonization is active increases the throughput (24).

Figure 6. Right shoulder use with speed harmonization – Germany (16).

Figure 7. Sign that informs drivers about speed limit indication and shoulder lane use (24).

Figure 8 shows the speed-volume relationship resulting from the use of speed harmonization with the use of the temporary shoulder lane (24). The figure shows that increasing the speed leads to a decrease in traffic volume, while limiting the speed to 100 km/h with the addition of a

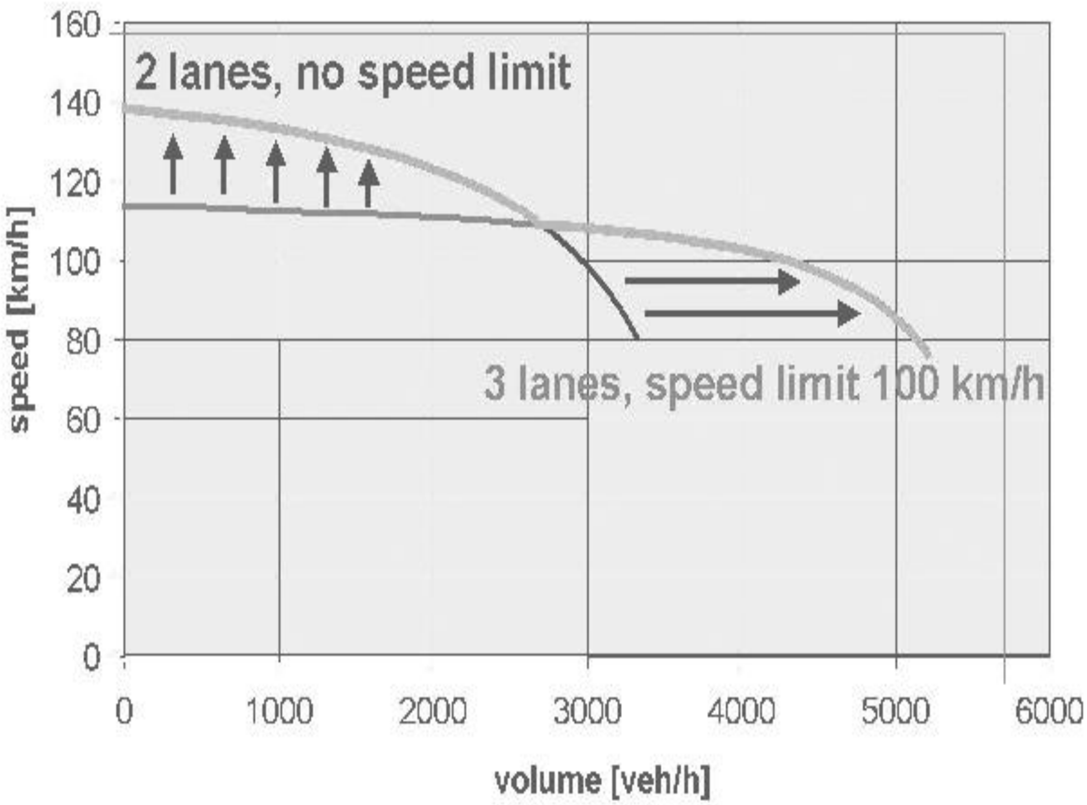

Figure 8. Speed-volume relationship of temporary shoulder use in Germany (24).

temporary shoulder lane results in an increase in traffic volume to 3,000 veh/h. Decreasing the speed to 80 km/h through speed harmonization strategies leads to an increase of traffic throughput to over 5,000 veh/h.

A Traffic Centre Hessen study that evaluated temporary hard shoulder use reported that releasing the hard shoulder increases the capacity of the standard three-lane motorway sections by 20% (30). This permits traffic volumes of over 7,000 vehicles per hour without traffic breakdown. Evaluations of the section of the A5 between the Frankfurt NW intersection and the Friedberg junction revealed that temporary hard shoulder usage saves congestion-related losses of approximately 3,200 vehicles per hour. Using time-cost rates, this means economic benefits from time losses avoided amounts to 50,000 euro per day or over 10 million euro per year. Not included in this calculation are the additional benefits created by minimizing environmental damage from exhaust and noise emissions due to the more steady traffic flow. The extent of the positive effect of temporary hard shoulder release on traffic flow is demonstrated when occasional vehicle breakdowns or accidents interrupt or prevent the release of the hard shoulder; in these cases, kilometers of congestion can occur.

In 2009, Germany demonstrated an innovative traffic regulation system along a 5.2-kilometer section of A73 (32). The system provides an on-line, video-monitored capability for opening temporary shoulder lanes and is Germany's second implementation site. With this system, the Bavarian Ministry of the Interior seeks to lessen the traffic load on this stretch of motorway, which is known for its morning peak period congestion. Since the first deployment, which was equipped with the same technology in January 2008, the situation has considerably improved. Both the risk of congestion, and the number of accidents are now significantly reduced.

The system is based on a video-based automatic incident detection system from Siemens, a first in traffic engineering. Without delay, the system detects any accident or broken-down vehicle, even in darkness or under extreme weather conditions, and immediately blocks the lane. Simultaneously, the detection function makes it easier for the operator in the traffic control and operations center in Nuremberg-Fischbach to check, prior to opening the shoulder lane, it if can be used in its entirety. The speed limit required in case of shoulder lane use is displayed on the eight overhead sign gantries installed in the second section (Figure 9). These gantries are part of the higher-level motorway control system and equipped with a total of 41 variable message signs, eleven lateral prismatic displays and two dynamic overhead direction signs (32).

Figure 9. Temporary shoulder lane coupled with an automated incident detection system - Germany (32).

To assist in the selection of proper implementation locations for temporary shoulder lane deployments and to identify the best strategy (i.e., permanent, temporary, with speed harmonization), Germany's Federal Highway Research Institute (BASt) developed a software package. The software conducts an economic assessment of the implementation of the different hard shoulder use strategies (24). This software calculates the benefits and cost of using the hard shoulder to determine the effectiveness and possibility of implementation (5). The software considers capital cost, operation cost, traffic safety and incidents, speed and travel time, emissions, and maintenance cost.

2.2.3.2 Implementation in England

In an effort to address congestion in a systematic and cost-effective manner, the transportation authorities in England implemented a pilot ATM strategy on the M42 motorway in the West Midlands southeast of Birmingham. (Figure 10). On September 12, 2006, motorists on the M42 were England's first to drive on the hard shoulder during busy periods as part of a scheme to cut congestion without building additional lanes.

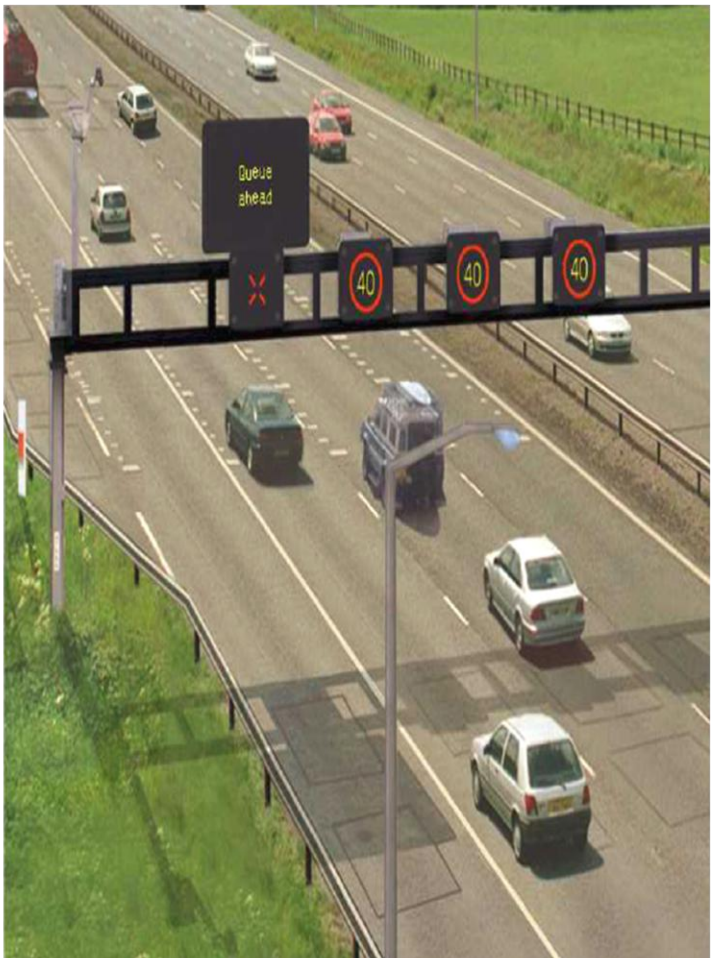

Figure 10. ATM- M42 – Birmingham, England (37).

Installation of the first scheme began in November 2004 and involved the introduction of technologies to enable variable speed limits application. The ATM final stage included temporary shoulder lane use along M42 between junction 3A for the M40 motorway and junction 7 for the M6 motorway, a distance of 12 miles (19 km). This part of the motorway carries 120,000 vehicles per day, composed of long distance traffic, local traffic, Birmingham International Airport travelers and visitors to the National Exhibition Centre (NEC). This segment also has as a higher number of accidents than the national average (13).

Safety was of critical importance during the design of the scheme, and emergency refuge areas were provided at regular intervals to provide motorists with a safe place to stop away from the traffic in the event of vehicle problems. These refuge areas are linked by telephone and CCTV cameras to the nearby regional control center, as shown in Figure 11.

Figure 11. Emergency refuge area and call boxes – England (16).

The Highways Agency also worked closely with emergency services to provide them easy access to the motorway in the event of an incident. Highways Agency control room staffers have access to over 200 cameras on the 11-mile stretch, allowing them to easily spot an incident as it occurs. They can then close individual lane(s) by putting a red ‘X’ on the electronic signs above the lane(s) affected to protect the vehicles involved in the incident as well as clear lanes to allow emergency vehicle access.

2.2.3.2.1 Scheme Description and Technology Requirements

The section of the roadway subject to ATM is monitored by Motorway Incident Detection and Automatic Signaling sensor loops placed in the road every 100 m (328 ft) to observe traffic flows. A computerized system monitors the traffic flows and can dynamically set the best speed limit for the current flow of traffic and switch on speed limit signs mounted on gantries up to 2 km (1.24 miles) before an incident (Figure 12). Operators can also monitor 150 CCTV cameras along the route and can control both the speed limits and information signs. Overhead variable message signs are used to direct drivers to use the hard shoulder during busy periods.

Figure 12. M42 speed harmonization and hard shoulder lane (13).

When the speed limit is lowered to 80 km/h (50 mph) or below, the hard shoulder can be opened as an additional lane. To facilitate this and still maintain safety, refuge areas have been created approximately every 500 m (1,640 ft) along that stretch of the road. These are located on the side of the hard shoulder and contain emergency phones. In the event of a vehicle breaking down on the hard shoulder, operators can close the shoulder lane or they can close another lane to allow emergency services to access an incident. The hard shoulder is never opened on the sections under a junction between the off and on ramps. Close to junctions, use of the hard shoulder as a lane is restricted to traffic exiting or entering at that junction (14).

The system utilizes automatic number plate recognition cameras that monitor traffic flows. Digital enforcement cameras are also mounted on gantries and operated by police to enforce the mandatory variable speed limits. As reported by the U.K. Highways Agency, the completed system includes installation and use of the following technologies:

- Lightweight gantries
- Lane control signals
- Dynamic speed limit signals
- Dynamic message signs
- Digital enforcement technology
- CCTV cameras
- Enhanced lighting
- Roadway sensors
- Emergency roadside telephones
- Hard shoulder running
- Emergency refuge areas

2.2.3.2.2 Deployment Assessment

The UK scheme was initially criticized for exposing people to potentially higher risks in the event of a breakdown or emergency. Environmental campaigners also argued that the scheme would not reduce the environmental impacts of automobile use. The government was also criticized for introducing the scheme as a cheaper alternative to proper widening. However, follow-up studies have proven the concept to be very effective, both from the operational and financial perspectives, and the strategy to be a great success.

The Highways Agency report into the first 6 months of the scheme showed a reduction in travel times of up to 25% (13). The travel time statistics show that northbound journey times were reduced by 26%, equating to an average reduction of four minutes as compared to the period when the variable speed limits were on but the hard shoulder was not being used, and 9% southbound (equating to one minute) during the afternoon peak hour. The report also indicated a fall in the number of accidents from over 5 a month to 1.5 per month on average. The Agency stated that normally accident statistics should be compared over a three-year period, so the initial results should be treated with caution. They also stated that no accidents had been caused by hard shoulder use as a normal lane.

Additional benefits from the ATM strategy implementation were cited in the report, including a 10% fall in pollution and 4% fall in fuel consumption. The report also indicated a compliance rate of 98% to the indicated speed limits when using the hard shoulder. As far as public acceptance is concerned, the Highways Agency surveyed drivers soon after implementation, who stated that 84% felt confident using the hard shoulder, 68% felt better informed about traffic conditions, and that around 66% wanted the scheme expanding to other roads.

With respect to cost, and compared with road widening, ATM is significantly more cost effective. The cost for implementing the temporary shoulder lane use strategy along with speed harmonization requires an investment of £6 million per km, or five times less than widening the 1 km of the motorway by one lane. In addition, it would take approximately 10 years to implement a widening scheme as opposed to the two years required for temporary shoulder lane use deployment. Still the latter provides comparable benefits including increased capacity, reduced journey times, increased travel time reliability, lower emissions and lower fuel consumption.

Following the success of this pilot project, the U.K. Secretary of State for Transport has announced that the government is to introduce a similar ATM scheme onto two sections of the M6 by 2011 for £150 million. A further study into the use of the strategy on the M1, M4, M20, and M25 motorways was also announced.

2.2.3.3 Implementation in the Netherlands

The Netherlands, in addition to allowing temporary use of the right shoulder, deploys temporary use of the left shoulder under congested conditions. The left lane, or plus lane, is opened when traffic volumes reach levels that indicate congestion is growing. An example of implementation from the Netherlands is shown in Figure 13 (16).

Figure 13. Plus lane – The Netherlands (23).

The temporary right shoulder use, also referred to as hard shoulder running or peak period lane utilization, began back in 2003 as part of a larger program to improve the use of the existing infrastructure. As can be seen in Figure 14 and Figure 15, a gantry with lane control signals indicates clearly whether the shoulder is available for use.

Figure 14. Closed shoulder lane (12).

Figure 15. Open shoulder lane (12).

Evaluating the implementation of temporary shoulder use, the overall capacity increased by 7% to 22%, travel times decreased by one to tjree minutes, and traffic volumes increased up to 7% during congested periods and depending on usage level (38). In addition, the Dutch have seen a reduction in incident levels on different motorways with temporary shoulder use.

Figure 16 shows the reduction in accidents after the deployment of shoulder lanes in four different locations. Accident rates before the shoulder lane implementation are shown for comparison. As in Germany, temporary use of the left lane is allowed only when speed

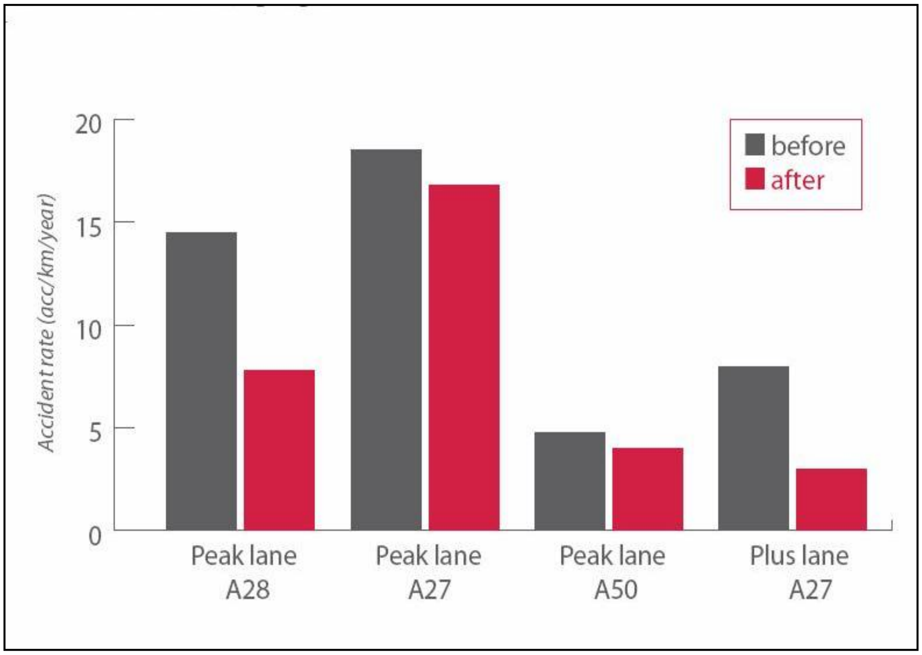

Figure 16. Incident reductions for Dutch temporary shoulder use (24).

harmonization is in effect. Additional facilities implemented to mitigate any adverse safety consequences of temporary shoulder use include overhead lane signs, emergency refuge areas with automatic vehicle detection, speed reduction, variable route signs at junctions, advanced incident detection, CCTV surveillance, incident management, and public lighting (12).

2.2.3.4 Implementation in Virginia and Washington, D.C.

The right shoulder lane of I-66 through Virginia and Washington, D.C., is used as an additional lane to accommodate more volume during the peak hour. This arrangement provides three unrestricted travel lanes during the periods when the left (median) lane is converted to HOV use.

Observation and experience shows that the number of accidents does not significantly increase and the drivers were not confused in this area. Anecdotal evidence also suggests that the driving public has been supportive of the treatment, and very few complaints have been received. Interestingly, VDOT has received complaints when the shoulder lanes were not opened during off-peak periods, when capacity-restricting incidents occur in the other regular traffic lanes. For this reason, VDOT maintains a flexible operating policy that allows them to activate the shoulder traffic lane as an incident management tool to increase the segment capacity when conditions warrant their use (28).

2.2.3.4.1 Deployment Assessment

A study was performed in Virginia to review the operational safety of the newly implemented shoulder and HOV lanes and to discuss the most efficient usage of signs and control devices in order to provide safety and convenience to the users (44). The study found that overall most commuters perceive the eight-mile stretch of I-66 that operated the temporary shoulder lane to be safe. In comparison with other major highways in the area, about one-fifth felt I-66 between the Capitol Beltway and Route 50 during peak periods was "more safe", while 48% felt it was as safe as other major highways.

Moreover, the study concluded that most commuters understood shoulder lane restrictions. A very high percentage of commuters said the red "X" indicated "the lane is closed to traffic" (93%), and 6% said it indicates "emergency stopping only." On the other hand, a sizeable group of commuters did not know what the penalty was for using the shoulder lane illegally. Nearly two out of three commuters (65%) were aware that driving in the shoulder lane illegally was a moving violation punishable by a $44 fine and up to three points on their driving record, but 34% were not aware of the penalty.

Most of the commuters suggested the installation of reflective pavement markers and stripes to indicate where drivers could enter the shoulder and begin exiting I-66. Additionally they recommended more law enforcement of shoulder lane violators by the state police as well as providing more information to the users on how to use I-66 on that specific eight-mile stretch (44).

2.2.3.5 Implementation in Washington

The WSDOT is currently embarking on a $42 million federally-funded program that includes installation of electronic signs and sign bridges on SR 520 and I-90 as part of an ATM initiative. The project is financed through the FHWA Urban Partnership, which is a partnership between WSDOT, King County, and the Puget Sound Regional Council (PSRC) (46).

WSDOT crews plan to install a series of electronic speed-limit and lane status signs over each lane on the SR 520 and I-90 bridges over Lake Washington. They include the following:

- 19 sign locations along SR 520 between I-5 and 130th Ave NE in Bellevue. This includes new sign bridges and signs mounted on existing structures.
- 25 sign locations along I-90 between I-5 and 150th Avenue SE. This also includes new sign bridges and signs mounted on existing structures.

The new signs will post variable speed limits that will warn drivers of backups ahead and smooth out traffic as it approaches a lane block incident. The overhead signs also can quickly close entire lanes and provide warning information to drivers before they reach slower traffic. This advance notification and variable speed limits will help reduce collisions that cause backups and stop-and-go traffic. Installing ATM signs on SR 520 and I-90 is expected to help reduce congestion-related collisions and smooth out traffic. The project is scheduled to begin in April 2009 and be completed by 2011 (46).

3 U.S. State-of-the-Practice Review

The study team contacted system managers from several state transportation agencies to discuss current Active Traffic Management initiatives in the U.S. and identify potential implementation issues. Though ATM is still in its infancy in the U.S., the study team did identify four state agencies that have either implemented or are in the process of implementing ATM projects in their highways systems:

- Virginia DOT (VDOT)
- Minnesota DOT (MnDOT)
- Washington State DOT (WSDOT)
- California DOT (CalTrans)

A summary of current ATM initiatives in each state follows.

3.1 Virginia DOT (VDOT)

The Virginia DOT has several ATM projects either in operation or in the planning stages. All of the current programs are located in the Northern Virginia/Washington, D.C. area. They include the use of shoulder lanes, variable speed limits, and the construction of HOT lanes in the I-495 corridor.

VDOT currently has a shoulder lane use program in operation in the I-66 corridor. Historically the shoulder lanes have been used only during strictly defined AM and PM peak periods, regardless of traffic conditions, and only in the peak direction. Recently, however, VDOT has extended the use of shoulder lanes to 5:30 – 11:00 in the morning and 2:00 – 8:00 in the afternoon to handle growing traffic congestion. More importantly, VDOT has also begun to allow shoulder lane use during major incidents or when construction causes lanes to be closed. This has effectively made the shoulder use program an ATM strategy. VDOT currently does not use other ATM strategies, such as variable speed limits, with the shoulder lane program. It should also be noted that the decision to make shoulder lanes available during non-peak times required FHWA approval.

VDOT does use variable speed limits (VSL) as part of the Woodrow Wilson Bridge project on I-95/495. The variable speed limit signs have been used primarily to reduce vehicle speeds, improve traffic flow, and improve safety during periods of construction. The system is active on a seven-mile segment of the I-95/495 corridor just west of the Wilson Bridge. The system has been successful enough that in May 2009, VDOT decided to extend the use of the VSL system to the AM and PM peak periods, when it functions as a speed harmonization system. VDOT is currently collecting data on its effectiveness.

Another planned ATM initiative is the construction of HOT lanes on I-459 and I-95. While traditional HOV-3 vehicles and motorcycles will be able to use the lanes for free, non-HOV vehicles will be able to pay to use the lanes. Lane usage fees will vary depending on demand and road conditions. Project construction has begun on the I-459 project but operation is not anticipated until 2013.

Discussions with VDOT staff indicated a commitment to implement ATM strategies. At this point, the major obstacle to implementation is seen as funding. ATM measures require extensive infrastructure for surveillance and traffic control; implementation of ATM strategies can therefore be quite costly and funding is not available for a larger program at this point. Nonetheless, reactions to initial projects have been positive.

Implementation issues to this point have been seen as manageable. VDOT has monitored traffic operations in the I-66 corridor to ensure that the use of shoulder lanes has not reduced safety. To date their experience has been similar to that of other agencies that have implemented shoulder lane programs, which have found minimal impacts to safety. VDOT staff indicated that new ATM programs will be monitored extensively to ensure that they are producing cost effective results.

3.2 Washington State DOT (WSDOT)

The Washington State DOT currently has two ATM projects in the construction stages: the SR 520/I-90 ATM Project and the I-5 Variable Speed Safety Project. The SR 520/I-90 project is installing variable speed signs and lane control signals on the SR 520 and I-90 bridges over Lake Washington in Seattle. The goal is to improve speed control and better cope with incidents during the reconstruction of the SR 520 floating bridge. The I-5 project will install variable speed limit and lane control signs on the northbound lanes of I-5 approaching Seattle. This will be a speed harmonization system that will automatically adjust speed limits based on prevailing traffic conditions to optimize throughput and safety. Both systems should be operational in 2010/2011.

The WSDOT is treating these two projects as the beginning of a broader ATM program and the outcomes will be closely monitored. At present, funding is seen as one of the major obstacles to the expansion of this program. Both current ATM projects have unique funding sources: the I-5 project is being funded as part of a mitigation plan for the reconstruction of the downtown Seattle viaduct. The SR 520/I-90 project is being funded under an FHWA Urban Partnership agreement and is tied to the replacement of the SR 520 bridge across Lake Washington. As yet, there is no specific funding for additional ATM efforts.

The costs for each program are averaging about $4.0 million per mile, with lane control sign structures located approximately every ½ mile. WSDOT staff did not identify any substantial implementation issues with either project, although because both are the first of their kind in the state they will be monitored very closely.

3.3 Minnesota DOT (MnDOT)

The Minnesota DOT has one major ATM project currently under development. The I-35W project will convert/construct HOT lanes on a 14-mile segment of I-35W near Minneapolis. Part of this effort will require the implementation of a shoulder lane use program on the last two mile segment into Minneapolis. The shoulder lanes will be used only during peak hours and will require a toll, which can be varied based on prevailing traffic conditions. Overhead lane control signing will be placed approximately every half mile and speed advisories will be conveyed via standard CMS message signs. The project is expected to be opened to the public in fall 2009.

The MnDOT had to obtain legislative approval to implement a shoulder use program for I-35W. This will be the first shoulder lane use program in the state for passenger vehicles, although MnDOT has already implemented extensive shoulder use programs for transit vehicles. The experience with transit shoulder use has been excellent and helped with public education about the project, because motorists are already familiar with seeing shoulder use during peak periods. The program is being funded under an FHWA urban partnership agreement.

Minnesota is also viewing this project as the first of a possibly broader ATM program. MnDOT staff indicated that the program will be monitored extensively when opened and that results will be used to assess the feasibility of future projects.

3.4 California DOT (CalTrans)

CalTrans was contacted to assess the status of ATM in the state. CalTrans staff said that there are currently no ATM projects active within the state, although the first is in the planning stages for Alameda County and the Bay Area. The I-80 Integrated Corridor Mobility (ICM) Project will incorporate several ATM strategies, namely adaptive ramp metering, variable speed limits (speed harmonization), and adaptive lane controls. These strategies will be combined to regulate the flow of traffic in the I-80 corridor in order to maximize throughput, minimize incidents, and better handle incidents when they occur.

CalTrans staff said there is currently no long-term ATM plan beyond the current I-80 project and that the state's current financial problems are a limiting factor in that regard. Staff did indicate, however, that they felt ATM would become more important in state planning in the future. One of the primary areas of focus for managing congestion in the future will be HOV/HOT lanes and those will likely require extensive shoulder use programs to be feasible. CalTrans staff indicated that ATM would have to be an integral part of such programs. Staff also indicated that the state has interest in testing speed harmonization in the future, although there are no firm plans in the works.

