THE UNIVERSITY OF TEXAS AT AUSTIN
CENTER FOR TRANSPORTATION RESEARCH

PEAK PERIOD BUS USE OF FREEWAY SHOULDERS

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ABSTRACT

With an objective of improved bus reliability and reduced travel times, many cities are allowing transit buses to use freeway shoulders to bypass slow or stopped freeway traffic. Safety based protocols are an important part of all buses on shoulders operations. The bus-on-shoulder system in the Twin Cities of Minneapolis and St. Paul, Minnesota is currently the most extensive. Besides the Twin Cities' system, others examined in this study include those in: San Diego, California; Columbus, Cincinnati, and Cleveland, Ohio; Miami, Florida; and Fairfax County, Virginia. Descriptions of technical, financial, and legal characteristics of these systems are followed by an analysis of implications for bus-on-shoulder implementation in Austin, TX.

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The purpose of this effort is to explore the feasibility of implementing Buses on Shoulders (BOS) in Austin, TX. Part 1 provides a review of experiences with BOS in other cities and countries.

1.1 BUS-ONLY-SHOULDER OR BUS-ON-SHOULDER (BOS) SYSTEMS

"A BOS [Bus-Only-Shoulder] is a street or highway shoulder constructed, modified, or enhanced to support bus traffic" (Douma, 2007). Generally, buses are permitted to use shoulders during peak traffic periods to bypass congested sections of freeways or arterial roadways. The first known instance of buses utilizing shoulders to bypass congestion was in Seattle, Washington in the 1970s. Seattle's BOS system, however, does not greatly resemble more recently implemented, well-known, and successful BOS systems from an operational standpoint. The nearly 5 miles of shoulder used for buses and carpools in Seattle have no speed or time-of-day restrictions, which in other cities are seen as important safety regulations (Martin, 2007). In 1991, the Twin Cities of Minneapolis and St. Paul, Minnesota renewed the concept of bus-only-shoulders, starting a trend that now extends to over a dozen cities around the world. MetroTransit's goal was to create a "transit advantage" that would encourage more people to ride the bus due to shorter travel times. BOS systems are also a solution for decreasing congestion with a constrained budget. They initiated a pilot project in 1991 on Highway 252, an arterial roadway, where buses were allowed to by-pass traffic by using the right shoulder. The first instance of buses on shoulders on a Minneapolis area freeway was on MN 77 in 1993. Today the BOS system in the Twin Cities includes over 300 miles (Conover, 2008 and www.metrotransit.org).

In December 2005, San Diego, CA instituted a bus-on-shoulder pilot project to stand as an interim measure until managed lanes or other costly long-term transit improvements could be made. The BOS project was a part of SANDAG's Transit First strategy to relieve congestion on freeways and arterials. The two year pilot program allowed exclusive use of about 4 miles of shoulders on SR-52 and I-805 by express bus Route 960 (Martin, 2007). The successful pilot program resulted in an announcement in August 2008 that 20 more miles of bus-only-shoulder lanes along I-805 would be added to San Diego's system (Schmidt, 2008).

Columbus, Ohio opened a BOS system in November 2006 along 10 miles of I-70. The project team, called Transit Advantage Group Partners, implemented the bus-only-shoulders as a one-year pilot project. Three bus routes use the BOS roadway section daily (Martin, 2007). In

July of 2007, another Ohio city, Cincinnati, entered the bus-on-shoulder market with a one-year pilot project. The project is intended to reduce traffic by encouraging transit usage and make full use of the highway's capacity. The BOS section is 11.7 miles along I-71 northbound and southbound and is used by bus Rt. 71X and Rt. 72 (Metro's I-71…, 2008). Cincinnati's pilot project was made permanent in August 2008 (O.D.O.T. Agrees…, 2008). The successful Columbus and Cincinnati BOS experiences prompted a third Ohio City to explore the use of buses on shoulders. Cleveland, Ohio transit stakeholders including Greater Cleveland Regional Transit Authority and Laketran began testing BOS on stretches of Interstate 90 in June 2008 (Hollander).

Bus-only-shoulders in Miami, Florida appeared in March 2007 along SR 874 (Don Shula Expressway) and SR 878 (Snapper Creek Expressway), about 9 miles of BOS total. The three year pilot program was supported by the People's Transportation Plan (PTP) of 2002, and intended as an interim measure until permanent transit lanes could be built. Two bus routes currently operate on SR 874 and three on SR 878. Smaller than average buses 30 ft. long operate on the shoulders called Kendall Area Transit (KAT) (Martin, 2007).

In the early 2000s, Fairfax County, Virginia widened a 1.3 mile long shoulder along VA-267 that feeds to West Falls Church Metro Rail Station. This project is unique because it acts more as a queue jumper for a small congestion area resulting from vehicles merging onto congested I-66 rather than a bypass for miles of heavy congestion along the BOS corridor. Fairfax County added a BOS expansion to I-66 (Martin, 2006).

In the United Kingdom, usage of the shoulder is known as hard shoulder running. In September 2006 a pilot project on an 11-mile stretch of the M42 motorway, near Birmingham began. The project proved very successful, with bus travel times decreasing by 26% northbound and 9% southbound and travel time variability decreasing by 27%. Safety improved with average accident rates dropping from 5.2 to 1.5 per month. The system has been expanded to the M6, M1 and M25, with plans to include parts of M60 and M62 by 2015.

Though many other BOS systems exist, their basic function is either not very similar to that proposed for Austin, TX or there is not a lot of readily available information about them. A table of the basic information that is known about each system is included in the Appendix. Cities that allow bus use of shoulders on freeways include:

- Seattle, Washington, US (since 1970s, 4.9 miles)
- Minneapolis/St. Paul, Minnesota, US (since 1991, over 270 miles)
- Auckland, New Zealand (since 1991, length of corridors unknown)
- Ottawa, Ontario, Canada (since 1992, 14 miles)
- Dublin, Ireland (since 1998, 50 to 70 miles)
- Vancouver, British Columbia, Canada (year started unknown)
- Maryland, Washington, US (year started unknown, 3 miles)
- Fairfax County, Virginia, US (since at least 2000, 1.3 miles)
- Toronto, Ontario, Canada (since 2003, 3 miles)
- Atlanta, Georgia, US (since November 2005, 12 miles)
- San Diego, California (since December 2005, 4 miles)
- Columbus, Ohio (since November 2006,
- Old Bridge, New Jersey, US (since December 2006, 3 miles)
- Miami, Florida, US (since March 2007)
- Cincinnati, Ohio (since July 2007)

- Cleveland, Ohio (since June 2008)
- Birmingham, UK (since 2006)
- Durham County, NC (since 2013)
- Calgary, Canada (since 20120
- Kansas City, Kansas (since 2011)

1.2 GEOMETRIC AND PHYSICAL CONSTRAINTS

Minneapolis / St. Paul, MN

In Minnesota, bus-only-shoulders are located exclusively on the right shoulder of the freeway (see Figure 1.1). Though this creates conflict points with entering and exiting traffic, it allows the buses to exit and enter the freeway without having to fight through lanes of traffic to reach the left shoulder. Bus drivers in Minnesota helped determine standard widths for bus-only shoulders. This width is 10 ft., except on bridges where it is 11.5 ft. On bridges, drivers did not feel safe driving very close to bridge barriers. Since the 10 ft. shoulder only leaves 9 inches of space on either side of the bus, the preference in the Twin Cities, however, is for a 12 ft. shoulder. Most new construction accommodates this preference (Douma, 2007).

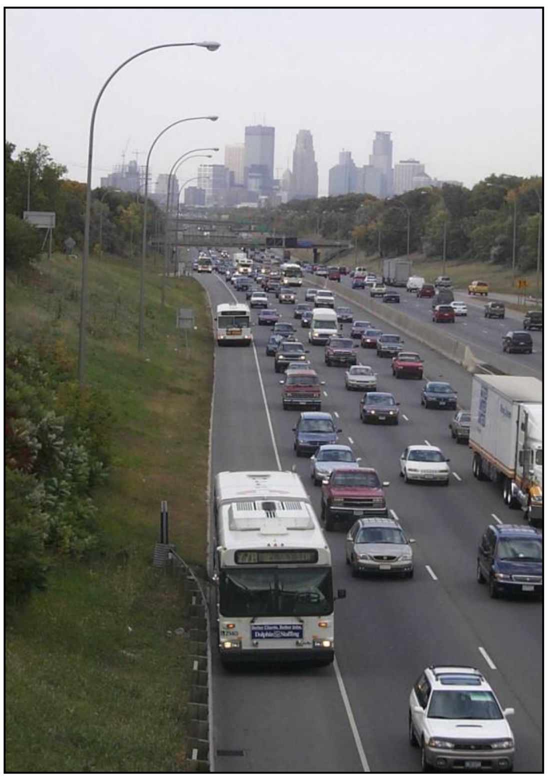


FIGURE 1.1 BOS in Action in the Twin Cities (Conover, 2008).

In Minnesota, the standard thickness for bus-only shoulder surface layer pavement is 7 inches, like main lanes. Before the 1980s, shoulder pavements were often made only 2 inches thick. Since then, most new roads use the standard 7 inches for their shoulders. During pilot

BOS projects in Minnesota few buses used the shoulders so little wear and tear could be seen in the structural integrity of the roadway. As the number of buses on the shoulders increased, the pavement and structure of older shoulders began to wear down, and 2-inch thick shoulder pavements had to be reinforced to 7 inches thick (Douma, 2007). Table 1.1 lists all structural requirements of bus-only-shoulders in Minnesota.

Problems with rain water catch basins also arose on bus-only-shoulders in the Twin Cities. Catch basins were typically raised over the surface of the road so that buses driving over them caused damage to the basin and discomfort to riders. A new design was created with a reinforced concrete pad around the basin to bring it level with the road surface. The new design solved the problem, but reduced the efficiency of the basins slightly. An additional physical constraint encountered in the Twin Cities was the presence of rumble strips in the shoulder to alert drivers that they have veered from the main road. The rumble strips were moved outward so that the bus wheels would straddle them (Douma, 2007).

Shoulder Width	10 ft. (11.5 on bridges) minimum & 12 ft. desired
Bridge Structural Capacity	HS-25 Minimum Design Load (New Bridges)
Pavement Thickness	7in minimum for long term
Normal Cross Slope	2 - 5 %
Horizontal Clearance to Obstructions	0 ft.
Vertical Clearance Under Bridge	14 ft.
Stopping Sight Distance	250 ft. min
Horizontal Alignment (Radius)	Match Existing Roadway
Grades	Match Existing Roadway
Inslopes	1:06
Vertical Alignment (K Value)	Match Existing Roadway
Superelevation	.06 maximum

TABLE 1.1 Structural Components of MN BOS System (Douma, 2007).

San Diego, CA

Like the Twin Cities, San Diego's bus-only-shoulders are located on the right freeway shoulder. Before the project began, an optimal 10 ft. shoulder width was decided upon. In many places, the right-most main lane would have had to be narrowed in order to widen the shoulder to 10 ft. Once the project began, however, it was determined that buses could still safely operate on shoulders narrower than 10 ft., so the re-striping never occurred. For the 2-year pilot project, little damage was expected to shoulder pavements, so they were not strengthened (Leiter, 2006).

San Diego's 20 new miles of bus-only-shoulder lanes, opened in the fall of 2009, are located on the left freeway shoulder. Cincinnati was the first city to use this unique design for their pilot BOS project in 2007 (see below). The shoulders are designed to be 11 ft. wide. In order to accommodate the new width of the existing 8 ft. shoulders, at least three of the freeway main lanes were re-striped at 11 ft. (Schmidt, 2008).

Ohio

Bus-only shoulders in Columbus, Ohio are located on the right shoulder. The I-70 corridor was chosen in Columbus, Ohio because the key structural and geometrical components already met regulation. Shoulders are 10 ft. wide and pavements are full depth. Cincinnati's pilot BOS project, which opened in 2007, was the first to utilize the left shoulder of the freeway for bus transit usage. Shoulders are 12 ft. wide (Metro's I-71…, 2008). Bus-only-shoulders in Cleveland are all at least 10 ft. wide (Hollander, 2008).

Miami, FL

Located on the right shoulder, BOS lanes in Miami are a minimum of 10 ft. wide. This minimum is raised to 12 ft. where truck volumes exceed 250 vph. Cross slopes are between 2 and 6%. In considering corridors for BOS, Miami set a minimum usable segment length of 2,500 ft. Often there are obstructions along shoulders that force buses to remerge into traffic such as a bridge, a narrowing of the shoulder, or conflict with an intersection. In Miami, segments between merge points that are less than 2,500 ft. are not considered for BOS (Guerra, 2008).

1.3 OPERATIONAL REGULATIONS AND SAFETY CONSIDERATIONS

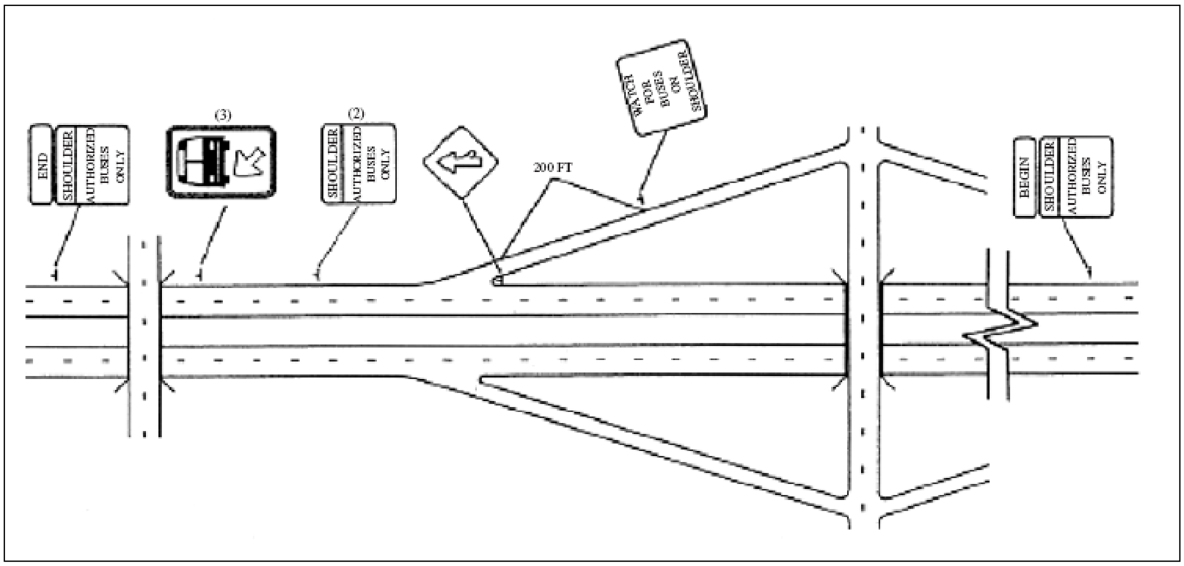
Minneapolis / St. Paul, MN

Minnesota state law outlines the operational regulations for Bus-Only-Shoulders in the Twin Cities metro area. Buses are not allowed to exceed 35 mph in the shoulder. Feedback from bus drivers helped set speed regulations. Bus drivers did not feel safe going more than 35 mph in the shoulder. Therefore, buses do not use the shoulder unless traffic in the main lanes has slowed to less than 35 mph. Buses are allowed to use the shoulder when they have passengers or when they are "deadheading" (driving to or from a parking lot with no passengers). To avoid costly accidents, buses are not allowed to drive more than 15 mph greater than the traffic in the main lanes (Douma, 2007). Buses must always have their four-way flashers on when in the shoulder (Martin, 2007).

No road markings are used on the bus-only shoulders. Signs reading "Shoulder – Authorized Buses Only" are placed along BOS corridors every quarter to half mile (See Figure 1.2). Signs at the beginning and end of a BOS corridor are marked as such. Signs are also placed at on-ramps that read "Watch for Buses on Shoulders" about 200 ft. before the ramp meets the freeway (Martin, 2007). Small yellow warning signs are placed along the corridor where conflicts exist such as a weaving point, a narrowing lane, or an intersection (Martin, 2006). Of course, the original purpose of a shoulder was to allow for the passage of emergency vehicles, a safe spot to pull over in the event of car trouble, or a temporary storage location for large debris. If such an obstruction should appear on the shoulder, buses can easily merge back into slow-moving traffic, and typically do this approximately 1,000 ft. before the obstacle.

Debris is typically removed from shoulders less frequently than on mainlines, however, BOS implementation requires more attention to shoulder debris removal (Douma, 2007).

The signalized intersection of an arterial roadway facilitates safe operations of buses on shoulders on such roads. Signals control intersections and maintain speed limits. Conflict points on freeways, however, are not controlled by signals. Before bus-only shoulders were implemented on freeways, there were concerns about buses crossing auxiliary lanes. To address these concerns, buses are required to yield to entering and exiting vehicles. In the Twin Cities, ramp metering helps create gaps in entering queues for buses (Douma, 2007). Some auxiliary lanes, however, can be accompanied by high amounts of traffic weaving. When ramp volumes exceed about 1500 vph, buses may be instructed to merge back into mainline traffic. Buses are not allowed to use the shoulder at locations that have double-width entrance or exit ramps (Martin, 2007).



(1) Install near midpoint when zone exceeds 3 mi and continues at approximately 1.5 mi spacing
(2) Install as needed to warn bus drivers where shoulder is less than 10 ft.

FIGURE 1.2 MN BOS Signage (Martin, 2006).

Many safety considerations formed the operational procedures in the Twin Cities for use of bus-only shoulders. Bus drivers must be trained to drive on the shoulder by their respective transit service providers. Charter bus services can use the shoulder if they have registered with the Minnesota's MetroTransit. In the Twin Cities, however, charter buses seldom use the shoulders. They do not have as much experience as transit bus drivers. Bus drivers are never required to drive on the shoulder. They only use bus-only shoulders if and when they feel comfortable doing so. This ensures that a driver never enters a situation he or she feels is unsafe. The state patrol is responsible for ensuring proper use of the shoulders. They are kept aware of who has authorization to use them. An early fear in Minnesota that other vehicles would follow the buses and drive on the shoulder never materialized (Douma, 2007).

San Diego, CA

Buses can only use the shoulder when mainline speeds fall below 35 mph and cannot exceed other traffic by more than 10 mph. BOS signage in San Diego consists of signs along the shoulder reading "Transit Lane – Authorized Buses Only." San Diego also uses pavement markings that read "Only Bus Transit." Only express bus route 960 was allowed to initially use the shoulder. The section of shoulder used in the San Diego BOS pilot project consists of the I-805 and the SR-52 roadways surrounding the intersection of the two freeways. The result is that there is one complex freeway to freeway interchange in the middle of the project. Buses use auxiliary lanes to help them make this weave. Many of the ramps along the section have ramp-metering to help break up entering traffic. During or after rainstorms, when there is a chance of ponding, buses are not supposed to use shoulders (Martin, 2007).

The 20 new miles of bus-only-shoulders in San Diego can be used by buses only during rush hour when speeds fall below 30 mph and may not exceed 35 mph on the shoulder. Disabled vehicles and emergency vehicles are still encouraged to use the shoulder when necessary; buses have to merge back into traffic to go around such vehicles. In the event that a bus breaks down in the shoulder, another bus would pick up the stranded passengers. The BOS lanes are planned to run alongside the median (or left shoulder) of I-805 southbound and northbound. Use of the left shoulder is significant because in order to execute the one scheduled stop on the express route, the bus has to maneuver through several lanes of congested traffic to exit and re-enter the freeway. Enforcement is by the California Highway Patrol (Schmidt, 2008).

