I-94 Managed Lanes Study

Final Report

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Minnesota Department of Transportation

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# I-94 Managed Lanes Study

*Final Report*

## Resources

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Introduction

The Minnesota Department of Transportation (Mn/DOT) conducted this study of the I-94 corridor between downtown Minneapolis and downtown St. Paul. Mn/DOT’s purpose was to identify potential improvements to the physical facilities and traffic operations that existed prior to the I-35W bridge collapse in August 2007, while establishing an overall vision for potential improvements in the I-94 corridor, including improvements for both general traffic operations and transit services. Recommendations that result from this study were focused on meeting or exceeding the established project goals:

- Better utilize existing infrastructure investments;
- Preserve or enhance advantages for transit and carpoolers, as well as for general traffic;
- Provide a congestion-free choice for Single Occupancy Vehicles (SOV);
- Preserve or enhance corridor safety.

Mn/DOT Activities Following I-35W Bridge Collapse

After the I-35W bridge collapse, the I-94 corridor between I-35W and TH 280 was designated as the official detour routing and thus experienced a major increase in traffic volumes. Mn/DOT recognized the urgent need for additional capacity, and re-striped I-94 to add an additional lane in each direction between the TH 280 interchange and downtown Minneapolis by narrowing the existing traffic lanes and shoulders. This effort provided value to the traveling public but at the same time negated the transit advantage enjoyed by buses that had previously made use of I-94’s shoulders. A short segment of the bus shoulder was subsequently reinstated, but Mn/DOT and the other stakeholders have recognized a need to study alternatives for better managing the I-94 corridor. A managed freeway would potentially offer benefits for transit and carpools, and may provide other options for relieving congestion and improving safety for all traffic.

Research for International Managed Lanes Experience

This study identified options that would fit in the existing corridor envelope ranging from a no-build alternative, to added general purpose lanes, to managed lanes. Worldwide experience with High Occupancy Vehicle (HOV) lanes, priced Managed Lanes (ML) and Dynamic Shoulder Lanes (DSL), as well as narrowed lanes and bus-only shoulders were researched with regards to success, safety, and best practices. Four basic alternatives, including High Occupancy Toll (HOT) lanes, Priced Dynamic Shoulder Lanes (PDSL), DSL and bus shoulders, along with hybrid scenarios were developed, reviewed and analyzed. Alternatives included three-lane and four-lane segments, and right and left entering/exiting ramps. The resulting recommendation of the study has identified an overall vision for the corridor with respect to managed lanes, along with minor rehabilitation and full reconstruction implementation strategies. The benefits of Active Traffic Management (ATM) in addressing the serious safety issues in the I-94 corridor were recognized and the most promising options were evaluated for cost-effectiveness.

With congestion increasing and vehicle miles traveled outpacing population growth in almost every large city in the United States; major metropolitan areas are creatively addressing their approach to transportation infrastructure. Highway construction costs continue to grow, right of way is becoming
more and more limited and traditional transportation funding sources have continually lost purchasing power. There is a growing acceptance that cities will be unable to build their way out of congestion. Emerging technologies have allowed for the development and refinement of strategies to meet these challenges. Flexible operating strategies coupled with minimal roadway capacity improvements offer a means of addressing mobility needs and providing new travel options. The managed lanes concept is growing in popularity as an approach to effectively and efficiently use existing facilities, address community objectives and provide alternatives to congested roadways.

**Minnesota Experience**

Minnesota has led the nation in the consideration and implementation of managed lanes, including the implementation of I-394, the United States’ fifth operational managed lane facility, in 2005. The current UPA project, which introduced a PDSL to I-35W on the south approach to downtown Minneapolis, is yet a further demonstration of Mn/DOT’s leadership in managing freeways to get the most benefits from existing public investments.