3.5 Summary

Active Traffic Management is still in initial development in this country; consequently, there are very few ATM projects in operation and very little data available. The interviews indicate that there is interest in implementing ATM strategies in this country but the initial deployments will be limited. The primary implementation issues identified were:

1. Funding. All state representatives interviewed said that available funding was a limiting factor in their decisions to develop ATM programs. Only a few projects have been initiated and most of the ones that are have unique funding sources (e.g., they are mitigation measures tied to a larger highway project). The infrastructure required for ATM strategies can be extensive so funding is an ongoing concern.
2. Legal. Although all agencies interviewed were able to obtain the legal and legislative clearances needed, some ATM strategies, such as shoulder lane use, raise questions about public safety that will need to be addressed at a local level.
3. Public Education. ATM strategies will require efforts to educate the public about their proper use, because many of the strategies are new to this country. VDOT, for example, has developed a public education campaign for the variable speed limit system at the I-459 Wilson Bridge Project. The campaign includes advertisements and a website explaining the purpose and function of the system. Because so few ATM projects have been implemented, an assessment of the best public education strategies would prove useful.

In general, the states interviewed did not see major technical hurdles to implementing ATM strategies. The technology, for the most part, is viewed as having been proven either in isolated ITS applications or in European ATM applications. The most likely initial applications of ATM technologies seemed to include:

- Shoulder lane use
- Speed harmonization
- Adaptive lane controls
- HOT lanes

3.6 Interviewees:

Minnesota DOT:	Mr. Ken Buckeye
Virginia DOT:	Ms. Connie Sorrell
	Mr. Gummada Murthy
	Mr. Ling Li
Washington State DOT:	Mr. Ted Trepanier
CalTrans:	Mr. John Wolf

4 Study Methodology

4.1 Background

ATM strategies present an exciting new opportunity as a tool to address recurring congestion issues in urban areas in Alabama. In 2003, 9.7 million person-hours were wasted in Birmingham alone due to congestion. This translates to a cost of congestion amounting to $165 million dollars, or three times the figure reported a decade ago ($53 million in 1993). The *2007 Urban Mobility Study* by the Texas Transportation Institute listed Birmingham as a medium-sized urban area with higher congestion and a faster increase in urban congestion than its counterparts (19).

Given the fact that capacity expansion through construction of new facilities is neither a desirable nor economically viable option, an opportunity presents itself to investigate innovative approaches that utilize existing roadway capacity in Birmingham in a more effective way. Drawing from the European experience and with input from the few available U.S. studies, a study procedure was developed and implemented in order to assess the feasibility of temporary shoulder lane use as a strategy to reduce congestion in the Birmingham region. This included the following steps:

- Identification of candidate corridors
- Preliminary assessment of implementation potential
- Quantitative evaluation of operational impacts from implementation
- Estimation of benefits and costs

Details on the approach followed in each step of the shoulder lane feasibility are discussed next.

4.1.1 Identification of Candidate Corridors

Using engineering judgment and input from local transportation agencies, we identified corridors that presented a need and opportunity for implementation of ATM techniques within the Birmingham region. In particular, we focused on interstate corridors in Birmingham that would make good candidates for temporary shoulder lane testing (with or without speed harmonization).

4.1.2 Preliminary Assessment of Implementation Potential

We performed a preliminary assessment of temporary shoulder lane use implementation based on level of service (LOS), and physical characteristics and geometric restrictions. We prioritized corridors for further analysis based on their likelihood to benefit from potential ATM strategies. We selected a 12.5-mile segment of the I-65 corridor from Valleydale Road to I-20/59 as a high-priority corridor for further analysis. Based on traffic counts reported by the Alabama Department of Transportation (ALDOT), the 2005 daily traffic volumes along this segment of I-65 ranged from 75,000 to 125,000 with a 10% truck volume. Table 2 summarizes the operational characteristics of the study segment based on local studies performed in 2005 and 2006 (31).

Table 2. LOS along I-65 Corridor-NB Direction (31)

Segments	LOS	v/c Ratio
Valleydale Road to I-459	F	1.55
I-459 to US 31	E	0.99
US 31 to Alford Ave	F	1.47
Alford Ave to Lakeshore Dr	F	1.47
Lakeshore Dr to Oxmoor Rd	F	1.42
Oxmoor Rd to Greensprings Ave	F	1.50
Greensprings Ave to University Blvd	F	1.26
University Blvd to 3rd-4th Ave S	D	0.84
3rd-4th Ave S to 3rd-6th Ave	C	0.67
From 3rd-6thAve to I-20/59	C	0.64

4.1.3 Quantitative Evaluation of Operational Impacts from Implementation

Simulation modeling was undertaken to analyze the impacts of a temporary shoulder lane use system on a subsection of the I-65 corridor extending from U.S. 31 to University Blvd, which corresponds to the portion of the study corridor that experiences the worst LOS. (See Table 2.)

The microscopic simulation model CORSIM was used to perform the analysis. CORSIM is one of the tools available within TSIS, a suite of simulation models developed by FHWA and used extensively by transportation agencies and practitioners in the U.S. and abroad for over three decades. The CORSIM simulator in TSIS can simulate traffic operations on integrated networks containing freeway and surface streets. The model has the ability to simulate fairly complex geometric conditions and realistic driver behavior after it is appropriately calibrated and validated. Moreover, the model offers the capability to analyze a variety of lane management strategies, a feature of importance for this case study (34).

The Birmingham case study considered the potential use of a shoulder lane in response to both recurring and non-recurring congestion. Key measures of effectiveness (MOEs) and resulting improvements in operational efficiency were obtained for several scenarios and used to assess operational impacts and determine the feasibility of implementation of the proposed strategy. Details on the simulation study design, scenarios considered and results are available in the next section.

4.1.4 Estimation of Benefits and Costs

Quantification of expected benefits and costs from deployment of temporary shoulder lanes along the I-65 corridor in Birmingham was also performed to estimate economic impacts from possible deployment and determine the most economically efficient investment alternative. The cost-benefit analysis considered life-cycle costs and life-cycle benefits of the project alternatives under study. The life-cycle costs include engineering, construction, and maintenance. Life-cycle benefits include savings in vehicle operation and travel time, safety, and emission reduction. Following the analysis, the costs and benefits were discounted on year-to-year basis and projected for the analysis period 2010 to 2020.

A description of the study site characteristics, the simulation model used in the analysis, and the scenarios tested follows.

4.2 Study Area

I-65 is a major North-South interstate freeway that goes through Birmingham. It extends from Gary, IN in the north to Mobile, AL in the south. I-65 is a major commuter route within the Birmingham metropolitan area. I-65 interchanges with I-20, I-59, and I-459 serve traffic with destinations to the east and west of the state.

Earlier studies confirm that traffic demand on portions of I-65 exceeds the existing design capacity of the corridor in the peak hours. This makes the daily commute inconvenient for the daily users. Additionally, the morning northbound peak hour on I-65 experiences unacceptable levels of service between I-459 and downtown Birmingham (29).

According to the Mobility Matters Project in Birmingham, the 2005 average daily traffic volumes on I-65 from Valleydale to I-20/59 range between 111,000 and 146,000 vehicles per day. This number is expected to range between 179,000 and 221,000 vehicles per day by 2030 (29). Based on the hourly traffic volumes collected by ALDOT along the I-65, the morning peak hour (which affects primarily the northbound direction) is more critical than the evening peak hour, that primarily affects southbound traffic (1).

The study area chosen to examine the implementation of temporary shoulder lane usage in this research study was northbound I-65 from the junction with I-459 to the University Blvd junction. The selected segment has three lanes and both left and right shoulders. Figure 17 shows the Google map for the selected segment with the exits marked along the interstate.

Figure 17. Google map for I-65 from I-459 to University Blvd junction (11).

4.2.1 Geometric Characteristics

In order to build a simulation model that represents real traffic conditions, geometric characteristics had to be accurately extracted and modeled. Table 3 shows the number of lanes, the lane widths, and the shoulder lane widths for all segments of I-65 within the study area. The data were obtained from aerial maps and by using Google Earth tools.

Table 3. Geometric Characteristics along the Study Area of I-65

Segment	Number of Lanes	Lane Width (ft)	Shoulder Lane Width (ft)	
			Left	Right
Valleydale Road to I-459	3	12.0	9.5	12.3
I-459 to US 31	4	12.0	9.5	12.5
US 31 to Alford Ave	3	12.0	12.0	12.5
Alford Ave to Lakeshore Dr	3	12.0	20.0	12.0
Lakeshore Dr to Oxmoor Rd	3	11.5	7.0	12.0
Oxmoor Rd to Green Springs Ave	3	12.0	13.0	8.0
Green Springs Ave to University Blvd	3	12.0	10.0	11.5

4.2.2 Traffic Volumes on I-65

ALDOT maintains one permanent traffic counter within the study section. This is counter ATR124 in Homewood (Figure 18). Historical traffic volume data were extracted from the ALDOT website and analyzed to gain a better understanding of trends (1).

Figure 18. ALDOT traffic counter locations (1).

Table 2 shows the volume-to-capacity ratio (v/c) for each segment, and the corresponding LOS. As can be noticed, the LOS for all segments varies from LOS E to LOS F, which indicates severe congestion. This observation confirms the need to perform research studies along this corridor in order to identify solutions with a potential to reduce congestion and improve the level of service in the short- and long-term future.

Table 4 shows the average hourly traffic volumes for sic days (from January 5th to January 10th 2009) at the Homewood traffic counter location. By analyzing the data (Table 4), it can be concluded that the volumes are fairly consistent, as compared to historical data. Moreover, it can be confirmed that northbound demand is more critical than southbound demand during the morning peak hours (6:30 AM to 8:30 AM).

Table 4. Average Hourly Traffic Volumes (vph) on I-65 at ATR124 in Homewood for Six Consecutive Days in January 2009 Versus Historical Counts

Time	North		South	
	Current	Historical	Current	Historical
0:00	558	573	546	579
1:00	343	367	370	442
2:00	302	288	328	356
3:00	262	291	333	375
4:00	484	519	474	511
5:00	1451	1439	1098	1116
6:00	3603	3591	2463	2574
7:00	5303	5064	3697	3745
8:00	4606	4311	3290	3250
9:00	3471	3480	2746	2965
10:00	3089	3102	2985	3090
11:00	3194	3203	3454	3586
12:00	3514	3568	3699	3817
13:00	3625	3743	3755	3776
14:00	3841	3882	4107	4150
15:00	3890	4074	4744	4870
16:00	4164	4318	5155	5152
17:00	3862	4065	4558	4686
18:00	3097	3211	3789	3762
19:00	2184	2378	2587	2771
20:00	1797	1944	1863	2135
21:00	1894	1985	1739	1868
22:00	1304	1435	1264	1383
23:00	1045	1064	932	985

Figure 19 shows the hourly distribution of the average traffic volumes for the six-day analysis period and the average historical northbound traffic volumes. From this distribution it can be concluded that there exist two peak periods in the day. The morning peak period is more critical, and therefore, this study focuses on the evaluation of network performance on the northbound direction before, during, and after the morning peak.

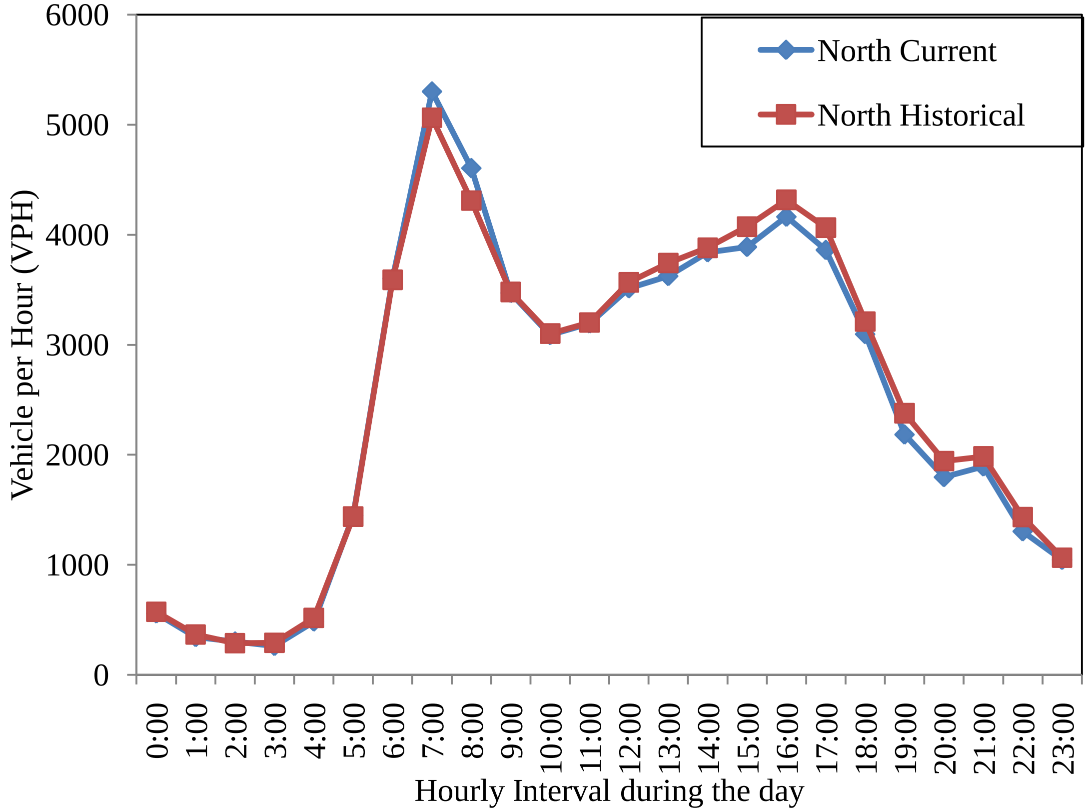

Figure 19. Distribution of average traffic volumes on I-65 at ATR124 in the northbound direction.

4.3 Simulation Model Selection

As stated earlier, the CORSIM microscopic simulation model was selected to examine the operational impacts of using shoulder lanes on the I-65 segment. TSIS-CORSIM is a well-known microscopic traffic simulation software package for simulation of freeway and arterial networks. TSIS includes a few sub-models for input development, simulation, and animation (22).

The CORSIM environment models transportation networks and driver behavior in detail and has the capability to run different types of traffic management and operation. CORSIM provides detailed output reports that summarize a variety of MOEs, such as speed, delay time, total travel time, volumes, and queue lengths. Additionally it gives information on environmental measurements, such as fuel usage and NO, HC, and CO emissions.

The animation module (TRAFU) is an important feature that allows the user to check the network state and observe the movement of vehicles on the traffic lanes. It should be noted that CORSIM is a stochastic model and provides the option to the user of changing the seed numbers when desirable in order to introduce randomness in the vehicle arrivals and represent actual traffic conditions in a more realistic manner (22).

4.4 Development of the I-65 Study Testbed

As mentioned before, the Birmingham study area was selected to examine the effectiveness of the use of the shoulder lane on northbound I-65 from I-459 to University Blvd. Figure 20 shows the I-65 study testbed that was built in CORSIM using the TSIS. The study network includes a total of 69 nodes and 68 links.

4.5 Data Analysis Scenarios

Study scenarios were developed and tested with the TSIS simulation model for a period of four hours of the day, from 5:30 AM to 9:30 AM, which includes the morning peak hour from 6:30 AM to 8:30 AM. The scenarios aimed at examining traffic operations along the study corridor with and without the use of temporary shoulder lanes under normal and incident traffic conditions. A detailed description of the scenarios considered follows.

4.5.1 Normal Traffic Condition Scenarios

Four scenarios were developed assuming normal traffic conditions to examine the efficiency of using temporary shoulder lanes to ease recurrent traffic congestion on the northbound I-65 corridor. In all four scenarios, the free flow speed was set to 60 mph.

The first scenario (Scenario 1) served as a baseline for comparisons and assumed that the network operates under normal conditions without the use of the shoulder lanes. The second scenario (Scenario 2) simulated the network with the utilization of the left shoulder as an additional lane from U.S. 31 to the end of the network. The shoulder lane was open during the entire simulation period and represented the case of an added lane.

The third scenario (Scenario 3) was similar to the second (i.e, left shoulder used from U.S. 31 to University Blvd); however, the temporary shoulder lane was available for use only in the morning peak hour (between 6:30 AM and 8:30 AM). Scenario 3 is a typical example of an ATM application where the temporary shoulder lane is used in response to congestion.

The fourth scenario (Scenario 4) simulated the network under normal conditions while opening a small portion (600 feet) of the right shoulder upstream of three exits for the total simulation time, namely Alford Ave (Exit 254), Lakeshore Pkwy (Exit 255), and Oxmoor Rd (Exit 256). This scenario tested the possibility of using the right shoulder as an additional exit lane in order to minimize the potential impact that long queues of exiting vehicles may have on traffic operations along the mainline. Table 5 provides a summary of scenarios considered as part of the incident case study.

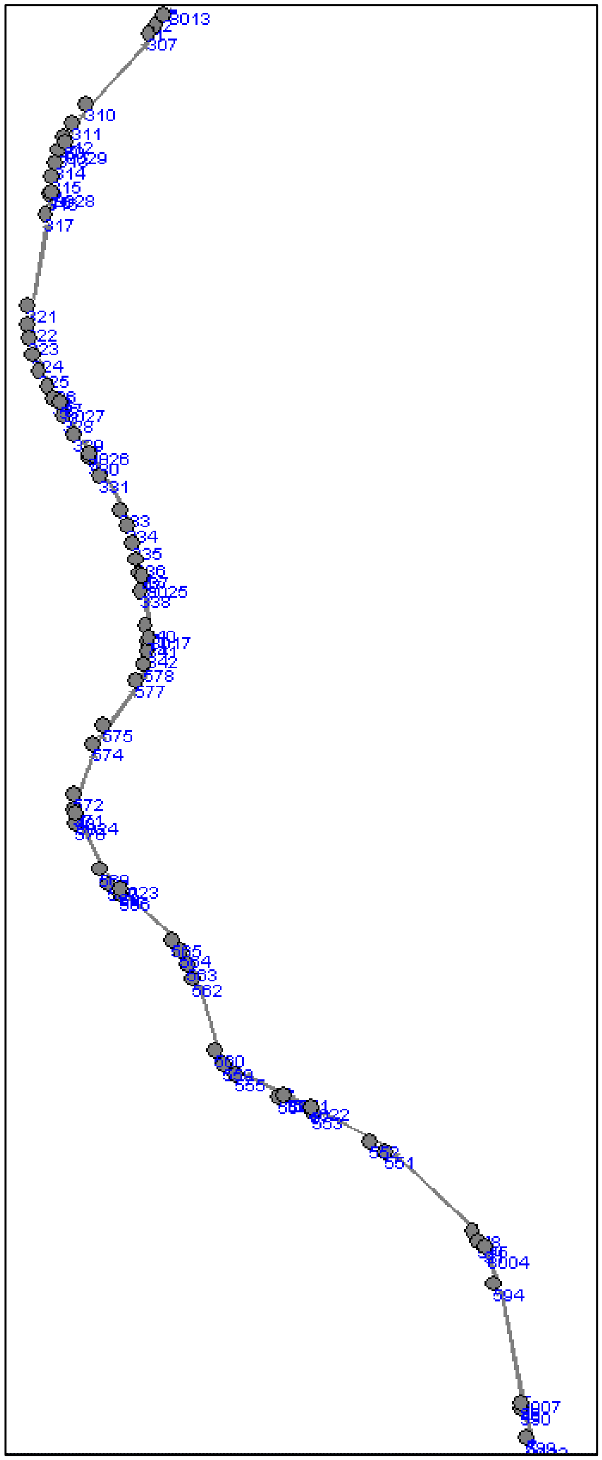

Figure 20. Model of the I-65 study network on TSIS.

Table 5. Summary of Normal Traffic Condition Scenarios

Scenarios	Description	Number of available lanes	Left shoulder lane in use (Duration)	Right shoulder lane in use (Duration)
1	No shoulder use	3	0 (5:30 AM to 9:30 AM)	0 (5:30 AM to 9:30 AM)
2	Continuous Left shoulder lane use	3	1 (5:30 AM to 9:30 AM)	0 (5:30 AM to 9:30 AM)
3	Continuous Left temporary shoulder lane use	3	1 (6:30 AM to 8:30 AM)	0 (5:30 AM to 9:30 AM)
4	Right shoulder lane use at exits	3	0 (5:30 AM to 9:30 AM)	1 (5:30 AM to 9:30 AM)

4.5.2 Incident Condition Scenarios

Three scenarios were developed on northbound I-65 in case of incident conditions to examine the efficiency of using temporary shoulder lanes in different incident cases. For practical purposes these were numbered consequently as Scenarios (5 through 7). All incident scenarios assumed that an incident occurred blocking the right lane of link (564,565) for one hr from 6:30 AM to 7:30 AM. The incident site is located roughly in the middle of the study network.

The fifth study scenario (Scenario 5) considered the presence of the incident and assumed that no actions were taken. This scenario serves as the incident case base line for comparison purposes (i.e., the do-nothing approach). Figure 21 shows a snapshot of the network analyzed in CORSIM under Scenario 5.

The sixth scenario (Scenario 6) simulated the network with the incident presence but assumed that vehicles were allowed to ride on the left shoulder lane downstream of the incident for one hour, i.e., from 6:30 AM to 7:30 AM, in an effort to minimize the impact of the incident on traffic operations (Figure 21 and Figure 22).

The last scenario considered (Scenario 7) is similar to Scenario 6, except for the fact that the left shoulder lane downstream the incident is open for use for two hours, i.e., from 6:30 AM to 8:30 AM, to further expedite the clearance of the incident and return to normal operations. Table 6 provides a summary of scenarios considered as part of the incident case study.

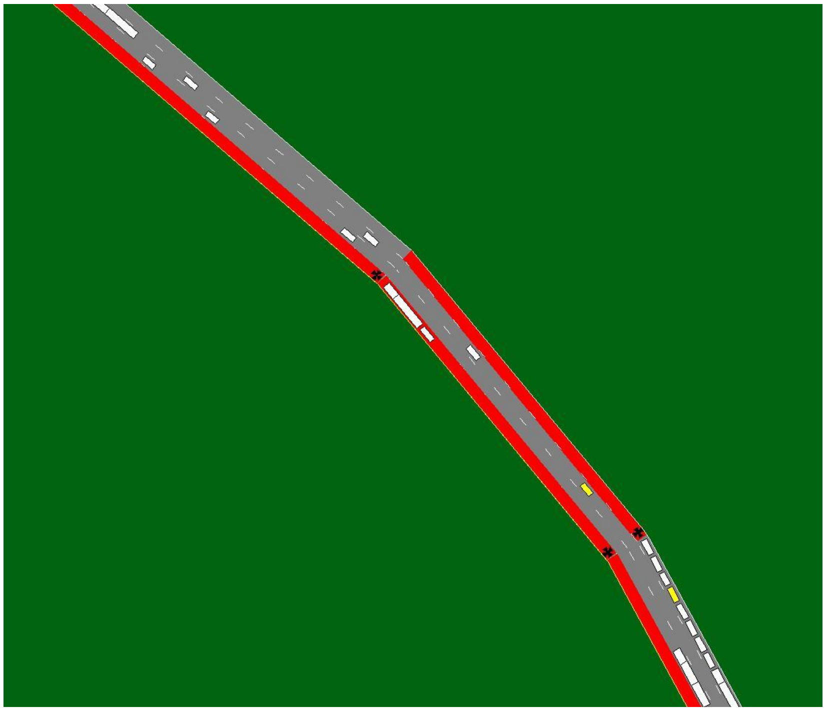

Figure 21. Incident on right lane, no shoulder use - Scenario 5.

Figure 22. Incident on right lane with temporary shoulder lane use downstream - Scenarios 6 and 7.

Table 6. Summary of Incident Condition Scenarios

Scenarios	Explanation	Number of available lanes	Left shoulder lane in use (Duration)
5	No shoulder use	3 or 2	0 (5:30 AM to 9:30 AM)
6	Continuous left temporary shoulder lane use downstream the incident	3 or 2	1 (6:30 AM to 7:30 AM)
7	Continuous left temporary shoulder lane use downstream the incident	3 or 2	1 (6:30 AM to 8:30 AM)

5 Traffic Impacts Analysis Results

5.1 Background

In this chapter, results from the traffic impact analysis performed in this research are presented. Five replications (runs) were performed for each of the seven study scenarios by selecting five different “seed numbers” and the results were averaged. For each seed, a random assignment of traffic demand takes place to introduce randomness typically associated with traffic patterns and ensure that the models are representing real traffic situations.

Simulations were run for a four-hrs period (from 5:30 AM to 9:30 AM). The simulation considered three time periods, the first time period from 5:30 AM to 6:30 AM, the second from 6:30 AM to 8:30 AM, and the last from 8:30 AM to 9:30 AM. The analysis was limited to the northbound direction that carries suburban and local traffic into the city of Birmingham during the morning peak.

5.2 Network-wide Results

The results presented in Table 7 are for the entire study corridor (i.e., network wide statistics) for the seven scenarios considered in the study. MOEs considered include the total travel time (hours), the total delay time (hours), the average travel speed (mile/hour), the delay time (hours), and the total time (hours). Analysis and interpretation of the results under normal - and incident conditions follows.

5.3 Scenarios with Normal Traffic Conditions – No Incidents

According to the findings in Table 7, the use of the left shoulder lane (Scenarios 2 and 3) results in considerable savings in travel time and delays as compared to the baseline (Scenario 1). As expected, the continuous availability of an extra lane (Scenario 2) results in the largest improvements, slashing total time by 42% (6,790 hrs in Scenario 1; 3,963 hrs in Scenario 2).

The temporary use of the NB shoulder lane for two hrs during the morning peak (Scenario 3) still shows a significant improvement over current conditions resulting in a reduction in the total network travel time by 34% and delay by 71% compared to the baseline (Scenario 1). Similar gains are observed in average speed where the 29.9 mph average network speed observed under regular conditions (Scenario 1) increases by 56% (from 29.9 mph to 46.6 mph) under the ATM operations, i.e., when the left shoulder lane is open during the peak period from 6:30 AM to 8:30

Table 7. Network-Wide Results for All Scenarios; Birmingham, AL Case Study

Scenario	1	2	3	4	5	6	7
Shoulder lane use	No Shoulder Lane	Left	Left; Peak only	Right; 3 exits	No	Left; 1hr	Left; 2 hrs
Traffic Conditions	Normal	Normal	Normal	Normal	Incident	Incident	Incident
Total Travel Time (hrs)	6,790	3,963	4,478	6,523	7,872	6,758	5,498
Total Delay Time (hrs)	3,394	446	991	3,127	4,598	3,337	1,963
Avg. Travel Speed (mph)	29.90	53.10	46.60	31.30	25.10	30.30	38.70
Delay Time (min/mi)	1.01	0.13	0.28	0.92	1.42	0.98	0.57
Total Time (min/mi)	2.01	1.13	1.29	1.93	2.43	1.99	1.57

AM. These results clearly indicate the excellent potential of temporary shoulder lane use as an ATM tool for addressing recurrent congestion along I-65. On the other hand, the use of the right northbound shoulder lane upstream of three exit locations (Scenario 4) shows a small positive impact and results in a small reduction in the total network travel (4%) time and delay (9%) over Scenario 1. A slight increase (5%) in average speed was also noticed (from 29.9 mph to 31.3 mph).