Ohio

Buses are allowed to use the shoulders in Columbus when traffic speeds drop below 35 mph and buses cannot exceed 35 mph on the shoulder. They also cannot go more than 15 mph faster than general-purpose lane traffic. Signage for the Columbus BOS system is identical to the Twin Cities' except that a more traditional yellow warning sign is used at on-ramps. No pavement markings are used. The Columbus BOS system has several tricky interchanges along its route that cause a great deal of weaving. Some of the interchanges have double on and off ramps. The buses are allowed to travel through these interchanges at their own discretion. They do not have to merge back into general traffic, though they must yield to entering and exiting vehicles. There are no metered on-ramps. As usual, four-way flashers are required for buses on shoulders. Debris is cleared from the shoulder every week instead of the previous every three weeks. Incident response is conducted by a team called FIRST (Martin, 2007).

In Cincinnati, buses are restricted from using BOS shoulders until traffic speeds fall below 30 mph. They cannot exceed 35 mph on the shoulder and cannot go more than 15 mph faster than general traffic. Use of the shoulder is permitted to buses and emergency vehicles only, and buses must yield to emergency vehicles. Since Cincinnati's buses use the left shoulder instead of the right, there are no conflicts between the bus and other vehicles entering and exiting the freeway. Any concerns that buses would have problems maneuvering through traffic to reach the left lane did not come to fruition. To ensure safety, a company called ARTIMIS provides real-time camera footage to Metro so they can monitor traffic (Metro's I-71…, 2008). The Ohio State Highway Patrol and local law enforcement agencies are charged with ensuring proper use of BOS lanes (O.D.O.T. Agrees…, 2008).

In Cleveland, BOS buses are permitted to use shoulders when traffic falls below 35 mph and cannot exceed 35 mph on the shoulder. Appropriate warning signs are located at on-ramps and along the BOS corridor. Buses must yield to emergency vehicles and are required to merge back into general traffic at exit and entrance ramps (Hollander, 2008).

Miami, FL

The BOS system in Miami utilizes the right shoulder to allow buses to bypass congested traffic. Buses are not allowed to use the shoulders until speeds drop below 25 mph and cannot operate more than 15 mph faster than other traffic and cannot exceed 35 mph. BOS signage in Miami is unique. Signs along the shoulder read "Emergency Stopping Only on Shoulder – Authorized Bus Lane." On-ramp signs read "Buses Traveling on Shoulder." While most BOS corridors place signs 10 ft. from the edge of the shoulder, Miami places signs 30 ft. away to avoid sign congestion. Buses are required to yield to all types of traffic that might be occupying the shoulder including merging and exiting traffic, emergency vehicles, and law enforcement vehicles. This is especially important when congestion occurs due to incidents in which emergency vehicles often need to use the shoulder. Buses on the shoulder are also required to have their 4-way flashers on at all times. The fine for misusing the shoulder including failure to yield or following a bus is $133.50 and points on the driver's record (Martin, 2007). The Florida Highway Patrol is responsible for enforcement of BOS lanes (Guerra, 2008).

Fairfax County, Virginia

Bus use of shoulders is limited to periods of traffic congestion when mainline speeds are less than 25 mph Monday through Friday between 4pm and 8pm. Buses cannot exceed 25 mph on the shoulder. A double solid white line separates the BOS shoulder from mainline lanes. Only public transit buses going to WFC metro station are allowed to use the shoulder. The legal agreement between Fairfax County and VDOT to use the shoulders for buses emphasizes that buses must yield the shoulder to emergency vehicles. If there is an incident that causes emergency vehicles to use the shoulder, the bus driver is required to merge back into mainline traffic (Martin, 2006).

1.4 COSTS AND FUNDING

Minneapolis / St. Paul, MN

The first bus-only shoulders in Minnesota required minimal capital. Since shoulders needing reconstruction were avoided, money was only needed for signing and re-striping. Initial capital funding for BOS projects in Minnesota came from Mn/DOT and Metro Transit. As the system expanded, Mn/DOT funded the construction of the early bus-only shoulders when reinforcement was required, while Metro Transit paid for the necessary park-and-ride facilities. Often, the reinforcement of the shoulder could be incorporated into other highway projects to save money. Bus-only shoulders along county roads were paid for with county funds. In 1997 the Mn/DOT and MetroTransit began to set aside $2 million per year for BOS construction. This amount was reduced to $1 million per year in 2006. In 2003, a bonding package was passed that granted $46 million to the capital costs of bus-only shoulders. This money was in addition to the $2 million per year. Capital costs for conversion to a BOS corridor range from $1,500 per mile to $100,000 per mile depending upon the condition of the shoulder (Douma, 2007).

Operating costs of the bus-only shoulders are paid by the individual transit providers. In 2002 the Twin Cities received $14.7 million from the FTA for their bus-only shoulders since they fit TEA-21's requirements of a transit service that uses an exclusive right-of-way or fixed guideway. This money distributed first to the Met Council, and then to MetroTransit and other transit service providers, was used almost exclusively for bus operating costs. Federal dollars were also received from the Congestion Mitigation Air Quality Improvement Program (CMAQ), jointly administered by the FHWA and the FTA (Douma, 2007).

San Diego, CA

Total cost of implementing San Diego's pilot project in 2005 was about $100,000. The U.S. Department of Transportation donated $18 million toward San Diego's new 20-mile BOS extension. The U.S. DOT views this project as a trial for lane-guidance technology. The other $22.5 million needed for the project comes from local sales tax (Schmidt, 2008).

1.5 STAKEHOLDERS AND LEGAL/LEGISLATIVE REQUIREMENTS

Minneapolis / St. Paul, MN

The primary players in the creation of the Twin Cities BOS system were the Minnesota Department of Transportation and Metro Transit. Other stakeholders included bus drivers and supervisors, members of the Minnesota State Patrol, suburban transit providers, the FHWA, and the Federal Transit Administration (FTA) (Douma, 2007).

Initial BOS projects did not require a formal process to establish legality. However, as more projects were successfully implemented, pressure increased to codify operating regulations and standards. The FHWA realized that the National Uniform Vehicle Code (UVC) does not allow driving on shoulders or passing on the right. In 1992, MN adopted an alternative standard to the UVC which allowed buses to run on shoulders. State law was passed in 2001 describing the conditions under which BOS routes could be operated and who was authorized to use them. According to statues BOS can be implemented only on freeways or expressways, though arterials can have bus-only shoulders with the approval of the transportation commissioner. The law also authorized police officers to issue tickets to any vehicle misusing the shoulder. Recent legislation authorized the commissioner to permit transit buses and Metro Mobility buses use of shoulders in the seven-county metro area. These statutes are very important because the National Uniform Vehicle Code, which aims to unify transportation infrastructure and regulations among states, prohibits driving on shoulders. States that allow buses to use shoulders without the proper statues face greater liability (Douma, 2007).

San Diego, CA

The California State Streets and Highway Code prohibits use of shoulder lanes as travel lanes, including by transit. The creation of transit-only lanes requires an engineering study. The BOS corridor in San Diego was officiated by a formal agreement between Caltrans and SANDAG for a two year pilot project. Shoulders were re-designated as transit lanes instead of shoulders, however, disabled cars may use them if necessary (Martin, 2007).

Ohio

The Ohio Revised Code contains a section legalizing bus use of shoulders in Ohio. Section 4511.25 allows COTA buses to use the shoulder during the trial BOS project in Columbus (Martin, 2007). The project partners in Cincinnati's BOS system include the transit operator Metro, the Ohio Department of Transportation, the Federal Highway Administration, and ARTIMIS (see Operational and Safety Considerations). ODOT and the FHWA granted permission for Cincinnati to conduct the pilot BOS project (Metro's I-71…, 2008).

Miami, FL

The primary players involved in BOS implementation in Miami include: Miami–Dade Transit, the Miami– Dade Expressway Authority, and the Florida DOT. Legislation to legalize bus-use of shoulders passed in Miami in 2005 before their pilot project began. The pilot project could of course have been implemented without this legislation, but the statutes would be necessary for long-term usage. An Interlocal Agreement between Miami-Dade transit and District 6 of the Florida DOT was created to authorize the three-year pilot program (Martin, 2007).

Fairfax County, VA

An agreement between VDOT and Fairfax County outlines the legal function of the bus shoulder lane. VDOT in turn gained approval for the project from the FHWA (Martin, 2006).

1.6 RESULTS OF BOS SYSTEMS

Minneapolis / St. Paul, MN

Over the 23 years of BOS existence in the Twin Cities, very few accidents have occurred. Between 1992 and 2001 only 20 accidents occurred on the shoulder involving a bus, all-resulting only in property damage. These accidents were characterized by minor scrapes or mirror damage. After 2001, one accident occurred on a shoulder that resulted in a fatality. The bus driver was ruled not to be at fault as an auto drove into the bus (Douma, 2007). Drivers have reported no conflicts with stalled vehicles in the shoulders or with emergency vehicles (Douma, 2006).

The implementation of BOS corridors in the Twin Cities is vastly regarded as a huge success and has resulted in many economic benefits. Transit ridership has increased while transit operational costs have decreased. More predictable bus scheduling is attractive to riders and results in less over-time for drivers. Often, the time saved by a bus using a shoulder during congestion is minimal, but the perception of time saved by the rider is substantial. Rider time savings has benefited transit providers. For example, Maple Grove Transit was able to eliminate 90% of their marketing budget once they were allowed to use shoulders. Apparently, a bus being able to speed past congested traffic is advertising enough to fill buses already in service and new ones. Part of the success of the BOS system is the availability of park-and-rides. Today, Minnesota will not fund a park-and-ride of less than 200 parking stalls. The larger park-and-rides appeal to more people as they generally offer more and better services (Douma, 2007).

Responses to BOS have been overwhelmingly positive from both bus drivers and bus riders. Cases have been reported in which "jealous" drivers straddle the right lane and the right shoulder so that bus drivers cannot pass. Though annoying to bus drivers, this occurrence does not pose much of a safety threat (Douma, 2007).

San Diego, CA

One of the goals of San Diego's BOS pilot project was to assess safety, bus travel time and reliability, bus and auto driver and bus passenger perceptions of bus-only-shoulders, maintenance, and necessary physical improvements to shoulders for long-term use. Six months into the two-year pilot project, no accidents had occurred. There were also no issues related to enforcement or Caltrans maintenance of the shoulders. Buses on Route 960 boasted that they were on-time 99% of the time, saving up to five minutes of travel time when congestion was heavy. Other traffic on the freeway seemed not to be affected by buses on shoulders. The project led to the conclusion that 10 ft. shoulders were optimal for buses; narrower shoulders resulted in slower service. Finally, Bus drivers and passengers exhibited positive responses to buses on shoulders and drivers felt that operations were safe and a good idea. Passengers, too, felt safe and that time savings were significant (Martin, 2007).

Ohio

The Columbus BOS system is supported by bus riders who like the feeling of beating traffic. Instances of vehicles other than buses using the shoulders have been rare (Hollander, 2008). In Cincinnati, at the end of the BOS pilot project's year long duration, no BOS-related accidents had occurred. Additionally, no problems were reported with buses merging back into traffic. This is highly significant for the first usage of the left shoulder for a BOS project. Bus routes 71X and 72 were reported to use the bus-only-shoulder on about 21% of trips made along the BOS corridor. An overwhelming positive response to BOS has come from surveyed bus riders. About 99% of the surveyed felt safe on the shoulder and that their travel time had been reduced. Nearly the same percentage would recommend bus usage to others as a result of using the BOS system (Metro's I-71…, 2008). Due to the successes of the pilot project, ODOT approved Cincinnati's decision to make their BOS system permanent in August 2008 (O.D.O.T. Agrees…, 2008).

Miami, FL

In Miami, after just a few months of operation, late buses were reduced by 50%. In addition, no accidents had been reported since the program began. A study determined that the weight of the buses did not have a negative impact on pavement and after six months, there was no adverse impact to shoulder, drainage culverts, or pavement. The drivers and riders in Miami are largely satisfied with buses on shoulders, though drivers would like wider lanes. Their largest problem thus far has been with drivers not allowing buses to merge back into traffic (Guerra, 2008).

Fairfax County, VA

Initial problems with enforcement caused very stringent regulations to be written on shoulder usage. Riders are thrilled with bus schedule reliability (Martin, 2006).

1.7 CHOOSING CORRIDORS FOR BOS

The concept of bus usage of shoulders is a low-cost solution for relieving buses from the pressures of traffic congestion. Because cost is a constraint, BOS cannot be implemented just anywhere. Only corridors with high levels of bus usage and significant peak period congestion would result in enough benefits to bus riders to warrant costs. Minor improvements to shoulders can be made to accommodate buses, but most of the elements required for bus usage must be in place at the start to make projects non cost-prohibitive. Table 1.2 shows a cost break-down for Minnesota roadway conversion to BOS. In the ideal case, a corridor would only need appropriate signage to implement BOS.

Many cities that have implemented BOS developed a list of criteria for choosing potential BOS corridors. In Minnesota this list is as follows [Mn/DOT]:

- There must be predictable congestion delays, meaning the traffic running speed must be less than 35 mph during the peak period and/or approaches to intersections have continuous backups.
- Congestion delays must occur one or more days per week.
- A minimum of six transit buses per day must use the proposed bus shoulder.
- The expected time savings of using the shoulder must be greater than eight minutes per mile per week.
- The proposed shoulder must have a continuous shoulder width of at least 10 feet.

TABLE 1.2 Minnesota/ Twin Cities Cost Break-Down (Douma, 2007).

Condition	Costs plus signing and striping
Shoulder width and bituminous depth are adequate. Catch basins do not need adjustment. Signing and striping are only requirements.	\$ 1,500 per mile – Freeway \$ 2,500 per mile - Expressway
Shoulder width and bituminous depth are adequate. Minor shoulder repairs and catch basin adjustments are needed.	\$ 5,000 per mile – Freeway \$ 5,000 per mile – Expressway
Shoulder width is adequate but bituminous depth requires a 2" overlay. This assumes shoulder and roadway can be overlayed at the same time.	\$ 12,000 per mile – Freeway \$ 12,000 per mile - Expressway
Same as above but adjacent roadway is not being overlayed. Shoulder must be removed, granular base adjusted and increased bituminous depth replaced.	\$ 80,000 - \$ 100,000 per mile
Shoulder width and depth replacement are required.	\$ 42,000 - \$ 66,000 per mile for both freeway and expressway
Installing a 12 ft shoulder rather than a 10 ft shoulder in a new construction project.	\$ 30,000 per mile for both freeway and expressway

Miami is more likely to choose a corridor for BOS that is already planned for corridor improvements in hopes that any upgrades to the shoulder can be combined with other construction to reduce overall costs. Ideal corridors should also have potential for park and ride locations and continuous shoulder segments of at least 2,500 ft. between merge locations (Guerra, 2008).

Sometimes no viable corridors are identified in a city. In 2007, Marin County, California completed a potential BOS corridor study. The California Highway Patrol expressed concern about the legality of BOS and the cost of the physical upgrades necessary for implementation. Though these concerns may not be prohibitive, they have certainly caused delay for beginning BOS operations in Marin County (Martin, 2007).

1.8 IMPLICATIONS FOR AUSTIN, TX

Those considering implementing BOS corridors in Austin, TX must have concerns about the effectiveness of BOS, safety for buses and other vehicles, loss of intended shoulder function, legal basis, and costs. These concerns have been addressed by successful examples of BOS in other cities. The proposed bus usage of shoulders in Austin is intended as an interim measure to bypass freeway congestion until managed lanes can be built according to the CAMPO 2030 plan. Several BOS systems have this purpose including those in San Diego, Miami, and Ohio. After ten years of operation, the Twin Cities' system is more of a permanent fixture, but its long-term success is still a great example for Austin from a physical and operational standpoint. The queue jumper BOS in Fairfax County, Virginia is an example of how BOS can be used to bypass congestion at interchanges. This may be a technique worth exploring for congested interchanges in Austin. From a bus rider's perspective, bus usage of shoulders has certainly been successful in these cities in terms of time savings and trip reliability; both ridership and schedule reliability have increased. Though rider perceived time savings is generally much greater than their actual time savings, perception is what counts in mode choice.

Safety was a prime concern for parties involved in the implementation of BOS in other cities, as well. Low accident histories indicate that the safety precautions used in Minnesota, California, Ohio, Florida, and Virginia were adequate to ensure the safety of buses and other vehicles. Speed limits of 25 to 35 mph combined with a maximum differential speed with mainline traffic of 10 to 15 mph are comfortable for both bus and vehicle drivers. Low speeds allow all drivers adequate time to respond to any conflicts. A key component of safety for bus usage of shoulders is that if the driver is not comfortable driving on the shoulder, he or she never has to. Training and experience help drivers to become more confident driving on the shoulder. Adequate signage and pavement markings are also important elements to ensure safety on BOS corridors. Signage and pavement markings help alert mainline traffic to the presence of buses, especially on ramps as they enter freeways where buses may be on the shoulder. Signs should be placed well in advance of remerge points so buses have enough time to maneuver back into traffic. Law enforcement is important to ensure that buses obey speed limits and that un-authorized vehicles do not use bus lanes.

Reducing the number of conflicts for bus drivers on shoulders can be handled by choosing the correct shoulder to implement BOS. The right shoulder, most commonly used, allows buses greater freedom to exit and enter the freeway but creates more conflict points at ramps and intersections in terms of weaving. When the right shoulder is used, bus drivers are instructed to use caution and yield to other vehicles. In some cases when weaving volume is particularly high, buses can be required to merge back into mainline traffic. At low speeds merging back into traffic does not seem to be an issue. Vehicles in main lanes are required to yield to buses attempting to merge. If buses are not required to exit the freeway very often over the course of a BOS corridor, use of the left shoulder can greatly reduce conflict points.

Reaching the left shoulder, however, can be somewhat more difficult for bus drivers. The left shoulder was used for BOS in Cincinnati in 2007 and for San Diego's BOS extension on I-805 in 2009. There is very little quantitative data on the success of using the left shoulder, but Cincinnati has not reported any hardships with buses merging through mainline traffic.

Adequate structural components can help to alleviate safety issues, as well. Shoulder widths of 10 ft. are generally sufficient for buses to maintain speeds of 35 mph on shoulders; less than 10 ft. causes a speed reduction. Shoulders greater than 10 ft. in width are more desirable, especially on bridges where drivers can become nervous driving very close to railings. Wider shoulders reduce the impact that buses have on adjacent lane motorists. Shoulder slopes of no more than 2% are important for rider comfort. A reduction in slope, however, must be accompanied with adequate drainage and debris removal so that ponding and other obstructions do not hinder bus usage of shoulders. Short term bus use of shoulders should not result in damage to shoulder pavements, but over time, pavement should be updated to full depth.

The intended use of shoulders along freeways is to provide shelter for disabled vehicles and access for emergency vehicles. Bus usage of shoulders should not inhibit the shoulder's intended use. Disabled vehicles can be encouraged to exit the freeway, but buses should merge back into traffic to maneuver around those that cannot. Buses should always yield the shoulder to emergency vehicles. In general, bus usage of shoulders operates the same way whether congestion arises from peak period traffic or incidents. However, if emergency vehicles need to occupy the shoulder in the case of an incident, buses merge back into the main lanes.

To implement BOS, cooperation between involved parties including transit agencies, DOTs, MPOs, and law enforcement is essential. Instituting BOS as a pilot project or an interim measure is an easier task legally, requiring only permission and approval from state DOTs and the FHWA. For long-term implementation, state vehicle codes and statutes need to be amended for bus use of shoulders.

1.9 BOS SYSTEM RECOMMENDATIONS FOR AUSTIN, TX

Based upon the significant BOS experience documented in the previous sections, recommendations for an Austin pilot test are listed below:

1. All BOS shoulders be at least 10 ft. in width and have adequate pavement depth to support bus usage,
2. Buses use the right shoulder and continuous shoulder segments be at least 2,500 ft. (buses will utilize auxiliary lanes when present instead of shoulders),
3. Buses not exceed 35 mph on the shoulder or 15 mph faster than traffic in the main lanes,
4. BOS signs be placed on ramps and along BOS corridors,
5. Bus operators be trained properly for BOS and only use the shoulder if comfortable doing so,
6. Buses yield to emergency vehicles or stalled vehicles stopped on the shoulder,
7. At least six buses travel along the corridor per day,
8. A BOS corridor needs no structural improvements to the shoulder and minimal restriping,
9. Texas Transportation Code should be updated to allow a BOS Pilot Program.