The concept of managed lanes has evolved significantly over the past 30 years. The first iteration of managed lane corridors comprised exclusive-use facilities for buses in the 1970s. Over the years, these facilities adapted to allow for high occupancy vehicles (HOV), and recently, single occupant vehicles (SOV) that agree to pay a toll for access, such as on the I-394 high occupancy / toll (HOT) lane facility. Managed lanes not only include exclusive-lane facilities, but also involve an expansive use of pricing, eligibility, and management technology for enhancing the utilization of available capacity. Minnesota’s application of bus-on-shoulders (BOS) strategies comprises a different type of managed lane from that of I-394 and I-35W. BOS and other temporary shoulder use systems manage access to the capacity through vehicle eligibility, thereby satisfying a component of managed lanes. The ultimate purpose of managed lanes is to provide improved mobility and safety by the active management of traffic within designated systems of corridors and connecting facilities.

Of particular interest in the Twin Cities region are those managed lane applications that enhance traffic operations through flow maximization, improve average vehicle occupancies and transit ridership, reduce incidents, and improve travel time reliability. Recent experience on I-94 following the collapse of the Mississippi River Bridge on I-35W with adapting BOS-operated shoulders for general purpose traffic indicates expanded use of shoulder lanes may partly satisfy these managed lane objectives. As a result, Mn/DOT developed a series of managed lane alternatives for I-94 following the reopening of the Mississippi River bridge to be evaluated as part of this study.

Managed lanes have many operational variants, including not only occupancy allowances, but also any application that involves system-management techniques such as time-of-day restrictions, vehicle-type restrictions, and value pricing. Whereas Minnesota has implemented BOS, HOT lanes, and PDSL, Europe’s approach has involved a system of ATM, which combines traffic and system management strategies to enhance throughput and safety.

In order to better inform decisions regarding the short-term and long-term development of managed lanes on I-94 between Minneapolis and St. Paul, this study examined the possibilities, configurations, benefits, and costs associated with implementing managed lanes on I-94. Although a variety of alternatives were developed, refinements concentrated the analysis upon three primary alternatives: a baseline condition representing a “no build” scenario; a rehabilitation condition which served to enhance
already existing infrastructure and configurations; and a full corridor reconstruction condition which provides a framework for future managed lanes development.

**State of the Practice for Managed Lane Concepts**

Managed lanes have been in existence for nearly 30 years and represent a family of operational strategies designed to address a wide array of transportation goals. The term itself is ambiguous and can mean different things to different stakeholders in the transportation industry. One key aspect that all managed lane facilities share in common is active demand and system management. Oftentimes, the development of managed lanes has come from the realization that high demand on existing facilities necessitates the efficient management of those facilities. This holds especially true in situations where options for constructing new capacity are limited. Latent demand in moderate to severely congested corridors can quickly fill added capacity that is not managed.

Managed lanes, including those applied in Minnesota, typically comprise three principal elements:

- **Eligibility.** Eligibility refers to the restriction of certain vehicles and vehicle types from accessing a given facility, which is most often based on occupancy or vehicle type. Restrictions based on occupancy generally stipulate that only vehicles carrying a certain number of occupants – usually 2 or greater – may enter a facility for free. In the case of traditional HOV lanes, single occupant vehicles (SOV) are barred completely from accessing such facilities, whereas in HOT lane applications, they are allowed to access facilities with the payment of a toll. Restrictions based on vehicle type generally bar certain types of vehicles from entering a facility, such as large commercial trucks, or provide free access for others, such as low emission vehicles or motorcycles. Eligibility may also vary by time of day or change over the life of the facility in response to changing volumes of various vehicle classes. HOT lane facilities, for example, may experience growth in the volume of users such that congestion begins to occur and the level of service on the facility is degraded. In this case, a hierarchy of users is established, and eligibility requirements may be adjusted so as to price out lower priority users such as SOVs.

- **Access Control.** A common feature of managed lanes is the physical separation of vehicles on managed facilities from those on adjacent general purpose lanes. Access control is often accomplished by physically separating a managed lane facility from other facilities via barrier or buffer, such as those found on the I-394 HOT lane. In some situations, such as a bus-on-shoulder program in a confined urban area, right of way (ROW) may not be sufficient to construct a barrier or buffer, and a simple stripe with supplemental signing has to suffice.