When comparing the two temporary lane options, i.e., continuous left lane shoulder versus right shoulder near exits, the former is clearly a winner, as the anticipated benefits clearly overshadow those expected from its short length, temporary, right shoulder use counterpart.

5.4 Scenarios with Incident Conditions

As anticipated, an incident blocking one general purpose traffic lane for one hour (Scenario 5) further degraded the performance of the study network. Compared to non-incident conditions (Scenario 1), the do-nothing approach under incident conditions resulted in a decrease in average speed of 16% (from 29.9 mph to 25.1 mph) and an average delay time increase of 41 % (from 1.01 min/mile to 1.42 min/mile).

The left shoulder lane downstream of the incident site was opened just for one hour following the onset of the incident (Scenario 6). Specifically, the simulation results show that the average network speed increased by 21% (from 25.1 mph to 30.3 mph), and the average delay time decreased by 31%, in Scenario 6 as compared to Scenario 5, resulting in a network performance comparable to non-incident conditions. As expected, the savings in travel time and delay further increase when the temporary shoulder lane remains in operation for an extra hour following incident removal (Scenario 7).

Overall, the network-wide results from the incident case study demonstrate the great potential operational benefits of the temporary shoulder lane use significantly as a traffic management in case of an incident.

5.5 Link-by-Link Scenario Results

In addition to considering network-wide MOEs, close attention was paid to link-by-link results. Table A7 to Table A27 in the Appendix present the detailed average link-by-link results from the average of the five seeds for each study scenario at the end of each time period. The first time period extends from 5:30 to 6:30 AM and represents pre-peak conditions; the second extends from 6:30 to 8:30 AM and refers to morning peak traffic conditions for the study network; and the third one covers the post-peak period from 8:30 to 9:30 AM.

The tabular results in the Appendix show the speed on each link (mile/hour), delay time (seconds/vehicle), and the delay difference between the subject Scenario (i.e., Scenarios 2 through 7) and the base case (Scenario 1). To assist in identifying the location of the various links in the CORSIM Birmingham network, Figure A1 to Figure A5 in the Appendix show the network links. Figure A1 shows the whole network, while Figure A2 to Figure A5 depict four zoom-in snapshots of the network links.

A sample of the link-by-link data is provided in Table 8 for two network links, namely (564, 565) and (571, 572). It can be seen that average speeds are fairly constant at the end of Period 1 for all scenarios with the exception of Scenario 2, where the presence of an extra lane (left shoulder lane use) results in an increase in average speed, as expected. It should be noted that the temporary shoulder lane use or the incident considered in the study do not start until later in the simulation, thus they do not impact traffic operations in Period 1.

When compared with results from Period 1, baseline average speeds (Scenario 1) obtained from the start of simulation at 5:30 AM to 8:30 AM are significantly lower due to oversaturated conditions experienced during the morning peak. Dramatic improvements in link travel times can be achieved during the same time period when the shoulder lanes are in operation. For link (564, 565), for example, average speed increases from 30.2 mph (Scenario 2) to 53.8 mph when a temporary left shoulder lane operates during the two hours of morning peak (Scenario 3), and to 35 mph for right turn shoulder lane use upstream of 3 exits (Scenario 4).

Figure 23 and Figure 24 show average speeds for all study links at the end of each time period under normal and incident conditions, respectively. One can observe the degrading of the speed at the end of the peak period (8:30 AM) in Scenario 1 in the majority of network links and clearly see that the network operates in nearly non-peak levels after the implementation of left shoulder use.

Table 8. Sample of Link-by-Link Average Speeds

	Scenario						
	1	2	3	4	5	6	7
Link	Average Speed at 6:30 AM (End of Period 1)						
(564,565)	49.0	57.1	49.4	49.0	48.9	49.0	49.0
(571,572)	35.1	46.9	34.8	35.2	35.3	32.1	32.1
	Average Speed at 8:30 AM (End of Period 2)						
(564,565)	30.2	57.1	53.8	35.0	18.9	52.3	31.7
(571,572)	19.3	56.4	50.2	21.2	21.9	44.2	40.9
	Average Speed at 9:30 AM (End of Period 3)						
(564,565)	29.2	55.9	54.4	33.8	26.4	27.7	50.7
(571,572)	21.0	46.8	39.1	22.0	24.2	22.5	34.0

Similar conclusions can be reached by considering the results reported in Table A2, Table A4, and Table A6 concerning changes in delays over time for each link of the study network under the different study scenarios. Figure 25 uses such data to illustrate the differences in delay gains at the end of the pre-peak time period (Period 1) and the peak period (Period 2). Compared to Scenario 1, negligible differences in delays are observed in Scenarios 2 and 3 early on in the simulation (6:30 AM), but as traffic increases during morning peak until 8:30 AM, all links experience significant improvements in delays when a shoulder lane is used, ranging from 20% to 100%. Moderate delay reductions can be also achieved for the majority of study links in the presence of a temporary right shoulder lane upstream of selected links.

While the results vary from link to link, the trends observed are fairly consistent and are in close agreement with the conclusions of the network-wide analysis.

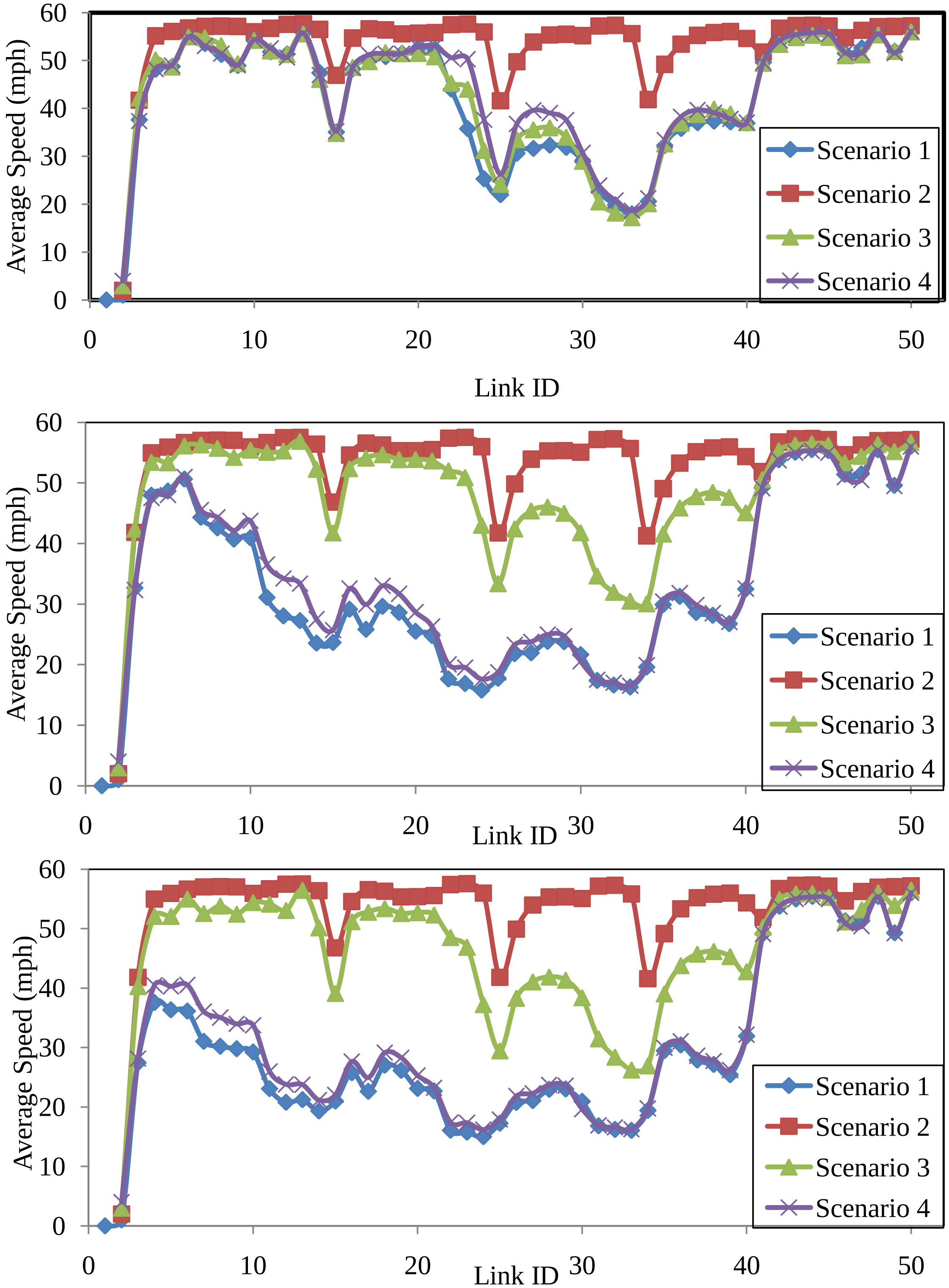

Figure 23. Average speed for no incident conditions at 6:30, 8:30 and 9:30 AM, respectively, for all links.

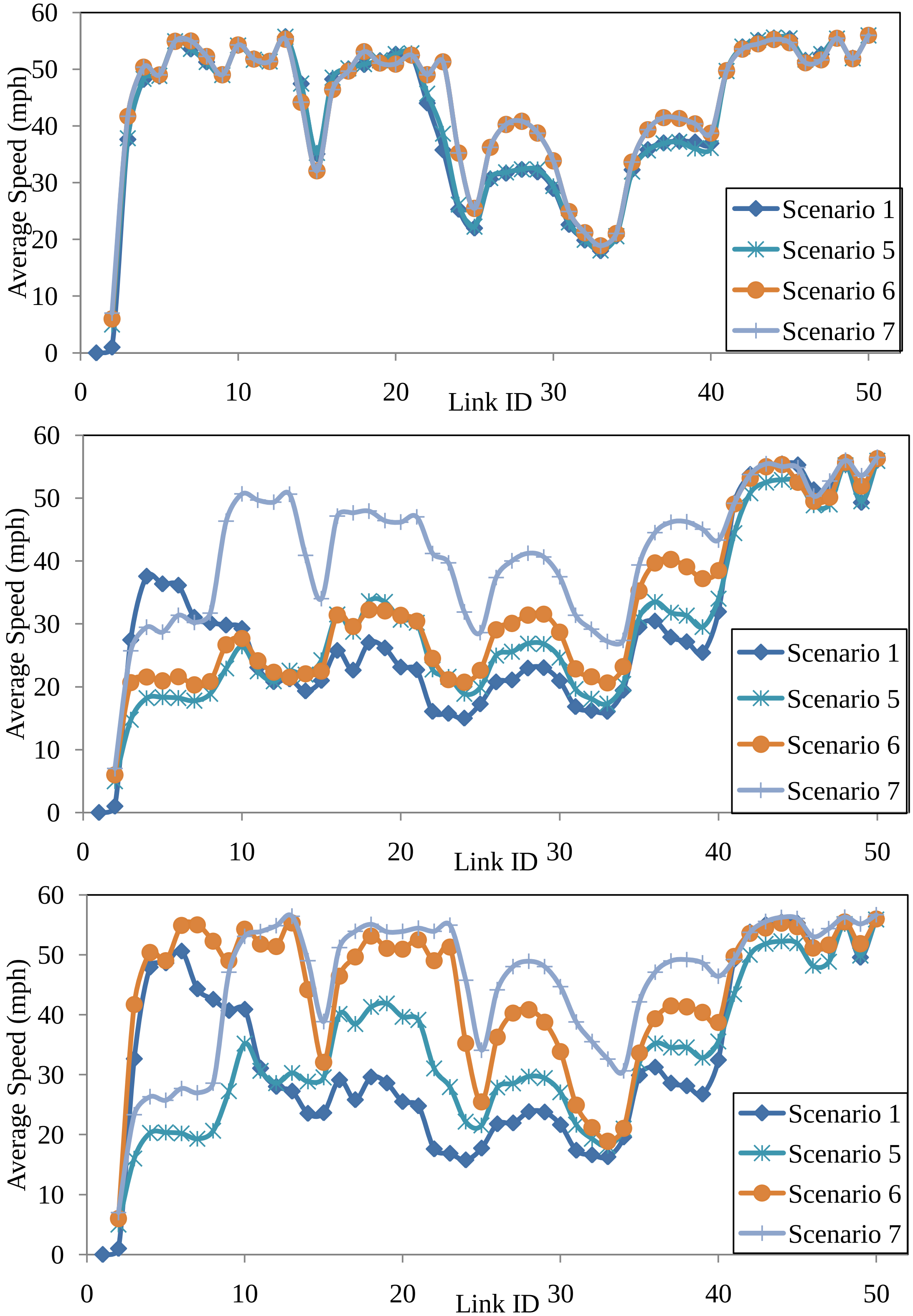

Figure 24. Average speeds for incident conditions at 6:30, 8:30, and 9:30 AM, respectively, for all links.

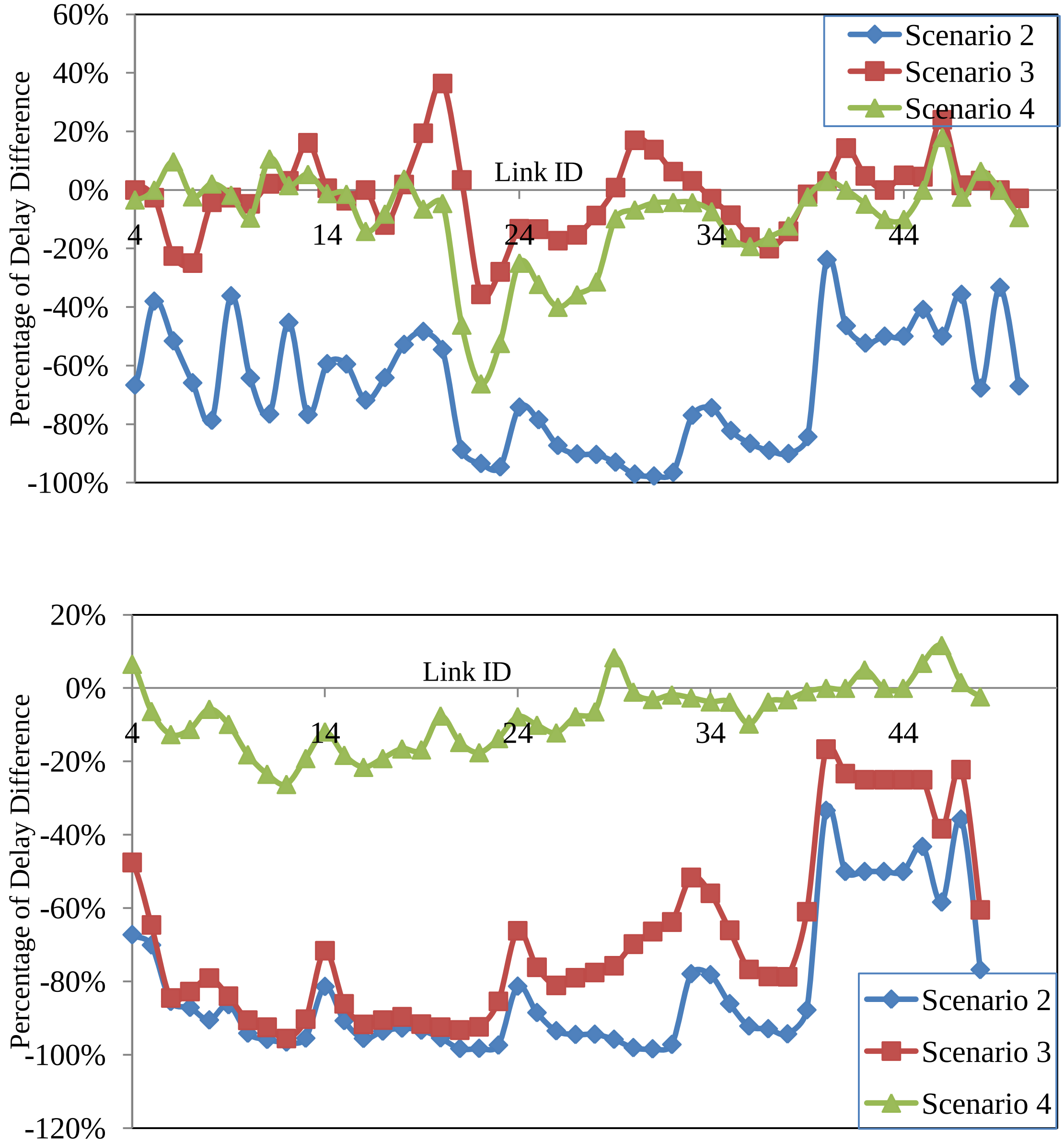

Figure 25. Delay difference for non-incident scenarios compared to the first scenario at 6:30 and 8:30 AM for all study links.

5.6 Environmental Impacts Analysis Results

5.6.1 Effect of Shoulder Lane Utilization on Vehicle Emissions

In addition to operational impacts, CORSIM provides MOEs that can be used to assess the environmental impacts of alternative options. The amount of emissions is calculated, taking different types of vehicles into consideration, as shown in Table 9.

Table 9. Description of Vehicle Types Considered in CORSIM

Vehicle Type	Type Description
FRESIM 1	Low-performance passenger car
FRESIM 2	High-performance passenger car
FRESIM 3	Single-unit truck
FRESIM 4	Semi-trailer truck with medium load
FRESIM 5	Semi-trailer truck with full load
FRESIM 6	Double-bottom trailer truck
FRESIM 7	Conventional bus
FRESIM 8	Low-performance passenger car
FRESIM 9	High-performance passenger car

Table 10 provides a summary of the amount of hydrocarbon (HC) gram/mile emitted by different types of vehicles and the weighted average HC for all vehicle types in each scenario. Cumulative total emissions along the model length are shown in Table 11. Percentage changes in HC emissions as compared to current conditions (Scenario 1) are shown in Table 12.

Table 10. HC (Gram/Mile) Emissions for All Scenarios

Scenario	Vehicle Type						
	1	2	3	4	5	6	AVG
1	0.20	0.24	13.00	10.08	9.03	7.70	0.73
2	0.14	0.16	11.41	8.87	7.78	6.51	0.62
3	0.16	0.18	11.86	9.23	8.01	6.60	0.65
4	0.18	0.22	12.88	9.99	8.98	7.55	0.72
5	0.20	0.24	13.32	10.33	9.22	7.70	0.74
6	0.19	0.23	13.01	10.12	8.93	7.59	0.72
7	0.17	0.19	12.33	9.57	8.33	6.85	0.67

From the review of the findings, it is clear that utilizing the shoulder lane in response to recurrent and/or non-recurrent congestion reduces the amount of HC emissions. A 10% reduction in HC emissions is observed with the temporary use of the shoulder lane during the two-hour traffic peak (Scenario 3) as compared to the baseline (Scenario 1).

Table 11. HC (Grams) Emissions for All Scenarios

Scenario	Vehicle Type						
	1	2	3	4	5	6	AVG
1	1.96	2.36	129.98	100.78	90.30	77.01	7.28
2	1.42	1.58	114.11	88.73	77.78	65.10	6.21
3	1.56	1.78	118.64	92.34	80.15	66.03	6.45
4	1.82	2.20	128.81	99.92	89.84	75.45	7.17
5	1.99	2.40	133.24	103.28	92.22	76.97	7.42
6	1.91	2.30	130.07	101.22	89.29	75.87	7.24
7	1.68	1.95	123.31	95.67	83.26	68.48	6.72

Table 12. Percentage Change in HC Emissions for All Scenarios as Compared to Current Conditions

Scenario	Vehicle Type						
	1	2	3	4	5	6	AVG
1	0%	0%	0%	0%	0%	0%	0%
2	-27%	-33%	-12%	-12%	-14%	-15%	-13%
3	-20%	-24%	-9%	-8%	-11%	-14%	-10%
4	-7%	-7%	-1%	-1%	-1%	-2%	-1%
5	2%	2%	3%	2%	2%	0%	2%
6	-2%	-3%	0%	0%	-1%	-1%	0%
7	-14%	-18%	-5%	-5%	-8%	-11%	-7%

Furthermore, the highest amount of HC emissions occurs in case of an incident, where a significant increase in emissions is observed. This is due to the increase in traffic congestion and stop-and-go conditions (Scenario 5). Utilizing the shoulder lane to address incident-related congestion in Scenarios 6 and 7 reduces the emissions considerably, to levels comparable to non-incident conditions.

5.7 Cost-Benefit Analysis Results

A detailed cost-benefit analysis was performed to estimate economic impacts from possible deployment of temporary shoulder lane use strategies along the 9.54-mile study segment of the I-65 freeway. The cost-benefit analysis compared anticipated costs and benefits from each of the study scenarios to the base case scenario (Scenario 1) in order to find the most cost-effective method. A summary of the scenarios along with the methodology used in the cost-benefit analysis follow.

The CORSIM traffic simulation model employed in the traffic impacts analysis returned various MOEs, including Vehicle Miles Traveled (VMT), move time, delay time, average speed, fuel consumption, emission, and total vehicle times. These outputs are used in the cost-benefit analysis to calculate the benefit-cost ratios of different scenarios and contrast them with current benefits and costs, as represented by Scenario 1.

5.7.1 Costs of Shoulder Lane Conversion

The costs are calculated based on the latest available bid/quotation used by ALDOT. The regular maintenance work includes crack seal repair, the unit cost of which is $1,500 per lane mile. The cost for resurfacing with traffic stripes is $278,985 per lane mile (1). The regular maintenance cost for the 9.54-mile study segment of I-65 is estimated at $0.115M per year. The total estimated cost for opening a continuous shoulder lane is $2.244M for the first year. This cost was used for the cost-benefit analysis.

5.7.2 Benefits of Different Scenarios

The major benefits of highway improvement works arise from savings in the following areas: (i) vehicle operation, (ii) travel time, (iii) accident costs and, (iv) emission costs. All of these benefits were quantified in dollar values and used for the analysis.

5.7.2.1 Vehicle Operating Cost Savings

Vehicle Operating Costs (VOC) were calculated based on the fuel consumption (in gallons) data that were generated from the CORSIM simulation analysis for each scenario. To calculate total fuel costs, fuel consumption was multiplied by fuel cost per gallon minus taxes (currently $1.70). Non-fuel costs were not considered in the analysis.

5.7.2.2 Value of Travel Time Savings

The value of time (VOT) is the opportunity cost of the time that a traveler spends on a journey. In essence, VOT is the amount that a traveler would be willing to pay in order to save time, or the amount they would accept as compensation for lost time. One of the main justifications for transportation improvements is the amount of time that travelers will save. Different agencies are using different monetary (dollar) values for VOT based on different estimation procedures. The VOT used for the analysis is $14.85 per hour for automobiles and $21.20 for trucks, based on the value proposed by the Texas Transportation Institute (19).

5.7.2.3 Safety Benefits – Accident Cost Savings

Reducing the number of vehicle accidents is a primary motivation for many highway capital investments or improvement projects. Reductions in the number or severity of accidents can be converted to an annual benefit, measured in dollars, and included in a benefit-cost analysis. An assessment of accident savings for proposed highway projects requires an examination of the historical accident rates for the area, or historical rates for the roadway type. For these estimation purposes, accident types were divided into three broad categories of severity – fatal, injury, and property damage only. Two factors were considered in estimating the value of accident costs: (i) frequency of accidents and (ii) value of accidents. The historical accident statistics of the U.S. and those of the state of Alabama were reviewed and incorporated in the analysis (4). The unit costs of accidents by severity as estimated by the National Safety Council, is presented in Table 13 and used in the analysis (27).

Table 13. Unit Costs of Accidents by Severity (27)

Types of Accident	Accident Costs [$]
Fatal	3,460,000
Injury	188,000
Property Damage Only (PDO)	2,100

5.7.2.4 Emissions Costs Savings

Highway infrastructure projects that increase the capacity of a facility may reduce vehicle emissions by reducing congestion, which is considered to be a significant benefit of transportation infrastructure improvement works. In this analysis, the simulation model output of HC, carbon monoxide (CO), and nitrogen oxide (NOx) emissions were used to estimate the cost of emissions for all study scenarios. The emission health cost rates are expressed in dollar per ton of emissions and are available at the U.S. Environmental Protection Agency website (6). The unit costs of emissions that were used in the analysis are summarized in Table 14.

Table. 14 Unit Costs of Emissions (6)

Types of Emissions	Costs [$/Tons]
HC	8,693
CO	435
NO	11,209

5.7.3 Benefit-Cost Analysis Results for Different Scenarios

From the CORSIM outputs for different scenarios presented earlier, the fuel consumption, vehicle miles of travel, travel time, and emissions outputs were obtained and used to calculate VOC, VOT, accident costs, and emission costs. These costs were utilized to calculate and compare the benefit-cost ratios for different scenarios on an annual basis. The benefit components for different scenarios are summarized in Table 15. Based on these components the benefit-cost ratios for different scenarios are calculated and presented in Table 15.

Table 15. Benefit Components for Different Scenarios

Scenario No	VOC [Mil $/year]	VOT [Mil $/year]	Accident Cost [Mil $/year]	Emission Cost [Mil $/year]
Shoulder Lane Operation				
Scenario 1	7.607	34.213	11.226	0.0043
Scenario 2	5.881	19.964	11.645	0.0041
Scenario 3	6.304	22.563	11.538	0.0042
Scenario 4	7.519	32.867	11.226	0.0043
Incident Management				
Scenario 5	7.975	39.662	10.826	0.0044
Scenario 6	7.632	34.719	11.173	0.0043
Scenario 7	6.880	27.498	11.557	0.0042

Table 15 shows clearly that VOC, VOT, accident costs and emission costs are lower when shoulder lane use is permitted.

Table 16 indicates that the temporary use of the left shoulder lane along the I-65 study section during the 2 hour morning peak (Scenario 3) is expected to result in $12.6M in savings. Further savings can be realized by utilizing the shoulder lane for more extended periods of time (such as in Scenario 2). For alleviation of traffic congestion due to incidents, the most cost-effective option studied is provided by Scenario 7.

The findings of benefit-cost analysis match with those of the traffic impact analysis presented earlier.

Table 16. Benefit Cost Ratios for Different Scenarios

Scenario No.	Total Costs [M $/year]	Total Benefit Components [M $/year]	Total Benefits with respect to Base Case [M$/year]	B/C Ratios
Shoulder Lane Operation				
Scenario 1: Base Case	0.043	53.050	-	
Scenario 2	1.122	37.494	15.556	13.9
Scenario 3	1.122	40.409	12.641	11.3
Scenario 4	1.434	51.613	1.434	3.8
Incident Management				
Scenario 5: Base Case	0.043	58.467	-	-
Scenario 6	1.108	53.528	4.939	4.5
Scenario 7	1.108	45.939	12.528	11.3

6 Implementation Potential of Active Traffic Management in U.S.

The benefits realized because of the deployment of ATM overseas are a testament to its potential for the United States (Table 17). For this reason, a team of experts who studied European ATM systems as part of a 2006 International Technology Scanning Program agreed that ATM is the next evolution in congestion management in the U.S.