1.10 BUS DRIVER TRAINING

The pioneers of BOS systems are the Minnesota Department of Transportation and MetroTransit. Their system has been used as an example by many other cities. MetroTransit supplies a training manual, route pamphlets, and safety pamphlets to the bus drivers. Drivers participate in class-room instruction including a training video as well as on-board training. The major point that is stressed through all the resources is slow equals safe. The training is the responsibility of the transit authority. There is no mandate that dictates the specifics of a driver training program. The extensiveness of a training program is determined by the authority and the bus drivers. There is no enforcement program in Minnesota specifically focusing on BOS drivers. If there are any general problems associated with a driver, they are handled by a garage supervisor. The bus drivers understand that their job depends on operating a bus safely and efficiently.

Safety based evaluations of the Minnesota bus driver training program indicate that it has been successful since accident reports from Minnesota show an excellent safety record. For example, in the first 9 years of operation, the State Patrol only reported 20 crashes involving a bus traveling along a shoulder. All 20 crashes were property damage only. Today there are over 300 miles of BOS guide way in Minnesota, and there has been only one injury crash.

CHAPTER 2 CENTRAL TEXAS CASE STUDY

The review of experiences with Bus-on-Shoulder systems revealed key best practices in design and operations. For a section of freeway to be viable for BOS it must have a shoulder at least 10 ft. in width, experience peak hour speeds of less than 35 mph, serve at least six buses per day, and be at least 2500 ft. in length. Using these constraints, in 2008, a Central Texas Case study was done on six freeway corridors in Austin, TX including:

- IH-35 NB and SB between Slaughter Ln and Howard Ln
- Loop 1 (MoPac Expressway) NB and SB between Loop 360 (south of the CBD) and Braker Ln
- US-183 (Research Blvd) EB and WB between IH-35 and SH-45

Seven years later, in 2015, sections of IH-35 and US-183 are likely still viable for BOS operations, however, Loop 1 is currently undergoing modifications to provide toll lanes and other cross-sectional changes. Therefore, in this update to the 2008 examination, Loop 1 has been removed from consideration for BOS operations.

This 2015 analysis indicates several sections of both IH-35 and US-183 could be appropriate for BOS implementation at low cost with minimal or no lane re-striping. Each of the sections were subsequently modeled in CORSIM to demonstrate the benefits of a BOS system in terms of bus time savings and the impact of BOS on regular traffic.

2.1 DATA COLLECTION

In order to assess the viability of IH-35 and US 183 for BOS implementation, roadway geometry, bus volumes, and average vehicle speeds were collected. Operating speed data were collected during late November and early December 2014 by driving the study sections multiple times during AM and PM peak periods. Data were collected per section of roadway divided by ramps, thus the point of the gore area for each entrance and exit ramp was denoted as section beginning or ending points. The Appendix contains synthesized tables of all the data collected for each corridor.

2.1.1 Roadway Geometry

For each section several pieces of geometric data were gathered. This includes the number of thru lanes, lane width, presence of an auxiliary lane, auxiliary lane width, left shoulder width, right shoulder width, and section length. The data was gathered using aerial images from Google Earth in conjunction with Google Earth's measuring tool (see Figure 2.1). Though CAPCOG's Aerial photos were not of a resolution high enough to measure distances on the order of a few feet, the photos were used to verify field observed characteristics gathered with windshield surveys. The error for lane widths is on the order of +/- 1 ft. and for section lengths on the order of +/- 5 ft.

Bus Volumes

To find the bus volumes in each section, the different routes that travel in each of the three corridors were evaluated. The route map and route schedule, obtained from the Capital Metro website, were used to find the number of buses that travel on each segment of each corridor. Only weekday routes were evaluated. The number of buses that travel each route all day and during the AM and PM peak periods was calculated. The AM peak period used was roughly from 7:00 am to 9:00 am. The PM peak period used was roughly from 4:30 pm to 6:30 pm. It is important to note that the University of Texas Shuttle Routes does not follow a set schedule. Their frequency is an estimated time interval. Therefore, the minimum number of buses for these routes was used in the calculations for total number of buses in each section.

Average Vehicle Speeds

Average vehicle speeds were determined for each section by timing how long it took to drive the section during both AM and PM peak hours. Using the drive time and section length, average speeds were calculated. Each corridor was driven multiple times in order to verify consistency of speeds.

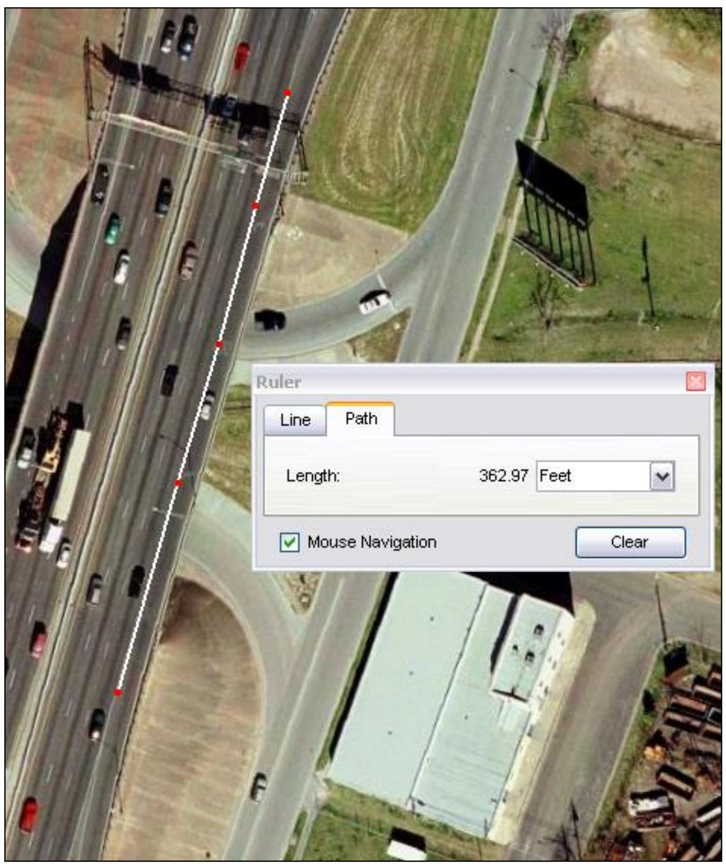


FIGURE 2.1 Sections were measured between ramps designated by the tip of the gore area (Google Earth, 2003).

2.2 CORRIDOR SELECTION

Each corridor was analyzed to determine which sections met the criteria needed for BOS. These criteria include bus volumes of at least six vehicles per day, average peak hour speeds less than 35 mph, and continuous shoulder width 10 ft. or more for sections of no less than 2500 ft. in length. Tables for each corridor with all the collected data are located in the APPENDIX.

2.2.1 IH-35 Northbound

Forty-two sections of IH-35 NB were analyzed as part of the 2008 initial BOS study. These sections included the path from Slaughter Ln north to the exit for Howard Ln, a total of about 20 miles. Based upon that analysis, the shoulder widths and pavement quality for the IH-35 NB sections were found to be very inconsistent along the 20 mile length. Therefore IH-35 NB was not chosen as a recommended pilot test section and since 2008, no significant geometric changes were made to these sections. Updated travel speed and other data were not collected for the IH-35 NB sections.

2.2.2 IH-35 Southbound

Forty sections of IH-35 SB were analyzed, from the exit for Howard Ln to the exit for Slaughter Ln (see Table 2.1). These sections also comprise about 20 miles of the corridor. The Bus Routes columns of Table 2.1 show that from the Howard Ln on-ramp to the Riverside Dr exit there are enough buses per day to meet the six bus minimum. Like the IH-35 NB corridor, the heaviest traveled section is from 15th/MLK to Riverside Drive due to the University of Texas shuttle bus routes.

TABLE 2.1 Geometry, Speeds and Bus Data for IH-35 SB.

IH35 Southbound							All Dates	Critical Time Period
Section								
From	To	Distance (ft)	Aux. Ln Width	L Shoul Width	R Shoul Width	Sum Shoul & Aux.	AM Speed (mph)	Buses Using BOS
Exit Howard	On-Ramp	2706.03	0	6	12	18	58	0
On-Ramp	Exit Parmer	5894.61	12	10	12	34	68	0
Exit Parmer	On-Ramp	5815.41	0	10	10	20	31	10
On-Ramp	Exit Braker	3157.49	0	10	10	20	25	10
Exit Braker	On-Ramp	5718.85	0	10	12	22	34	10
On-Ramp	Exit Rundberg	4783.44	12	2	9	23	24	10
Exit Rundberg	On-Ramp	3490.44	0	2	15	17	14	13
On-Ramp	Exit US 183	4091.30	12	2	8	22	17	13
Exit US 183	On-Ramp	4092.89	0	9	10	19	16	16
On-Ramp	On-Ramp	2185.26	12	8	7	27	10	16
On-Ramp	Exit FM2222/US 290E	3010.69	12	8	9	29	11	16
Exit FM2222/US 290E	On-Ramp	1260.59	0	9	10	19	21	16
On-Ramp	Exit 51st Street	1404.71	0	4	12	16	8	16
Exit 51st Street	On-Ramp	2334.66	0	4	10	14	12	16
On-Ramp	On-Ramp	3096.06	0	4	12	16	13	16
On-Ramp	Exit Airport	1339.70	12	3	3	18	20	16
Exit Airport	Split: Start of Elev	1207.84	0	2	10	12	25	16
Split: Start of Elev	On-Ramp	649.93	0	0	7	7	30	16
On-Ramp	Exit 15th St, MLK	7232.60	0	4	11	15	35	16
Exit 15th St, MLK	Split Ends	1619.97	0	4	11	15	38	16
Split Ends	Exit 12-11th	1580.44	0	6	11	17	51	3
Exit 12-11th	On-Ramp	896.21	0	4	10	14	39	0
On-Ramp	Exit 8th-3rd St	924.75	12	4	2	18	50	0
Exit 8th-3rd St	On-Ramp	2143.54	0	4	8	12	86	0
On-Ramp	Exit Cesar Chavez	720.65	12	3	1	16	51	0
Exit Cesar Chavez	On-Ramp	1514.54	0	2	2	4	23	0
On-Ramp	Exit Riverside	697.61	13	2	2	17	34	0
Exit Riverside	Exit Woodland	3664.75	0	2	6	8	71	13
Exit Woodland	On-Ramp	1688.24	0	4	12	16	55+	13
On-Ramp	Exit Oltorf	1469.20	13	5	12	30	55+	13
Exit Oltorf	On-Ramp	1407.47	0	5	10	15	55+	13
On-Ramp	Exit Woodward	1282.29	0	5	10	15	55+	13
Exit Woodward	On-Ramp	1899.53	0	4	11	15	55+	13
On-Ramp	Exit US 290/SH 71	1645.33	12	2	10	24	55+	13
Exit US 290/SH 71	Exit 230A Stassney	3452.74	0	14	10	24	55+	13
Exit 230A Stassney	On-Ramp	6571.46	0	10	16	26	55+	13
On-Ramp	Exit William Cannon	1843.46	12	2	10	24	55+	13
Exit William Cannon	On-Ramp	3732.00	0	10	16	26	55+	13
On-Ramp	Exit Slaughter	5641.73	0	2	10	12	55+	13

Legend	Possible BOS Test Cooridor	No physical improvements needed: at least 10 ft shoulder or aux lane	At least 6 buses per day
Speeds less than 35 mph		Speeds 55+ mph experence free-flow traffic	

In the AM peak, speeds drop below 35 mph after traffic from US-183 merges onto IH-35. Low speeds are maintained until the exit for MLK/15th St. In the PM peak, speeds fall below 35 mph at about 51st St and stay low until the exit for Woodward St.

Many sections have right shoulders of 10 ft. or greater, but just as many do not. Again, in most cases redistributing space on the left shoulder to the right shoulder by restriping could result in a 12 ft. shoulder, except for three sections. These include a portion of the elevated section, a portion of the section after the exit for Cesar Chavez, and a portion of the section after the exit for Riverside Dr. In all of these cases it would be extremely difficult to obtain a 12 ft. right shoulder, even by reducing main lane width.

2.2.3 US-183 Northbound

Twenty-two sections composing about 11.5 miles of US-183 NB were analyzed from the on-ramp from IH-35 to the exit for SH-45 (see Table 2.2). US-183 is highly traveled by Capital Metro buses, most of which are flyer and express buses. The entire stretch of the study area meets the minimum six buses per day. The total number of buses per day on US-183 NB ranges from 2 to 23.

TABLE 2.2 Geometry, Speeds and Bus Data for US-183 NB.

US 183 Northbound							All Dates	Critical Time Period
Section: From	Section: To	Distance (ft)	Aux. Ln Width	L Shoul Width	R Shoul Width	Sum Shoul & Aux.	PM Speed (mph)	Buses Using BOS
To 183 Ramp from IH35	On-ramp from IH35	3267	0	3	4	7	39	2
On-ramp from IH35	On-ramp	2443	0	9	10	19	41	2
On-ramp	Ohlen Road Exit	1047	12	7	10	29	24	2
Ohlen Road Exit	On-ramp	1941	0	10	10	20	24	2
On-ramp	Burnet Exit	5747	0	10	10	20	32	2
Burnet Exit	On-ramp	1960	0	9	10	19	29	2
On-ramp	Mopac Exit	2543	12	8	10	30	24	2
Mopac Exit	On-ramp	1724	0	8	10	18	16	2
On-ramp	Loop 360/Great Hills Exit	1758	0	8	10	18	8	23
Loop 360/Great Hills Exit	On-ramp (2 lanes)	2342	0	9	10	19	15	23
On-ramp (2 lanes)	On-ramp	2062	0	9	10	19	12	11
On-ramp	Braker Lane Exit	1480	12	10	10	32	17	8
Braker Lane Exit	On-ramp	3680	0	10	10	20	22	8
On-ramp	Duval Exit	2779	12	9	8	29	23	8
Duval Exit	Oak Knoll Exit	3065	0	11	11	22	32	8
Oak Knoll Exit	On-ramp	3654	0	9	10	19	33	11
On-ramp	Spicewood Sp Exit	2072	12	10	10	32	34	11
Spicewood Sp Exit	On-ramp	1967	0	10	10	20	37	11
On-ramp	Anderson Mill Exit	1772	0	10	10	20	36	11
Anderson Mill Exit	On-ramp	7822	0	10	10	20	65	11
On-ramp	RM 620 Exit	2619	12	10	10	32	62	11
RM 620 Exit	SH 45 East	2474	0	10	10	20	32	11

Legend	Possible BOS Test Cooridor	No physical improvements needed: at least 10 ft shoulder or aux lane	Atleast 6 buses per day
Speed less than 35 mph		Speeds 55+ mph experence free-flow traffic	

In the AM peak, there is little to no congestion on the corridor and speeds never fall below 35 mph. In the PM peak, bottlenecks develop due to reductions in the number of thru lanes and speeds of less than 35 mph are typical from the exit for Burnet Rd to the exit for Duval Rd.

The geometry on US-183 is excellent. All right shoulders and most left shoulders are between 8 and 10 ft. Re-striping could result in 10 ft. right shoulders through the entire length of the corridor.

2.2.4 US-183 Southbound

Twenty-five sections (about 13 miles) of US-183 SB were analyzed from the on-ramp from SH-45 to the exit for IH-35 as part of the 2008 BOS study. In the AM peak, speeds below 35 mph were sporadic and inconsistent. In the PM peak, speeds rarely fall below 35 mph on US-183 SB. Geometry on US-183 SB is excellent. Almost all the right shoulders have widths of 10 ft. or more and the few with 8 or 9 ft. could be increased by re-striping. Like US-183 NB, the SB corridor meets the six buses per day minimum. The total number of buses on US-183 NB range from 2 to 27. Based on the observed speeds SB US-183 was not chosen as an ideal location for pilot BOS testing.

2.3 CHOSEN CANDIDATES FOR BOS AND CORRIDOR MODELING

Two sections were considered exemplary candidates for BOS pilot testing. These include IH-35 SB from the US 183 exit to the start of the elevated IH 35 section and US-183 NB from the Burnet Rd exit to the Duval exit. These sections were chosen primarily based on ease of implementation.

2.3.1 US-183 Northbound from Burnet Road Exit to Duval Exit

A 4.94-mi section of US-183 NB was modeled consisting of 9 sections (see Table 2.3). Speeds drop below 35 mph on these sections during the PM peak and all but one section has 9 or 10 ft. right shoulder widths making implementation economical.

TABLE 2.3 US-183 NB Test Corridor Geometry, Speeds and Bus Data.

US 183 Northbound								All Dates	Critical Time Period
Section									
From	To	Distance (ft)	Aux. Ln Width	L Shoul Width	R Shoul Width	Sum Shoul & Aux.	PM Speed (mph)	Buses Using BOS
On-ramp	Ohlen Road Exit	1047	12	7	10	29	24	2
Ohlen Road Exit	On-ramp	1941	0	10	10	20	24	2
On-ramp	Burnet Exit	5747	0	10	10	20	32	2
Burnet Exit	On-ramp	1960	0	9	10	19	29	2
On-ramp	Mopac Exit	2543	12	8	10	30	24	2
Mopac Exit	On-ramp	1724	0	8	10	18	16	2
On-ramp	Loop 360/Great Hills Exit	1758	0	8	10	18	8	23
Loop 360/Great Hills Exit	On-ramp (2 lanes)	2342	0	9	10	19	15	23
On-ramp (2 lanes)	On-ramp	2062	0	9	10	19	12	11
On-ramp	Braker Lane Exit	1480	12	10	10	32	17	8
Braker Lane Exit	On-ramp	3680	0	10	10	20	22	8
On-ramp	Duval Exit	2779	12	9	8	29	23	8
Duval Exit	Oak Knoll Exit	3065	0	11	11	22	32	8
Oak Knoll Exit	On-ramp	3654	0	9	10	19	33	11
On-ramp	Spicewood Sp Exit	2072	12	10	10	32	34	11

Legend	Possible BOS Test Cooridor	No physical improvements needed: at least 10 ft shoulder or aux lane	Atleast 6 buses per day
Speed less than 35 mph		Speeds 55+ mph experience free-flow traffic	

2.3.2 IH-35 Southbound from US-183 exit to the start of the IH-35 elevated section

This 3.78 mile section of IH-35 typically has speeds less than 35 mph during AM peak times and six of the ten segments have right shoulder widths equal to or greater than 10 ft. Due to the variability in shoulder widths it is somewhat less desirable as a pilot test section compared to the chosen US-183 section. However, since BOS lanes can begin or end at any chosen entry or exit ramp, the sections with right shoulder widths less than 10 ft. could be excluded from the pilot test if desired.

TABLE 2.4 IH-35 SB Test Corridor Geometry, Speeds and Bus Data.