- **Pricing.** The pricing aspect of managed lanes refers to the use of price controls for the purposes of controlling volumes and generating revenue on managed lanes facilities. Most contemporary managed lanes – such as HOV facilities, bus on shoulders, and other such facilities – do not feature a pricing component. However, many recent facilities do include a pricing element that can be structured to accomplish a number of goals. Pricing may be fixed, with one flat rate being charged for all users during all times of the day; set on a variable schedule, where rates change pursuant to a pre-established schedule; or dynamic such as on I-394 and planned for I-35W, where the price for access increases during times of day when volumes are the highest. Dynamic pricing entails adjusting the price for facility access in real time in relation to the vehicular volume on the facility. As the number of vehicles increases, so does the price.
Shoulder Use for Managed Lanes

Although a variety of managed lane applications are available for corridor-wide projects, this study concentrated upon those that have the likeliest application for I-94 between Minneapolis and St. Paul. As the corridor has neither sufficient dominant peak directionality, nor the apparent ability to significantly expand the right of way envelope to accommodate widening, the project team examined managed lane strategies which incorporated use of shoulders and the existing facility. This discounted a variety of options, including reversible flow, contra-flow, and dual-dual facilities.

Dedicated Shoulder Lanes

Since the 1950 publication of the Highway Capacity Manual and 1973 AASHTO Red Book, 10 ft shoulders have been the Interstate minimum design standard for urban freeways, with 12 ft shoulders desirable on routes with heavy truck traffic. Furthermore, a minimum of 4.5 ft lateral clearance is required, with 6 – 8 ft recommended in the vicinity of pier structures. However, by the 1980s in response to rising levels of congestion and a lack of right-of-way for contemporary expansion of capacity, many states adopted the use of dedicated shoulder lanes sometimes in conjunction with or instead of narrowed lane widths. By the 1990s, only four states had chosen to extensively use shoulders and/or narrow lanes on freeways: California (Los Angeles and Bay Area), Texas (Houston), Virginia (Fairfax County), and Washington (Seattle).

In dedicated shoulder lane operations, either general purpose or HOV-specific capacity has been added through the permanent conversion of shoulders. Most HOV applications use the interior or left lane for HOV operations while the exterior or right shoulder is used for general purpose traffic so as to maintain the same number of general purpose lanes as existed prior to implementation. A typical application would convert a three-lane freeway with 12 ft lanes, 10 ft exterior shoulder, and 8 ft interior shoulder to 11 ft general purpose lanes, 14 ft (including buffer striping) HOV lane, 5 ft exterior shoulder, and 2 ft interior shoulder.

In most cases, the shoulders have been converted to general purpose capacity, at least for a short distance. However, in a few applications, the implementing agency has attempted to recover use of the shoulder for refuge purposes during some portions of the day. On Massachusetts state highways 128 and 3 in the Boston area, all vehicles are permitted on shoulders in the peak periods only. Similarly, in Virginia on I-66, the shoulder carries general purpose traffic from 5:30 – 11 am (eastbound) and 2 pm – 8 pm (westbound); however, during this time, the interior general purpose lane is open to HOV traffic only. I-66 uses extensive lane use signage in order to communicate the active times of shoulder lane service.

Bus Only Shoulders

Bus Only Shoulders (BOS) programs, generally considered special-use applications of dedicated shoulder lanes, are most often implemented as a means of increasing the reliability of transit service in congested corridors in order to encourage increased use by the public. BOS was the established managed lane solution on the I-94 corridor prior to the Mississippi River bridge collapse on I-35W. It is generally a low cost and quick to implement solution that does not require costly expansion of highway right of way. They may be implemented on both highway and arterial corridors, but arterial BOS applications must often rely on additional operational treatments such as signal prioritization in order to maintain a time advantage over automobile travel.
BOS is the most common shoulder-lane application in the United States. Additionally, Minnesota has served as a continental leader in the state of the practice, both in the extent of application of BOS lanes as well as development of policies and authorizing legislation for BOS. Minnesota’s network is comprehensive, having established over 270 miles of BOS lanes throughout the Twin Cities since 1991. Today, BOS operations exist throughout the Twin Cities network, including long segments of I-694, I-35W, I-35E, I-94, I-494, US 169, SH 36, and US 10.