Table 17. Potential Benefits from ATM Implementation (24)

Active Traffic Management Strategy	Potential Benefits												
	Increased throughput	Increased capacity	Decrease in primary incidents	Decrease in secondary incidents	Decrease in incident severity	More uniform speeds	Decreased headways	More uniform driver behavior	Increased trip reliability	Delay onset of freeway breakdown	Reduction in traffic noise	Reduction in emissions	Reduction in fuel consumption
Speed harmonization	●		●		●	●	●	●	●	●	●	●	●
Temporary shoulder use	●	●							●	●			
Queue warning			●	●	●	●	●	●	●		●	●	●
Dynamic merge control	●	●	●			●		●	●	●	●	●	●
Construction site management	●	●							●		●	●	●
Dynamic truck restrictions	●	●				●		●	●			●	●
Dynamic rerouting and traveler information	●		●	●				●	●			●	●
Dynamic lane markings	●	●							●				
Automated speed enforcement			●		●	●		●	●			●	●

The scanning program was sponsored by the FHWA, the American Association of State Highway and Transportation Officials (AASHTO), and the National Cooperative Highway Research Program (NCHRP). In their report to FHWA, the experts identified nine key recommendations related to congestion management with a potential to ease congestion if implemented in the United States (24):

- Promote ATM to optimize existing infrastructure during recurrent and non-recurrent congestion.
- Emphasize customer orientation and focus on trip reliability.
- Integrate active management into infrastructure planning and programming processes.
- Make operations a priority in planning, programming, and funding processes.
- Develop tools to support active management investment decisions.
- Consider public-private partnerships and innovative financing and delivery strategies.
- Provide consistent messages to roadway users.
- Consider pricing as only one component of a total management package.
- Include managed lanes as part of the overall management of congested facilities.

Planning for ATM is an important ingredient for success. Whether or not to implement ATM and its operational strategies is a policy decision that must be made at the appropriate governing level. To that end, policymakers should develop both short- and long-range plans that incorporate ATM into the framework of transportation alternatives. Furthermore, agencies should approach ATM proactively by including it in current and future plans for target corridors. They should assess what ATM capabilities already exist in those corridors and what components need to be added to facilitate active management, even if conditions do not currently warrant such operational strategies. This forward-thinking approach will ensure that the infrastructure is put into place during future projects so that ATM can be implemented when warranted by congestion levels and mobility needs. In some regions, legislative support may be necessary to make this operational approach possible (24).

Implementation, operation, maintenance, enforcement, and marketing are some of the policy decisions that govern a successful ATM system. Potential policy decisions that would need to be made in tandem with the planning and implementation of temporary shoulder lane use are being reviewed and documented. Special emphasis is being placed on the development of a set of procedures that will clearly describe how to open and close the shoulder to traffic operation, and assign roles and responsibilities. Moreover, considerations related to maintenance, compliance, and enforcement, and institutional issues (such as regulatory and legal issues, finance, organization and management issues, and human resources) must be studied carefully (8).

Another key consideration in the viability of a transportation project is the availability of funding. Therefore, funding resources at the federal, state, or local level that can potentially support design, implementation, operation, maintenance, and marketing of the project should be identified.

In addition, various institutional issues are essential to the successful implementation of ATM and include customer orientation; the priority of operations in planning, programming, and funding processes; cost-effective investment decisions; public-private partnerships; and a desire for consistency across borders. These issues need to be considered carefully prior to implementation in order to maximize the potential for success.

The technologies required for implementation are currently available in the market; however, research and development may be required to refine existing systems, and careful selection of available technologies should take place to improve cost/effectiveness while accounting for local needs and special conditions. The FHWA *International Scan Tour Report* (24) offers the following recommendations for ATM implementation in response to recurrent congestion.

6.1 Speed Harmonization

The United States should implement speed harmonization on freeways as a strategy to actively manage the network and delay the onset of congestion under normal operating conditions. The system should include the following elements:

- Sufficient sensor deployment for traffic and weather monitoring to support the strategy
- Adequate installation of sign gantries to ensure that at least one speed limit sign is in sight at all times
- Placement of speed limit signs over each travel lane
- An expert system that deploys the strategy based on prevailing roadway conditions without requiring operator intervention. It is critical that this expert system be reliable and accurate to gain the trust and acceptance of the public.
- Connection to a traffic management center that serves as the focal point for the system
- Passage of enabling legislation and related laws to allow for dynamic speed limits
- Uniform signing related to speed harmonization and its components
- Modeling tools to assess the impacts of speed harmonization on overall network operations
- Closed-circuit television cameras to support the monitoring of the system
- Dynamic message signs to provide traveler information and regulatory signs as appropriate
- Automated speed enforcement to deter violations

6.2 Temporary Shoulder Lane Use

Temporary shoulder lane use should be implemented where appropriate to temporarily increase capacity during peak travel periods. Specific elements of the operational strategy should include the following:

- Deployment in conjunction with speed harmonization
- Passage of enabling legislation and related laws to allow the shoulder to be used as a travel lane

- A policy for uniform application of the strategy through entrance and exit ramps and at interchanges
- Adequate installation of sign gantries to provide operational information and to ensure that they are in sight at all times
- Placement of lane control signals over each travel lane
- Uniform signing and markings related to temporary shoulder use
- CCTV cameras with sufficient coverage to verify the clearance of the shoulder before deployment
- Provision of pullouts at regular intervals with automatic vehicle detection to provide refuge areas for minor incidents
- Provision of roadside emergency call boxes at emergency pullouts
- Special lighting to enhance visibility of the shoulder
- Advanced incident detection capabilities
- Comprehensive incident management program
- Connection to a traffic management center that serves as the focal point for the system
- Dynamic message signs to provide guide sign information and regulatory signs to adapt to the addition of the shoulder as a travel lane

6.3 Queue Warning

Queue warning message displays should be implemented at regular intervals to warn of the presence of upstream queues based on dynamic traffic detection. Specific elements of the operational strategy should include the following:

- Deployment in conjunction with speed harmonization
- Sufficient sensor deployment for traffic monitoring to support the strategy
- Adequate installation of sign gantries to ensure that at least one queue warning sign is in sight at all times
- An expert system that deploys the strategy based on prevailing roadway conditions without requiring operator intervention. It is critical that this expert system be reliable and accurate to gain the trust and acceptance of the public.
- Uniform signing to indicate congestion ahead
- Connection to a traffic management center that serves as the focal point for the system

6.4 Dynamic Merge Control

At merges from major interchange ramps, consideration should be given to dynamically metering or closing specific upstream lanes, depending on traffic demand. This could easily incorporate existing ramp metering systems and could offer the potential of delaying the onset of main lane congestion and balancing demands between upstream roadways. Specific elements of the operational strategy should include the following:

- An expert system that deploys the strategy based on prevailing roadway conditions without requiring operator intervention. It is critical that this expert system be reliable and accurate to gain the trust and acceptance of the public.
- CCTV cameras to support the monitoring of the system
- Installation of lane control signals over the main lanes and the ramp lanes with a signal over each travel lane
- Adequate installation of sign gantries upstream of the deployment to ensure sufficient advance warning is provided to roadway users through the use of dynamic message signs
- Adequate installation of sign gantries with dynamic message signs upstream of the deployment to provide guide sign information and regulatory signs to adapt to the changes in lane use
- Uniform signing to indicate merge control is in use
- Automated enforcement to deter violations
- A bypass lane for emergency vehicles, transit, or other identified exempt users
- Connection to a traffic management center that serves as the focal point for the system

7 Conclusions, Recommendations, and Future Research

7.1 Conclusions

Overall, ATM seeks to introduce new congestion management strategies to the U.S. while enhancing the effectiveness of existing strategies. It should be viewed as the next logical step in the evolution of congestion management in this country rather than a radical change from previous practice. The European experience with ATM clearly demonstrates its positive impacts on traffic operations and safety and its tremendous potential for alleviating traffic congestion in the U.S.

It should be noted that the implementation of ATM is a significant investment, so the potential benefits must be clearly defined and sufficient to justify the costs. To better assess potential costs and gains, we developed and implemented a procedure to screen candidate test sites; assess their operational impacts; identify opportunities and impediments from implementation; and document technology, policy, and other needs. As part of a case study, a simulation analysis was performed to quantify the potential benefits of a temporary left shoulder lane use system on a segment of I-65 in Birmingham in response to recurrent and non-recurrent congestion. The results from the simulation analysis, coupled with findings from a cost-benefit analysis, were used to demonstrate the potential of the strategy to improve traffic operations and safety and justify the need for deployment of the proposed strategy at the study location.

It was found that the use of temporary shoulder lanes can have a very positive impact on traffic operations along I-65 when implemented in response to recurrent- and/or non-recurrent congestion. In this study, the temporary use of the left northbound shoulder lane for two hours during the morning peak (Scenario 3) resulted in a reduction in the total network travel time by 34% and delay by 71% compared to current operations (Scenario 1). The use of right shoulder lanes upstream of exit ramps tested in this study provide some relief but had far less impact on network performance, compared to the continuous left shoulder lane usage. Moreover, environmental benefits can be realized from a reduction of traffic congestion and improved traffic operations. The study showed an overall reduction in traffic emissions and fuel consumption under the temporary shoulder lane use scenarios tested. These results clearly indicate the tremendous potential of temporary shoulder lane use as an active traffic management tool for addressing recurrent congestion along I-65.

It was also found that considerable improvements in traffic operations can be achieved by utilizing the temporary shoulder lane downstream of the incident as an ATM measure. More specifically, under incident conditions, the utilization of the temporary shoulder lane resulted in an increase in average network speed by 21%, and a decrease in average delay time by 31%, as compared to the do-nothing approach. These gains are significant and provide further proof of the potential that ATM has as a tool for incident management.

The results from the benefit-cost analysis provide further justification for the use on temporary shoulder lanes. It can be seen that the total benefits from implementation of this strategy outweigh the total costs, which further confirms that the temporary shoulder lane use treatment is an economically viable solution both in the short and long terms.

7.2 Recommendations and Future Research

It is recommended that additional analysis be performed to refine the current scenarios and compare the effectiveness of temporary shoulder lane use to other potential ATM strategies. Moreover, additional model calibration and validation is needed to further improve modeling accuracy and confidence in the model findings.

It is also recommended that alternative simulation software tools be considered to address some of the limitations of the TSIS software. For example, models with sophisticated Dynamic Traffic Assignment capabilities can be considered as potential candidates for further analysis, as they better emulate the behavior of individual drivers and how they distribute themselves into the transportation network while traffic conditions change dynamically.

Last but not least, the success of implementation greatly depends on public support for the project and positive public perception. Thus, the role of public education in the early planning stage is critical and should not be overlooked. Focus groups, open public discussion forums, public information sessions, and media coverage are useful tools that can help local agencies obtain input from the public and other local stakeholders and educate the road users about their rights and responsibilities.

8 References

1. ALDOT Transportation Planning (2009). Retrieved March 15, 2009, from http://aldotgis.dot.state.al.us/traffic_counts/
2. Atlanta Regional Commission (2007) *Managed Lanes Concept.* Retrieved April 29, 2009, from: http://www.atlantaregional.com/documents/e6_managed__lanes.pdf
3. BBC (2004). *Creative ways to beat congestion*. Retrieved April 13, 2009, from BBC News: http://news.bbc.co.uk/2/hi/uk_news/magazine/4044803.stm
4. CARE (2007). Retrieved May 5, 2009, from http://care.cs.ua.edu/
5. Differt, D. H., Berman, W., Aufschneider, K., DeCorla-Souza, P., Flemer, A., Hoang, L. T., et al. (2006). *Managing Travel Demand: Applying European Perspectives to U.S. Practice.* Washington, DC: Federal Highway Administration.
6. EPA (2009). Retrieved May 5, 2009, from USA Environnemental Protection Agency : http://www.epa.gov/
7. FHWA (2003). *Freeway Management and Operations Handbook -Roadway Improvements.* Office of Transportation Management. Washington, D.C.
8. FHWA (1994). *IVHS Institutional Issues and Case Studies.* U.S. Department of Transportation. Cambridge, MA: Federal Highway Administration.
9. Fuhs, C., and Obenberger, J. (2002). HOV Facility Development: A Review of National Trends.
10. GADOT (2007). *High Occupancy Vehicles (HOV)*. Retrieved March 2, 2009, from http://www.dot.state.ga.us/specialsubjects/hov/index.shtml
11. Google. (2009). *Google Earth*. Retrieved January 07, 2009.
12. Helleman, B. (2006). *Managed Lanes in the Netherlands.* Netherlands: AVV Transport Research Centre, Ministry of Transport.
13. Highways Agency. (2007). *M42 Active Traffic Management Results –First Six Months.* Highways Agency. U.K.: Department for Transport Report.
14. Highways Agency. (2007b). *When Should I Use the Hard Shoulder? M42 Jct 3a - Jct 7 Active Traffic Management.* Highways Agency. U.K: Department for Transport.
15. Highway and Transportation History (n.d.) *Washington D.C. Area Interstate HOV is a Success*. Retrieved March 16, 2009, from: http://www.roadstothefuture.com/DC_Area_HOV_Study.htm
16. Kuhn, B. (2008). Smart Traffic 2008. Texas: Texas Transportation Institute.
17. Kuhn, B., Goodin, G., Ballard, A., Brewer, M., and Brydia, R. (2005). *Managed Lanes Handbook.*
18. Lomax, T., and Schrank, D. (2005). *The 2005 Urban Mobility Report.* Texas: Texas Transportation Institute The Texas A&M University System.
19. Lomax, T., & Schrank, D. (2007). *The 2007 Urban Mobility Report.* Texas: Texas Transportation Institute, The Texas A&M University System.

20. Los Angeles County Metropolitan Transportation Authority *(n.d.)Los Angeles County HOV System*. Retrieved June 22, 2007, from: http://www.metro.net/projects_programs/HOV/hov_system.htm#TopOfPage
21. Mazzenda, N. J., and Demetsky, M. J. (2009). *Investigation of Solutions to Recurring Congestion on Freeways.* Charlottesville, VA: Virginia Transportation Research Council.
22. *McTrans Moving Technology*. (2009). (McTrans) Retrieved March 10, 2009, from http://mctrans.ce.ufl.edu/featured/TSIS/
23. Middelham, F. (2006). *Dynamic Traffic Management.* Netherlands: Ministry of Transport, Public Works and Water Management, Directorate-General of Public Works and Water Management, AVV Transport Research Centre.
24. Mirshahiet, M., Obenberge, J., Fuhs, C. A., Howard, C. E., Krammes, R. A., & Kuhn, B. T. (2007). *Active Traffic Management: The Next Step in Congestion Management.* Washington, DC: Federal Highway Administration, FHWA-PL-07-012.
25. MUTCD. (2003). *Manual on Uniform Traffic Control Devices*. Retrieved April 29, 2009, from Federal Highway Administration: http://mutcd.fhwa.dot.gov/
26. NCDOT. (n.d.). *High Occupancy Vehicle (HOV)*. Retrieved December 28, 2008, from North Carolina Department of Transportation: http://www.ncdot.org/projects/HOV/
27. NSC. (2005). Retrieved May 5, 2009, from National Safety Council: http://www.nsc.org/resources/issues/estcost.aspx
28. Pain, R., Knapp, B., Hostetter, R., and Mace, D. (1982). *Signing and Delineation of Special Usage Lanes.* Washington, D.C.: Federal Highway Administration, U.S. Department of Transportation.
29. PBS&J. (2009). *Tier 1 Alternatives Evaluation:I-65 / US 31 Mobility Matters Project.* PBS&J Team Project.
30. Riegelhuth, G., and Pilz, A. (2007). *Temporary Hard Shoulder Use in Hessen–Experiences and Strategic Planning.* Aalborg, Denmark: PilzTraffic Centre Hessen (CENTRICO).
31. RPCGB. (2006). *Magic 65: Existing Conditions Technical Memorandum.* Birmingham: Regional Planning Commission of Greater Birmingham.
32. Siemens. (2009). *Slovakia to Realize the World's Second Satellite-Based Toll Collection System*. Retrieved April 29, 2009, from ITS Magazine: http://www.industry.siemens.de/traffic/EN/news/itsmagazine/html/0901/projekte_1.html
33. Sisiopiku, V. P., and Cavusoglu, O. (2007). Implementation of High Occupancy Vehicle Lanes. Huntsville, AL: Huntsville Simulation Conference Proceedings, Huntsville, AL.
34. Sisiopiku, V. P., and Cavusoglu, O. (2008). Operational Impacts from Managed Lanes Implementation in Birmingham: ITE Annual Meeting and Exhibit Compendium of Technical Papers, Anaheim, CA.
35. Sisiopiku, V. P., Cavusoglu, O., and Fadel, G. (2009). Active Traffic Management Opportunites and Challenges for Implementaion: ITE Technical Confrerence and Exhibit Compendium of Technical Papers, Phoenix, AZ.
36. Skowronek, D., Ranft, S., and Slack, J. (1999). *Project 7-3942:Investigation of HOV Lane Implementation and Operational Issues.* Texas Department of Transportation.
37. Stone, C., Hammond, P., and Lenzi, J. (2007). *Active Traffic Management: The Next Step in Congestion Management.* Washington: Washington State Department of Transportation.

38. Taale, H. (2006). *Regional Traffic Management Method and Tool.* Rotterdam, Netherlands: Ministry of Transport, Public Works, and Water Management, Directorate-General of Public Works and Water Management, AVV Transport Research Centre.
39. TCRP. (2006). *HOV Facilities: Traveler Response to Transportation System Changes.* Retrieved April 29, 2009, from Transit Cooperative Research Program TCRP Report 95: http://onlinepubs.trb.org/onlinepubs/tcrp/tcrp_rpt_95c2.pdf
40. Tignor, S. C., Brown, L. L., Butner, J. L., Cunard, R., Davis, S. C., Hawkins, H. G., et al. (1999). *Innovative Traffic Control Technology and Practice in Europe.* Washington, D.C.: Federal Highway Administration.
41. Transportation System Performance Homepage. (2009). Retrieved March 16, 2009, from Boston Metropolitan Planning Orgnization: http://bostonmpo.org/bostonmpo/1_about_us/2_ctps/ctps.html
42. TxDOT. (2000). *Executive Edition New Jersey I-80 and I-287 HOV Lane Case Study.* The Texas A&M University System and Parsons Brinckerhoff Quade and Douglas. Texas Transportation Institute.
43. Ullman, G., Wohlschlaeger, S., Dudek, C., and Wiles, P. (1993). *Driver Interpretations of Existing and Potential Lane Control Signal Symbols for Freeway Traffic Management.* College Station, TX: Texas Transportation Institute, The Texas A&M University System.
44. VDOT. (1993). *I-66 Commuter Study Regarding HOV/Shoulder Lanes From I-495 To Route 50.* Virginia Department of Transportation.
45. Vithen, C. (2006). *Traffic Management during the Extension of Motorway M3.* Denmark: Danish Ministry of Transport and Energy.
46. WSDOT. (2009). *SR 520 / I-90 - Active Traffic Management*. Retrieved April 29, 2009, from Washigton State Department of Transportation WSDOT: http://www.wsdot.wa.gov/projects/lkwamgt/lkwaatm

Appendix: Link-by-Link Detailed Output

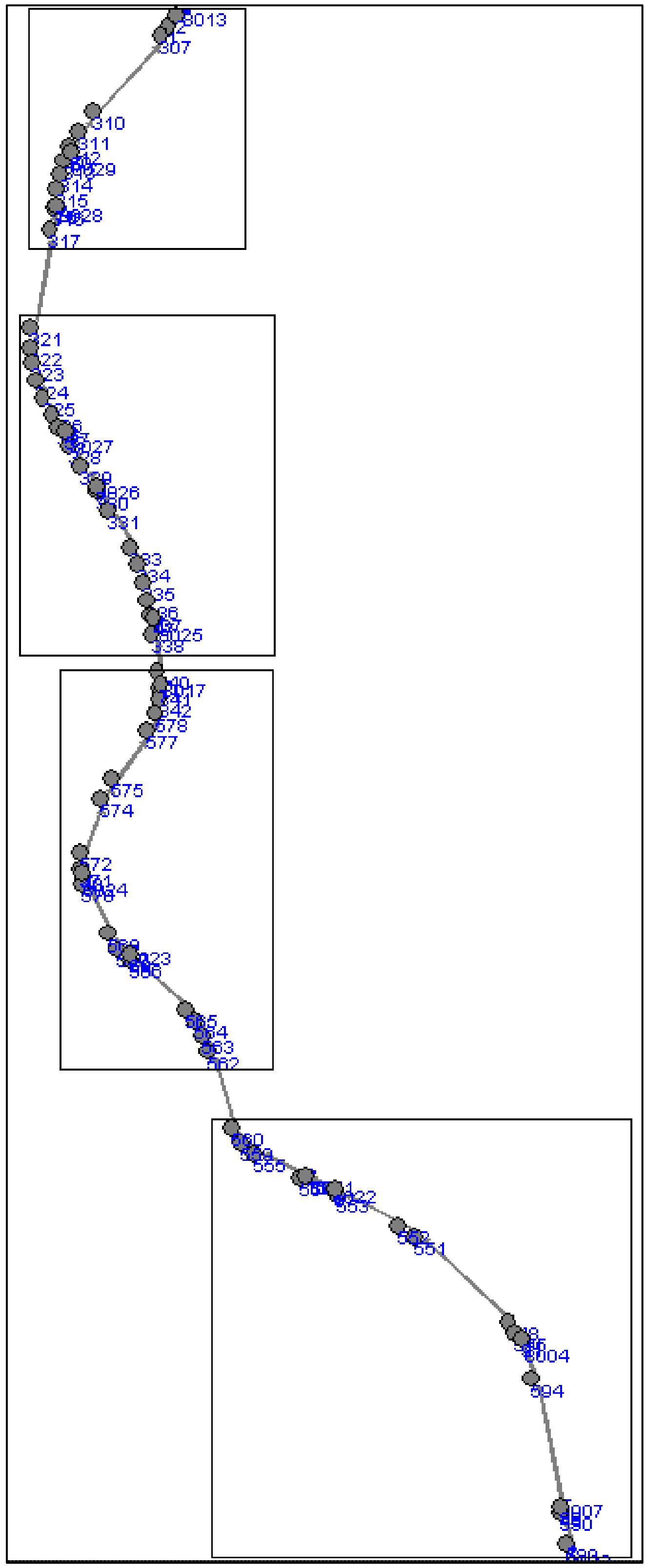

Figure A1. The four detailed frame snapshots for the Birmingham study network.

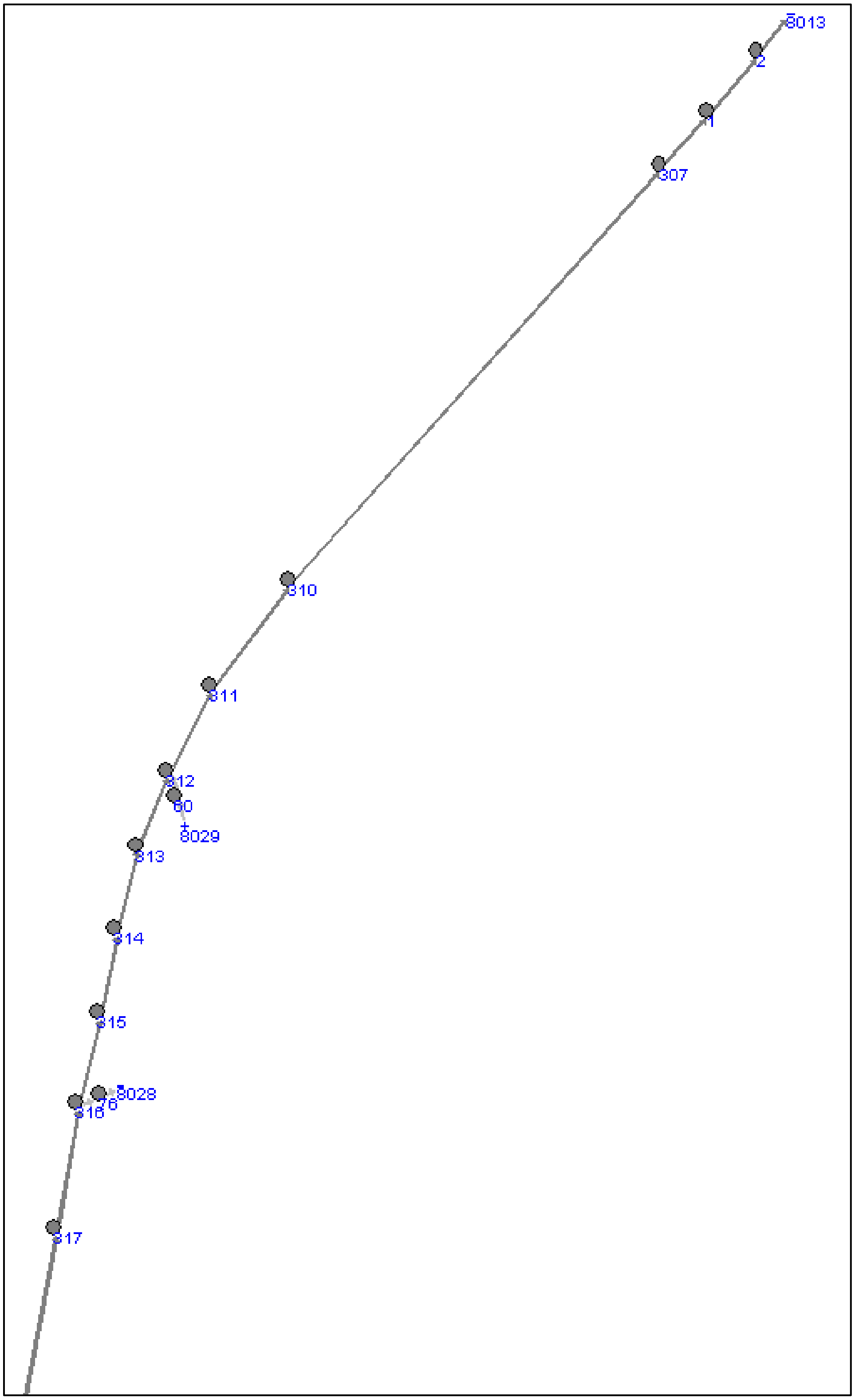

Figure A2. Birmingham study network - Snapshot 1.