IH35 Southbound							All Dates	Critical Time Period
Section								
From	To	Distance (ft)	Aux. Ln Width	L Shoul Width	R Shoul Width	Sum Shoul & Aux.	AM Speed (mph)	Buses Using BOS
On-Ramp	Exit Braker	1596.01	0	10	10	20	25	10
Exit Braker	On-Ramp	5718.85	0	10	12	22	34	10
On-Ramp	Exit Rundberg	4783.44	12	2	9	23	24	10
Exit Rundberg	On-Ramp	3490.44	0	2	15	17	14	13
On-Ramp	Exit US 183	4091.30	12	2	8	22	17	13
Exit US 183	On-Ramp	4092.89	0	9	10	19	16	16
On-Ramp	On-Ramp	2185.26	12	8	7	27	10	16
On-Ramp	Exit FM2222/US 290E	3010.69	12	8	9	29	11	16
Exit FM2222/US 290E	On-Ramp	1260.59	0	9	10	19	21	16
On-Ramp	Exit 51st Street	1404.71	0	4	12	16	8	16
Exit 51st Street	On-Ramp	2334.66	0	4	10	14	12	16
On-Ramp	On-Ramp	3096.06	0	4	12	16	13	16
On-Ramp	Exit Airport	1339.70	12	3	3	18	20	16
Exit Airport	Split: Start of Elev	1207.84	0	2	10	12	25	16
Split: Start of Elev	On-Ramp	649.93	0	0	7	7	30	16
On-Ramp	Exit 15th St, MLK	7232.60	0	4	11	15	35	16

Legend	Possible BOS Test Cooridor	No physical improvements needed: at least 10 ft shoulder or aux lane	At least 6 buses per day
Speeds less than 35 mph		Speeds 55+ mph experence free-flow traffic	

2.4 FINAL RECOMMENDATIONS

The two chosen BOS pilot testing candidates can be ranked in order of preference based on ease of implementation and impact on bus speeds. The rankings are as follows:

1. US-183 NB: On-Ramp before Ohlen Road Exit to Spicewood Sp. Exit (7.17 mi)
2. IH-35 SB: On-Ramp before Braker Lane Exit to 15th St, MLK Exit (9.00 mi)

CHAPTER 3 BENEFIT AND COST EVALUATION

An ideal corridor for a BOS pilot study is a corridor that requires minimal capital cost and will provide high time savings benefits. A benefit-cost analysis evaluation was performed for the two recommended pilot test sites:

1. US-183 NB: On-Ramp before Ohlen Road Exit to Spicewood Sp. Exit (7.17 mi)
2. IH-35 SB: On-Ramp before Braker Lane Exit to 15th St, MLK Exit (9.00 mi)

3.1 CAPITAL COSTS FOR BOS IMPLEMENTATION

Implementation of a BOS system can involve costs that could include roadway structural improvements, signage, re-striping, enforcement, advertising, and driver training. An ideal test corridor will have minimal implementation costs so cost is a criterion for pilot test sites.

For the evaluation of these corridors, costs associated with enforcement, advertising, and driver training were considered negligible. The cost of signing was set equal to the signage costs reported by Minneapolis, $1,500 per mile. The cost of structural improvements and re-stripping were evaluated by Dr. Mike Murphy, Research Engineer at The University of Texas Center for Transportation Research (CTR) and retired TxDOT pavement engineer. The cost of lane re-striping in Austin depends on pavement type, therefore IH-35 and US-183 will have varying costs associated with re-striping and re-paving. The pavements on IH-35 are primarily hot mix asphalt concrete over crushed granular base, however, since US-183 is much newer than IH-35, all pavement is Continuously Reinforced Concrete Pavement (CRCP). When freeways are re-striped, in order to leave clean new lines and remove the shadows of the old lines, they are often overlaid as well. It is unlikely that IH-35 would be re-striped without being re-paved. Because US-183 is a new freeway with concrete pavement, re-striping would be considered without re-paving (Murphy, 2009).

Table 3.1 shows cost estimates for restriping and repaving IH-35, and US-183. A detailed description of how these costs were determined is included in Appendix C. Cost estimates are in terms of dollars per lane mile for a typical cross-section of each freeway. Because the cross-section of a freeway can change, a multiplying factor was applied in the cost calculations to account for any deviations. Also, because these freeways experience high traffic volumes, restriping and repaving would have to be accomplished at night. A multiplier factor for night construction was also applied to the cost estimates (Murphy, 2009).

TABLE 3.1 Cost Estimates for Re-striping and Re-paving.

Corridor	Re-Striping Costs ($ per lane mile)	Re-Paving Costs ($ per lane mile)
IH-35	$12,620.00	$401,166.67
US-183	$12,624.25	N/A

The costs of re-striping and especially re-paving a freeway section are extremely high compared to the costs of BOS signage. For this reason, no test corridors were chosen for a pilot study that would require physical alterations. The test corridors and the required implementation costs are shown in Table 3.2. Bus access to shoulder lanes can be interrupted along the length of any section as buses leave and re-enter main lanes as they cross entry or exit traffic streams. Therefore, particularly along the IH-35 section, the BOS lanes could be provided only on those sections with currently adequate shoulder widths. The most economical way to widen a shoulder less than 10 ft. in width would be to move the edge of pavement line inward and decrease the width of the right-most lane. This method should only be considered if one can show that narrowing the right-most lane would not interfere with freeway performance.

TABLE 3.2 Cost Estimates for Implementation.

Test Corridor	Miles	Signage Costs
IH-35 SB: Braker Exit to IH-35 split	9.00	$5,670
US-183 NB: Ohlen Exit to Duval Exit	7.17	$5,775

3.2 BENEFITS

The economic benefits of a BOS corridor are derived from the monetary value of the time saved due to BOS. Time savings can be quantified by using the following equation:

$$Rider\ Savings\ (\$/Day) = R_t \times D \times S \times V$$

Where: Rt = Daily bus ridership during the critical traffic period, t
D =Distance traveled by each bus route on each corridor
S = Bus time savings in minutes/mile
V =Dollar value of time

The critical traffic period is the time for which speeds on a corridor are less than 35 mph and these times were identified by driving the paths and measuring travel speeds and travel times during November and December 2014.

3.2.1 Computing the Dollar Value of Time for Austin Bus Riders (V)

There are several widely used methods for determining the dollar value of time. The two used in this report divide the median per capita income by a time value. Two different time values were used. The first conservative method is to divide median personal income by the total number of hours in the year (8,760). The second, a more non-conservative method, is to divide median personal income by the number of working hours in a year (2,080 hrs.).

Transit riders in Austin primarily live in three counties: Travis, Williamson, and Hays Counties. The United States Census Bureau provides the 2013 per capita income for each of these counties (Census, 2013). A weighted average was calculated of these three incomes based on their 2013 populations (see Table 3.3)

TABLE 3.3 Average per Capita Income for Region.

County	Per Capita income in past 12 months (2013 dollars)	Population, 2013 Estimate	% of Total Population	Weighted Average Income
Travis	$33,206	1,122,748	63.42%	$21,057.83
Williamson	$31,070	471,225	26.62%	$8,269.60
Hays	$26,873	176,483	9.97%	$2,678.76
Sum		1,770,456		**$32,006.19**

The dollar per hour value when dividing per capita income by the total number of hours in a year is:

$$\frac{\$}{hr} = \frac{\$32{,}006}{8760hrs} = \$3.65/hr$$

The dollar per hour value when dividing per capita income by the total number of working hours in a year is:

$$\frac{\$}{hr} = \frac{\$32{,}006}{2080hrs} = \$15.39/hr$$

Both of these dollar values of time were used to calculate benefits. A great deal of Austin bus users are students without an income. The more conservative value ($3.65/hr.) would be a more accurate assessment of corridors with high student ridership.

A third value of time is also used in the following calculations. The Texas Transportation Institute (TTI) recommends a value of time $16.79 per hour in their 2012 Urban Mobility Report. While the above values of time will be used in calculations, the standard $16.79 will be used to rank the test corridors.

3.2.2 Determining the Critical Traffic Period and Bus Time Savings (S)

Assuming the pilot BOS sections would use a protocol that permits bus use of BOS lanes only when main lane speeds are less than 35 mph, one must estimate how many hours per day speeds will be less than 35 mph to determine how many hours buses could use the lanes. Based upon the driving test runs performed during November and December 2014, a best case estimate of daily two hour duration of speeds less than 35 mph is estimated for both pilot test sections. This estimated two hour duration, during the AM peak for southbound IH-35, and during the PM peak for Northbound US 183, is conservative because it does not include longer durations induced by traffic crashes or more general traffic incidents. Crashes, or incidents of some type, are rather routine occurrences for both test sections and effects of these events are often long lasting but the estimated typical two hours of speeds less than 35 mph does not include these effects.

Tables 3.4 and 3.5 describe the average speeds used to determine the critical traffic period. The potential min/mile time savings on IH-35 SB and US-183 NB is given for buses.

TABLE 3.4 IH-35 SB Calculations of Peak Period Length and Min/Mile Time Savings (December 2014).

1. Speed Interval (mph)	2. Number of Minutes per Interval	3. % of Total Peak Traffic Period	4. Average Car Speed over Interval (mph)	5. Average Allowable Bus Speed over Interval (mph)	6. Car Travel Time (min/mile)	7. Bus Travel Time (min/mile)	8. Bus Time Savings (min/mile)	9. Weighted Average (min/mile)
≥ 30 and < 35	4	13.99%	32.5	35	1.85	1.71	0.13	0.02
≥ 25 and < 30	1	3.12%	27.5	35	2.18	1.71	0.47	0.01
≥ 20 and < 25	4	13.96%	22.5	35	2.67	1.71	0.95	0.13
≥ 15 and < 20	6	18.51%	17.5	35	3.43	1.71	1.71	0.32
≥ 10 and < 15	13	43.76%	12.5	27.5	4.80	2.18	2.62	1.15
≥ 5 and < 10	2	6.66%	7.5	22.5	8.00	2.67	5.33	0.36
≥ 0 and < 5	0	0.00%	2.5	17.5	24.00	3.43	20.57	0.00
SUM	31							1.98

For IH-35 SB, speeds of less than 35 mph were experienced by drivers for 31 minutes. The average time savings along this corridor that a bus on a bus-only-shoulder would experience is 1.98 minutes/mile.

TABLE 3.5 US-183 NB Calculations of Peak Period Length and Min/Mile Time Savings (December 2014).

1. Speed Interval (mph)	2. Number of Minutes per Interval	3. % of Total Peak Traffic Period	4. Average Car Speed over Interval (mph)	5. Average Allowable Bus Speed over Interval (mph)	6. Car Travel Time (min/mile)	7. Bus Travel Time (min/mile)	8. Bus Time Savings (min/mile)	9. Weighted Average (min/mile)
≥ 30 and < 35	5	25.23%	32.5	35	1.85	1.71	0.13	0.03
≥ 25 and < 30	1	3.78%	27.5	35	2.18	1.71	0.47	0.02
≥ 20 and < 25	6	29.20%	22.5	35	2.67	1.71	0.95	0.28
≥ 15 and < 20	2	11.06%	17.5	35	3.43	1.71	1.71	0.19
≥ 10 and < 15	4	18.85%	12.5	27.5	4.80	2.18	2.62	0.49
≥ 5 and < 10	2	11.88%	7.5	22.5	8.00	2.67	5.33	0.63
≥ 0 and < 5	0	0.00%	2.5	17.5	24.00	3.43	20.57	0.00
SUM	20							1.65

US-183 NB shows drivers experiencing speeds of less than 35 mph for 20 minutes. The critical traffic period of US-183 NB is from 4:00 PM to 6:30 PM, and the average time savings is 1.65 minutes per mile. The critical traffic period of IH 35 SB is from 6:00 AM to 8:30 AM, and due to slower congestion speeds than US-183, the average time savings could be as much as 5 minutes per mile.

3.2.3 Determining Ridership during the Critical Traffic Period (R_t)

Vehicle ridership data was obtained from Capital Metro to calculate the daily bus ridership during the critical traffic period. The data included the boarding, alighting, and maximum loads for major stops along each route (Capital Metro, 2015). The maximum load between two major stops was assumed to occur while the bus traveled along a test corridor. The time at which the bus travels along a test corridor is needed to find the ridership during the critical traffic period. Since times associated with the data only state the point at which a bus is at a major stop, the information was used to find when each bus was actually on the test corridor. The ridership for each trip was averaged to find the mean of the ridership for each trip on each route. The ridership of the trips that occurred during the critical traffic period was summed to find the daily bus ridership during the critical traffic period (see Table 3.6).

TABLE 3.6 IH-35 SB Ridership and Projected Daily Time Savings.

Route	# Riders During Critical Traffic Period	Miles Traveled on Test Corridor	Time Savings (min/mile)	Time Savings (min per rider)	Total Time Savings (min/day)
142	40	6.7	1.98	13.27	530.64
935	185	9	1.98	17.82	3296.70
985	47	5.27	1.98	10.43	490.43
Sum	272				**4,317.77**

There are three bus routes (one flyer shuttle and two express routes) that travel along the IH-35 SB test corridor during the assumed critical traffic period, 6:00 AM to 8:30 AM. Table 3.6 shows routes, ridership, and distance traveled on the IH-35 SB corridor. It also shows the calculated time savings for each route and the total corridor. For example, the flyer shuttle route 142 travels about 6.7 miles on the test corridor and saves nearly 1.98 minutes a mile. The time savings acquired through this route was approximately 13.27 minutes per rider. The number of riders during the critical period on average is 40 giving a total time savings for the flyer shuttle route 142 of 530.64 minutes a day.

Considering the frequency of the shuttle headways in the morning, it is likely that shuttle ridership would dramatically increase the total number of bus riders on the test corridor. A bus-on-shoulder system along this corridor could provide nearly 4,317.77 minutes of time savings to bus riders each day.

TABLE 3.7 US-183 NB Ridership and Projected Daily Time Savings.

Route	# Riders During Critical Traffic Period	Miles Traveled on Test Corridor	Time Savings (min/mile)	Time Savings (min per rider)	Total Time Savings (min/day)
982	226	0.78	1.65	1.29	290.86
983	33	2.25	1.65	3.71	122.51
985	49	7.17	1.65	11.83	579.69
987	104	4.34	1.65	7.16	744.74
Sum	412				**1,737.81**

Four express bus routes travel along the US-183 NB test corridor each afternoon during the critical traffic period, 4:00 PM to 6:30 PM: 982, 983, 985, 987. Table 3.7 shows the average number of riders per route during the critical traffic period each afternoon. The express route 982 travels about 0.78 miles on the test corridor saving nearly 1.65 minutes a mile. The time savings along this path is approximately 1.29 minutes per rider. With an average of 226 riders during the critical period, this active express route provides a total time savings of 290.86 minutes a day. A bus-on-shoulder system could provide a total of 1,737.81 minutes of time savings to bus riders each day.

3.3 TEST CORRIDOR COSTS AND BENEFITS SUMMARY

With all the information provided, BOS costs and benefits can finally be compared. Table 3.8 shows both costs and economic benefits in terms of time savings for both the conservative and non-conservative values of time that were previously described. The last column displays the number of days it would take for BOS costs to equal benefits.

TABLE 3.8 Comparison of Costs and Benefits.

Test Corridor	**Capital Costs (Signage Only)**	**Benefits**					
		Value of Time	*$/hr (per rider)*	*Daily Time Savings (min/day)*	*Rider Benefits $/ Day*	*$/Year (255 Days/Year)*	**Costs = Benefits (# Week Days)**
1. IH-35 SB	$5,670	Cons	3.65	4317.8	$262.66	**$66,979.35**	**21.59**
		Non-Cons	15.36	4317.8	$1,105.35	$281,863.78	5.13
3. US-183 NB	$5,775	Cons	3.65	1737.8	$105.72	**$26,957.82**	**54.63**
		Non-Cons	15.36	1737.8	$444.88	$113,444.43	12.98

3.4 FINAL RECOMMENDATIONS

When costs were compared to benefits the IH-35 SB pilot test section seems to be slightly less costly and only slightly more beneficial than US-183 NB. The corridors therefore are ranked for recommendation for a BOS pilot program in the following order:

1. US-183 NB: On-Ramp before Ohlen Road Exit to Spicewood Sp. Exit (7.17 mi)
2. IH-35 SB: On-Ramp before Braker Lane Exit to 15th St, MLK Exit (9.00 mi)

CHAPTER 4 PREDICTING INCREMENTAL TRANSIT PATRONAGE FOR BOS OPERATIONS

4.1 INTRODUCTION

One of the objectives of BOS implementation in other cities has included attracting additional riders to the transit routes demonstrating reduced travel times. This section will look at how BOS can affect transit ridership and includes 5 sub-sections. Sub-section 4.2 looks at ridership data from the Minneapolis-Saint Paul Metropolitan area. The long history of BOS in the Twin Cities allows a clear depiction of the effect BOS on ridership. Before and after ridership data was used to determine the incremental effect of BOS and what factors determine this change. Ridership data contains inherent time-wise patterns that were removed to help isolate and separate the effect of BOS from other influences.

To determine how Austinites would receive BOS, a stated preference survey was administered in Austin, Texas. The survey was administration via the WEB and targeted groups that would provide cross-sections of the potential rider population. The conclusions from the survey are discussed in Sub-section 4.4. The survey was able to gage the reaction Austinites would have to a BOS system and what benefits they would expect. Conclusions from Sub-Section 4.2 were applied to known ridership data from Austin, Texas to determine possible ridership changes if BOS was implemented in Austin.

4.2 RIDERSHIP CHANGES IN MINNEAPOLIS-SAINT PAUL

4.2.1 Data Collection

The analysis of the Minneapolis-Saint Paul ridership data was route based. The routes that were used were determined from the assessment of three main data sets. First, information describing the characteristics and location of each BOS section and when it opened was obtained from MetroTransit. Second, speed data for all major corridors in the region was obtained from The Minnesota Department of Transportation (MnDOT). Third, route specific ridership data was obtained from two separate transit agencies in the Minneapolis-Saint Paul region.

4.2.2 BOS Segment Data Collection

Team Transit is an organization within the MnDOT, which is behind the success of BOS in the Minneapolis-Saint Paul metropolitan region. A list of all BOS sections was obtained from Team Transit along with the section lengths, when opened and, in the case of a few sections, when closed. The BOS system in the Twin Cities is extremely extensive with over 300 miles. More recently, the addition of BOS lanes has been a result of area freeway expansion. If possible whenever a new freeway is being developed or reconditioned in the area it is built with the intention of the shoulder being BOS accessible. Therefore many of the new sections are put in areas that may not currently warrant BOS but will most likely in the future (Jensen, 2009).

4.2.3 Speed Data Collection

MnDOT has an extensive and advanced ITS system. MnDOT provides a program that can be downloaded (via the WEB) which allows extraction of historical speed data from any sensor installed on any of the Twin Cities freeways. The earliest available data for a majority of the sensors is January 1994. The program allowed for data to be extract for any day and any time bracket. For all BOS sections, data was extracted for extended morning (6:30-9:30am) and evening (4:30-7:30pm) peak periods for every Tuesday, Wednesday and Thursday except for Holidays. Holidays that fell in the middle of the week were New Year's Day, July 4th, Thanksgiving and Christmas. The entire week of Thanksgiving and the entire week between Christmas and New Years were excluded from the analysis (Minnesota Department of Transportation, 2009).

4.2.4 Ridership Data Collection

The locations of sensors as well as the years for which data was available were cross-referenced with the location of BOS lanes from the supplied Team Transit BOS history. From the combination of the locations of sensors and the locations of BOS lanes, specific corridors were identified. From these corridors, historical route based data was requested from two transit agencies in the Minneapolis-Saint Paul region. Metro Transit is the primary transit agency in the area and operates the majority of routes through the area. There are a few minor agencies that focus on commuter routes from the suburbs into the Twin Cities. One of these smaller agencies is the Minnesota Valley Transit Authority (MVTA). The MVTA is based among five cities south of the Minneapolis-Saint Paul metropolitan region and operates 22 routes (Abegg, 2009). From these two transit agencies; route data was obtained for a majority of routes along North and South I-35W, South I-35E, Highway 62 and Truck Highway 77.

For analysis, routes were required to have monthly ridership data starting at least two years prior to the year BOS was implemented along the route. The two-year prior data requirement limited usable routes; also, usable routes were limited because of problems associated with the supplied data. In 2004, Metro Transit did major route restructuring on its southern routes, as a result very few routes had ridership data prior to 2004. For the few routes that did extend prior to 2004, the oldest data was from April 1996. The Metro Transit data was also limited because monthly ridership numbers were not recorded for every month; monthly ridership totals were only recorded for 2 or 4 months out of every year (Carlson, 2009). For the Metro Transit ridership data to be usable, a 12-point moving average was applied to fill in the missing monthly data. Fortunately, the data supplied by MVTA contained the monthly ridership numbers for every month for every route. The earliest available data is from January 1991 (Abegg, 2009). Due to the higher quality of MVTA data, the majority of routes assessed were MVTA commuter routes. A total of eighteen routes fit the criteria dictated by the constraints of the three data sources.