Of all active BOS projects, only the Seattle region’s SR-520 allows for HOV-3+ use of shoulders concurrent with buses (not including dynamically assigned HOV lanes, such as Virginia’s I-66).

**Dynamic Shoulder Lanes**

Dynamic (temporary) shoulder lanes is a congestion management strategy used extensively in Europe and typically deployed in conjunction with complementary traffic management strategies – such as variable speed limits (speed harmonization), queue warning, and ramp metering – to address capacity bottlenecks on the freeway network. The strategy provides additional vehicle-moving capacity during times of congestion and reduced travel speeds. When travel speeds are reduced, dynamic signs over or next to the shoulder indicate that travel on the shoulder is permitted.

A complete series of traffic signs indicate operations related to temporary shoulder use, including one with a supplemental speed limit indication (used when overhead gantries are not present). Temporary shoulder use is permitted only when speed harmonization is active and speed limits are reduced, thus providing an operating environment only when speeds are managed below posted levels. In addition to allowing temporary use of the right shoulder, the Dutch also deploy the use of traveling on a shoulder on the median side of the roadway, locally termed a “plus lane,” a narrowed extra travel lane provided by reconstructing the existing roadway while keeping the right hard shoulder open for travel use when traffic volumes reach levels that indicate congestion is growing.

**Conceptual Applications**

The key to success for managed lanes is to manage the number of vehicles on the facility so that the use of the facility is maximized without creating congestion.

Modern HOT lanes facilities accomplish this by incorporating a pricing element, which is most often either variable or dynamically set. In Minnesota’s use of dynamic pricing, such as on I-394 and I-35W, volumes on a given facility are actively monitored and toll rates are adjusted in near-real time in response to changing conditions. If volumes increase rapidly, toll rates for access are increased so as to discourage additional users and ensure that facility maintains free flowing traffic speeds.

**Active Traffic Management**

By comparison, ATM does this by dynamically managing traffic flow based on prevailing traffic conditions. Focusing on trip reliability, its goal is to maximize the effectiveness and efficiency of the facility under both recurring and non-recurring congestion as well as during capacity reductions involving incidents or road work. Through the flexible use of the roadway, it aims to increase system performance as well as traveler throughput and safety through the use of strategies that actively regulate the flow of traffic on a facility to match current operating conditions. ATM strategies can be automated, combined, and integrated to fully optimize the existing infrastructure and provide measurable benefits to the transportation network and the motoring public.
Active traffic management consists of a combination of operational strategies that, when implemented in concert with dynamic shoulder lanes, more fully optimize use of the existing infrastructure and provide measurable benefits to the transportation network and the motoring public. These strategies include but are not limited to speed harmonization, junction control, and dynamic signing and rerouting:

- **Speed Harmonization / Queue Warning.** Speed harmonization (also known as Variable Speed Limits) helps manage traffic by varying posted speed limits on a roadway or over each lane on an advisory or regulatory basis in real time. The deployment of the speed harmonization is automatic and begins immediately upstream of the congestion point; it does not require remote operator intervention. The system incrementally decreases speeds upstream in a cascading manner often in increments of 5 to 10 mph to smooth the deceleration of the traffic and help ensure more uniform flow while avoiding crashes.

- **Junction Control.** A variation of dynamic shoulder lanes involves dynamic lane assignment. Typically, the concept is applied at entrance ramps or merge-points where the number of downstream lanes is fewer than upstream lanes. The typical U.S. application to this geometric condition would be a lane drop for one of the outside lanes or a forced merge of two lanes, both of which are static treatments. The dynamic solution is to install lane control signals over both upstream approaches before the merge, and provide downstream lane priority to the higher volume and dynamically post a lane drop to the lesser volume roadway or approach. This is particularly effective when implemented with dynamic shoulder use at on-ramp locations where bottlenecks frequently form.