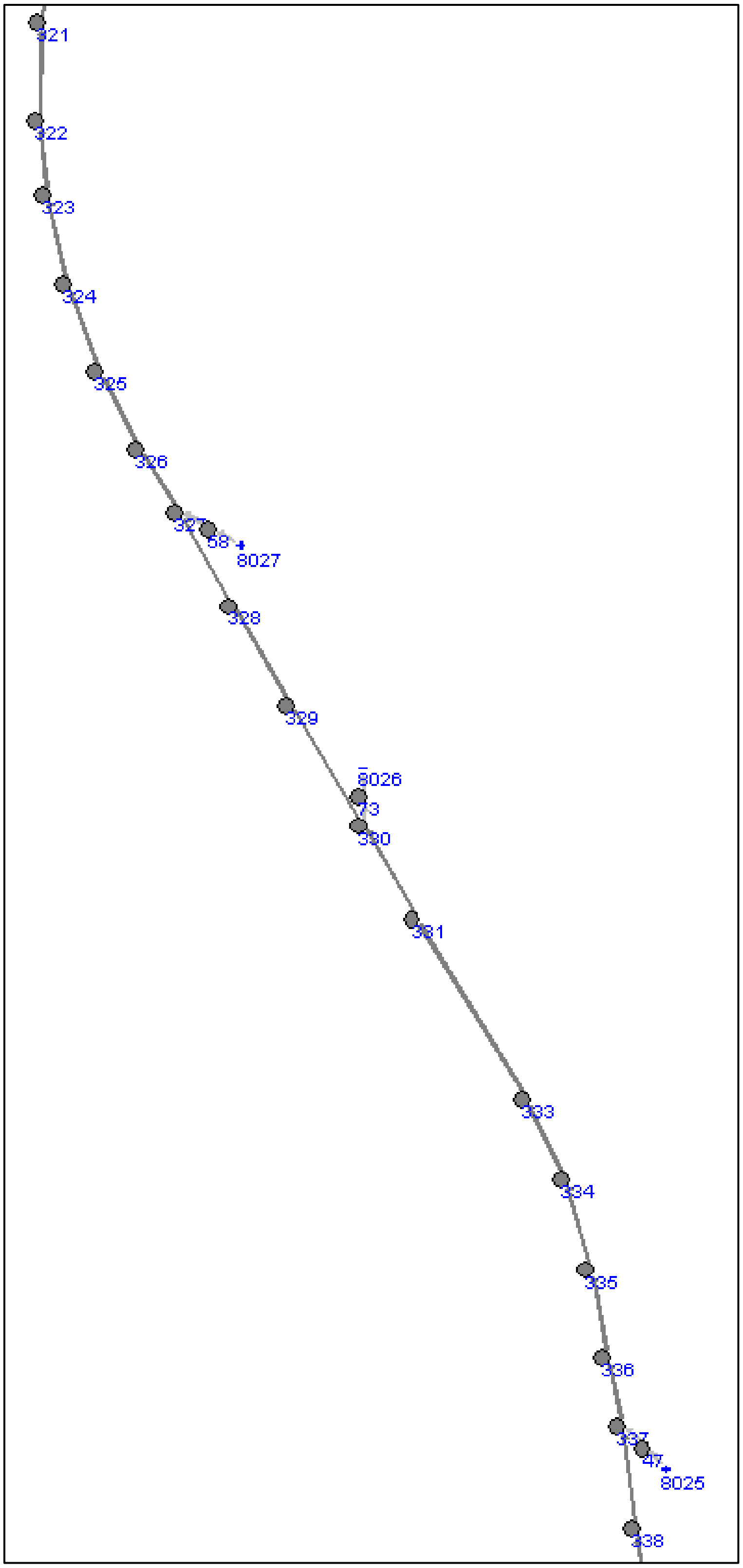

Figure A3. Birmingham study network - Snapshot 2.

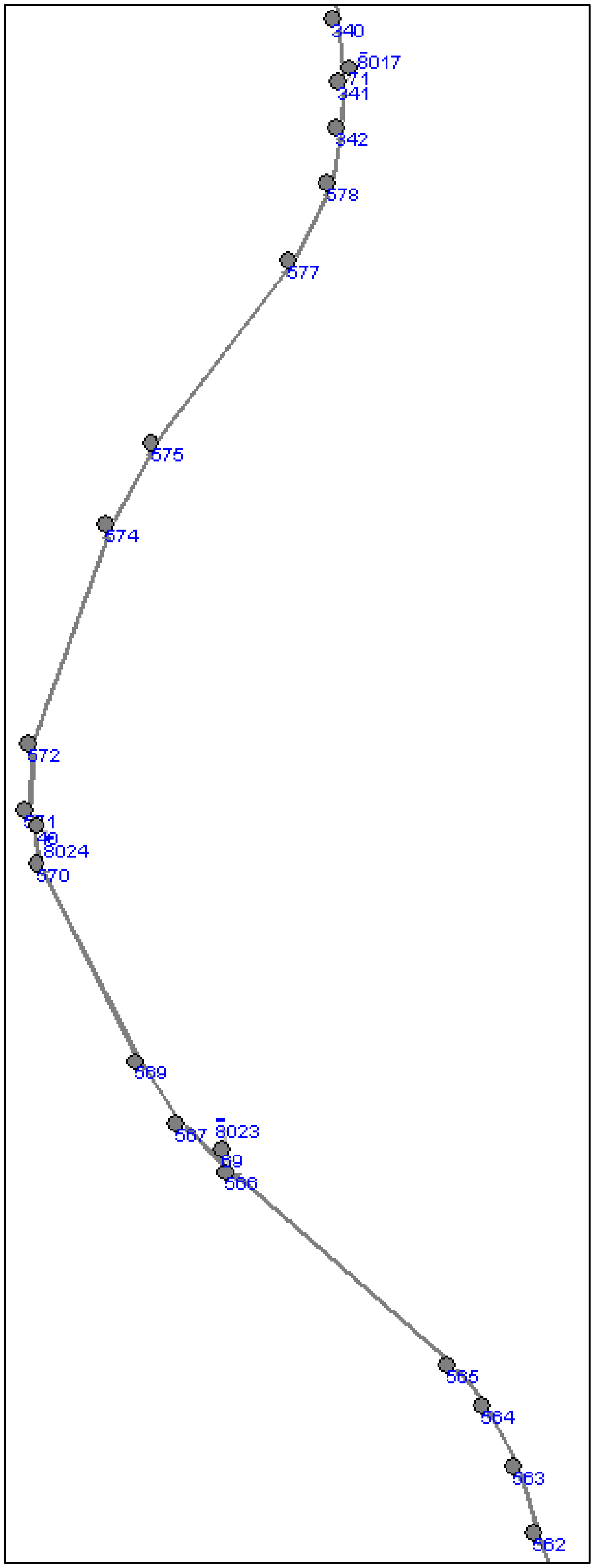

Figure A4. Birmingham study network - Snapshot 3.

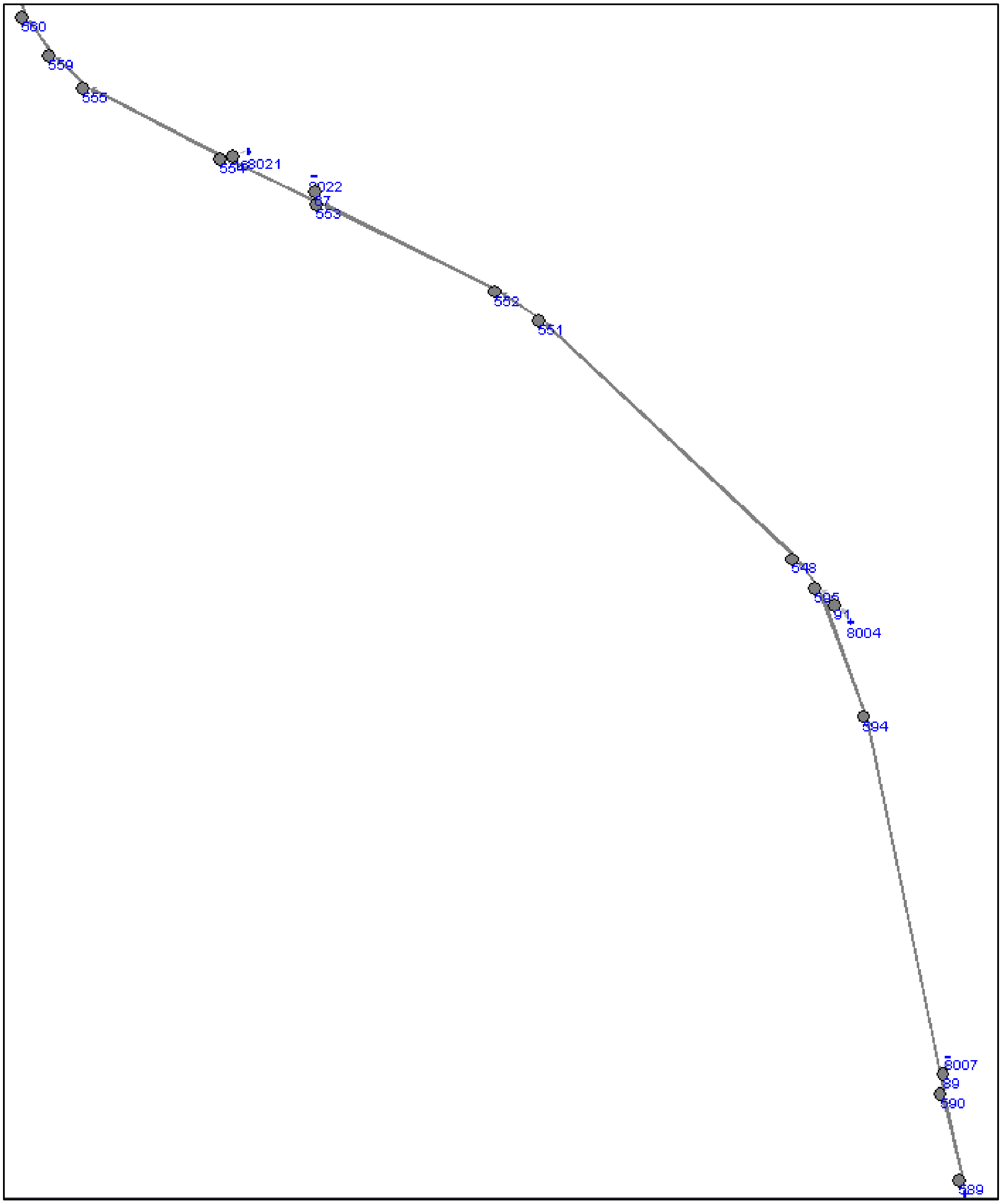

Figure A5. Birmingham study network - Snapshot 4.

Table A1. Average Speed for All Scenarios at 6:30 AM (End of Period 1)

LINK ID	LINK	Scenario						
		1	2	3	4	5	6	7
1	(554,555)	37.6	41.7	42.2	37.4	37.8	41.7	41.7
2	(555,559)	48.2	55.1	50.2	48.2	48.3	50.4	50.4
3	(559,560)	48.8	56.1	48.7	48.9	48.8	49.0	49.0
4	(560,562)	54.9	56.8	55.0	54.9	54.9	54.9	54.9
5	(562,563)	53.5	57.1	54.8	53.0	53.6	55.0	55.0
6	(563,564)	51.3	57.2	53.2	51.4	51.3	52.3	52.3
7	(564,565)	49.0	57.1	49.4	49.0	48.9	49.0	49.0
8	(565,566)	54.2	56.0	54.2	54.3	54.2	54.3	54.3
9	(566,567)	51.8	56.7	52.0	52.6	51.7	51.8	51.8
10	(567,569)	51.4	57.6	51.3	50.7	51.3	51.4	51.4
11	(569,570)	55.7	57.6	55.6	55.7	55.7	55.3	55.3
12	(570,571)	47.4	56.5	46.1	47.0	47.5	44.2	44.2
13	(571,572)	35.1	46.9	34.8	35.2	35.3	32.1	32.1
14	(572,574)	48.2	54.7	48.6	48.5	48.5	46.4	46.4
15	(574,575)	50.0	56.6	49.8	51.2	50.2	49.6	49.6
16	(575,577)	50.8	56.4	51.7	51.4	50.9	53.1	53.1
17	(577,578)	51.5	55.6	51.4	51.4	51.6	51.1	51.1
18	(578,342)	52.6	55.7	51.5	52.8	52.7	50.9	50.9
19	(342,341)	52.4	55.8	50.8	53.0	52.8	52.5	52.5
20	(341,340)	44.0	57.5	45.3	50.6	45.7	49.0	49.0
21	(340,338)	35.8	57.6	44.0	50.3	38.6	51.3	51.3
22	(338,337)	25.3	56.0	31.3	37.7	26.2	35.2	35.2
23	(337,336)	22.0	41.6	24.2	26.3	22.3	25.5	25.5
24	(336,335)	30.6	49.7	33.5	36.8	30.8	36.2	36.2
25	(335,334)	31.6	53.9	35.6	39.6	31.8	40.3	40.3
26	(334,333)	32.3	55.3	36.0	39.0	32.4	40.8	40.8
27	(333,331)	31.9	55.5	34.0	37.6	32.3	38.7	38.7
28	(331,330)	28.9	55.2	29.0	30.8	29.4	33.8	33.8
29	(330,329)	22.6	57.2	20.5	23.9	23.0	24.9	24.9
30	(329,328)	19.8	57.3	18.2	20.8	19.9	21.2	21.2
31	(328,327)	18.0	55.6	17.2	18.6	18.0	18.9	18.9
32	(327,326)	20.6	41.9	20.1	21.2	20.6	21.1	21.1
33	(326,325)	32.3	49.2	32.6	33.4	31.9	33.6	33.6
34	(325,324)	35.8	53.4	36.9	38.3	35.7	39.3	39.3
35	(324,323)	37.0	55.2	38.8	39.7	36.9	41.5	41.5
36	(323,322)	37.3	55.8	39.9	39.1	37.2	41.3	41.3
37	(322,321)	37.2	56.0	38.9	37.8	36.0	40.4	40.4
38	(321,317)	36.9	54.6	37.1	37.1	36.1	38.7	38.7
39	(317,316)	49.6	51.8	49.4	49.6	49.7	49.7	49.7
40	(316,315)	53.9	56.8	53.4	54.2	54.0	53.5	53.5
41	(315,314)	55.1	57.3	54.8	55.4	55.1	54.5	54.5
42	(314,313)	55.5	57.4	55.3	55.8	55.6	55.2	55.2
43	(313,312)	55.4	57.2	54.9	55.5	55.5	54.7	54.7
44	(312,311)	51.5	54.8	51.0	51.6	51.7	51.1	51.1
45	(311,310)	52.6	56.3	51.2	51.6	52.7	51.6	51.6
46	(310,307)	55.4	57.1	55.4	55.6	55.4	55.5	55.5
47	(307,1)	52.0	57.1	51.9	51.6	51.9	51.8	51.8
48	(1,2)	56.0	57.3	56.0	56.0	55.9	56.0	56.0
	Average =	42.9	54.8	43.7	44.6	43.1	44.8	44.8

Table A2. Changes in Delays for All Scenarios at 6:30 AM (End of Period 1)

Limk ID	LINK	Scenario												
		1	2		3		4		5		6		7	
1	(554,555)	9.7	7.0	-27%	6.8	-30%	9.9	2%	9.5	-1%	7.1	-27%	7.1	-27%
2	(555,559)	1.3	0.5	-62%	1.0	-21%	1.3	0%	1.2	-3%	1.0	-22%	1.0	-22%
3	(559,560)	1.2	0.4	-67%	1.2	0%	1.2	-3%	1.2	0%	1.2	-3%	1.2	-3%
4	(560,562)	2.3	1.4	-38%	2.2	-3%	2.3	0%	2.2	-1%	2.2	-1%	2.2	-1%
5	(562,563)	0.6	0.3	-52%	0.5	-23%	0.7	10%	0.6	0%	0.5	-23%	0.5	-23%
6	(563,564)	0.9	0.3	-66%	0.7	-25%	0.9	-2%	0.9	0%	0.8	-14%	0.8	-14%
7	(564,565)	0.9	0.2	-79%	0.9	-4%	1.0	2%	0.9	0%	0.9	0%	0.9	0%
8	(565,566)	2.3	1.5	-36%	2.3	-3%	2.3	-2%	2.3	0%	2.3	-3%	2.3	-3%
9	(566,567)	0.8	0.3	-64%	0.8	-5%	0.8	-10%	0.9	2%	0.8	-2%	0.8	-2%
10	(567,569)	0.9	0.2	-77%	1.0	2%	1.0	11%	0.9	0%	0.9	0%	0.9	0%
11	(569,570)	1.3	0.7	-45%	1.3	3%	1.3	2%	1.3	2%	1.4	9%	1.4	9%
12	(570,571)	1.1	0.3	-77%	1.3	16%	1.2	5%	1.1	0%	1.6	41%	1.6	41%
13	(571,572)	3.4	1.4	-59%	3.4	1%	3.4	-1%	3.4	-1%	4.2	24%	4.2	24%
14	(572,574)	4.3	1.7	-60%	4.1	-4%	4.2	-1%	4.2	-3%	5.2	21%	5.2	21%
15	(574,575)	1.4	0.4	-72%	1.4	0%	1.2	-14%	1.4	-1%	1.5	3%	1.5	3%
16	(575,577)	3.2	1.1	-64%	2.8	-12%	2.9	-8%	3.2	-1%	2.2	-30%	2.2	-30%
17	(577,578)	1.1	0.5	-53%	1.1	2%	1.1	4%	1.1	0%	1.1	6%	1.1	6%
18	(578,342)	0.6	0.3	-48%	0.7	19%	0.6	-6%	0.6	0%	0.8	26%	0.8	26%
19	(342,341)	0.4	0.2	-55%	0.6	36%	0.4	-5%	0.4	-5%	0.4	-9%	0.4	-9%
20	(341,340)	1.8	0.2	-89%	1.8	3%	1.0	-46%	1.5	-13%	1.1	-39%	1.1	-39%
21	(340,338)	7.7	0.5	-93%	4.9	-36%	2.6	-66%	6.7	-13%	2.1	-73%	2.1	-73%
22	(338,337)	8.9	0.5	-95%	6.4	-28%	4.3	-52%	8.4	-6%	4.9	-45%	4.9	-45%
23	(337,336)	7.2	1.9	-74%	6.3	-13%	5.4	-25%	7.1	-2%	5.7	-21%	5.7	-21%
24	(336,335)	5.2	1.1	-79%	4.5	-13%	3.5	-32%	5.2	-1%	3.6	-31%	3.6	-31%
25	(335,334)	5.2	0.7	-87%	4.3	-17%	3.1	-40%	5.1	-1%	2.9	-43%	2.9	-43%
26	(334,333)	4.7	0.5	-90%	4.0	-15%	3.0	-36%	4.7	-1%	2.7	-43%	2.7	-43%
27	(333,331)	11.7	1.1	-90%	10.7	-9%	8.0	-31%	11.3	-3%	7.4	-37%	7.4	-37%
28	(331,330)	7.2	0.5	-93%	7.2	1%	6.5	-10%	7.0	-3%	5.2	-27%	5.2	-27%
29	(330,329)	14.5	0.4	-97%	16.9	17%	13.5	-7%	14.1	-2%	12.8	-11%	12.8	-11%
30	(329,328)	14.2	0.3	-98%	16.2	14%	13.6	-4%	14.2	-1%	13.0	-8%	13.0	-8%
31	(328,327)	15.4	0.5	-96%	16.3	6%	14.7	-4%	15.3	-1%	14.3	-7%	14.3	-7%
32	(327,326)	8.4	1.9	-77%	8.7	3%	8.1	-4%	8.5	0%	8.1	-4%	8.1	-4%
33	(326,325)	4.6	1.2	-74%	4.5	-3%	4.3	-7%	4.7	2%	4.2	-10%	4.2	-10%
34	(325,324)	3.9	0.7	-82%	3.6	-9%	3.3	-16%	4.0	1%	3.0	-23%	3.0	-23%
35	(324,323)	3.7	0.5	-87%	3.1	-16%	3.0	-19%	3.7	0%	2.6	-30%	2.6	-30%
36	(323,322)	3.1	0.3	-89%	2.5	-20%	2.6	-16%	3.1	0%	2.2	-30%	2.2	-30%
37	(322,321)	4.2	0.4	-90%	3.6	-14%	3.7	-12%	4.5	5%	3.1	-27%	3.1	-27%
38	(321,317)	19.1	3.0	-84%	18.8	-2%	18.7	-2%	20.2	6%	16.5	-14%	16.5	-14%
39	(317,316)	1.3	1.0	-24%	1.4	3%	1.4	3%	1.3	0%	1.3	0%	1.3	0%
40	(316,315)	0.6	0.3	-46%	0.6	14%	0.6	0%	0.6	0%	0.6	14%	0.6	14%
41	(315,314)	0.4	0.2	-52%	0.4	5%	0.4	-5%	0.4	0%	0.5	14%	0.5	14%
42	(314,313)	0.4	0.2	-50%	0.4	0%	0.4	-10%	0.4	0%	0.4	5%	0.4	5%
43	(313,312)	0.4	0.2	-50%	0.4	5%	0.4	-10%	0.4	0%	0.4	10%	0.4	10%
44	(312,311)	0.9	0.5	-41%	0.9	5%	0.9	0%	0.9	-2%	0.9	5%	0.9	5%
45	(311,310)	1.0	0.5	-50%	1.2	24%	1.2	18%	1.0	0%	1.2	16%	1.2	16%
46	(310,307)	2.5	1.6	-36%	2.6	2%	2.5	-2%	2.5	1%	2.5	-1%	2.5	-1%
47	(307,1)	0.6	0.2	-68%	0.6	3%	0.7	6%	0.6	0%	0.6	3%	0.6	3%
48	(1,2)	0.3	0.2	-33%	0.3	0%	0.3	0%	0.3	0%	0.3	0%	0.3	0%
	Average			**-67%**		**-3%**		**-9%**		**-1%**		**-10%**		**-10%**

Table A3. Average Speed for All Scenarios at 8:30 AM (End of Period 2)

LINK	LINK	Scenario						
ID		1	2	3	4	5	6	7
1	(554,555)	32.7	41.8	42.4	32.3	16.0	41.7	23.3
2	(555,559)	47.9	55.0	53.4	47.5	20.3	50.4	26.3
3	(559,560)	48.6	55.9	53.3	48.0	20.4	49.0	25.7
4	(560,562)	50.6	56.7	56.1	51.0	20.2	54.9	27.7
5	(562,563)	44.3	57.0	56.3	45.5	19.3	55.0	27.0
6	(563,564)	42.6	57.1	55.7	44.3	20.6	52.3	28.6
7	(564,565)	40.7	57.0	54.2	42.2	27.3	49.0	47.1
8	(565,566)	40.9	56.0	55.4	43.7	35.2	54.3	53.1
9	(566,567)	31.1	56.7	55.1	36.5	30.6	51.8	53.9
10	(567,569)	28.0	57.5	55.3	34.2	28.6	51.4	54.8
11	(569,570)	27.2	57.5	56.9	33.4	30.3	55.3	56.4
12	(570,571)	23.5	56.4	52.3	27.5	28.9	44.2	49.0
13	(571,572)	23.6	46.8	41.8	25.7	29.5	32.1	38.9
14	(572,574)	29.1	54.6	52.4	32.6	40.1	46.4	51.2
15	(574,575)	25.8	56.6	54.1	29.9	38.5	49.6	53.9
16	(575,577)	29.6	56.3	54.7	33.0	41.3	53.1	55.1
17	(577,578)	28.6	55.3	53.9	31.7	41.9	51.1	53.8
18	(578,342)	25.5	55.3	53.9	28.7	39.7	50.9	53.9
19	(342,341)	24.8	55.5	53.6	26.3	39.1	52.5	54.4
20	(341,340)	17.6	57.4	52.0	20.0	31.0	49.0	53.9
21	(340,338)	16.9	57.5	50.9	19.5	27.9	51.3	54.9
22	(338,337)	15.8	56.0	43.0	17.6	22.2	35.2	45.8
23	(337,336)	17.7	41.8	33.4	18.7	21.5	25.5	34.1
24	(336,335)	21.8	49.8	42.4	23.3	27.9	36.2	44.2
25	(335,334)	21.9	53.9	45.4	23.8	28.5	40.3	48.0
26	(334,333)	23.8	55.3	46.0	25.0	29.7	40.8	48.9
27	(333,331)	23.8	55.3	45.0	24.7	29.4	38.7	48.0
28	(331,330)	21.6	55.1	41.8	20.5	27.1	33.8	44.7
29	(330,329)	17.4	57.1	34.7	17.5	21.7	24.9	38.8
30	(329,328)	16.6	57.3	32.0	17.0	19.3	21.2	35.5
31	(328,327)	16.3	55.7	30.5	16.5	18.1	18.9	32.6
32	(327,326)	19.6	41.3	30.1	19.9	21.0	21.1	30.6
33	(326,325)	29.9	49.1	41.6	30.4	32.0	33.6	42.1
34	(325,324)	31.2	53.3	45.9	31.8	35.2	39.3	47.1
35	(324,323)	28.6	55.2	47.8	29.8	34.5	41.5	49.0
36	(323,322)	28.1	55.8	48.5	28.5	34.5	41.3	49.2
37	(322,321)	26.7	56.0	47.6	27.0	32.8	40.4	48.6
38	(321,317)	32.5	54.3	45.1	32.6	35.5	38.7	46.4
39	(317,316)	49.2	51.9	50.6	49.1	43.4	49.7	49.2
40	(316,315)	53.8	56.7	55.3	53.8	50.0	53.5	53.7
41	(315,314)	55.0	57.3	56.2	55.0	51.8	54.5	55.5
42	(314,313)	55.5	57.3	56.5	55.3	52.2	55.2	56.2
43	(313,312)	55.3	57.2	56.2	55.0	51.9	54.7	56.1
44	(312,311)	51.4	54.7	53.3	50.9	48.2	51.1	53.0
45	(311,310)	51.5	56.3	54.4	50.5	48.8	51.6	54.4
46	(310,307)	55.4	57.0	56.4	55.4	55.1	55.5	56.3
47	(307,1)	49.6	57.0	55.2	49.5	49.9	51.8	55.1
48	(1,2)	56.0	57.2	56.7	56.0	55.9	56.0	56.7
	Average =	33.5	54.7	49.3	34.8	33.4	44.8	46.3

Table A4 Changes in Delays for All Scenarios at 8:30 AM (End of Period 2)