4.2.5 Data Analysis

From the 18 routes identified by the process described in section 4.2, 42 data sets were created, and each route was treated as a separate data point for each year of BOS lane implementation. Therefore if a route had BOS lanes added in 1994 and 1996, then there would be two different data sets, one for each initiation year. From these 42 data sets, 10 were removed due to data irregularities discussed in this section.

4.2.6 Removing Seasonality

The primary goal of this effort was to find the incremental effect that incorporating a BOS lane onto a corridor has on route ridership. It was determined that the best predictor for this would be percent change in ridership. The data provided by Team Transit regarding when each BOS section opened only stated the opening year, therefore the percent difference calculated was for the change from the year prior to BOS to the year after implementation. This yearly assessment would identify incremental and short-term effects BOS has on ridership.

Ridership can be affected by many elements, some predictable and some not. One predictable effect on ridership is seasonality. Typically ridership is higher in spring and fall and lower in summer and winter (Haire 2009). The seasonality of ridership was extensively addressed in work done by Dr. Ashley Haire on the short-term effects of fuel prices. Haire calculated monthly seasonal variables by following a process referred to as seasonal decomposition. The seasonal adjustment factors used were based on system wide monthly ridership data obtained from the National Transit Database (NTD). The factors used in this report were calculated from Metro Transit system wide ridership numbers. Compared to other transit agencies, Metro Transit shows low seasonal variation. This means that ridership trends do not change much from month to month and season to season. The NTD only compiles monthly ridership data from larger transit agencies; as a result the MVTA does not report their system wide monthly ridership data to the NTD. It was assumed that the Metro Transit trends would be the same as the MVTA trends and the seasonal adjustment factors calculated for Metro Transit were applied to both the Metro Transit and MVTA ridership data. Table 4.1 shows the Metro Transit seasonal adjustment factors (SAF) that were used on all analyzed routes to remove seasonality from monthly ridership data.

TABLE 4.1 Seasonal Adjustment Factors for Metro Transit.

Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
0.00%	-0.15%	-2.05%	1.34%	1.17%	-0.05%	-0.08%	0.93%	-0.22%	-0.01%	-0.66%	-0.21%

Due to a variety of inherit trends in all ridership data, Haire was unable to perform the additive season decomposition on the unlinked passenger trip (UPT) data obtained from the NTD. Haire used the percent difference in the logarithm (base 10) values of the UPT (*PDLOGUPT*) as the basis for her analysis. Therefore the SAF values must be applied to the ridership data that is transformed into a *PDLOGUPT* series. The transformation of ridership data for a particular point in time (month), Y_t, to the *PDLOGUPT* series was achieved using the equation below

$$PDLOGUPT_t = \frac{logY_t - logY_{t-1}}{logY_{t-1}} \times 100\%$$

Therefore to create a seasonally-adjusted time series, *SASt*, for each route, the SAF values in Table 4.1 were subtracted from the *PDLOGUPTt* time series. Using the arithmetic properties of logarithms, the seasonally adjusted series was easily converted back into the simpler form to total monthly ridership values (Haire 2009).

The seasonally adjusted total yearly ridership for the year before BOS implementation and the year after BOS implementation for each route and the calculated percent difference between these values was computed. The percent difference is the dependent variable used in this data analysis.

4.2.7 Appling 12 point Moving Average

From service changes to fare increases and also strikes, there are many factors that affect transit ridership data. While two major strikes that occurred at Metro Transit were identified many other factors were unidentifiable. To help reduce the effect of other external factors that affect ridership, a 12-point moving average was applied to all 18 routes analyzed. The 12-point moving average smoothed the data so that the effect due to BOS was much clearer. It also helped to identify times of ridership change that were not due to BOS, but due to strong external factors that could not be determined.

Figures 4.1 and 4.2 show MVTA route 464 versus time. Route 464 travels along IH-35W from the southern suburbs into Minneapolis. Figure 4.1 depicts the ridership starting in January 1991. Both figures clearly show the smoothing effect of the 12-point moving average. BOS sections along the 464 route opened in 1996 and in 2001. To better see the ridership increase in 1996, Figure 4.2 shows monthly ridership from 1995 through 1997. A clearly visible jump can be seen near March of 1996. A jump like this one is not always visible each year a BOS lane was added. This is most likely due to external factors. Figure 4.1 shows a peak around July of 2001. Although BOS was implemented along 464 in 2001, this peak is clearly not due to BOS implementation but other factors that are unknown. Route data that showed strong irregular behavior, like route 464 in 2001 was removed. A total of 8 data sets were removed, but is important to note that only sets with strong irregular behavior were removed. There were other sets where the data was most likely affected by external factors, but due to lack of information, properly identifying these factors was impossible.

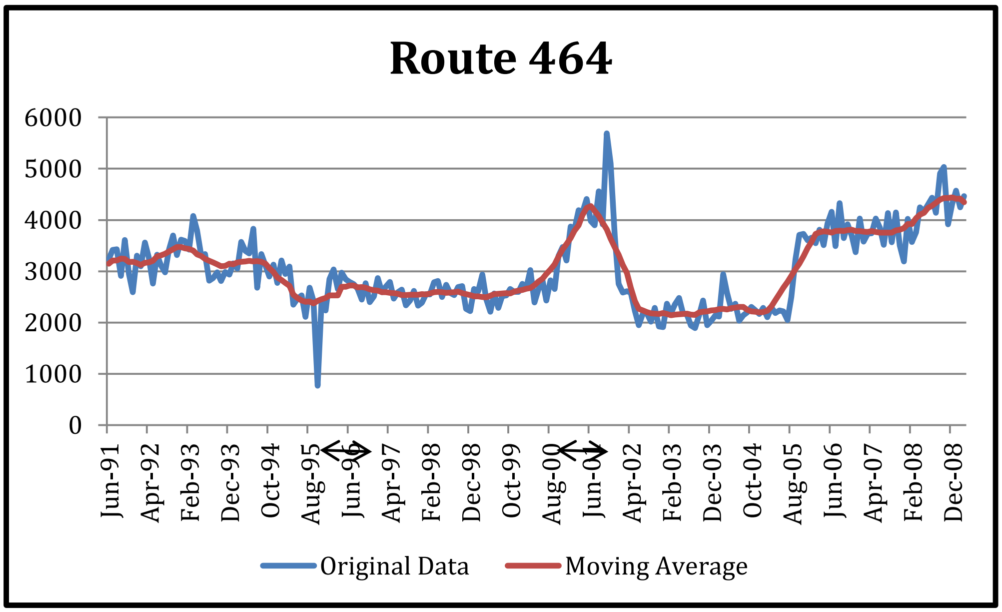


FIGURE 4.1 MVTA Route 464 Ridership from Jan 1991 to Oct 2008

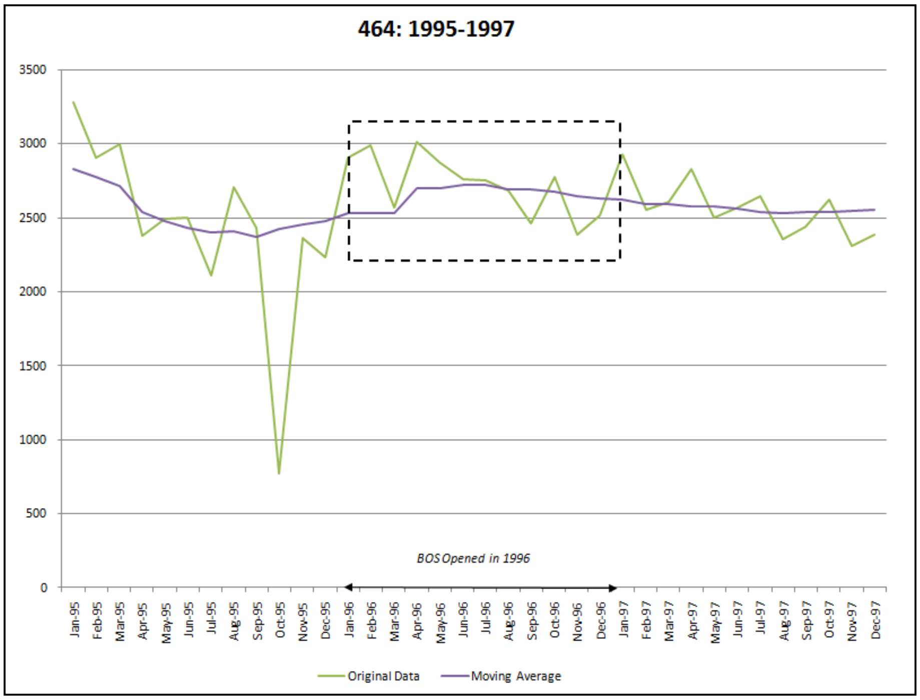


FIGURE 4.2 MVTA Route 464 Ridership from 1994 to 1998.

4.2.8 Independent variables

As previously stated a total of 32 data sets were compiled. Each data set was for a route during a certain year of BOS implementation. Each data set incorporated the inbound and outbound travel of that route. Therefore each route was considered a loop that would travel into town in the morning peak on half the loop and travel out of town in the evening peak on the other half of the loop.

Six potential predictor variables were identified for each data set. The first was a binary that stated whether that route had a BOS section on it previously. The second variable is related to the first; if a BOS section existed previously, then the second variable states how many years since the previous section was opened. The third is the total length of BOS section(s) along a route's loop.

The final three variables are all related to the speed data obtained from the MnDOT extraction program. The average number of minutes per day in which the speed was below 35 mph was determined. Then the average speed was calculated for the times during which the speeds were below 35mph. The sixth independent variable was the average bus passenger time saved when the freeway speed was below 35 miles per hour. This value was derived from the maximum possible speed differential between personal vehicles traveling at the average speed (when below 35mph) and a bus allowed to travel up to 15 mph faster along the shoulder (with a max speed of 35mph). Time saving values ranged from 0.213 minutes per mile to 1.596 minutes per mile.

4.2.9 Prediction Models

Three methods were used to analyze the 32 data sets: a multi-variable model, single-variable models, and a confidence interval. As previously stated the dependent variable was percent change in ridership from the year prior to BOS implementation to the year after implementation. The independent variables were, (A) the binary variable representing the inaugural year of BOS, (B) the years since a previous BOS section's implementation, (C) the total length of BOS sections on a corridor, (D) minutes per day that the freeway speed was below 35 mph, (E) the average speed of traffic when speeds were below 35 mph and (F) the average time savings for a bus on a BOS route when using the shoulder.

4.2.10 Multi-variable Model

Using the statistical computer program, SPSS, the 32 data sets were examined with the goal of finding a multi-variable model using some or all of the previously discussed independent variables. Linear regression analysis indicated none of the six independent variables were good predictors. This is most likely due to the limited number of data points and the amount of scatter within the data sets. As previously mentioned, there are many other external factors that can affect transit ridership. While a strongly significant model could not be created, a multi variable linear regression could be created using the variables with relatively strong significance. The created model is shown below as Equation 1.

$$[1]\quad PercentChange = -.107 - .061First\_Binary - 0.01Years\_From\_Previous + .012Average\_Speed$$

4.2.11 Single-variable model

A multi-variable model appeared to not be an effective way to model the incremental effects on ridership due to BOS. Therefore each independent variable was separately compared to the dependent variable, percent change. Comparisons were done using the correlation coefficient, r. Table 4.2 shows the correlation coefficients for each independent variable compared to percent difference as well as the Student's t-value.

TABLE 4.2 Correlation Coefficient and T-Stats for Each X Value Compared to Percent. Difference.

	A: First Year - Binary	B: Length	C: Years from Previous	D: Average Min/Day Speed below 35mph	E: Average Speed when below 35mph	F: Average Time Savings when Speed below 35mph (min/mile)
r	0.0292	-0.0823	-0.2489	-0.1409	0.3048	-0.2993
t	0.165	-0.467	-1.453	-0.805	1.810	-1.77

The variables with the strongest correlation to the percent change in ridership are variable E and F. Both of these values have sign's that are counter intuitive of what one would assume. The correlation coefficient for variable E is positive meaning when speeds increase (from 0 to 35mph) the percent difference in ridership also increases. The correlation coefficient for variable F is negative, meaning when the time savings decreases the percentage change in ridership increases. While the trends may be counterintuitive, a t-test on these values determined them to be somewhat significant. For a two tailed t distribution, t_{90} is equal to 1.694 and t_{95} is equal to 2.037. Therefore the correlation coefficient is significant at 90% but not at 95%. Because of the counterintuitive nature of the correlation coefficients, scatter plots were used to better understand the distribution of the data points. Figures 4.3 and 4.4 are scatter plots of percent change in ridership versus average bus time savings when freeway speed is below 35mph (variable F) and average freeway speed when below 35mph (variable E) respectively.

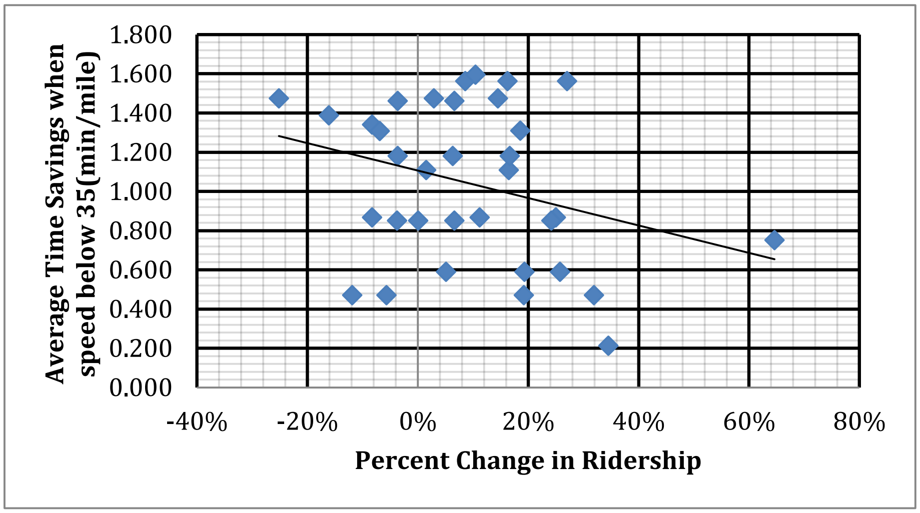


FIGURE 4.3 Scatter Plot of Average Time Savings vs. Percent Change in Ridership.

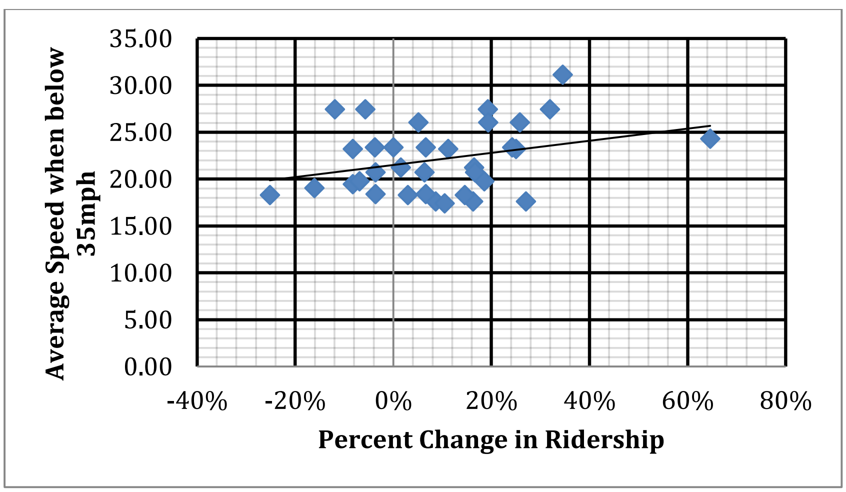


FIGURE 4.4 Scatter Plot of Average Speed vs. Percent Change in Ridership.

When the scatter plots in Figures 4.3 and 4.4 are examined, one can see that the majority of data points are clustered together with no apparent trends. When the few data points outside the cluster are evaluated, a slight trend is identified. Despite the t value being significant at 90% for both these variables, the trends between the percent change in ridership and the independent variables E and F are determined by only a few data points. A small part of the data sets are providing all the correlation. From the scatter plots, it was determined that there is no strong relationship between these values and percent difference.

A count of the observations with increases in ridership versus those with decreases indicates that there is a 71% chance that the route ridership will increase after BOS implementation. Also, if there is an increase in ridership, the average increase is 17%. When the average freeway speed (when the speed is below 35 mph) is between 15 mph and 25 mph, and the times savings is greater than 0.5 minutes per mile, the probability of an increase in ridership is 76% with an average increase of 15%.

4.2.12 Confidence Interval

A confidence interval was calculated from the mean and standard deviation of the sample. The mean percent difference was 9.41% and the standard deviation was 0.173. A 90 percent confidence interval returns a range of values from 4.5% to 14.3%. Therefore, with 90 percent confidence, implementation of a BOS section will increase ridership on a single route by at least 4.5% and as much as 14.3%.

4.2.13 Conclusion

Due to the limitations of the data set, creating a reliable and statistically significant multi-variable or single-variable model was not possible. In most cases, there is clear indication of ridership increase after BOS implementation. The predictor variables chosen were based on the available data as well as experience based hypotheses. The lack of statistically significant relationships shows that predicating human behavior is very difficult. While time savings, average speed and the time in which speeds are below 35 mph can be calculated based on empirical data, the average commuter likely responds only to perceptions of these values.

The data indicate with 90% confidence, ridership will increase by at least 4.5% and as much as 14.3%. There is 71% chance of ridership increase as a result of BOS implementation; and if there is a positive change in ridership it will be an average increase of 17%. It appears that people will be willing to switch to BOS because of the perceived benefit, not the actual benefits.

4.3 STATED PREFERENCE SURVEY

Section 4.2 discussed how BOS affected ridership in the Minneapolis-Saint Paul metropolitan area. Characteristics of transit systems and transit ridership vary city to city; therefore to characterize the city of Austin and how Austinites could respond to a BOS system, a stated preference survey was created. The survey consisted of nine questions. Table 4.3 gives a summary of the 9 questions asked; the complete survey is attached in Appendix D. Each question had multiple-choice answers. It was administered via an online survey platform: kwiksurveys.com. The goal of the survey was to gage how Austinites would respond to buses using a freeway shoulder during times of congestion. The survey targeted persons who commuted alone in their personal vehicle in the morning. The questions specifically asked about a person's morning commute instead of their round trip commute to simplify responses and avoid confusion.

TABLE 4.3 Stated Preference Survey Questions.

	Questions
1)	Do you currently drive alone and use Loop 1 (MoPac), IH-35 or US183 during the AM (7:00-9:00AM) traffic peak period?
2)	How long is your typical door-to-door commute time (include parking, walking to and from your car, etc)?
3)	What percentage of your trip is spent using Loop 1 (MoPac), IH-35 or US183?
4)	What percentage of your trip do you spend in congestion?
5)	Would you try a transit service knowing it will be able to use a shoulder to bypass congestion on the freeway?
6)	Do you have any flexibility in what time you arrive at your place of employment?
7)	If your place of employment does not allow for flexibility in your arrival time, how much earlier to do you leave home to ensure you are on time to work?
8)	Knowing that taking a bus on shoulder option will guarantee you a consistent travel time in the morning, would you switch from driving to taking the bus?
9)	How much time would a bus need to save on the freeway section of its route for you to use transit in the morning commute?

Questions 1 through 4 were intended to characterize the respondent's morning commute. Questions 6 through 8 were used to determine the importance of reliability for commuters and if an increase in service reliability would convince commuters to switch to transit. Question 9 was asked to help determine what commuters would expect in time savings to switch from their personal vehicles to transit. Question 5 was used to determine whether a person would try the transit service using BOS.