LINK ID	LINK	Scenario												
		1	2		3		4		5		6		7	
1	(554,555)	13.8	7.0	-49%	6.7	-51%	13.9	1%	47.0	242%	27.1	97%	26.0	89%
2	(555,559)	1.3	0.5	-62%	0.7	-49%	1.4	5%	11.0	743%	7.5	478%	6.7	412%
3	(559,560)	1.2	0.4	-67%	0.6	-48%	1.3	7%	10.8	782%	8.0	554%	7.0	472%
4	(560,562)	4.7	1.4	-70%	1.7	-65%	4.4	-6%	49.9	952%	35.8	656%	28.4	500%
5	(562,563)	2.1	0.3	-85%	0.3	-84%	1.8	-13%	11.8	472%	8.7	321%	6.5	217%
6	(563,564)	2.3	0.3	-87%	0.4	-83%	2.1	-11%	10.3	342%	7.9	241%	5.7	146%
7	(564,565)	2.1	0.2	-90%	0.4	-79%	2.0	-6%	5.0	138%	3.1	47%	1.1	-47%
8	(565,566)	11.0	1.5	-86%	1.8	-84%	9.9	-10%	15.7	43%	13.8	26%	2.8	-74%
9	(566,567)	5.1	0.3	-94%	0.5	-91%	4.2	-18%	5.0	-1%	4.2	-18%	0.6	-88%
10	(567,569)	6.7	0.3	-96%	0.5	-92%	5.1	-23%	6.2	-8%	5.4	-20%	0.5	-92%
11	(569,570)	20.7	0.7	-97%	0.9	-96%	15.3	-26%	16.4	-21%	16.4	-21%	1.1	-95%
12	(570,571)	6.6	0.3	-95%	0.6	-90%	5.3	-19%	4.5	-31%	4.5	-31%	1.0	-85%
13	(571,572)	7.4	1.4	-81%	2.1	-72%	6.5	-12%	4.9	-34%	5.6	-25%	2.6	-65%
14	(572,574)	18.8	1.8	-91%	2.6	-86%	15.4	-18%	8.8	-53%	8.9	-53%	3.1	-84%
15	(574,575)	9.4	0.4	-96%	0.8	-92%	7.4	-22%	4.0	-57%	3.4	-64%	0.8	-91%
16	(575,577)	18.0	1.2	-94%	1.7	-91%	14.5	-19%	7.9	-56%	7.8	-56%	1.6	-91%
17	(577,578)	7.1	0.5	-93%	0.7	-90%	6.0	-17%	2.9	-60%	3.0	-59%	0.8	-89%
18	(578,342)	6.0	0.4	-93%	0.5	-92%	5.0	-17%	2.3	-61%	2.2	-62%	0.5	-92%
19	(342,341)	4.8	0.2	-95%	0.4	-92%	4.4	-8%	1.8	-62%	1.7	-65%	0.3	-93%
20	(341,340)	11.5	0.2	-98%	0.8	-93%	9.8	-15%	4.6	-60%	3.7	-68%	0.5	-95%
21	(340,338)	28.3	0.5	-98%	2.2	-92%	23.3	-18%	13.2	-53%	10.7	-62%	1.0	-96%
22	(338,337)	18.1	0.5	-97%	2.6	-85%	15.6	-14%	11.3	-37%	8.0	-56%	2.1	-88%
23	(337,336)	10.0	1.9	-81%	3.4	-66%	9.3	-8%	7.6	-24%	5.5	-46%	3.2	-68%
24	(336,335)	9.5	1.1	-88%	2.3	-76%	8.6	-10%	6.4	-33%	4.1	-57%	2.0	-79%
25	(335,334)	10.0	0.7	-93%	1.9	-81%	8.8	-12%	6.5	-35%	3.7	-63%	1.5	-85%
26	(334,333)	8.3	0.5	-94%	1.7	-79%	7.6	-8%	5.7	-31%	3.3	-60%	1.2	-85%
27	(333,331)	19.9	1.1	-94%	4.5	-78%	18.7	-6%	13.9	-30%	8.0	-60%	3.3	-83%
28	(331,330)	11.8	0.5	-96%	2.9	-76%	12.7	8%	8.2	-30%	5.1	-56%	2.2	-81%
29	(330,329)	21.3	0.4	-98%	6.4	-70%	21.1	-1%	15.7	-27%	10.8	-50%	4.9	-77%
30	(329,328)	18.3	0.3	-98%	6.2	-66%	17.8	-3%	15.0	-18%	10.0	-45%	4.9	-73%
31	(328,327)	17.6	0.5	-97%	6.4	-64%	17.3	-2%	15.4	-13%	10.5	-40%	5.5	-69%
32	(327,326)	9.1	2.0	-78%	4.4	-52%	8.9	-3%	8.3	-10%	6.2	-32%	4.2	-54%
33	(326,325)	5.4	1.2	-78%	2.4	-56%	5.2	-4%	4.8	-12%	3.3	-40%	2.3	-58%
34	(325,324)	5.3	0.7	-86%	1.8	-66%	5.1	-4%	4.1	-22%	2.4	-55%	1.6	-70%
35	(324,323)	6.4	0.5	-92%	1.5	-77%	5.7	-10%	4.5	-30%	2.0	-69%	1.3	-80%
36	(323,322)	5.3	0.4	-93%	1.1	-79%	5.1	-4%	3.6	-33%	1.7	-69%	1.0	-81%
37	(322,321)	7.7	0.4	-94%	1.6	-79%	7.5	-3%	5.3	-31%	2.4	-69%	1.4	-81%
38	(321,317)	25.4	3.1	-88%	9.9	-61%	25.2	-1%	21.2	-17%	13.2	-48%	8.8	-66%
39	(317,316)	1.4	1.0	-33%	1.2	-17%	1.4	0%	2.7	85%	1.4	0%	1.4	-1%
40	(316,315)	0.6	0.3	-50%	0.5	-23%	0.6	0%	1.1	80%	0.7	17%	0.6	3%
41	(315,314)	0.4	0.2	-50%	0.3	-25%	0.4	5%	0.8	95%	0.4	10%	0.4	-5%
42	(314,313)	0.4	0.2	-50%	0.3	-25%	0.4	0%	0.8	90%	0.4	-5%	0.3	-25%
43	(313,312)	0.4	0.2	-50%	0.3	-25%	0.4	0%	0.8	95%	0.5	25%	0.3	-25%
44	(312,311)	0.9	0.5	-43%	0.7	-25%	0.9	7%	1.4	57%	1.0	11%	0.7	-20%
45	(311,310)	1.2	0.5	-58%	0.7	-38%	1.3	12%	1.7	43%	1.2	3%	0.8	-37%
46	(310,307)	2.5	1.6	-36%	2.0	-22%	2.6	2%	2.7	8%	2.3	-7%	2.0	-19%
47	(307,1)	0.9	0.2	-77%	0.3	-60%	0.8	-2%	0.8	-5%	0.5	-40%	0.4	-58%
48	(1,2)	0.3	0.2	0%	0.2	0%	0.3	0%	0.3	0%	0.3	0%	0.3	0%
	Average			**-81%**		**-68%**		**-7%**		**70%**		**20%**		**-19%**

Table A5. Average Speed for All Scenarios at 9:30 AM (End of Period 3)

LINK ID	LINK	Scenario 1	2	3	4	5	6	7
1	(554,555)	27.5	41.8	40.3	28.2	14.8	20.7	25.7
2	(555,559)	37.6	55.0	52.1	40.5	18.2	21.6	29.5
3	(559,560)	36.4	55.9	52.1	40.3	18.3	20.9	28.7
4	(560,562)	36.1	56.6	55.0	40.5	18.2	21.6	31.4
5	(562,563)	31.0	57.0	52.6	36.0	17.8	20.3	30.2
6	(563,564)	30.2	57.1	53.8	35.0	18.9	20.8	31.7
7	(564,565)	29.8	57.0	52.5	34.0	22.9	26.7	46.3
8	(565,566)	29.2	55.9	54.4	33.8	26.4	27.7	50.7
9	(566,567)	23.1	56.7	54.2	26.0	22.5	24.1	49.7
10	(567,569)	20.8	57.5	53.1	23.8	20.9	22.3	49.4
11	(569,570)	21.2	57.5	56.5	23.8	22.5	21.5	50.6
12	(570,571)	19.3	56.4	50.2	21.2	21.9	22.1	40.9
13	(571,572)	21.0	46.8	39.1	22.0	24.2	22.5	34.0
14	(572,574)	25.8	54.6	51.2	27.6	31.5	31.4	47.2
15	(574,575)	22.6	56.5	52.8	24.9	28.8	29.6	47.7
16	(575,577)	27.0	56.3	53.4	29.1	33.6	32.2	47.9
17	(577,578)	26.2	55.3	52.6	28.3	33.5	32.1	46.4
18	(578,342)	23.1	55.4	52.7	25.3	30.7	31.4	46.2
19	(342,341)	22.7	55.5	52.3	23.2	30.2	30.4	47.0
20	(341,340)	16.1	57.4	48.5	17.4	22.8	24.5	41.2
21	(340,338)	15.8	57.6	46.9	17.3	21.6	21.1	39.7
22	(338,337)	15.0	56.0	37.3	16.2	18.9	20.7	31.9
23	(337,336)	17.3	41.8	29.5	17.9	19.9	22.6	28.6
24	(336,335)	20.8	49.9	38.3	21.8	25.0	29.1	37.4
25	(335,334)	21.1	54.0	41.1	22.3	25.6	30.1	40.0
26	(334,333)	23.0	55.3	41.9	23.7	26.9	31.4	41.2
27	(333,331)	23.0	55.4	41.4	23.6	26.8	31.6	40.7
28	(331,330)	20.9	55.1	38.4	19.6	24.6	28.7	37.5
29	(330,329)	16.8	57.2	31.5	16.9	19.7	22.8	31.4
30	(329,328)	16.2	57.3	28.4	16.6	18.1	21.6	29.1
31	(328,327)	16.1	55.8	26.3	16.2	17.3	20.6	27.2
32	(327,326)	19.4	41.6	26.9	19.8	20.4	23.2	27.4
33	(326,325)	29.5	49.2	39.0	30.0	31.0	35.2	39.4
34	(325,324)	30.4	53.3	43.8	31.0	33.5	39.7	44.5
35	(324,323)	27.9	55.2	45.7	28.6	31.8	40.2	46.2
36	(323,322)	27.1	55.8	46.2	27.7	31.3	39.1	46.2
37	(322,321)	25.4	56.0	45.3	26.2	29.5	37.2	45.1
38	(321,317)	31.9	54.3	42.8	32.2	34.0	38.5	43.3
39	(317,316)	49.2	51.9	50.3	49.1	44.4	49.0	49.2
40	(316,315)	53.8	56.7	54.9	53.7	50.8	53.2	53.7
41	(315,314)	55.0	57.3	55.9	55.0	52.5	55.0	55.5
42	(314,313)	55.4	57.3	56.0	55.3	52.9	55.3	55.0
43	(313,312)	55.3	57.2	55.3	55.0	52.6	52.5	54.8
44	(312,311)	51.3	54.7	51.2	50.9	48.9	49.5	50.3
45	(311,310)	51.3	56.2	53.2	50.4	49.0	50.1	52.7
46	(310,307)	55.4	57.0	56.1	55.3	55.2	55.7	56.0
47	(307,1)	49.3	57.0	53.9	49.2	49.5	51.9	53.6
48	(1,2)	56.0	57.2	56.5	56.0	55.9	56.3	56.5
	Average =	30.3	54.7	47.2	31.6	30.1	32.6	42.4

Table A6. Changes in Delays for All Scenarios at 9:30 AM (End of Period 3)

LINK ID	LINK	Scenario												
		1	2		3		4		5		6		7	
1	(554,555)	20.1	7.0	-65%	7.9	-61%	19.1	-5%	51.2	154%	31.5	56%	22.0	9%
2	(555,559)	3.2	0.5	-84%	0.8	-76%	2.7	-16%	12.3	281%	9.3	189%	5.4	68%
3	(559,560)	3.6	0.4	-89%	0.8	-78%	2.8	-22%	12.1	238%	9.7	172%	5.7	59%
4	(560,562)	17.3	1.4	-92%	2.2	-87%	13.3	-23%	56.1	225%	43.3	151%	22.4	30%
5	(562,563)	5.1	0.3	-94%	0.8	-85%	4.0	-22%	12.8	152%	10.3	103%	5.3	4%
6	(563,564)	5.2	0.3	-94%	0.6	-89%	4.2	-19%	11.4	119%	9.7	86%	4.7	-10%
7	(564,565)	4.3	0.2	-95%	0.6	-86%	3.6	-16%	6.7	57%	5.2	21%	1.3	-70%
8	(565,566)	23.8	1.5	-94%	2.2	-91%	19.6	-18%	28.2	18%	25.9	9%	4.3	-82%
9	(566,567)	8.6	0.3	-97%	0.6	-93%	7.6	-12%	8.8	3%	7.8	-9%	1.2	-86%
10	(567,569)	10.7	0.3	-98%	0.7	-93%	9.1	-15%	10.5	-1%	9.5	-11%	1.4	-87%
11	(569,570)	30.7	0.7	-98%	1.1	-97%	26.4	-14%	27.7	-10%	29.9	-3%	3.7	-88%
12	(570,571)	8.9	0.3	-97%	0.8	-91%	7.9	-11%	7.3	-18%	7.2	-19%	2.1	-76%
13	(571,572)	8.9	1.4	-85%	2.6	-71%	8.3	-7%	7.1	-21%	8.0	-11%	3.7	-59%
14	(572,574)	23.6	1.8	-93%	3.0	-87%	21.0	-11%	16.0	-32%	16.1	-32%	4.9	-79%
15	(574,575)	11.6	0.4	-96%	1.0	-92%	10.1	-13%	7.6	-34%	7.2	-38%	1.9	-84%
16	(575,577)	21.2	1.2	-95%	2.2	-90%	18.6	-12%	13.7	-36%	15.0	-29%	4.5	-79%
17	(577,578)	8.4	0.5	-94%	0.9	-89%	7.3	-12%	5.1	-39%	5.6	-33%	2.0	-77%
18	(578,342)	7.0	0.4	-94%	0.6	-91%	6.1	-13%	4.2	-40%	4.0	-43%	1.4	-81%
19	(342,341)	5.5	0.2	-96%	0.4	-92%	5.4	-2%	3.3	-40%	3.2	-42%	0.9	-83%
20	(341,340)	13.1	0.2	-98%	1.2	-91%	11.8	-9%	7.9	-40%	6.9	-47%	2.3	-82%
21	(340,338)	31.1	0.5	-98%	3.7	-88%	27.4	-12%	19.9	-36%	20.4	-34%	6.1	-81%
22	(338,337)	19.3	0.5	-98%	4.2	-78%	17.4	-10%	14.2	-27%	12.2	-37%	5.7	-70%
23	(337,336)	10.4	1.8	-82%	4.4	-58%	9.9	-5%	8.5	-18%	7.0	-33%	4.6	-56%
24	(336,335)	10.3	1.1	-89%	3.2	-69%	9.5	-7%	7.7	-25%	5.8	-44%	3.3	-68%
25	(335,334)	10.7	0.7	-94%	2.8	-74%	9.8	-8%	7.8	-27%	5.8	-46%	2.9	-73%
26	(334,333)	8.8	0.5	-95%	2.5	-72%	8.3	-5%	6.8	-23%	5.0	-43%	2.5	-72%
27	(333,331)	21.0	1.1	-95%	6.2	-71%	20.2	-4%	16.4	-22%	11.8	-44%	6.2	-70%
28	(331,330)	12.4	0.5	-96%	3.8	-69%	13.6	10%	9.6	-22%	7.2	-42%	3.9	-68%
29	(330,329)	22.3	0.4	-98%	8.1	-64%	22.1	-1%	18.0	-19%	14.2	-36%	8.0	-64%
30	(329,328)	19.0	0.3	-98%	7.9	-59%	18.4	-3%	16.4	-14%	12.5	-34%	7.5	-61%
31	(328,327)	18.0	0.5	-97%	8.4	-53%	17.7	-2%	16.3	-10%	12.6	-30%	7.9	-56%
32	(327,326)	9.2	2.0	-78%	5.4	-41%	9.0	-3%	8.6	-7%	7.0	-24%	5.3	-43%
33	(326,325)	5.5	1.2	-79%	2.9	-48%	5.4	-3%	5.1	-9%	3.8	-32%	2.8	-49%
34	(325,324)	5.6	0.7	-87%	2.1	-62%	5.4	-4%	4.6	-17%	2.9	-47%	2.0	-64%
35	(324,323)	6.6	0.5	-92%	1.8	-73%	6.2	-6%	5.2	-21%	2.8	-57%	1.7	-74%
36	(323,322)	5.7	0.4	-94%	1.4	-75%	5.4	-4%	4.4	-23%	2.5	-56%	1.4	-75%
37	(322,321)	8.3	0.4	-95%	2.0	-76%	7.9	-5%	6.4	-23%	3.8	-55%	2.0	-76%
38	(321,317)	26.3	3.1	-88%	12.0	-54%	25.9	-2%	23.1	-12%	16.8	-36%	11.5	-56%
39	(317,316)	1.4	1.0	-31%	1.3	-11%	1.5	3%	2.4	70%	1.5	3%	1.4	0%
40	(316,315)	0.6	0.3	-50%	0.5	-20%	0.6	0%	0.9	57%	0.7	13%	0.6	3%
41	(315,314)	0.4	0.2	-50%	0.3	-20%	0.4	0%	0.7	75%	0.4	5%	0.4	0%
42	(314,313)	0.4	0.2	-50%	0.3	-20%	0.4	0%	0.7	70%	0.4	5%	0.4	10%
43	(313,312)	0.4	0.2	-50%	0.4	-10%	0.4	0%	0.7	70%	0.6	60%	0.4	5%
44	(312,311)	0.9	0.5	-44%	0.9	2%	0.9	4%	1.2	38%	1.1	27%	1.0	13%
45	(311,310)	1.2	0.5	-60%	0.9	-26%	1.4	11%	1.7	35%	1.4	16%	1.0	-19%
46	(310,307)	2.5	1.6	-35%	2.1	-16%	2.6	2%	2.7	5%	2.4	-6%	2.2	-14%
47	(307,1)	0.9	0.2	-77%	0.5	-47%	0.9	5%	0.9	0%	0.6	-28%	0.5	-44%
48	(1,2)	0.3	0.2	-33%	0.3	0%	0.3	0%	0.3	0%	0.3	0%	0.3	0%
	Average			**-83%**		**-64%**		**-7%**		**21%**		**-3%**		**-45%**

Table A7. Link-by-Link Results for the First Scenario at Time 6:30 AM

LINK ID	LINK	Total Time (Sec/Veh)	Delay Time (Sec/Veh)	Speed (Mile/hr)
1	(554,555)	26.4	9.7	37.6
2	(555,559)	6.3	1.3	48.2
3	(559,560)	6.3	1.2	48.8
4	(560,562)	26.2	2.3	54.9
5	(562,563)	5.8	0.6	53.5
6	(563,564)	6.0	0.9	51.3
7	(564,565)	5.0	0.9	49.0
8	(565,566)	24.6	2.3	54.2
9	(566,567)	6.1	0.8	51.8
10	(567,569)	6.5	0.9	51.4
11	(569,570)	17.9	1.3	55.7
12	(570,571)	5.3	1.1	47.4
13	(571,572)	8.5	3.4	35.1
14	(572,574)	21.9	4.3	48.2
15	(574,575)	8.4	1.4	50.0
16	(575,577)	20.5	3.2	50.8
17	(577,578)	7.5	1.1	51.5
18	(578,342)	5.0	0.6	52.6
19	(342,341)	3.8	0.4	52.4
20	(341,340)	6.5	1.8	44.0
21	(340,338)	18.8	7.7	35.8
22	(338,337)	15.4	8.9	25.3
23	(337,336)	12.0	7.2	22.0
24	(336,335)	10.6	5.2	30.6
25	(335,334)	11.0	5.2	31.6
26	(334,333)	10.2	4.7	32.3
27	(333,331)	24.8	11.7	31.9
28	(331,330)	13.9	7.2	28.9
29	(330,329)	23.2	14.5	22.6
30	(329,328)	21.2	14.2	19.8
31	(328,327)	21.9	15.4	18.0
32	(327,326)	13.6	8.4	20.6
33	(326,325)	9.9	4.6	32.3
34	(325,324)	9.7	3.9	35.8
35	(324,323)	9.4	3.7	37.0
36	(323,322)	7.7	3.1	37.3
37	(322,321)	10.3	4.2	37.2
38	(321,317)	49.0	19.1	36.9
39	(317,316)	8.4	1.3	49.6
40	(316,315)	5.7	0.6	53.9
41	(315,314)	5.1	0.4	55.1
42	(314,313)	5.1	0.4	55.5
43	(313,312)	4.8	0.4	55.4
44	(312,311)	6.1	0.9	51.5
45	(311,310)	8.2	1.0	52.6
46	(310,307)	33.1	2.5	55.4
47	(307,1)	4.6	0.6	52.0
48	(1,2)	4.5	0.3	56.0
	Average =			**42.9**
	Total =	**603.0**	**197.1**	

Table A8. Link-by-Link Results for the Second Scenario at Time 6:30 AM

LINK ID	LINK	Total Time (Sec/Veh)	Delay Time (Sec/Veh)	Speed (Mile/hr)	Delay Difference
1	(554,555)	23.7	7.0	41.7	-27%
2	(555,559)	5.6	0.5	55.1	-62%
3	(559,560)	5.5	0.4	56.1	-67%
4	(560,562)	25.3	1.4	56.8	-38%
5	(562,563)	5.5	0.3	57.1	-52%
6	(563,564)	5.4	0.3	57.2	-66%
7	(564,565)	4.3	0.2	57.1	-79%
8	(565,566)	23.8	1.5	56.0	-36%
9	(566,567)	5.6	0.3	56.7	-64%
10	(567,569)	5.8	0.2	57.6	-77%
11	(569,570)	17.3	0.7	57.6	-45%
12	(570,571)	4.5	0.3	56.5	-77%
13	(571,572)	6.3	1.4	46.9	-59%
14	(572,574)	19.3	1.7	54.7	-60%
15	(574,575)	7.4	0.4	56.6	-72%
16	(575,577)	18.5	1.1	56.4	-64%
17	(577,578)	7.0	0.5	55.6	-53%
18	(578,342)	4.7	0.3	55.7	-48%
19	(342,341)	3.6	0.2	55.8	-55%
20	(341,340)	5.0	0.2	57.5	-89%
21	(340,338)	11.5	0.5	57.6	-93%
22	(338,337)	6.9	0.5	56.0	-95%
23	(337,336)	6.4	1.9	41.6	-74%
24	(336,335)	6.6	1.1	49.7	-79%
25	(335,334)	6.4	0.7	53.9	-87%
26	(334,333)	5.9	0.5	55.3	-90%
27	(333,331)	14.1	1.1	55.5	-90%
28	(331,330)	7.2	0.5	55.2	-93%
29	(330,329)	9.1	0.4	57.2	-97%
30	(329,328)	7.3	0.3	57.3	-98%
31	(328,327)	7.1	0.5	55.6	-96%
32	(327,326)	6.7	1.9	41.9	-77%
33	(326,325)	6.5	1.2	49.2	-74%
34	(325,324)	6.4	0.7	53.4	-82%
35	(324,323)	6.2	0.5	55.2	-87%
36	(323,322)	5.0	0.3	55.8	-89%
37	(322,321)	6.5	0.4	56.0	-90%
38	(321,317)	32.8	3.0	54.6	-84%
39	(317,316)	8.1	1.0	51.8	-24%
40	(316,315)	5.4	0.3	56.8	-46%
41	(315,314)	4.9	0.2	57.3	-52%
42	(314,313)	4.9	0.2	57.4	-50%
43	(313,312)	4.6	0.2	57.2	-50%
44	(312,311)	5.8	0.5	54.8	-41%
45	(311,310)	7.7	0.5	56.3	-50%
46	(310,307)	32.1	1.6	57.1	-36%
47	(307,1)	4.2	0.2	57.1	-68%
48	(1,2)	4.4	0.2	57.3	-33%
	Average =			**54.8**	**-67%**
	Total =	**444.8**	**40.0**		

Table A9. Link-by-Link Results for the Third Scenario at Time 6:30 AM

LINK ID	LINK	Total Time (Sec/Veh)	Delay Time (Sec/Veh)	Speed (Mile/hr)	Delay Difference
1	(554,555)	23.5	6.8	42.2	-30%
2	(555,559)	6.1	1.0	50.2	-21%
3	(559,560)	6.3	1.2	48.7	0%
4	(560,562)	26.2	2.2	55.0	-3%
5	(562,563)	5.7	0.5	54.8	-23%
6	(563,564)	5.8	0.7	53.2	-25%
7	(564,565)	5.0	0.9	49.4	-4%
8	(565,566)	24.5	2.3	54.2	-3%
9	(566,567)	6.1	0.8	52.0	-5%
10	(567,569)	6.6	1.0	51.3	2%
11	(569,570)	18.0	1.3	55.6	3%
12	(570,571)	5.5	1.3	46.1	16%
13	(571,572)	8.5	3.4	34.8	1%
14	(572,574)	21.8	4.1	48.6	-4%
15	(574,575)	8.5	1.4	49.8	0%
16	(575,577)	20.1	2.8	51.7	-12%
17	(577,578)	7.5	1.1	51.4	2%
18	(578,342)	5.1	0.7	51.5	19%
19	(342,341)	4.0	0.6	50.8	36%
20	(341,340)	6.6	1.8	45.3	3%
21	(340,338)	16.0	4.9	44.0	-36%
22	(338,337)	12.9	6.4	31.3	-28%
23	(337,336)	11.0	6.3	24.2	-13%
24	(336,335)	10.0	4.5	33.5	-13%
25	(335,334)	10.1	4.3	35.6	-17%
26	(334,333)	9.4	4.0	36.0	-15%
27	(333,331)	23.7	10.7	34.0	-9%
28	(331,330)	13.9	7.2	29.0	1%
29	(330,329)	25.6	16.9	20.5	17%
30	(329,328)	23.2	16.2	18.2	14%
31	(328,327)	22.9	16.3	17.2	6%
32	(327,326)	13.9	8.7	20.1	3%
33	(326,325)	9.8	4.5	32.6	-3%
34	(325,324)	9.3	3.6	36.9	-9%
35	(324,323)	8.8	3.1	38.8	-16%
36	(323,322)	7.1	2.5	39.9	-20%
37	(322,321)	9.7	3.6	38.9	-14%
38	(321,317)	48.7	18.8	37.1	-2%
39	(317,316)	8.5	1.4	49.4	3%
40	(316,315)	5.8	0.6	53.4	14%
41	(315,314)	5.1	0.4	54.8	5%
42	(314,313)	5.1	0.4	55.3	0%
43	(313,312)	4.8	0.4	54.9	5%
44	(312,311)	6.2	0.9	51.0	5%
45	(311,310)	8.4	1.2	51.2	24%
46	(310,307)	33.1	2.6	55.4	2%
47	(307,1)	4.6	0.6	51.9	3%
48	(1,2)	4.5	0.3	56.0	0%
	Average =			**43.7**	**-3%**
	Total =	**593.8**	**187.5**		