The survey received 295 responses from Austin residents. Contingency tables and cross-classification of survey responses were used to evaluate the survey. Initially all questions were cross classified with Question 5 to get an understanding of the commuting characteristics of persons who would try a transit system using BOS. The Chi Squared Test was also used to identify any strong correlation among survey responses. The survey identified three factors for enticing drivers to try transit: 1) the typical commute time, 2) the percentage of trip spent in congestion and 3) the driver's desired time savings. The responses to Question 1 and Question 3 were not significant factors.

4.3.1 Typical Commute Time

This second question asked about the respondent's typical commute time. It should be noted that these are most likely perceived and approximate travel times. The majority of respondents, 54%, had a commute time between 10-30 minutes. When the responses to question 2 were cross classified with question 5 it was seen that as commute time increased, the probability of a person trying the bus increased. Figure 4.5 shows this trend.

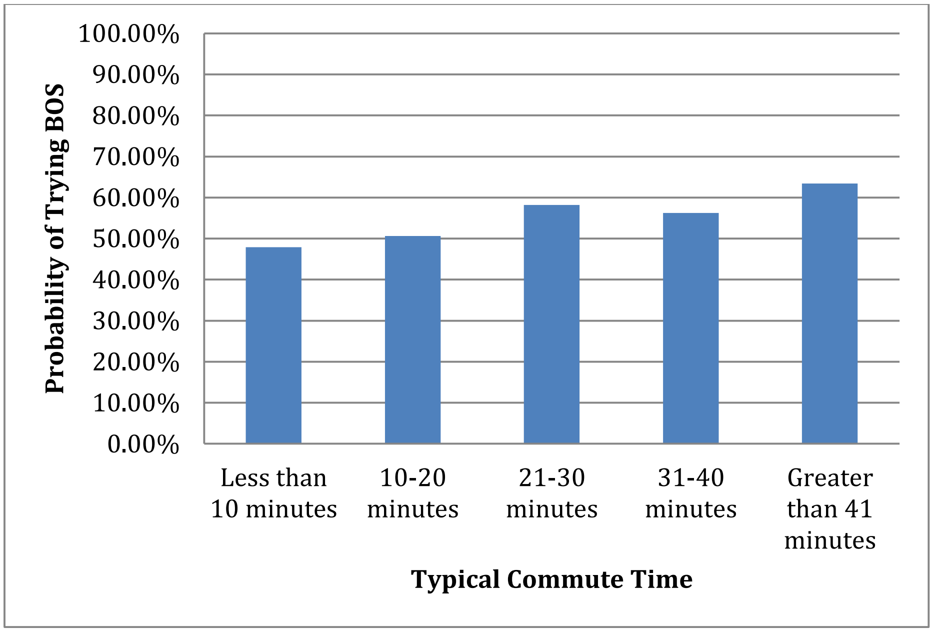


FIGURE 4.5 Probability of a driver trying the bus for a range of commute times.

4.3.2 Percent of Commute on Freeway

Question three asked about the perceived percentage of time the respondent typically spends in congestion during their morning commute. Figure 4.6 shows the probability that a driver will try transit with BOS for each percentage bracket. These values along with The Chi Squared Test performed on these responses shows there is no correlation between the percentages of time spent on a freeway and a driver's willingness to switch to BOS. Therefore, when targeting persons to try BOS, it is necessary to target a wider range of potential riders than only persons who use the three main freeway corridors in Austin. Targeting freeway commuters as well as drivers using arterials and collectors is also necessary.

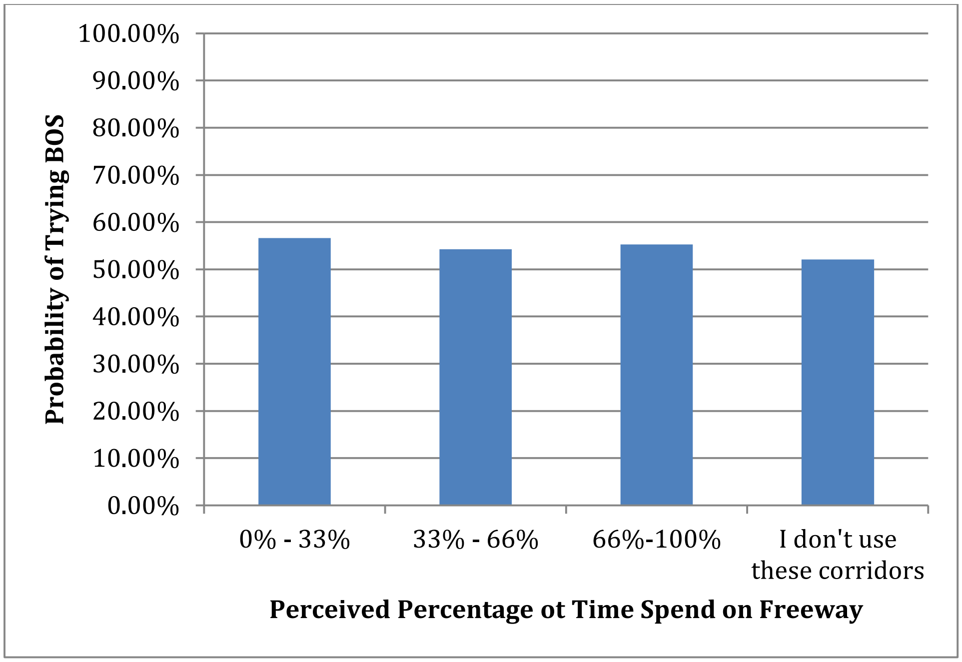


FIGURE 4.6 Probability of a driver trying the bus for a range of percent time spent on major Austin freeways.

4.3.3 Percent of Commute in Congestion

Question 4 looked at the percentage of a driver's trip spent in congestion. Like typical travel time, this is a perceived value. Traveler definitions of congestion vary as well as their perceptions of the durations of congested travel. Figure 4.7 shows the probably of a driver trying a BOS transit service with respect to their time spent in congestion.

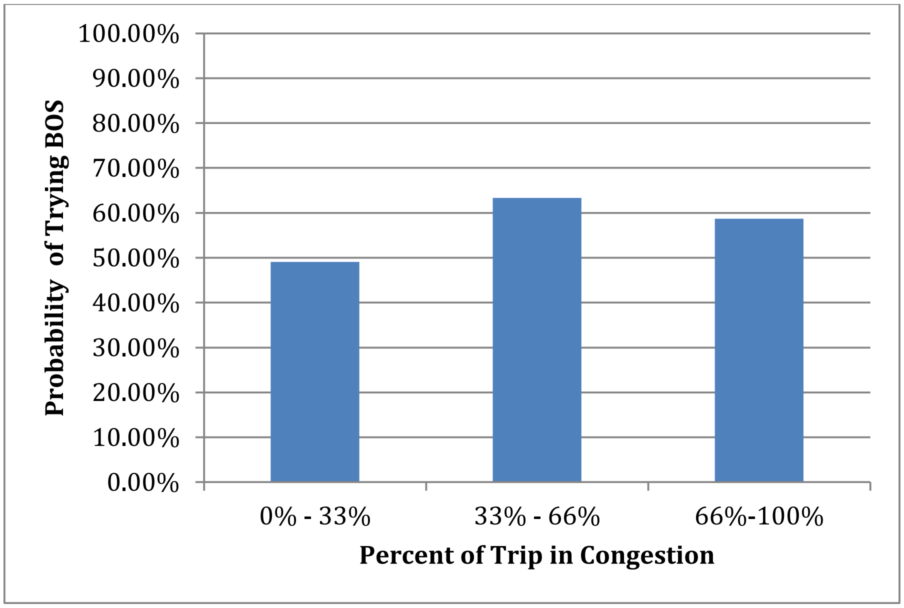


FIGURE 4.7 Probability of a driver trying BOS Transit with respect to congestion.

Figure 4.7 shows that a driver who perceives that 33% or more of the commute trip is spent in congestion is more likely to try transit than a person who perceives that less than 33% of the commute is congested. A Chi Squared test was also performed on responses to question 4 in relation to question 5. The Chi Square Test showed a strong association between willingness to try transit and time spent in congestion at a 10% level of significance.

4.3.4 Significance of Reliability

Question 6, 7 and 8 are all linked in determining the importance of reliability. Question 6 asked whether a person's employer allowed arrival time flexibility. If the employer did not allow flexibility, they were asked how much extra time the respondents add to their trip to ensure they get to work on time. Question 8 asked if an increase in reliably would entice a person to switch modes. The goal of these questions was to determine not only the importance of reliability but also a measure of how much reliability based time savings would entice one to try the service. Question 8 asked if a person would switch to BOS knowing it would increase their commute reliability, 44% said yes and 56% said no. These results coupled with the results from question 6 and 7 indicate that reliability is not a major factor for a commuter's mode choice.

4.3.5 Desired Time Savings

Question 9 asked how much a BOS bus would have to improve one's travel time to cause mode switch. The survey had 7 multiple-choice categories for responses to question 9. During the analysis of the survey responses, the categories were condensed to 4. When a Chi Squared test was preformed, there was a strong association between desired time saving and willingness to try transit at 5% significance. Figure 4.8 shows the probability of commuters trying transit for different desired time savings. The 5 to 7 minute category has a 100% probability of commuter switching. It is important to note, that while the probability is 100% there are only 5 responders in this category and they all responded yes. This figure shows that time savings is not necessary to entice single drivers to try transit, but having a high time savings can help.

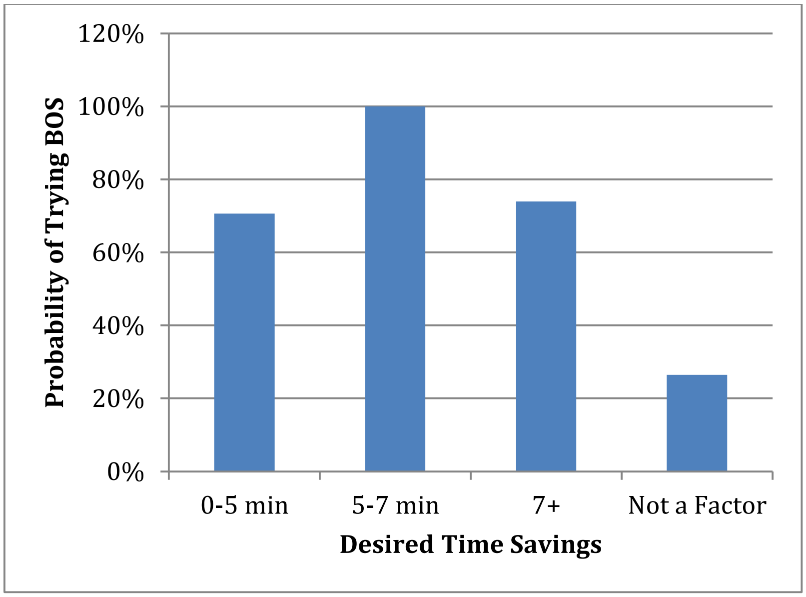


FIGURE 4.8 Probability of Switching to Transit for a Range of Desired Time Savings.

4.3.6 Conclusions

From the survey, it appears that there are 3 deciding factors for enticing drivers to try transit: (1) the typical commute time, (2) the trip percentage spent in congestion and (3) the driver's desired time savings. To better understand answers for Question 2 (typical commute time) and Question 9 (desired time savings) these were cross-classified. This cross-classification resulted in the graph shown in Figure 4.9. The graph shows that those who will try a BOS transit service, have a typical commute time over 21 minutes and they want at least seven minutes in time savings.

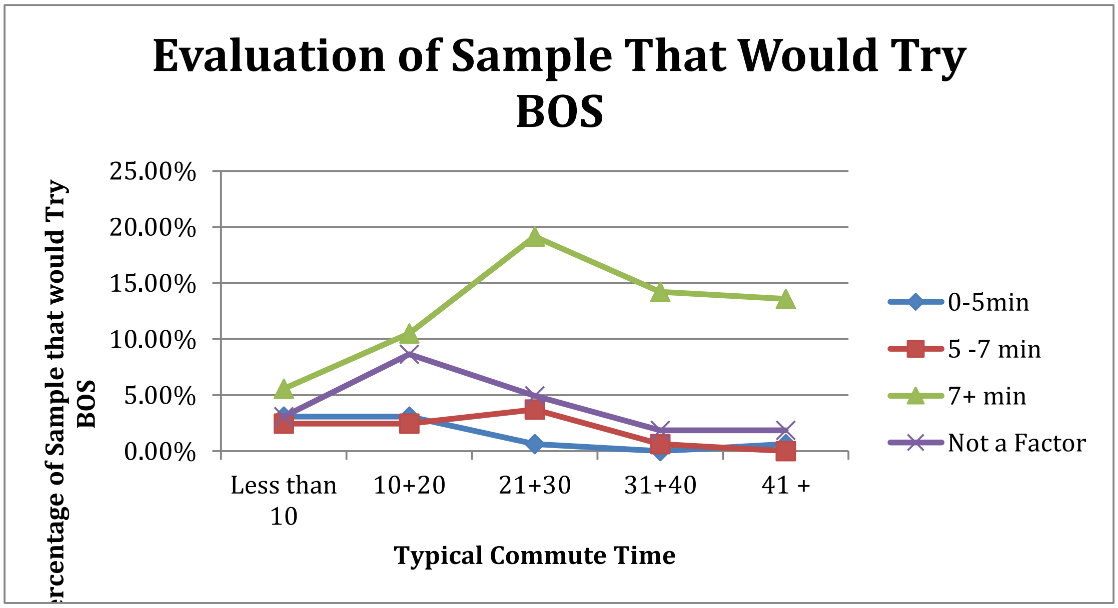


FIGURE 4.9 Cross Classification of Question 2 and 9 for Drivers Willing to Try Transit.

Figure 4.9 provides a characterization of Austin in terms of a BOS system. People cannot generally notice a time savings less than a few minutes. The survey responses show that commuters want to be able to perceive a timesaving if they are going to switch modes. The perceived threshold for time savings seems to be a value of 7 or more minutes. It can be determined from the Austin survey that routes with commuters traveling further are the target BOS customers and for those commuters to try BOS they want to see time savings.

4.4 POSSIBLE BOS EFFECTS ON AUSTIN RIDERSHIP

Two corridors have been identified as possible corridors for a BOS pilot project in Austin, Texas. These are:

1. US-183 NB: On-Ramp before Ohlen Road Exit to Spicewood Sp. Exit (7.17 mi)
2. IH-35 SB: On-Ramp before Braker Lane Exit to 15th St, MLK Exit (9.00 mi)

Section 4.2 concluded that (with 90% confidence) ridership will increase by at least 4.5% and as much as 14.3%. The average change in ridership for the Minneapolis Data was 9.41%. Also, there is 71% chance of ridership increase as a result of BOS implementation, and if there is a positive change in ridership it will be an average increase of 17%. This section will use these percentage increases in yearly route ridership to determine the ridership increase that would result on the four test corridors if the effects of BOS in Austin are similar to those found in the Minneapolis-Saint Paul area.

A total of seven bus routes traverse the two possible test corridors in Austin. Some routes only travel along one corridor while others use two. Total weekday ridership totals were obtained for these seven routes. For December 2014, Ridership data was obtained (Perteet 2015). These numbers were compared to the total August 2008 ridership for the entire Capital Metro bus operation obtained from the NTD (National Transit Database n.d.). Comparing the route ridership data to the total system data gives the percentage of the total Capital Metro ridership that is traveled on each route. Table 4.4 lists the seven routes along with the corridors they use, their average December 2014 daily ridership, and the cost of a one-way ride. Found on the Capital Metro Online Rider's Guide under fare and passes is the cost of a one-way ride or the cost of a single-ride fare for adults. This fare does not apply to individuals who are senior citizens or have physical disabilities.

Capital Metro is increasingly finding its system as a preferred way to get around. As given in the table, the flyer route 142 traveling on IH-35 SB has an average weekday ridership of nearly 985 where riders pay approximately $1.75. During the year of 2012, Capital Metro provided on average 112,000 rides each weekday. Thus, flyer route 142 experiences a percentage of 0.88 of the total Capital Metro ridership.

TABLE 4.4 Route Summary

Route	Corridors	Dec. 2014 Avg. Weekday Ridership[1]	Cost of One-Way Ride[2]	% Of Total Cap Metro Ridership
142	IH-35 SB	985	$1.75	0.88%
935	IH-35 SB	1301	$3.50	1.16%
985	IH-35 SB	228	$3.50	0.20%
982	US-183 NB	2232	$3.50	1.99%
983	US-183 NB	792	$3.50	0.71%
985	US-183 NB	240	$3.50	0.21%
987	US-183 NB	912	$3.50	0.81%

The ridership changes for Minneapolis were applied to the yearly ridership values in 2014 for each route as shown. Table 4.5 displays the changes to ridership that can be a result of BOS and possible increases in revenue as a result of BOS. A confidence interval (CI) is used to estimate ridership given the set of parameters in Minneapolis. This observed interval was calculated from the mean and standard deviation from the sample discussed previously in section 4.2. With a 90 percent confidence interval, a range of values from 4.5% to 14.3% is given. Seemingly, a BOS section will increase ridership on a single route by 4.5% to 14.3%.

TABLE 4.5 Changes to Ridership due to BOS for Austin BOS Pilot Corridors.

Test Corridor	Length	Capital Costs	CI Upper Bound 14.6%	CI Lower Bound 4.5%	Average 9.41%	Increase 17%	Rank
IH-35 SB	9.00 mi	$5,670	87,950	27,676	57,875	104,555	2
US-183 NB	7.17 mi	$5,775	114,102	35,906	75,084	135,645	1

Revenue increase calculations were also performed. The revenue calculations were based on the prices for one-way tickets presented in Table 4.4. Capital Metro does offer day passes which will allow a passenger to travel a round trip for a discounted rate. These day passes were not taken into consideration for these calculations. Only one-way rides or single-way fare were considered when expecting an increase in revenue. The revenue calculations were based solely on what a one-way standard fare ticket costs.

Capital Metro reported 27.4 million bus rides given for the fiscal year 2013, and there was a slight increase from the previous year (27.2 million). In essence, changes to ridership due to BOS were found calculating for each of the Austin BOS Pilot corridors. First, the yearly number of riders is calculated given the percentage of total Capital Metro Ridership and the 27.4 million bus rides given for the year. Second, yearly revenue is found by taking the product of the cost of a one-way ride and the yearly number of riders. The resulting calculations for possible revenue generation are summarized in Table 4.6.

TABLE 4.6 Possible Revenue Generation due to BOS on Austin Pilot Corridors.

Test Corridor	Length	Capital Costs	CI Upper Bound 14.6%	CI Lower Bound 4.5%	Average 9.41%	Increase 17%	Rank
IH-35 SB	9.00 mi	$5,670	$247,520	$ 77,891	$ 162,879	$ 294,255	2
US-183 NB	7.17 mi	$5,775	$511,325	$ 160,907	$ 336,473	$ 607,869	1

The total fare box revenue generated by the entire Capital Metro system in fiscal year 2008 was $6 million (Capital Metropolitan Transporation Authority FY 2008). The possible increases in fare box revenue shown in TABLE 4.6 could have a substantial effect on total revenue. As previously stated there are options for reduced fares with day passes which would reduce the actual revenue generation; however, there is no doubt that the readership increase predicted can have very advantageous effects on fare box revenue.

4.5 CONCLUSIONS

The survey responses show that commuters must be able to perceive a time savings. This counters what was seen from the evaluation of the ridership from Minnesota. From the Minnesota data it was shown that while time savings can be calculated, the average commuter does not make their decision based on the actual time savings. There is no strong relationship between time savings and increase in ridership; therefore commuters are likely making their decision based on perceived time savings. But while a statistically significant forecasting model was not determined, the Minnesota data clearly shows that BOS implementation will likely increase route ridership. There is 71% change of ridership increase as a result of BOS implementation. A 90% confidence interval yields a ridership increase of at least 4.5% and as much as 14.3%. While seasonality and noticeable external factors were removed from the data sets there were still other factors that could have affected the percent change in ridership. Knowing that other external factors affected the data, the observations still showed a substantial ridership increase. The concluding percent changes in ridership will have advantageous effects on fare box revenue in Austin. BOS implementation on the four pilot corridors could generate additional revenue as much as $250,000 annually.