Table A10. Link-by-Link Results for the Fourth Scenario at Time 6:30 AM

LINK ID	LINK	Total Time (Sec/Veh)	Delay Time (Sec/Veh)	Speed (Mile/hr)	Delay Difference
1	(554,555)	26.5	9.9	37.4	2%
2	(555,559)	6.3	1.3	48.2	0%
3	(559,560)	6.3	1.2	48.9	-3%
4	(560,562)	26.2	2.3	54.9	0%
5	(562,563)	5.9	0.7	53.0	10%
6	(563,564)	6.0	0.9	51.4	-2%
7	(564,565)	5.1	1.0	49.0	2%
8	(565,566)	24.5	2.3	54.3	-2%
9	(566,567)	6.0	0.8	52.6	-10%
10	(567,569)	6.6	1.0	50.7	11%
11	(569,570)	17.9	1.3	55.7	2%
12	(570,571)	5.4	1.2	47.0	5%
13	(571,572)	8.5	3.4	35.2	-1%
14	(572,574)	21.9	4.2	48.5	-1%
15	(574,575)	8.2	1.2	51.2	-14%
16	(575,577)	20.2	2.9	51.4	-8%
17	(577,578)	7.5	1.1	51.4	4%
18	(578,342)	5.0	0.6	52.8	-6%
19	(342,341)	3.8	0.4	53.0	-5%
20	(341,340)	5.7	1.0	50.6	-46%
21	(340,338)	13.6	2.6	50.3	-66%
22	(338,337)	10.7	4.3	37.7	-52%
23	(337,336)	10.1	5.4	26.3	-25%
24	(336,335)	9.0	3.5	36.8	-32%
25	(335,334)	8.9	3.1	39.6	-40%
26	(334,333)	8.5	3.0	39.0	-36%
27	(333,331)	21.1	8.0	37.6	-31%
28	(331,330)	13.2	6.5	30.8	-10%
29	(330,329)	22.2	13.5	23.9	-7%
30	(329,328)	20.6	13.6	20.8	-4%
31	(328,327)	21.3	14.7	18.6	-4%
32	(327,326)	13.3	8.1	21.2	-4%
33	(326,325)	9.6	4.3	33.4	-7%
34	(325,324)	9.0	3.3	38.3	-16%
35	(324,323)	8.7	3.0	39.7	-19%
36	(323,322)	7.2	2.6	39.1	-16%
37	(322,321)	9.8	3.7	37.8	-12%
38	(321,317)	48.5	18.7	37.1	-2%
39	(317,316)	8.5	1.4	49.6	3%
40	(316,315)	5.7	0.6	54.2	0%
41	(315,314)	5.0	0.4	55.4	-5%
42	(314,313)	5.1	0.4	55.8	-10%
43	(313,312)	4.8	0.4	55.5	-10%
44	(312,311)	6.1	0.9	51.6	0%
45	(311,310)	8.4	1.2	51.6	18%
46	(310,307)	33.0	2.5	55.6	-2%
47	(307,1)	4.6	0.7	51.6	6%
48	(1,2)	4.5	0.3	56.0	0%
	Average =			**44.6**	**-9%**
	Total =	**574.6**	**168.9**		

Table A11. Link-by-Link Results for the Fifth Scenario at Time 6:30 AM

LINK ID	LINK	Total Time (Sec/Veh)	Delay Time (Sec/Veh)	Speed (Mile/hr)	Delay Difference
1	(554,555)	26.2	9.5	37.8	-1%
2	(555,559)	6.3	1.2	48.3	-3%
3	(559,560)	6.3	1.2	48.8	0%
4	(560,562)	26.2	2.2	54.9	-1%
5	(562,563)	5.8	0.6	53.6	0%
6	(563,564)	6.0	0.9	51.3	0%
7	(564,565)	5.0	0.9	48.9	0%
8	(565,566)	24.6	2.3	54.2	0%
9	(566,567)	6.1	0.9	51.7	2%
10	(567,569)	6.5	0.9	51.3	0%
11	(569,570)	17.9	1.3	55.7	2%
12	(570,571)	5.3	1.1	47.5	0%
13	(571,572)	8.4	3.4	35.3	-1%
14	(572,574)	21.8	4.2	48.5	-3%
15	(574,575)	8.4	1.4	50.2	-1%
16	(575,577)	20.5	3.2	50.9	-1%
17	(577,578)	7.5	1.1	51.6	0%
18	(578,342)	5.0	0.6	52.7	0%
19	(342,341)	3.8	0.4	52.8	-5%
20	(341,340)	6.3	1.5	45.7	-13%
21	(340,338)	17.7	6.7	38.6	-13%
22	(338,337)	14.9	8.4	26.2	-6%
23	(337,336)	11.8	7.1	22.3	-2%
24	(336,335)	10.6	5.2	30.8	-1%
25	(335,334)	10.9	5.1	31.8	-1%
26	(334,333)	10.2	4.7	32.4	-1%
27	(333,331)	24.4	11.3	32.3	-3%
28	(331,330)	13.7	7.0	29.4	-3%
29	(330,329)	22.8	14.1	23.0	-2%
30	(329,328)	21.2	14.2	19.9	-1%
31	(328,327)	21.8	15.3	18.0	-1%
32	(327,326)	13.7	8.5	20.6	0%
33	(326,325)	10.0	4.7	31.9	2%
34	(325,324)	9.7	4.0	35.7	1%
35	(324,323)	9.4	3.7	36.9	0%
36	(323,322)	7.7	3.1	37.2	0%
37	(322,321)	10.5	4.5	36.0	5%
38	(321,317)	50.0	20.2	36.1	6%
39	(317,316)	8.4	1.3	49.7	0%
40	(316,315)	5.7	0.6	54.0	0%
41	(315,314)	5.1	0.4	55.1	0%
42	(314,313)	5.1	0.4	55.6	0%
43	(313,312)	4.8	0.4	55.5	0%
44	(312,311)	6.1	0.9	51.7	-2%
45	(311,310)	8.2	1.0	52.7	0%
46	(310,307)	33.1	2.5	55.4	1%
47	(307,1)	4.6	0.6	51.9	0%
48	(1,2)	4.5	0.3	55.9	0%
	Average =			**43.1**	
	Total =	**600.9**	**195.0**		

Table A12. Link-by-Link Results for the Sixth Scenario at Time 6:30 AM

LINK ID	LINK	Total Time (Sec/Veh)	Delay Time (Sec/Veh)	Speed (Mile/hr)	Delay Difference
1	(554,555)	23.8	7.1	41.7	-27%
2	(555,559)	6.1	1.0	50.4	-22%
3	(559,560)	6.3	1.2	49.0	-3%
4	(560,562)	26.2	2.2	54.9	-1%
5	(562,563)	5.7	0.5	55.0	-23%
6	(563,564)	5.9	0.8	52.3	-14%
7	(564,565)	5.0	0.9	49.0	0%
8	(565,566)	24.5	2.3	54.3	-3%
9	(566,567)	6.1	0.8	51.8	-2%
10	(567,569)	6.5	0.9	51.4	0%
11	(569,570)	18.1	1.4	55.3	9%
12	(570,571)	5.8	1.6	44.2	41%
13	(571,572)	9.3	4.2	32.1	24%
14	(572,574)	22.9	5.2	46.4	21%
15	(574,575)	8.5	1.5	49.6	3%
16	(575,577)	19.6	2.2	53.1	-30%
17	(577,578)	7.6	1.1	51.1	6%
18	(578,342)	5.2	0.8	50.9	26%
19	(342,341)	3.8	0.4	52.5	-9%
20	(341,340)	5.8	1.1	49.0	-39%
21	(340,338)	13.1	2.1	51.3	-73%
22	(338,337)	11.4	4.9	35.2	-45%
23	(337,336)	10.4	5.7	25.5	-21%
24	(336,335)	9.1	3.6	36.2	-31%
25	(335,334)	8.7	2.9	40.3	-43%
26	(334,333)	8.1	2.7	40.8	-43%
27	(333,331)	20.5	7.4	38.7	-37%
28	(331,330)	11.9	5.2	33.8	-27%
29	(330,329)	21.5	12.8	24.9	-11%
30	(329,328)	20.0	13.0	21.2	-8%
31	(328,327)	20.9	14.3	18.9	-7%
32	(327,326)	13.3	8.1	21.1	-4%
33	(326,325)	9.6	4.2	33.6	-10%
34	(325,324)	8.8	3.0	39.3	-23%
35	(324,323)	8.3	2.6	41.5	-30%
36	(323,322)	6.8	2.2	41.3	-30%
37	(322,321)	9.2	3.1	40.4	-27%
38	(321,317)	46.4	16.5	38.7	-14%
39	(317,316)	8.4	1.3	49.7	0%
40	(316,315)	5.8	0.6	53.5	14%
41	(315,314)	5.1	0.5	54.5	14%
42	(314,313)	5.1	0.4	55.2	5%
43	(313,312)	4.8	0.4	54.7	10%
44	(312,311)	6.2	0.9	51.1	5%
45	(311,310)	8.3	1.2	51.6	16%
46	(310,307)	33.0	2.5	55.5	-1%
47	(307,1)	4.6	0.6	51.8	3%
48	(1,2)	4.5	0.3	56.0	0%
	Average =			**44.8**	
	Total =	**566.5**	**160.4**		

Table A13. Link-by-Link Results for the Seventh Scenario at Time 6:30 AM

LINK ID	LINK	Total Time (Sec/Veh)	Delay Time (Sec/Veh)	Speed (Mile/hr)	Delay Difference
1	(554,555)	23.8	7.1	41.7	-27%
2	(555,559)	6.1	1.0	50.4	-22%
3	(559,560)	6.3	1.2	49.0	-3%
4	(560,562)	26.2	2.2	54.9	-1%
5	(562,563)	5.7	0.5	55.0	-23%
6	(563,564)	5.9	0.8	52.3	-14%
7	(564,565)	5.0	0.9	49.0	0%
8	(565,566)	24.5	2.3	54.3	-3%
9	(566,567)	6.1	0.8	51.8	-2%
10	(567,569)	6.5	0.9	51.4	0%
11	(569,570)	18.1	1.4	55.3	9%
12	(570,571)	5.8	1.6	44.2	41%
13	(571,572)	9.3	4.2	32.1	24%
14	(572,574)	22.9	5.2	46.4	21%
15	(574,575)	8.5	1.5	49.6	3%
16	(575,577)	19.6	2.2	53.1	-30%
17	(577,578)	7.6	1.1	51.1	6%
18	(578,342)	5.2	0.8	50.9	26%
19	(342,341)	3.8	0.4	52.5	-9%
20	(341,340)	5.8	1.1	49.0	-39%
21	(340,338)	13.1	2.1	51.3	-73%
22	(338,337)	11.4	4.9	35.2	-45%
23	(337,336)	10.4	5.7	25.5	-21%
24	(336,335)	9.1	3.6	36.2	-31%
25	(335,334)	8.7	2.9	40.3	-43%
26	(334,333)	8.1	2.7	40.8	-43%
27	(333,331)	20.5	7.4	38.7	-37%
28	(331,330)	11.9	5.2	33.8	-27%
29	(330,329)	21.5	12.8	24.9	-11%
30	(329,328)	20.0	13.0	21.2	-8%
31	(328,327)	20.9	14.3	18.9	-7%
32	(327,326)	13.3	8.1	21.1	-4%
33	(326,325)	9.6	4.2	33.6	-10%
34	(325,324)	8.8	3.0	39.3	-23%
35	(324,323)	8.3	2.6	41.5	-30%
36	(323,322)	6.8	2.2	41.3	-30%
37	(322,321)	9.2	3.1	40.4	-27%
38	(321,317)	46.4	16.5	38.7	-14%
39	(317,316)	8.4	1.3	49.7	0%
40	(316,315)	5.8	0.6	53.5	14%
41	(315,314)	5.1	0.5	54.5	14%
42	(314,313)	5.1	0.4	55.2	5%
43	(313,312)	4.8	0.4	54.7	10%
44	(312,311)	6.2	0.9	51.1	5%
45	(311,310)	8.3	1.2	51.6	16%
46	(310,307)	33.0	2.5	55.5	-1%
47	(307,1)	4.6	0.6	51.8	3%
48	(1,2)	4.5	0.3	56.0	0%
	Average =			**44.8**	
	Total =	**566.5**	**160.4**		

Table A14. Link-by-Link Results for the First Scenario at Time 8:30 AM

LINK ID	LINK	Total Time (Sec/Veh)	Delay Time (Sec/Veh)	Speed (Mile/hr)
1	(554,555)	30.4	13.8	32.7
2	(555,559)	6.4	1.3	47.9
3	(559,560)	6.3	1.2	48.6
4	(560,562)	28.7	4.7	50.6
5	(562,563)	7.2	2.1	44.3
6	(563,564)	7.4	2.3	42.6
7	(564,565)	6.2	2.1	40.7
8	(565,566)	33.2	11.0	40.9
9	(566,567)	10.3	5.1	31.1
10	(567,569)	12.3	6.7	28.0
11	(569,570)	37.3	20.7	27.2
12	(570,571)	10.8	6.6	23.5
13	(571,572)	12.6	7.4	23.6
14	(572,574)	36.4	18.8	29.1
15	(574,575)	16.4	9.4	25.8
16	(575,577)	35.3	18.0	29.6
17	(577,578)	13.6	7.1	28.6
18	(578,342)	10.3	6.0	25.5
19	(342,341)	8.1	4.8	24.8
20	(341,340)	16.3	11.5	17.6
21	(340,338)	39.3	28.3	16.9
22	(338,337)	24.5	18.1	15.8
23	(337,336)	14.8	10.0	17.7
24	(336,335)	15.0	9.5	21.8
25	(335,334)	15.8	10.0	21.9
26	(334,333)	13.7	8.3	23.8
27	(333,331)	33.0	19.9	23.8
28	(331,330)	18.4	11.8	21.6
29	(330,329)	30.0	21.3	17.4
30	(329,328)	25.3	18.3	16.6
31	(328,327)	24.2	17.6	16.3
32	(327,326)	14.3	9.1	19.6
33	(326,325)	10.7	5.4	29.9
34	(325,324)	11.1	5.3	31.2
35	(324,323)	12.0	6.4	28.6
36	(323,322)	10.0	5.3	28.1
37	(322,321)	13.8	7.7	26.7
38	(321,317)	55.2	25.4	32.5
39	(317,316)	8.5	1.4	49.2
40	(316,315)	5.7	0.6	53.8
41	(315,314)	5.1	0.4	55.0
42	(314,313)	5.1	0.4	55.5
43	(313,312)	4.8	0.4	55.3
44	(312,311)	6.2	0.9	51.4
45	(311,310)	8.4	1.2	51.5
46	(310,307)	33.1	2.5	55.4
47	(307,1)	4.8	0.9	49.6
48	(1,2)	4.5	0.3	56.0
	Average =			**33.5**
	Total =	**812.9**	**407.3**	

Table A15. Link-by-Link Results for the Second Scenario at Time 8:30 AM

LINK ID	LINK	Total Time (Sec/Veh)	Delay Time (Sec/Veh)	Speed (Mile/hr)	Delay Difference
1	(554,555)	23.7	7.0	41.8	-49%
2	(555,559)	5.6	0.5	55.0	-62%
3	(559,560)	5.5	0.4	55.9	-67%
4	(560,562)	25.4	1.4	56.7	-70%
5	(562,563)	5.5	0.3	57.0	-85%
6	(563,564)	5.4	0.3	57.1	-87%
7	(564,565)	4.3	0.2	57.0	-90%
8	(565,566)	23.8	1.5	56.0	-86%
9	(566,567)	5.6	0.3	56.7	-94%
10	(567,569)	5.9	0.3	57.5	-96%
11	(569,570)	17.4	0.7	57.5	-97%
12	(570,571)	4.5	0.3	56.4	-95%
13	(571,572)	6.3	1.4	46.8	-81%
14	(572,574)	19.4	1.8	54.6	-91%
15	(574,575)	7.4	0.4	56.6	-96%
16	(575,577)	18.5	1.2	56.3	-94%
17	(577,578)	7.0	0.5	55.3	-93%
18	(578,342)	4.7	0.4	55.3	-93%
19	(342,341)	3.6	0.2	55.5	-95%
20	(341,340)	5.0	0.2	57.4	-98%
21	(340,338)	11.5	0.5	57.5	-98%
22	(338,337)	6.9	0.5	56.0	-97%
23	(337,336)	6.3	1.9	41.8	-81%
24	(336,335)	6.5	1.1	49.8	-88%
25	(335,334)	6.5	0.7	53.9	-93%
26	(334,333)	5.9	0.5	55.3	-94%
27	(333,331)	14.1	1.1	55.3	-94%
28	(331,330)	7.2	0.5	55.1	-96%
29	(330,329)	9.1	0.4	57.1	-98%
30	(329,328)	7.3	0.3	57.3	-98%
31	(328,327)	7.1	0.5	55.7	-97%
32	(327,326)	6.8	2.0	41.3	-78%
33	(326,325)	6.5	1.2	49.1	-78%
34	(325,324)	6.5	0.7	53.3	-86%
35	(324,323)	6.2	0.5	55.2	-92%
36	(323,322)	5.0	0.4	55.8	-93%
37	(322,321)	6.5	0.4	56.0	-94%
38	(321,317)	32.9	3.1	54.3	-88%
39	(317,316)	8.1	1.0	51.9	-33%
40	(316,315)	5.4	0.3	56.7	-50%
41	(315,314)	4.9	0.2	57.3	-50%
42	(314,313)	4.9	0.2	57.3	-50%
43	(313,312)	4.6	0.2	57.2	-50%
44	(312,311)	5.8	0.5	54.7	-43%
45	(311,310)	7.7	0.5	56.3	-58%
46	(310,307)	32.2	1.6	57.0	-36%
47	(307,1)	4.2	0.2	57.0	-77%
48	(1,2)	4.4	0.2	57.2	
	Average =			**54.7**	**-81%**
	Total =	**445.6**	**40.4**		

Table A16. Link-by-Link Results for the Third Scenario at Time 8:30 AM

LINK ID	LINK	Total Time (Sec/Veh)	Delay Time (Sec/Veh)	Speed (Mile/hr)	Delay Difference
1	(554,555)	23.4	6.7	42.4	-51%
2	(555,559)	5.7	0.7	53.4	-49%
3	(559,560)	5.8	0.6	53.3	-48%
4	(560,562)	25.7	1.7	56.1	-65%
5	(562,563)	5.5	0.3	56.3	-84%
6	(563,564)	5.6	0.4	55.7	-83%
7	(564,565)	4.5	0.4	54.2	-79%
8	(565,566)	24.0	1.8	55.4	-84%
9	(566,567)	5.7	0.5	55.1	-91%
10	(567,569)	6.1	0.5	55.3	-92%
11	(569,570)	17.6	0.9	56.9	-96%
12	(570,571)	4.8	0.6	52.3	-90%
13	(571,572)	7.1	2.1	41.8	-72%
14	(572,574)	20.2	2.6	52.4	-86%
15	(574,575)	7.8	0.8	54.1	-92%
16	(575,577)	19.0	1.7	54.7	-91%
17	(577,578)	7.2	0.7	53.9	-90%
18	(578,342)	4.9	0.5	53.9	-92%
19	(342,341)	3.7	0.4	53.6	-92%
20	(341,340)	5.5	0.8	52.0	-93%
21	(340,338)	13.2	2.2	50.9	-92%
22	(338,337)	9.1	2.6	43.0	-85%
23	(337,336)	7.9	3.4	33.4	-66%
24	(336,335)	7.7	2.3	42.4	-76%
25	(335,334)	7.7	1.9	45.4	-81%
26	(334,333)	7.2	1.7	46.0	-79%
27	(333,331)	17.5	4.5	45.0	-78%
28	(331,330)	9.6	2.9	41.8	-76%
29	(330,329)	15.1	6.4	34.7	-70%
30	(329,328)	13.2	6.2	32.0	-66%
31	(328,327)	12.9	6.4	30.5	-64%
32	(327,326)	9.3	4.4	30.1	-52%
33	(326,325)	7.7	2.4	41.6	-56%
34	(325,324)	7.5	1.8	45.9	-66%
35	(324,323)	7.1	1.5	47.8	-77%
36	(323,322)	5.8	1.1	48.5	-79%
37	(322,321)	7.7	1.6	47.6	-79%
38	(321,317)	39.8	9.9	45.1	-61%
39	(317,316)	8.3	1.2	50.6	-17%
40	(316,315)	5.6	0.5	55.3	-23%
41	(315,314)	5.0	0.3	56.2	-25%
42	(314,313)	5.0	0.3	56.5	-25%
43	(313,312)	4.7	0.3	56.2	-25%
44	(312,311)	5.9	0.7	53.3	-25%
45	(311,310)	7.9	0.7	54.4	-38%
46	(310,307)	32.5	2.0	56.4	-22%
47	(307,1)	4.3	0.3	55.2	-60%
48	(1,2)	4.5	0.2	56.7	
	Average =			**49.3**	**-68%**
	Total =	**499.6**	**94.4**		

Table A17. Link-by-Link Results for the Fourth Scenario at Time 8:30 AM

LINK ID	LINK	Total Time (Sec/Veh)	Delay Time (Sec/Veh)	Speed (Mile/hr)	Delay Difference
1	(554,555)	30.6	13.9	32.3	1%
2	(555,559)	6.5	1.4	47.5	5%
3	(559,560)	6.5	1.3	48.0	7%
4	(560,562)	28.4	4.4	51.0	-6%
5	(562,563)	7.0	1.8	45.5	-13%
6	(563,564)	7.2	2.1	44.3	-11%
7	(564,565)	6.1	2.0	42.2	-6%
8	(565,566)	32.1	9.9	43.7	-10%
9	(566,567)	9.4	4.2	36.5	-18%
10	(567,569)	10.7	5.1	34.2	-23%
11	(569,570)	31.9	15.3	33.4	-26%
12	(570,571)	9.5	5.3	27.5	-19%
13	(571,572)	11.7	6.5	25.7	-12%
14	(572,574)	33.0	15.4	32.6	-18%
15	(574,575)	14.4	7.4	29.9	-22%
16	(575,577)	31.9	14.5	33.0	-19%
17	(577,578)	12.4	6.0	31.7	-17%
18	(578,342)	9.3	5.0	28.7	-17%
19	(342,341)	7.8	4.4	26.3	-8%
20	(341,340)	14.6	9.8	20.0	-15%
21	(340,338)	34.3	23.3	19.5	-18%
22	(338,337)	22.0	15.6	17.6	-14%
23	(337,336)	14.1	9.3	18.7	-8%
24	(336,335)	14.0	8.6	23.3	-10%
25	(335,334)	14.6	8.8	23.8	-12%
26	(334,333)	13.1	7.6	25.0	-8%
27	(333,331)	31.7	18.7	24.7	-6%
28	(331,330)	19.4	12.7	20.5	8%
29	(330,329)	29.8	21.1	17.5	-1%
30	(329,328)	24.8	17.8	17.0	-3%
31	(328,327)	23.9	17.3	16.5	-2%
32	(327,326)	14.1	8.9	19.9	-3%
33	(326,325)	10.5	5.2	30.4	-4%
34	(325,324)	10.8	5.1	31.8	-4%
35	(324,323)	11.4	5.7	29.8	-10%
36	(323,322)	9.8	5.1	28.5	-4%
37	(322,321)	13.5	7.5	27.0	-3%
38	(321,317)	55.0	25.2	32.6	-1%
39	(317,316)	8.5	1.4	49.1	0%
40	(316,315)	5.7	0.6	53.8	0%
41	(315,314)	5.1	0.4	55.0	5%
42	(314,313)	5.1	0.4	55.3	0%
43	(313,312)	4.8	0.4	55.0	0%
44	(312,311)	6.2	0.9	50.9	7%
45	(311,310)	8.5	1.3	50.5	12%
46	(310,307)	33.1	2.6	55.4	2%
47	(307,1)	4.8	0.8	49.5	-2%
48	(1,2)	4.5	0.3	56.0	
	Average =			**34.8**	**-7%**
	Total =	**774.2**	**368.2**		

Table A18. Link-by-Link Results for the Fifth Scenario at Time 8:30 AM

LINK ID	LINK	Total Time (Sec/Veh)	Delay Time (Sec/Veh)	Speed (Mile/hr)	Delay Difference
1	(554,555)	63.8	47.0	16.0	242%
2	(555,559)	16.1	11.0	20.3	743%
3	(559,560)	15.9	10.8	20.4	782%
4	(560,562)	73.7	49.9	20.2	952%
5	(562,563)	17.0	11.8	19.3	472%
6	(563,564)	15.4	10.3	20.6	342%
7	(564,565)	9.1	5.0	27.3	138%
8	(565,566)	37.9	15.7	35.2	43%
9	(566,567)	10.3	5.0	30.6	-1%
10	(567,569)	11.8	6.2	28.6	-8%
11	(569,570)	33.0	16.4	30.3	-21%
12	(570,571)	8.7	4.5	28.9	-31%
13	(571,572)	10.1	4.9	29.5	-34%
14	(572,574)	26.5	8.8	40.1	-53%
15	(574,575)	11.0	4.0	38.5	-57%
16	(575,577)	25.3	7.9	41.3	-56%
17	(577,578)	9.3	2.9	41.9	-60%
18	(578,342)	6.7	2.3	39.7	-61%
19	(342,341)	5.2	1.8	39.1	-62%
20	(341,340)	9.4	4.6	31.0	-60%
21	(340,338)	24.3	13.2	27.9	-53%
22	(338,337)	17.8	11.3	22.2	-37%
23	(337,336)	12.3	7.6	21.5	-24%
24	(336,335)	11.8	6.4	27.9	-33%
25	(335,334)	12.3	6.5	28.5	-35%
26	(334,333)	11.1	5.7	29.7	-31%
27	(333,331)	26.9	13.9	29.4	-30%
28	(331,330)	14.9	8.2	27.1	-30%
29	(330,329)	24.3	15.7	21.7	-27%
30	(329,328)	22.0	15.0	19.3	-18%
31	(328,327)	21.9	15.4	18.1	-13%
32	(327,326)	13.4	8.3	21.0	-10%
33	(326,325)	10.1	4.8	32.0	-12%
34	(325,324)	9.9	4.1	35.2	-22%
35	(324,323)	10.1	4.5	34.5	-30%
36	(323,322)	8.2	3.6	34.5	-33%
37	(322,321)	11.4	5.3	32.8	-31%
38	(321,317)	51.0	21.2	35.5	-17%
39	(317,316)	9.7	2.7	43.4	85%
40	(316,315)	6.2	1.1	50.0	80%
41	(315,314)	5.4	0.8	51.8	95%
42	(314,313)	5.5	0.8	52.2	90%
43	(313,312)	5.2	0.8	51.9	95%
44	(312,311)	6.7	1.4	48.2	57%
45	(311,310)	8.9	1.7	48.8	43%
46	(310,307)	33.3	2.7	55.1	8%
47	(307,1)	4.8	0.8	49.9	-5%
48	(1,2)	4.5	0.3	55.9	
	Average =			**33.4**	
	Total =	**820.2**	**414.3**		