CHAPTER 5 CONCLUSIONS

This project clearly shows that BOS could be an extremely effective project from a cost and benefit standpoint. Not only is a BOS system easy and inexpensive to implement, the benefits can be enormous. Part 1 outlined the nine criteria that should be used if an Austin system were to be implemented. Recommendations for an Austin pilot test are:

1. All BOS shoulders be at least 10 ft. in width and have adequate pavement depth to support bus usage,
2. Buses use the right shoulder and continuous shoulder segments should be at least 2,500 ft. (buses could possibly utilize auxiliary lanes when present instead of shoulders),
3. Buses should not exceed 35 mph on the shoulder or 15 mph faster than traffic in the main lanes,
4. BOS signs be placed on ramps and along BOS corridors,
5. Bus operators be trained properly for BOS and only use the shoulder if comfortable doing so,
6. Buses yield to emergency vehicles or stalled vehicles stopped on the shoulder,
7. At least six buses travel along the corridor per day,
8. A BOS pilot test corridor should need no structural improvements to the shoulder and minimal restriping,
9. Texas Transportation Code should be updated to allow a BOS Pilot Program.

Analyses in Chapter 2 show that there are two excellent locations for BOS on IH-35 and US-183 in Austin, TX that may provide significant benefits to bus riders. Chapter 3 presented an evaluation of the sites from a benefit-cost perspective. The corridors therefore are ranked for recommendation for a BOS pilot program in the following order:

1. US-183 NB: On-Ramp before Ohlen Road Exit to Spicewood Sp. Exit (7.17 mi)
2. IH-35 SB: On-Ramp before Braker Lane Exit to 15th St, MLK Exit (9.00 mi)

Chapter 4 examined ridership changes due to BOS. The data obtained from the Twin Cities clearly shows that BOS can result in increased ridership. There is 71% chance of ridership increase as a result of BOS implementation. A 90% confidence interval yields a ridership increase of at least 4.5% and as much as 14.6%. Chapter 4 also described results of a stated preference survey administered in Austin, Texas. The survey responses show that commuters must be able to perceive a time savings.

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APPENDICES

Appendix A: Active BOS Projects
Appendix B: Potential Characteristics for Austin BOS
Appendix C: Freeway Restriping and Repaving Cost Estimates (Murphy, 2009)
Appendix D: Survey of Austinites (administered via kiwksurveys.com)

APPENDIX A: ACTIVE BOS PROJECTS

	Seattle, Washington	Twin Cities, Minnesota	Auckland, New Zealand	Ottawa, Ontario, Canada	Dublin, Ireland	Vancouver, British Columbia
Year Started	1970's	Late 1991/ Early 1992	1991	1992	1998	--
Roads	SR-520 WB (Freeway) SR-522 (Arterial)	Numerous (Freeway and Arterial)	Northern, Northwest, and Southern Motorways	Regional Road 174 Regional Road 417	N2, N3, N4, N6, N8, N11 (mostly arterial)	Route 1 (Freeway, Queue Jumper)
Current Miles of BOS	2.7 mi (SR-520) 2.2 mi (SR-522)	over 270 mi	--	14 mi	50 to 70 mi	--
Max/Design Speed	Posted Speed Limit	35 mph	44 mph	Posted Speed Limit	Posted Speed Limit	--
Can use Shoulder when speeds drop below	N/A	35 mph	N/A	N/A	N/A	--
Max Speed Differential with Mainline Traffic	None	15 mph	--	None	N/A	--
Hours of Operation	No Restrictions	No Restrictions	No Restrictions	No Restrictions	Varies from No Restriction to only peak periods	--
Signage (Mainline)	Wayside HOV diamond lane traffic signs (SR-520) "Transit Only" (SR-522)	"Shoulder – Authorized Buses Only" every .25 to .5 mile	--	--	--	--
Signage (On-Ramp)	--	"Watch for Buses on Shoulders" on On-Ramps	--	--	--	--
Pavement Markings	HOV Diamonds (SR-520) "Only Transit" (SR-522)	None	--	--	"Bus Lane" and solid white line	--
Left/Right Shoulder	Right	Right	Right	Right	Right	Right
Shoulder Width	13-14ft	10ft (11.5 on bridges) Minimum & 12ft (Desired)	10ft (min)	16.4 ft (RR-174) & 3.5m bus lane, 1m shoulder, 1m refuge edge (RR-417)	10ft minimum	--
Pavement Thickness	--	7 in minimum	--	--	Full Thickness	--
Max Normal Cross Slope	--	2 - 5 %	--	2%	--	--
Eligible Vehicles	Buses and 3+ HOVs (SR-520) Buses (SR-522)	All Metro Transit buses and registered Charter buses	--	All Public Transit	Buses and Taxis	--

	Bethesda, Maryland	Fairfax County, Virginia	Wilmington, Delaware	Toronto, Ontario, Canada	Atlanta, Georgia	San Diego, California
Year Started	--	Around 2000	--	2003	September 2005	December 2005 (Original) Fall 2009 (Expansion)
Roads	US-29 NB (Arterial) & I-495 EB (Freeway, Queue Jumper)	EB Route-267 (Freeway)	US-202 SB (Freeway, Queue Jumper)	Highway 403	GA-400 (Freeway)	SR-52 & I-805 (Freeway, Original) I-805 (Expansion)
Current Miles of BOS	4 mi (US-29) & 3 mi (I-495)	1.3 mi (Queue Jumper)	1500 ft	3 mi	12 mi	4 mi (Original) 20 mi (Expansion)
Max/Design Speed	55 mph	25 mph	--	38 mph	35 mph	35 mph
Can use Shoulder when speeds drop below	--	25 mph	--	38 mph	35 mph	35 mph (Original) 30 mph (Expansion)
Speed Differential with Mainlane Traffic	--	--	--	12 mph	15 mph	10 mph
Hours of Operation	3pm to 8pm (US-29) & 6am to 9am; 3pm to 7pm (I-495)	Monday-Friday 4pm to 8pm	No Restrictions	No Restrictions	No Restrictions	No Restrictions
Signage (Mainline)	Typical HOV signage	--	Diamond & Light permitting bus use (green bus = go, green bus w/ red X = don't go)	"Authorized Buses Using Shoulder" every 200 to 300 meters	Same as Twin Cities	"Transit Lane - Authorized Buses Only" about every .5 mile
Signage (On-Ramp)	--	--	--	--	Same as Twin Cities except Black on White rather than Black on Yellow	--
Pavement Markings	HOV Diamond	double solid white line	Diamond	20cm wide solid white edge line	None	"Only Bus Transit"
Left/Right Shoulder	Right	Right	Right	Right	Right	Right (Pilot Project) Left (2009 Expansion)
Shoulder Width	--	--	--	12.3	Widened to 12ft	None Changed though 10 ft Desired (Original) 11ft (Expansion)
Pavement Thickness	--	--	--	--	--	--
Normal Cross Slope	--	--	--	--	--	--
Eligible Vehicles	--	--	--	Bus operators authorized by the MTO	MARTA buses	Route 960 Express Bus

	Columbus, Ohio	Mountainside & Old Bridge, New Jersey	Miami, FL	Cincinnati, Ohio	Cleveland, Ohio
Year Started	November 2006	Unknown (Route-22) November 2006 (Route 9)	March 2007	July 2007	June 2008
Roads	I-70 (Freeway)	Route-22 EB (Arterial) Route-9 NB & SB (Arterial)	SR-874 (Freeway) & SR-878 (Freeway)	I-71 NB (Freeway)	I-90 (Freeway)
Current Miles of BOS	10 mi	1 mi (Route-22) 4 mi (Route-9)	9 mi	11.7 mi	--
Max/Design Speed	35 mph	--	35 mph	35 mph	35 mph
Can use Shoulder when speeds drop below	35 mph	--	25 mph	30 mph	35 mph
Speed Differential with Mainlane Traffic	15 mph	--	15 mph	--	--
Hours of Operation	No Restrictions	Commute Period	No Restrictions	No Restrictions	No Restrictions
Signage (Mainline)	Same as Twin Cities	"Buses May Use Shoulder" (Route-22) "Bus O" (Route 9)	"Emergency Stopping Only on Shoulder - Authorized Bus Lane"	--	--
Signage (On-Ramp)	Yellow Warning Sign	--	"Buses Traveling on Shoulder"	--	--
Pavement Markings	None	None (Route-22) "Bus Only" (Route 9)	None	--	--
Left/Right Shoulder	Right	Right	Right	Left	Right
Shoulder Width	10ft	12-ft	10 ft Minimum (12ft where trucks >250 vph)	12ft	10ft
Pavement Thickness	Full Depth	Updated to Full Thickness	--	--	--
Normal Cross Slope	--	Updated from 4% to 2.5%	2 - 6%	--	--
Eligible Vehicles	COTA Buses	--	KAT Transit Buses	Rt-71X & Rt-72	--

APPENDIX B: POTENTIAL CHARACTERISTICS FOR AUSTIN BOS

Data for IH-35 SB

IH35 Southbound								All Dates	Critical Time Period
Section									
From	To	Distance (ft)	Aux. Ln Width	L Shoul Width	R Shoul Width	Sum Shoul & Aux.	AM Speed (mph)		Buses Using BOS
Exit Howard	On-Ramp	2706.03	0	6	12	18	58		0
On-Ramp	Exit Parmer	5894.61	12	10	12	34	68		0
Exit Parmer	On-Ramp	5815.41	0	10	10	20	31		10
On-Ramp	Exit Braker	1596.01	0	10	10	20	25		10
Exit Braker	On-Ramp	5718.85	0	10	12	22	34		10
On-Ramp	Exit Rundberg	4783.44	12	2	9	23	24		10
Exit Rundberg	On-Ramp	3490.44	0	2	15	17	14		13
On-Ramp	Exit US 183	4091.30	12	2	8	22	17		13
Exit US 183	On-Ramp	4092.89	0	9	10	19	16		16
On-Ramp	On-Ramp	2185.26	12	8	7	27	10		16
On-Ramp	Exit FM2222/US 290E	3010.69	12	8	9	29	11		16
Exit FM2222/US 290E	On-Ramp	1260.59	0	9	10	19	21		16
On-Ramp	Exit 51st Street	1404.71	0	4	12	16	8		16
Exit 51st Street	On-Ramp	2334.66	0	4	10	14	12		16
On-Ramp	On-Ramp	3096.06	0	4	12	16	13		16
On-Ramp	Exit Airport	1339.70	12	3	3	18	20		16
Exit Airport	Split: Start of Elev	1207.84	0	2	10	12	25		16
Split: Start of Elev	On-Ramp	649.93	0	0	7	7	30		16
On-Ramp	Exit 15th St, MLK	7232.60	0	4	11	15	35		16
Exit 15th St, MLK	Split Ends	1619.97	0	4	11	15	38		16
Split Ends	Exit 12-11th	1580.44	0	6	11	17	51		3
Exit 12-11th	On-Ramp	896.21	0	4	10	14	39		0
On-Ramp	Exit 8th-3rd St	924.75	12	4	2	18	50		0
Exit 8th-3rd St	On-Ramp	2143.54	0	4	8	12	86		0
On-Ramp	Exit Cesar Chavez	720.65	12	3	1	16	51		0
Exit Cesar Chavez	On-Ramp	1514.54	0	2	2	4	23		0
On-Ramp	Exit Riverside	697.61	13	2	2	17	34		0
Exit Riverside	Exit Woodland	3664.75	0	2	6	8	71		13
Exit Woodland	On-Ramp	1688.24	0	4	12	16	55+		13
On-Ramp	Exit Oltorf	1469.20	13	5	12	30	55+		13
Exit Oltorf	On-Ramp	1407.47	0	5	10	15	55+		13
On-Ramp	Exit Woodward	1282.29	0	5	10	15	55+		13
Exit Woodward	On-Ramp	1899.53	0	4	11	15	55+		13
On-Ramp	Exit US 290/SH 71	1645.33	12	2	10	24	55+		13
Exit US 290/SH 71	Exit 230A Stassney	3452.74	0	14	10	24	55+		13
Exit 230A Stassney	On-Ramp	6571.46	0	10	16	26	55+		13
On-Ramp	Exit William Cannon	1843.46	12	2	10	24	55+		13
Exit William Cannon	On-Ramp	3732.00	0	10	16	26	55+		13
On-Ramp	Exit Slaughter	5641.73	0	2	10	12	55+		13

Legend	Possible BOS Test Cooridor	No physical improvements needed: at least 10 ft shoulder or aux lane	At least 6 buses per day
Speeds less than 35 mph		Speeds 55+ mph experience free-flow traffic	

Data for IH-35 SB, Test Corridor

IH35 Southbound							All Dates	Critical Time Period
Section		Distance (ft)	Aux. Ln Width	L Shoul Width	R Shoul Width	Sum Shoul & Aux.	AM Speed (mph)	Buses Using BOS
From	To							
On-Ramp	Exit Braker	1596.01	0	10	10	20	25	10
Exit Braker	On-Ramp	5718.85	0	10	12	22	34	10
On-Ramp	Exit Rundberg	4783.44	12	2	9	23	24	10
Exit Rundberg	On-Ramp	3490.44	0	2	15	17	14	13
On-Ramp	Exit US 183	4091.30	12	2	8	22	17	13
Exit US 183	On-Ramp	4092.89	0	9	10	19	16	16
On-Ramp	On-Ramp	2185.26	12	8	7	27	10	16
On-Ramp	Exit FM2222/US 290E	3010.69	12	8	9	29	11	16
Exit FM2222/US 290E	On-Ramp	1260.59	0	9	10	19	21	16
On-Ramp	Exit 51st Street	1404.71	0	4	12	16	8	16
Exit 51st Street	On-Ramp	2334.66	0	4	10	14	12	16
On-Ramp	On-Ramp	3096.06	0	4	12	16	13	16
On-Ramp	Exit Airport	1339.70	12	3	3	18	20	16
Exit Airport	Split: Start of Elev	1207.84	0	2	10	12	25	16
Split: Start of Elev	On-Ramp	649.93	0	0	7	7	30	16
On-Ramp	Exit 15th St, MLK	7232.60	0	4	11	15	35	16

Legend	Possible BOS Test Cooridor	No physical improvements needed: at least 10 ft shoulder or aux lane	At least 6 buses per day
Speeds less than 35 mph		Speeds 55+ mph experience free-flow traffic	

Data for IH-35 SB, All Days

IH35 Southbound							Tues 12/2/14	Wed 12/3/14	Wed 12/3/14	Thurs 12/11/14	Thurs 12/11/14	Wed 12/17/14	Critical Time Period
Section		Distance (ft)	Aux. Ln Width	L Shoul Width	R Shoul Width	Scenario	AM Speed (mph)	AM Speed (mph)	AM Speed (mph)	AM Speed (mph)	AM Speed (mph)	AM Speed (mph)	Buses Using BOS
From	To												
Exit US 183	On-Ramp	4092.89	0	9	10	1	9	19	12	22	14	19	22
On-Ramp	On-Ramp	2185.26	12	8	7	2	10	16	12	7	8	7	25
On-Ramp	Exit FM2222/US 290E	3010.69	12	8	9	2	7	17	9	10	12	10	25
Exit FM2222/US 290E	On-Ramp	1260.59	0	9	10	1	0	57	21	27	11	12	25
On-Ramp	Exit 51st Street	1404.71	0	4	12	1	5	7	8	7	11	9	25
Exit 51st Street	On-Ramp	2334.66	0	4	10	1	9	14	14	10	15	10	25
On-Ramp	On-Ramp	3096.06	0	4	12	1	10	14	15	13	14	12	25
On-Ramp	Exit Airport	1339.70	12	3	3	2	8	20	19	5	22	28	25
Exit Airport	Split: Start of Elev	1207.84	0	2	10	1		24	36	11	20	24	18
Split: Start of Elev	On-Ramp	649.93	0	0	7	4	20	44	21	34	28	31	18

Legend	No physical improvements needed: at least 10 ft shoulder or aux lane	Speed less than 35 mph	Atleast 6 buses per day
	Meets Requirement of Length ≥ 2500 ft		

Data for IH-35 SB, Wednesday 12/03/2014

IH35 Southbound			Wed 12/3/14				Wed 12/3/14				Critical Time Period
Section		Distance (ft)	AM Speed (mph)	Time (s)	Time Elapsed ("To" to "From")	Time Stamp at "From" Location	AM Speed (mph)	Time (s)	Time Elapsed ("To" to "From")	Time Stamp at "From" Location	Buses Using BOS
From	To										
Exit US 183	On-Ramp	4092.89	19	148	0:02:28	7:16:26	12	241	0:04:01	8:09:30	22
On-Ramp	On-Ramp	2185.26	16	95	0:01:35	7:18:54	12	123	0:02:03	8:13:31	25
On-Ramp	Exit FM2222/US 290E	3010.69	17	123	0:02:02	7:20:29	9	241	0:04:01	8:15:34	25
Exit FM2222/US 290E	On-Ramp	1260.59	57	15	0:00:15	7:22:31	21	41	0:00:41	8:19:35	25
On-Ramp	Exit 51st Street	1404.71	7	138	0:02:18	7:22:46	8	113	0:01:53	8:20:16	25
Exit 51st Street	On-Ramp	2334.66	14	110	0:01:50	7:25:04	14	115	0:01:55	8:22:09	25
On-Ramp	On-Ramp	3096.06	14	155	0:02:35	7:26:54	15	137	0:02:17	8:24:04	25
On-Ramp	Exit Airport	1339.70	20	46	0:00:46	7:29:29	19	47	0:00:47	8:26:21	25
Exit Airport	Split: Start of Elev	1207.84	24	35	0:00:35	7:30:15	36	23	0:00:23	8:27:08	18
Split: Start of Elev	On-Ramp	649.93	44	10	0:00:10	7:30:50	21	21	0:00:21	8:27:31	18

Legend	No physical improvements needed: at least 10 ft shoulder or aux lane	Speed less than 35 mph	Atleast 6 buses per day

Data for IH-35 SB, Thursday 12/11/14

IH35 Southbound			Thurs 12/11/14				Thurs 12/11/14				Critical Time Period
Section		Distance (ft)	AM Speed (mph)	Time (s)	Time Elapsed ("To" to "From")	Time Stamp at "From" Location	AM Speed (mph)	Time (s)	Time Elapsed ("To" to "From")	Time Stamp at "From" Location	Buses Using BOS
From	To										
Exit US 183	On-Ramp	4092.89	22	128	0:02:08	7:38:50	14	195	0:03:15	8:58:08	22
On-Ramp	On-Ramp	2185.26	7	204	0:03:24	7:40:58	8	192	0:03:12	9:01:23	25
On-Ramp	Exit FM2222/US 290E	3010.69	10	206	0:03:26	7:44:22	12	168	0:02:48	9:04:35	25
Exit FM2222/US 290E	On-Ramp	1260.59	27	32	0:00:32	7:47:48	11	79	0:01:19	9:07:23	25
On-Ramp	Exit 51st Street	1404.71	7	143	0:02:23	7:48:20	11	90	0:01:30	9:08:42	25
Exit 51st Street	On-Ramp	2334.66	10	159	0:02:39	7:50:43	15	108	0:01:48	9:10:12	25
On-Ramp	On-Ramp	3096.06	13	42	0:00:42	7:53:22	14	152	0:02:32	9:12:00	25
On-Ramp	Exit Airport	1339.70	5	196	0:03:16	7:54:04	22	42	0:00:42	9:14:32	25
Exit Airport	Split: Start of Elev	1207.84	11	73	0:01:13	7:57:20	20	42	0:00:42	9:15:14	18
Split: Start of Elev	On-Ramp	649.93	34	13	0:00:13	7:58:33	28	4	0:00:04	9:15:56	18

Legend	No physical improvements needed: at least 10 ft shoulder or aux lane	Speed less than 35 mph	Atleast 6 buses per day