Table A19. Link-by-Link Results for the Sixth Scenario at Time 8:30 AM

LINK ID	LINK	Total Time (Sec/Veh)	Delay Time (Sec/Veh)	Speed (Mile/hr)	Delay Difference
1	(554,555)	43.9	27.1	22.8	97%
2	(555,559)	12.6	7.5	24.8	478%
3	(559,560)	13.1	8.0	24.0	554%
4	(560,562)	59.8	35.8	24.5	656%
5	(562,563)	13.9	8.7	22.9	321%
6	(563,564)	13.0	7.9	23.9	241%
7	(564,565)	7.2	3.1	34.4	47%
8	(565,566)	36.1	13.8	37.0	26%
9	(566,567)	9.5	4.2	33.4	-18%
10	(567,569)	11.0	5.4	30.7	-20%
11	(569,570)	33.0	16.4	30.3	-21%
12	(570,571)	8.7	4.5	28.9	-31%
13	(571,572)	10.7	5.6	27.7	-25%
14	(572,574)	26.5	8.9	40.0	-53%
15	(574,575)	10.4	3.4	40.5	-64%
16	(575,577)	25.2	7.8	41.4	-56%
17	(577,578)	9.4	3.0	41.3	-59%
18	(578,342)	6.6	2.2	39.8	-62%
19	(342,341)	5.0	1.7	39.7	-65%
20	(341,340)	8.5	3.7	33.7	-68%
21	(340,338)	21.7	10.7	30.5	-62%
22	(338,337)	14.5	8.0	26.8	-56%
23	(337,336)	10.1	5.5	26.0	-46%
24	(336,335)	9.5	4.1	34.4	-57%
25	(335,334)	9.5	3.7	36.5	-63%
26	(334,333)	8.8	3.3	37.4	-60%
27	(333,331)	21.1	8.0	37.2	-60%
28	(331,330)	11.8	5.1	33.8	-56%
29	(330,329)	19.4	10.8	27.0	-50%
30	(329,328)	17.0	10.0	24.7	-45%
31	(328,327)	17.1	10.5	23.1	-40%
32	(327,326)	11.2	6.2	25.0	-32%
33	(326,325)	8.6	3.3	37.3	-40%
34	(325,324)	8.1	2.4	42.5	-55%
35	(324,323)	7.7	2.0	44.5	-69%
36	(323,322)	6.3	1.7	44.2	-69%
37	(322,321)	8.5	2.4	43.3	-69%
38	(321,317)	43.0	13.2	41.7	-48%
39	(317,316)	8.6	1.4	49.0	0%
40	(316,315)	5.8	0.7	53.0	17%
41	(315,314)	5.1	0.4	55.0	10%
42	(314,313)	5.1	0.4	55.7	-5%
43	(313,312)	4.9	0.5	53.9	25%
44	(312,311)	6.2	1.0	50.6	11%
45	(311,310)	8.4	1.2	51.2	3%
46	(310,307)	32.9	2.3	55.8	-7%
47	(307,1)	4.5	0.5	53.1	-40%
48	(1,2)	4.5	0.3	56.3	
	Average =			**37.3**	
	Total =	**704.3**	**298.3**		

Table A20. Link-by-Link Results for the Seventh Scenario at Time 8:30 AM

LINK ID	LINK	Total Time (Sec/Veh)	Delay Time (Sec/Veh)	Speed (Mile/hr)	Delay Difference
1	(554,555)	42.8	26.0	23.3	89%
2	(555,559)	11.8	6.7	26.3	412%
3	(559,560)	12.1	7.0	25.7	472%
4	(560,562)	52.4	28.4	27.7	500%
5	(562,563)	11.7	6.5	27.0	217%
6	(563,564)	10.8	5.7	28.6	146%
7	(564,565)	5.2	1.1	47.1	-47%
8	(565,566)	25.1	2.8	53.1	-74%
9	(566,567)	5.9	0.6	53.9	-88%
10	(567,569)	6.1	0.5	54.8	-92%
11	(569,570)	17.7	1.1	56.4	-95%
12	(570,571)	5.1	1.0	49.0	-85%
13	(571,572)	7.7	2.6	38.9	-65%
14	(572,574)	20.7	3.1	51.2	-84%
15	(574,575)	7.8	0.8	53.9	-91%
16	(575,577)	18.9	1.6	55.1	-91%
17	(577,578)	7.2	0.8	53.8	-89%
18	(578,342)	4.9	0.5	53.9	-92%
19	(342,341)	3.7	0.3	54.4	-93%
20	(341,340)	5.3	0.5	53.9	-95%
21	(340,338)	12.1	1.0	54.9	-96%
22	(338,337)	8.5	2.1	45.8	-88%
23	(337,336)	7.8	3.2	34.1	-68%
24	(336,335)	7.4	2.0	44.2	-79%
25	(335,334)	7.2	1.5	48.0	-85%
26	(334,333)	6.7	1.2	48.9	-85%
27	(333,331)	16.3	3.3	48.0	-83%
28	(331,330)	8.9	2.2	44.7	-81%
29	(330,329)	13.6	4.9	38.8	-77%
30	(329,328)	11.9	4.9	35.5	-73%
31	(328,327)	12.1	5.5	32.6	-69%
32	(327,326)	9.2	4.2	30.6	-54%
33	(326,325)	7.6	2.3	42.1	-58%
34	(325,324)	7.3	1.6	47.1	-70%
35	(324,323)	7.0	1.3	49.0	-80%
36	(323,322)	5.7	1.0	49.2	-81%
37	(322,321)	7.5	1.4	48.6	-81%
38	(321,317)	38.6	8.8	46.4	-66%
39	(317,316)	8.5	1.4	49.2	-1%
40	(316,315)	5.7	0.6	53.7	3%
41	(315,314)	5.0	0.4	55.5	-5%
42	(314,313)	5.0	0.3	56.2	-25%
43	(313,312)	4.7	0.3	56.1	-25%
44	(312,311)	6.0	0.7	53.0	-20%
45	(311,310)	7.9	0.8	54.4	-37%
46	(310,307)	32.5	2.0	56.3	-19%
47	(307,1)	4.3	0.4	55.1	-58%
48	(1,2)	4.5	0.3	56.7	
	Average =			**46.3**	
	Total =	**562.5**	**157.1**		

Table A21. Link-by-Link Results for the First Scenario at Time 9:30 AM

LINK ID	LINK	Total Time (Sec/Veh)	Delay Time (Sec/Veh)	Speed (Mile/hr)
1	(554,555)	36.8	20.1	27.5
2	(555,559)	8.3	3.2	37.6
3	(559,560)	8.7	3.6	36.4
4	(560,562)	41.2	17.3	36.1
5	(562,563)	10.3	5.1	31.0
6	(563,564)	10.4	5.2	30.2
7	(564,565)	8.4	4.3	29.8
8	(565,566)	46.0	23.8	29.2
9	(566,567)	13.8	8.6	23.1
10	(567,569)	16.3	10.7	20.8
11	(569,570)	47.4	30.7	21.2
12	(570,571)	13.1	8.9	19.3
13	(571,572)	14.2	8.9	21.0
14	(572,574)	41.2	23.6	25.8
15	(574,575)	18.6	11.6	22.6
16	(575,577)	38.6	21.2	27.0
17	(577,578)	14.8	8.4	26.2
18	(578,342)	11.4	7.0	23.1
19	(342,341)	8.9	5.5	22.7
20	(341,340)	17.9	13.1	16.1
21	(340,338)	42.1	31.1	15.8
22	(338,337)	25.8	19.3	15.0
23	(337,336)	15.2	10.4	17.3
24	(336,335)	15.7	10.3	20.8
25	(335,334)	16.5	10.7	21.1
26	(334,333)	14.2	8.8	23.0
27	(333,331)	34.0	21.0	23.0
28	(331,330)	19.0	12.4	20.9
29	(330,329)	31.0	22.3	16.8
30	(329,328)	26.0	19.0	16.2
31	(328,327)	24.5	18.0	16.1
32	(327,326)	14.4	9.2	19.4
33	(326,325)	10.9	5.5	29.5
34	(325,324)	11.3	5.6	30.4
35	(324,323)	12.3	6.6	27.9
36	(323,322)	10.3	5.7	27.1
37	(322,321)	14.4	8.3	25.4
38	(321,317)	56.1	26.3	31.9
39	(317,316)	8.5	1.4	49.2
40	(316,315)	5.7	0.6	53.8
41	(315,314)	5.1	0.4	55.0
42	(314,313)	5.1	0.4	55.4
43	(313,312)	4.8	0.4	55.3
44	(312,311)	6.2	0.9	51.3
45	(311,310)	8.4	1.2	51.3
46	(310,307)	33.1	2.5	55.4
47	(307,1)	4.9	0.9	49.3
48	(1,2)	4.5	0.3	56.0
	Average =			**30.3**
	Total =	**906.3**	**500.3**	

Table A22. Link-by-Link Results for the Second Scenario at Time 9:30 AM

LINK ID	LINK	Total Time (Sec/Veh)	Delay Time (Sec/Veh)	Speed (Mile/hr)	Delay Difference
1	(554,555)	23.7	7.0	41.8	-65%
2	(555,559)	5.6	0.5	55.0	-84%
3	(559,560)	5.5	0.4	55.9	-89%
4	(560,562)	25.4	1.4	56.6	-92%
5	(562,563)	5.5	0.3	57.0	-94%
6	(563,564)	5.4	0.3	57.1	-94%
7	(564,565)	4.3	0.2	57.0	-95%
8	(565,566)	23.8	1.5	55.9	-94%
9	(566,567)	5.6	0.3	56.7	-97%
10	(567,569)	5.8	0.3	57.5	-98%
11	(569,570)	17.4	0.7	57.5	-98%
12	(570,571)	4.5	0.3	56.4	-97%
13	(571,572)	6.4	1.4	46.8	-85%
14	(572,574)	19.4	1.8	54.6	-93%
15	(574,575)	7.4	0.4	56.5	-96%
16	(575,577)	18.5	1.2	56.3	-95%
17	(577,578)	7.0	0.5	55.3	-94%
18	(578,342)	4.7	0.4	55.4	-94%
19	(342,341)	3.6	0.2	55.5	-96%
20	(341,340)	5.0	0.2	57.4	-98%
21	(340,338)	11.5	0.5	57.6	-98%
22	(338,337)	6.9	0.5	56.0	-98%
23	(337,336)	6.3	1.8	41.8	-82%
24	(336,335)	6.6	1.1	49.9	-89%
25	(335,334)	6.4	0.7	54.0	-94%
26	(334,333)	5.9	0.5	55.3	-95%
27	(333,331)	14.1	1.1	55.4	-95%
28	(331,330)	7.2	0.5	55.1	-96%
29	(330,329)	9.1	0.4	57.2	-98%
30	(329,328)	7.3	0.3	57.3	-98%
31	(328,327)	7.1	0.5	55.8	-97%
32	(327,326)	6.8	2.0	41.6	-78%
33	(326,325)	6.5	1.2	49.2	-79%
34	(325,324)	6.5	0.7	53.3	-87%
35	(324,323)	6.2	0.5	55.2	-92%
36	(323,322)	5.0	0.4	55.8	-94%
37	(322,321)	6.5	0.4	56.0	-95%
38	(321,317)	33.0	3.1	54.3	-88%
39	(317,316)	8.1	1.0	51.9	-31%
40	(316,315)	5.4	0.3	56.7	-50%
41	(315,314)	4.9	0.2	57.3	-50%
42	(314,313)	4.9	0.2	57.3	-50%
43	(313,312)	4.6	0.2	57.2	-50%
44	(312,311)	5.8	0.5	54.7	-44%
45	(311,310)	7.7	0.5	56.2	-60%
46	(310,307)	32.2	1.6	57.0	-35%
47	(307,1)	4.2	0.2	57.0	-77%
48	(1,2)	4.4	0.2	57.2	-33%
	Average =			**54.7**	**-83%**
	Total =	**445.7**	**40.3**		

Table A23. Link-by-Link Results for the Third Scenario at Time 9:30 AM

LINK ID	LINK	Total Time (Sec/Veh)	Delay Time (Sec/Veh)	Speed (Mile/hr)	Delay Difference
1	(554,555)	24.6	7.9	40.3	-61%
2	(555,559)	5.9	0.8	52.1	-76%
3	(559,560)	5.9	0.8	52.1	-78%
4	(560,562)	26.1	2.2	55.0	-87%
5	(562,563)	5.9	0.8	52.6	-85%
6	(563,564)	5.7	0.6	53.8	-89%
7	(564,565)	4.7	0.6	52.5	-86%
8	(565,566)	24.5	2.2	54.4	-91%
9	(566,567)	5.8	0.6	54.2	-93%
10	(567,569)	6.3	0.7	53.1	-93%
11	(569,570)	17.7	1.1	56.5	-97%
12	(570,571)	5.0	0.8	50.2	-91%
13	(571,572)	7.6	2.6	39.1	-71%
14	(572,574)	20.7	3.0	51.2	-87%
15	(574,575)	8.0	1.0	52.8	-92%
16	(575,577)	19.5	2.2	53.4	-90%
17	(577,578)	7.4	0.9	52.6	-89%
18	(578,342)	5.0	0.6	52.7	-91%
19	(342,341)	3.8	0.4	52.3	-92%
20	(341,340)	6.0	1.2	48.5	-91%
21	(340,338)	14.7	3.7	46.9	-88%
22	(338,337)	10.7	4.2	37.3	-78%
23	(337,336)	9.0	4.4	29.5	-58%
24	(336,335)	8.6	3.2	38.3	-69%
25	(335,334)	8.6	2.8	41.1	-74%
26	(334,333)	7.9	2.5	41.9	-72%
27	(333,331)	19.2	6.2	41.4	-71%
28	(331,330)	10.5	3.8	38.4	-69%
29	(330,329)	16.8	8.1	31.5	-64%
30	(329,328)	14.9	7.9	28.4	-59%
31	(328,327)	15.0	8.4	26.3	-53%
32	(327,326)	10.4	5.4	26.9	-41%
33	(326,325)	8.2	2.9	39.0	-48%
34	(325,324)	7.9	2.1	43.8	-62%
35	(324,323)	7.4	1.8	45.7	-73%
36	(323,322)	6.0	1.4	46.2	-75%
37	(322,321)	8.1	2.0	45.3	-76%
38	(321,317)	41.9	12.0	42.8	-54%
39	(317,316)	8.4	1.3	50.3	-11%
40	(316,315)	5.6	0.5	54.9	-20%
41	(315,314)	5.0	0.3	55.9	-20%
42	(314,313)	5.1	0.3	56.0	-20%
43	(313,312)	4.8	0.4	55.3	-10%
44	(312,311)	6.2	0.9	51.2	2%
45	(311,310)	8.1	0.9	53.2	-26%
46	(310,307)	32.7	2.1	56.1	-16%
47	(307,1)	4.4	0.5	53.9	-47%
48	(1,2)	4.5	0.3	56.5	0%
	Average =			**47.2**	**-64%**
	Total =	**526.5**	**121.1**		

Table A24. Link-by-Link Results for the Fourth Scenario at Time 9:30 AM

LINK ID	LINK	Total Time (Sec/Veh)	Delay Time (Sec/Veh)	Speed (Mile/hr)	Delay Difference
1	(554,555)	35.7	19.1	28.2	-5%
2	(555,559)	7.8	2.7	40.5	-16%
3	(559,560)	7.9	2.8	40.3	-22%
4	(560,562)	37.2	13.3	40.5	-23%
5	(562,563)	9.2	4.0	36.0	-22%
6	(563,564)	9.4	4.2	35.0	-19%
7	(564,565)	7.7	3.6	34.0	-16%
8	(565,566)	41.9	19.6	33.8	-18%
9	(566,567)	12.9	7.6	26.0	-12%
10	(567,569)	14.7	9.1	23.8	-15%
11	(569,570)	43.0	26.4	23.8	-14%
12	(570,571)	12.1	7.9	21.2	-11%
13	(571,572)	13.6	8.3	22.0	-7%
14	(572,574)	38.6	21.0	27.6	-11%
15	(574,575)	17.1	10.1	24.9	-13%
16	(575,577)	35.9	18.6	29.1	-12%
17	(577,578)	13.8	7.3	28.3	-12%
18	(578,342)	10.5	6.1	25.3	-13%
19	(342,341)	8.7	5.4	23.2	-2%
20	(341,340)	16.6	11.8	17.4	-9%
21	(340,338)	38.4	27.4	17.3	-12%
22	(338,337)	23.9	17.4	16.2	-10%
23	(337,336)	14.7	9.9	17.9	-5%
24	(336,335)	14.9	9.5	21.8	-7%
25	(335,334)	15.6	9.8	22.3	-8%
26	(334,333)	13.8	8.3	23.7	-5%
27	(333,331)	33.2	20.2	23.6	-4%
28	(331,330)	20.3	13.6	19.6	10%
29	(330,329)	30.8	22.1	16.9	-1%
30	(329,328)	25.4	18.4	16.6	-3%
31	(328,327)	24.3	17.7	16.2	-2%
32	(327,326)	14.2	9.0	19.8	-3%
33	(326,325)	10.7	5.4	30.0	-3%
34	(325,324)	11.1	5.4	31.0	-4%
35	(324,323)	11.9	6.2	28.6	-6%
36	(323,322)	10.0	5.4	27.7	-4%
37	(322,321)	14.0	7.9	26.2	-5%
38	(321,317)	55.7	25.9	32.2	-2%
39	(317,316)	8.6	1.5	49.1	3%
40	(316,315)	5.8	0.6	53.7	0%
41	(315,314)	5.1	0.4	55.0	0%
42	(314,313)	5.1	0.4	55.3	0%
43	(313,312)	4.8	0.4	55.0	0%
44	(312,311)	6.2	0.9	50.9	4%
45	(311,310)	8.6	1.4	50.4	11%
46	(310,307)	33.1	2.6	55.3	2%
47	(307,1)	4.9	0.9	49.2	5%
48	(1,2)	4.5	0.3	56.0	0%
	Average =			**31.6**	**-7%**
	Total =	**863.8**	**457.8**		

Table A25. Link-by-Link Results for the Fifth Scenario at Time 9:30 AM

LINK ID	LINK	Total Time (Sec/Veh)	Delay Time (Sec/Veh)	Speed (Mile/hr)	Delay Difference
1	(554,555)	68.0	51.2	14.8	154%
2	(555,559)	17.4	12.3	18.2	281%
3	(559,560)	17.2	12.1	18.3	238%
4	(560,562)	80.1	56.1	18.2	225%
5	(562,563)	18.0	12.8	17.8	152%
6	(563,564)	16.6	11.4	18.9	119%
7	(564,565)	10.8	6.7	22.9	57%
8	(565,566)	50.4	28.2	26.4	18%
9	(566,567)	14.1	8.8	22.5	3%
10	(567,569)	16.1	10.5	20.9	-1%
11	(569,570)	44.3	27.7	22.5	-10%
12	(570,571)	11.5	7.3	21.9	-18%
13	(571,572)	12.3	7.1	24.2	-21%
14	(572,574)	33.6	16.0	31.5	-32%
15	(574,575)	14.6	7.6	28.8	-34%
16	(575,577)	31.0	13.7	33.6	-36%
17	(577,578)	11.6	5.1	33.5	-39%
18	(578,342)	8.6	4.2	30.7	-40%
19	(342,341)	6.7	3.3	30.2	-40%
20	(341,340)	12.6	7.9	22.8	-40%
21	(340,338)	30.9	19.9	21.6	-36%
22	(338,337)	20.7	14.2	18.9	-27%
23	(337,336)	13.3	8.5	19.9	-18%
24	(336,335)	13.1	7.7	25.0	-25%
25	(335,334)	13.6	7.8	25.6	-27%
26	(334,333)	12.2	6.8	26.9	-23%
27	(333,331)	29.4	16.4	26.8	-22%
28	(331,330)	16.3	9.6	24.6	-22%
29	(330,329)	26.7	18.0	19.7	-19%
30	(329,328)	23.4	16.4	18.1	-14%
31	(328,327)	22.8	16.3	17.3	-10%
32	(327,326)	13.8	8.6	20.4	-7%
33	(326,325)	10.4	5.1	31.0	-9%
34	(325,324)	10.3	4.6	33.5	-17%
35	(324,323)	10.9	5.2	31.8	-21%
36	(323,322)	9.0	4.4	31.3	-23%
37	(322,321)	12.5	6.4	29.5	-23%
38	(321,317)	53.0	23.1	34.0	-12%
39	(317,316)	9.5	2.4	44.4	70%
40	(316,315)	6.1	0.9	50.8	57%
41	(315,314)	5.3	0.7	52.5	75%
42	(314,313)	5.4	0.7	52.9	70%
43	(313,312)	5.1	0.7	52.6	70%
44	(312,311)	6.5	1.2	48.9	38%
45	(311,310)	8.9	1.7	49.0	35%
46	(310,307)	33.2	2.7	55.2	5%
47	(307,1)	4.8	0.9	49.5	0%
48	(1,2)	4.5	0.3	55.9	0%
	Average =			**30.1**	
	Total =	**927.0**	**521.1**		

Table A26. Link-by-Link Results for the Sixth Scenario at Time 9:30 AM

LINK ID	LINK	Total Time (Sec/Veh)	Delay Time (Sec/Veh)	Speed (Mile/hr)	Delay Difference
1	(554,555)	48.3	31.5	20.7	56%
2	(555,559)	14.4	9.3	21.6	189%
3	(559,560)	14.9	9.7	20.9	172%
4	(560,562)	67.2	43.3	21.6	151%
5	(562,563)	15.5	10.3	20.3	103%
6	(563,564)	14.9	9.7	20.8	86%
7	(564,565)	9.3	5.2	26.7	21%
8	(565,566)	48.2	25.9	27.7	9%
9	(566,567)	13.1	7.8	24.1	-9%
10	(567,569)	15.1	9.5	22.3	-11%
11	(569,570)	46.5	29.9	21.5	-3%
12	(570,571)	11.4	7.2	22.1	-19%
13	(571,572)	13.2	8.0	22.5	-11%
14	(572,574)	33.7	16.1	31.4	-32%
15	(574,575)	14.2	7.2	29.6	-38%
16	(575,577)	32.4	15.0	32.2	-29%
17	(577,578)	12.1	5.6	32.1	-33%
18	(578,342)	8.4	4.0	31.4	-43%
19	(342,341)	6.6	3.2	30.4	-42%
20	(341,340)	11.7	6.9	24.5	-47%
21	(340,338)	31.4	20.4	21.1	-34%
22	(338,337)	18.7	12.2	20.7	-37%
23	(337,336)	11.6	7.0	22.6	-33%
24	(336,335)	11.2	5.8	29.1	-44%
25	(335,334)	11.6	5.8	30.1	-46%
26	(334,333)	10.4	5.0	31.4	-43%
27	(333,331)	24.8	11.8	31.6	-44%
28	(331,330)	13.9	7.2	28.7	-42%
29	(330,329)	22.9	14.2	22.8	-36%
30	(329,328)	19.5	12.5	21.6	-34%
31	(328,327)	19.1	12.6	20.6	-30%
32	(327,326)	12.1	7.0	23.2	-24%
33	(326,325)	9.1	3.8	35.2	-32%
34	(325,324)	8.7	2.9	39.7	-47%
35	(324,323)	8.5	2.8	40.2	-57%
36	(323,322)	7.1	2.5	39.1	-56%
37	(322,321)	9.8	3.8	37.2	-55%
38	(321,317)	46.6	16.8	38.5	-36%
39	(317,316)	8.6	1.5	49.0	3%
40	(316,315)	5.8	0.7	53.2	13%
41	(315,314)	5.1	0.4	55.0	5%
42	(314,313)	5.1	0.4	55.3	5%
43	(313,312)	5.1	0.6	52.5	60%
44	(312,311)	6.4	1.1	49.5	27%
45	(311,310)	8.6	1.4	50.1	16%
46	(310,307)	32.9	2.4	55.7	-6%
47	(307,1)	4.6	0.6	51.9	-28%
48	(1,2)	4.5	0.3	56.3	0%
	Average =			**32.6**	
	Total =	**834.9**	**428.8**		

Table A27. Link-by-Link Results for the Seventh Scenario at Time 9:30 AM

LINK ID	LINK	Total Time (Sec/Veh)	Delay Time (Sec/Veh)	Speed (Mile/hr)	Delay Difference
1	(554,555)	38.8	22.0	25.7	9%
2	(555,559)	10.5	5.4	29.5	68%
3	(559,560)	10.9	5.7	28.7	59%
4	(560,562)	46.3	22.4	31.4	30%
5	(562,563)	10.5	5.3	30.2	4%
6	(563,564)	9.8	4.7	31.7	-10%
7	(564,565)	5.4	1.3	46.3	-70%
8	(565,566)	26.5	4.3	50.7	-82%
9	(566,567)	6.5	1.2	49.7	-86%
10	(567,569)	7.0	1.4	49.4	-87%
11	(569,570)	20.3	3.7	50.6	-88%
12	(570,571)	6.3	2.1	40.9	-76%
13	(571,572)	8.8	3.7	34.0	-59%
14	(572,574)	22.5	4.9	47.2	-79%
15	(574,575)	8.9	1.9	47.7	-84%
16	(575,577)	21.9	4.5	47.9	-79%
17	(577,578)	8.4	2.0	46.4	-77%
18	(578,342)	5.7	1.4	46.2	-81%
19	(342,341)	4.3	0.9	47.0	-83%
20	(341,340)	7.1	2.3	41.2	-82%
21	(340,338)	17.1	6.1	39.7	-81%
22	(338,337)	12.1	5.7	31.9	-70%
23	(337,336)	9.2	4.6	28.6	-56%
24	(336,335)	8.7	3.3	37.4	-68%
25	(335,334)	8.7	2.9	40.0	-73%
26	(334,333)	7.9	2.5	41.2	-72%
27	(333,331)	19.3	6.2	40.7	-70%
28	(331,330)	10.6	3.9	37.5	-68%
29	(330,329)	16.7	8.0	31.4	-64%
30	(329,328)	14.5	7.5	29.1	-61%
31	(328,327)	14.5	7.9	27.2	-56%
32	(327,326)	10.2	5.3	27.4	-43%
33	(326,325)	8.1	2.8	39.4	-49%
34	(325,324)	7.7	2.0	44.5	-64%
35	(324,323)	7.4	1.7	46.2	-74%
36	(323,322)	6.0	1.4	46.2	-75%
37	(322,321)	8.1	2.0	45.1	-76%
38	(321,317)	41.3	11.5	43.3	-56%
39	(317,316)	8.5	1.4	49.2	0%
40	(316,315)	5.8	0.6	53.7	3%
41	(315,314)	5.0	0.4	55.5	0%
42	(314,313)	5.2	0.4	55.0	10%
43	(313,312)	4.8	0.4	54.8	5%
44	(312,311)	6.3	1.0	50.3	13%
45	(311,310)	8.2	1.0	52.7	-19%
46	(310,307)	32.7	2.2	56.0	-14%
47	(307,1)	4.5	0.5	53.6	-44%
48	(1,2)	4.5	0.3	56.5	0%
	Average =			**42.4**	
	Total =	**599.9**	**194.5**		