Data for IH-35 SB, Wednesday 12/17/14

IH35 Southbound				Wed 12/17/14			Critical Time Period
Section		Distance (ft)	AM Speed (mph)	Time (s)	Time Elapsed ("To" to "From")	Time Stamp at "From" Location	Buses Using BOS
From	To						
Exit US 183	On-Ramp	4092.89	19	147	0:02:27	7:47:40	22
On-Ramp	On-Ramp	2185.26	7	209	0:03:29	7:50:07	25
On-Ramp	Exit FM2222/US 290E	3010.69	10	206	0:02:26	7:53:36	25
Exit FM2222/US 290E	On-Ramp	1260.59	12	69	0:01:09	7:56:02	25
On-Ramp	Exit 51st Street	1404.71	9	112	0:01:52	7:57:11	25
Exit 51st Street	On-Ramp	2334.66	10	157	0:02:37	7:59:03	25
On-Ramp	On-Ramp	3096.06	12	172	0:02:52	8:01:40	25
On-Ramp	Exit Airport	1339.70	28	33	0:00:33	8:04:32	25
Exit Airport	Split: Start of Elev	1207.84	24	34	0:00:34	8:05:05	18
Split: Start of Elev	On-Ramp	649.93	31	2	0:00:02	8:05:39	18

Legend	No physical improvements needed: at least 10 ft shoulder or aux lane	Speed less than 35 mph	Atleast 6 buses per day

Data for US-183 NB

US 183 Northbound								All Dates	Critical Time Period
Section		Distance (ft)	Aux. Ln Width	L Shoul Width	R Shoul Width	Sum Shoul & Aux.	PM Speed (mph)	Buses Using BOS
From	To							
To 183 Ramp from IH35	On-ramp from IH35	3267	0	3	4	7	39	2
On-ramp from IH35	On-ramp	2443	0	9	10	19	41	2
On-ramp	Ohlen Road Exit	1047	12	7	10	29	24	2
Ohlen Road Exit	On-ramp	1941	0	10	10	20	24	2
On-ramp	Burnet Exit	5747	0	10	10	20	32	2
Burnet Exit	On-ramp	1960	0	9	10	19	29	2
On-ramp	Mopac Exit	2543	12	8	10	30	24	2
Mopac Exit	On-ramp	1724	0	8	10	18	16	2
On-ramp	Loop 360/Great Hills Exit	1758	0	8	10	18	8	23
Loop 360/Great Hills Exit	On-ramp (2 lanes)	2342	0	9	10	19	15	23
On-ramp (2 lanes)	On-ramp	2062	0	9	10	19	12	11
On-ramp	Braker Lane Exit	1480	12	10	10	32	17	8
Braker Lane Exit	On-ramp	3680	0	10	10	20	22	8
On-ramp	Duval Exit	2779	12	9	8	29	23	8
Duval Exit	Oak Knoll Exit	3065	0	11	11	22	32	8
Oak Knoll Exit	On-ramp	3654	0	9	10	19	33	11
On-ramp	Spicewood Sp Exit	2072	12	10	10	32	34	11
Spicewood Sp Exit	On-ramp	1967	0	10	10	20	37	11
On-ramp	Anderson Mill Exit	1772	0	10	10	20	36	11
Anderson Mill Exit	On-ramp	7822	0	10	10	20	65	11
On-ramp	RM 620 Exit	2619	12	10	10	32	62	11
RM 620 Exit	SH 45 East	2474	0	10	10	20	32	11

Legend	Possible BOS Test Cooridor	No physical improvements needed: at least 10 ft shoulder or aux lane	Atleast 6 buses per day
Speed less than 35 mph		Speeds 55+ mph experience free-flow traffic	

Data for US-183 NB, Test Corridor

US 183 Northbound							All Dates	Critical Time Period
Section		Distance (ft)	Aux. Ln Width	L Shoul Width	R Shoul Width	Sum Shoul & Aux.	PM Speed (mph)	Buses Using BOS
From	To							
On-ramp	Ohlen Road Exit	1047	12	7	10	29	24	2
Ohlen Road Exit	On-ramp	1941	0	10	10	20	24	2
On-ramp	Burnet Exit	5747	0	10	10	20	32	2
Burnet Exit	On-ramp	1960	0	9	10	19	29	2
On-ramp	Mopac Exit	2543	12	8	10	30	24	2
Mopac Exit	On-ramp	1724	0	8	10	18	16	2
On-ramp	Loop 360/Great Hills Exit	1758	0	8	10	18	8	23
Loop 360/Great Hills Exit	On-ramp (2 lanes)	2342	0	9	10	19	15	23
On-ramp (2 lanes)	On-ramp	2062	0	9	10	19	12	11
On-ramp	Braker Lane Exit	1480	12	10	10	32	17	8
Braker Lane Exit	On-ramp	3680	0	10	10	20	22	8
On-ramp	Duval Exit	2779	12	9	8	29	23	8
Duval Exit	Oak Knoll Exit	3065	0	11	11	22	32	8
Oak Knoll Exit	On-ramp	3654	0	9	10	19	33	11
On-ramp	Spicewood Sp Exit	2072	12	10	10	32	34	11

Legend	Possible BOS Test Cooridor	No physical improvements needed: at least 10 ft shoulder or aux lane	Atleast 6 buses per day
Speed less than 35 mph		Speeds 55+ mph experience free-flow traffic	

Data for US-183 NB, Wednesday 12/3/14

US 183 Northbound		Wed. 12/3/14				Wed. 12/3/14				Critical Time Period
Section										
From	To	PM Speed (mph)	Time (s)	Time Elapsed ("To" to "From")	Time Stamp at "From" Location	PM Speed (mph)	Time (s)	Time Elapsed ("To" to "From")	Time Stamp at "From" Location	Buses Using BOS
To 183 Ramp from IH35	On-ramp from IH35	44	51	0:00:51	16:51:15	no data	no data	no data	no data	2
On-ramp from IH35	On-ramp	36	46	0:00:46	16:52:06	46	36	0:00:36	17:42:27	2
On-ramp	Ohlen Road Exit	29	41	0:00:41	16:52:52	21	34	0:00:34	17:43:03	2
Ohlen Road Exit	On-ramp		30	0:00:30	16:53:33	28	48	0:00:48	17:43:37	2
On-ramp	Burnet Exit	38	104	0:01:44	16:54:03	15	265	0:04:25	17:44:25	2
Burnet Exit	On-ramp	58	23	0:00:23	16:55:47	31	43	0:00:43	17:48:50	2
On-ramp	Mopac Exit	48	36	0:00:36	16:56:10	7	237	0:03:57	17:49:33	2
Mopac Exit	On-ramp	45	26	0:00:26	16:56:46	6	213	0:03:33	17:53:30	2
On-ramp	Loop 360/Great Hills Exit	14	87	0:01:27	16:57:12	6	185	0:03:05	17:57:03	23
Loop 360/Great Hills Exit	On-ramp (2 lanes)	10	162	0:02:42	16:58:39	27	59	0:00:59	18:00:08	23
On-ramp (2 lanes)	On-ramp	6	233	0:03:53	17:01:21	14	173	0:02:53	18:01:07	11
On-ramp	Braker Lane Exit	36	28	0:00:28	17:05:14					8
Braker Lane Exit	On-ramp	15	163	0:02:43	17:05:42	19	129	0:02:09	18:04:00	8
On-ramp	Duval Exit	20	93	0:01:33	17:08:25	17	112	0:01:52	18:06:09	8
Duval Exit	Oak Knoll Exit		79	0:01:19	17:09:58		101	0:01:41	18:08:01	8
Oak Knoll Exit	On-ramp		104	0:01:44	17:11:17		21	0:00:21	18:09:42	11
On-ramp	Spicewood Sp Exit	31	16	0:00:16	17:13:01	36	49	0:00:49	18:10:03	11
Spicewood Sp Exit	On-ramp	31	39	0:00:39	17:13:17	36	33	0:00:33	18:10:52	11
On-ramp	Anderson Mill Exit	37	33	0:00:33	17:13:56	45	27	0:00:27	18:11:25	11
Anderson Mill Exit	On-ramp	67	80	0:01:20	17:14:29	68	79	0:01:19	18:11:52	11
On-ramp	RM 620 Exit	74	24	0:00:24	17:15:49	94	19	0:00:19	18:13:11	11
RM 620 Exit	SH 45 East	35	48	0:00:48	17:16:13	29	59	0:00:59	18:13:30	11

Legend	Possible BOS Test Cooridor	No physical improvements needed: at least 10 ft shoulder or aux lane	Atleast 6 buses per day
Speed less than 35 mph		Speeds 55+ mph experience free-flow traffic	

Data for US-183 NB, Wednesday 12/10/14

US 183 Northbound		Wed. 12/10/14				Wed. 12/10/14			
Section									
From	To	PM Speed (mph)	Time (s)	Time Elapsed ("To" to "From")	Time Stamp at "From" Location	PM Speed (mph)	Time (s)	Time Elapsed ("To" to "From")	Time Stamp at "From" Location
To 183 Ramp from IH35	On-ramp from IH35	51	17	0:00:17	17:07:04				
On-ramp from IH35	On-ramp		17	0:00:17	17:07:21	62	27	0:01:27	17:55:53
On-ramp	Ohlen Road Exit	51	39	0:00:39	17:07:38	6	116	0:01:56	17:57:20
Ohlen Road Exit	On-ramp		94	0:01:34	17:08:17	6	217	0:03:37	17:59:16
On-ramp	Burnet Exit		25	0:00:25	17:09:51	38	103	0:01:43	18:02:53
Burnet Exit	On-ramp	33	41	0:00:41	17:10:16	18	73	0:01:13	18:04:36
On-ramp	Mopac Exit	28	61	0:01:01	17:10:57	25	70	0:01:10	18:05:49
Mopac Exit	On-ramp	11	103	0:01:43	17:11:58	8	148	0:02:28	18:06:59
On-ramp	Loop 360/Great Hills Exit	6	187	0:03:07	17:13:41	6	196	0:03:16	18:09:27
Loop 360/Great Hills Exit	On-ramp (2 lanes)	9	185	0:03:05	17:16:48	21	190	0:03:10	18:12:43
On-ramp (2 lanes)	On-ramp	16	88	0:01:28	17:19:53				
On-ramp	Braker Lane Exit	5	199	0:03:19	17:21:21				18:17:02
Braker Lane Exit	On-ramp	33	75	0:01:15	17:24:40	33	76	0:01:16	18:20:12
On-ramp	Duval Exit	21	89	0:01:29	17:25:55	21	91	0:01:31	18:21:28
Duval Exit	Oak Knoll Exit	35	119	0:01:59	17:27:24	36	111	0:01:51	18:22:59
Oak Knoll Exit	On-ramp		38	0:00:38	17:29:23		42	0:00:42	18:24:50
On-ramp	Spicewood Sp Exit		31	0:00:31	17:30:01		40	0:00:40	18:25:32
Spicewood Sp Exit	On-ramp	35	22	0:00:22	17:30:32	36	13	0:00:13	18:26:12
On-ramp	Anderson Mill Exit	14	84	0:01:24	17:30:54	15	80	0:01:20	18:26:25
Anderson Mill Exit	On-ramp	64	83	0:00:37	17:32:18	64	83	0:00:32	18:27:45
On-ramp	RM 620 Exit				17:32:55				18:28:17

Legend	Possible BOS Test Cooridor	No physical improvements needed: at least 10 ft shoulder or aux lane	Atleast 6 buses per day
Speed less than 35 mph		Speeds 55+ mph experience free-flow traffic	

US-183 NB, Wednesday 12/17/14

US 183 Northbound		Wed. 12/17/14				Wed. 12/17/14				Critical Time Period
Section										
From	To	PM Speed (mph)	Time (s)	Time Elapsed ("To" to "From")	Time Stamp at "From" Location	PM Speed (mph)	Time (s)	Time Elapsed ("To" to "From")	Time Stamp at "From" Location	Buses Using BOS
To 183 Ramp from IH35	On-ramp from IH35	35	63	0:01:03	17:15:22	25	128	0:02:08	18:12:27	2
On-ramp from IH35	On-ramp	27	61	0:01:01	17:16:25		22	0:00:22	18:14:35	2
On-ramp	Ohlen Road Exit	13	54	0:00:54	17:17:26	25	3	0:00:03	18:14:57	2
Ohlen Road Exit	On-ramp	12	109	0:01:49	17:18:20		26	0:00:26	18:15:00	2
On-ramp	Burnet Exit	24	165	0:02:45	17:20:09		217	0:03:37	18:15:26	2
Burnet Exit	On-ramp	12	112	0:01:52	17:22:54	23	57	0:00:57	18:19:03	2
On-ramp	Mopac Exit	9	187	0:03:07	17:24:46	25	69	0:01:09	18:20:00	2
Mopac Exit	On-ramp	9	137	0:02:17	17:27:53	18	66	0:01:06	18:21:09	2
On-ramp	Loop 360/Great Hills Exit	7	167	0:02:47	17:30:10	10	119	0:01:59	18:22:15	23
Loop 360/Great Hills Exit	On-ramp (2 lanes)	10	168	0:02:48	17:32:57	12	128	0:02:08	18:24:14	23
On-ramp (2 lanes)	On-ramp	7	214	0:03:34	17:35:45	7	212	0:03:32	18:26:22	11
On-ramp	Braker Lane Exit	9	117	0:01:57	17:39:19	15	68	0:01:08	18:29:54	8
Braker Lane Exit	On-ramp	12	210	0:03:30	17:41:16	18	138	0:02:18	18:31:02	8
On-ramp	Duval Exit	27	99	0:01:39	17:44:46	29	66	0:01:06	18:33:20	8
Duval Exit	Oak Knoll Exit	27	53	0:00:53	17:46:25	26	80	0:01:20	18:34:26	8
Oak Knoll Exit	On-ramp		42	0:00:42	17:47:18	33	76	0:01:16	18:35:46	11
On-ramp	Spicewood Sp Exit		95	0:01:35	17:48:00	40	35	0:00:35	18:37:02	11
Spicewood Sp Exit	On-ramp	42	32	0:00:32	17:49:35	41	33	0:00:33	18:37:37	11
On-ramp	Anderson Mill Exit	55	22	0:00:22	17:50:07	53	23	0:00:23	18:38:10	11
Anderson Mill Exit	On-ramp	64	83	0:00:33	17:50:29	61	87	0:01:27	18:38:33	11
On-ramp	RM 620 Exit	19	96	0:01:36	17:51:02				18:40:00	11
RM 620 Exit	SH 45 East				17:52:38					11

Legend	Possible BOS Test Cooridor	No physical improvements needed: at least 10 ft shoulder or aux lane	Atleast 6 buses per day
Speed less than 35 mph		Speeds 55+ mph experience free-flow traffic	

APPENDIX C: FREEWAY RESTRIPING AND REPAVING COST ESTIMATES (MURPHY, 2009)

IH-35 Corridor: No resurfacing and no restriping needed

US-183 Corridor: Resurfacing Only (no restriping)

US-183 Pavement Resurfacing – Unit costs

Item 341 2014 Dense Graded Hot Mix (QCQA) Ty- B PG 70- 22	Ton	72.78
Item 354 2052 Plane asphalt concrete pavement (0" – 3- 1/2")	SY	2.50

Striping and Markers – Unit costs

Item 8020 2003 Reflectorized profile pavement marking 6" Ty 1 (white)	LF	0.91
Item 8020 2008 Reflectorized profile pavement marking 6" Ty 1 (yellow)	LF	0.91
Item 666 2015 Reflectorized pavement marking 6" (Broken) (white)	LF	0.41
Item 672 2012 Reflectorized pavement marker Ty 1 – White	EA	3.25
Item 677 2001 Eliminate pavement markings and markers	LF	0.58
Item 678 2001 Pavement surface preparation for markings (6")	LF	0.01

Striping material and installation cost per center- line mile (6 lanes total)

Solid white profile edge stripe = 2 lines x 5280 = 10,560 LF of striping x 0.91 =	$9610
Solid yellow profile edge strip = 2 lines x 5280 = 10,560 LF of striping x 0.91 =	$9610
	$19,220

Multiplier to account for additional markings for ramp gores, accel / decel lanes etc. 2.00

Estimated cost per center line mile for materials and installation to stripe IH 35
= 2.00 x $19,220
= $38,440 per center- line mile

***striping not needed for IH-35 or US-183**

Pavement Resurfacing – Unit costs

Plane (mill) existing 2" surface and stockpile.

1X10' (outside shldr) = 10' wide paved surface x 5280 LF
= 52800 SF/9SF/SY
= 5867 SY x $2.50
= $14,667

Hot mix Ty B = 110 lbs / SY / inch thick
3"/SY = 330 lbs/SY/2000lbs/ton
= 0.165 tons/SY x 5867 SY x $72.78 ton HMAC
= $70,455

Multiplier to account for Mobilization, traffic control, ancillary items, possible night placement
=2.0 x ($14,667+$70,455) = **$170,244 (resurface) = $170,244 per lane mile (average)**

APPENDIX D: SURVEY OF AUSTINITES

Bus on Shoulder Survey

This survey, administered via kiwksurveys.com, is targeted at persons who commute during the morning by personal vehicle. Many Austinites use freeways during their morning commute. Most of these freeways are plagued with congestion during these times. Speeds during the morning are often below 10 miles per hour. Traffic on these corridors can add not only considerable time to a person's commute trip but also stress. Traffic on these corridors is variable with some days adding even more time to a person's commute. The option of allowing buses to start using freeway shoulders like bus bypass lanes is being considered. A bus would be able to use the shoulder to bypass congestion on Austin's freeways. A bus using a shoulder will be able to move faster than personal vehicles and will allow for bus riders to save on their commute time. It will also add reliability to a commuter's trip. Since the bus's travel time will no longer be directly affected by any variability in traffic.

1) Do you currently drive alone and use Loop 1 (MoPac), IH-35 or US183 during the AM (7:00-9:00AM) traffic peak period?
   a.Yes
   b.No
2) How long is your typical door to door commute time (include parking, walking to and from your car, etc.)?
   a. Less than 10 minutes
   b.10-20 minutes
   c. 21-30 minutes
   d.31-40 minutes
   e.Greater than 41 minutes
3) What percentage of your trip is spent using Loop 1 (MoPac), IH-35 or US183?
   a.0%-33%
   b.33%-66%
   c.66%-100%
   d. I don't use these corridors
4) What percentage of your trip do you spend in congestion?
   a.0%-33%
   b.33%-66%
   c.66%-100%
5) Would you try a transit service knowing it will be able to use a shoulder to bypass congestion on the freeway?
   a.Yes
   b.No

For Questions 6-8
Congestion on Austin’s Freeways is variable. The bus’ ability to use the shoulder will allow for an increase reliability in bus service. Using the bus for morning commute will allow for a consistent commute time.

6) Do you have any flexibility in what time you arrive at your place of employment?
   a.Yes, my employer allows for flexibility in my arrival time
   b.No, I have to be at work at a specific time

7) If your place of employment does not allow for flexibility in your arrival time, how much earlier do you leave home to ensure you are on time to work?
   a.0-5 minutes
   b.5-10 minutes
   c.10-15 minutes
   d.15-20 minutes
   e. More than 20 minutes
   f. My place of employment allows for flexibility in what time I arrive

8) Knowing that taking a bus on shoulder option will guarantee you a consistent travel time in the morning, would you switch from driving to taking the bus?
   a.Yes
   b.No

Most commuter bus routes in Austin travel from “Park and Rides” to Central Austin (University of Texas campus, The Capital, and Downtown). Switching to transit may require time to travel from home to the bus route and then from a bus stop to your destination. While there may be added time at the beginning and end of your trip, the time spent in congestion will be less.

9) How much time would a bus need to save on the freeway section of its route for you to use transit in the morning commute?
   a.0 minutes
   b.1-3 minutes
   c.3-5 minutes
   d.5-7 minutes
   e.7-10 minutes
   f. Greater than 10 minutes