- **Dynamic Rerouting.** The practice involves utilizing dynamic overhead message signs or other changeable roadway signs and route markers that dynamically change the primary routing of a major thoroughfare to an alternate route where capacity is available, in response to changing with traffic conditions. If an incident occurs downstream, operators at the Traffic Management Center deploy alternate guide sign information combinations that provide alternate route information to roadway users. Similar information is also provided on full-matrix DMS installed on other roadways.

### Analysis for Managed Lanes / Shoulder Use Development

The findings from the literature review indicated that the use of shoulders often reduces speeds in favor of maintaining adequate flow at high volumes. For a managed corridor, either through the implementation of managed lanes or through active traffic management techniques in conjunction with shoulder lanes, travel time reliability should be the key metric. Reducing the variability of speeds is a necessary component to reliability and maintaining traffic flow. Furthermore, variability has a negative impact upon accidents, especially near ingress / egress ramps in medium-to-high volume situations. Additionally, truck volumes must be considered in these situations, both as a contributor to degraded flow in stop-and-go situations, and to accident severity when involving a passenger vehicle.

Already, Mn/DOT restricts entering volumes to I-94 through the system’s extensive ramp metering program. As volumes are managed, the next variable to consider is speed limits – speed harmonization may be considered as a necessary complement to shoulder lanes. Europe’s experience with combining speed harmonization with dynamic shoulder lanes indicates a positive outcome may result. Furthermore, the European guidance provided for sight distance indicated an appropriate consideration for queue warning and emergency refuge locations, which have been incorporated in the conceptual plans.
Conceptual Development for I-94

Early in the project and continuing through subsequent analyses, the project team developed the concepts and associated cost estimates for managed lanes strategies along I-94. Input for identification of strategies came from a review of prior concepts developed by Mn/DOT, available and collected traffic data, as-built plans, and input from project team and open house meetings. Concepts are identified by segments east and west of T.H. 280, and involve both right and left side orientations.

Preferred Design Components

The following represent preferred design components for contiguous single-lane managed lane facilities, added in freeway corridors without HOV lanes.

- 12-ft lane widths, with a 2-ft buffer
- 10-ft residual shoulders on one or both sides of the mainline roadway
- Where access is restricted for left side lane orientations, minimum weaves per lane are 600 ft per main lane weave upstream and downstream of respective ingress and egress zones
  - For entrance ramp to the managed lane, from the nearest upstream right side ramp where ramp taper joins the main lanes to the beginning of the solid stripe leading into the lane (see Figure 1 below).
  - For exit ramp from the managed lane, the distance from where the managed lane exit ramp stripe tapers to join the left mainline edge stripe to the right side gore of the next downstream right side exit from the main lanes.

![Figure 1: Ingress/Egress to Restricted Access Treatments](image)

Design Principles

- **Design Speed**: Same as freeway or ramp (35-65 mph)
- **Grade (maximum)**: 3% for mainline, 6% for ramps
- **Design vehicles**: All classes except trucks of more than three axles

Concurrent-flow lanes were the preferred approach to identified concepts for the I-94 corridor due to the existing design constraints for near-term strategies and congestion characteristics which typically occur in one or both directions in various parts of the corridor. Contraflow, reversible and barrier-separated treatments were not amenable to the operational and design setting except for ramp connections to/from Downtown Minneapolis. For this reason, concurrent flow treatments, focused primarily on the inside and outside shoulders, were the most appropriate.
Some form of delineation is needed for any kind of concurrent-flow lane to differentiate it from adjacent lanes, at least during the operating periods. AASHTO’s latest guidance recommends buffers for concurrent-flow lanes, consistent with existing Mn/DOT implementation on I-394. Figure 2 shows typical sections for desirable and minimum conditions. A variety of design techniques exist for buffer separated lanes. The buffer width should nominally be 2 to 4 feet and no less than 1.5 feet. A much wider buffer width of 6 to 8 feet may appear as a refuge for vehicle breakdowns where high speed traffic exposes the driver to a safety hazard on both sides. It is difficult to accommodate the requisite pavement markings in a buffer of less than 18 inches. A buffer separated lane may apply a conventional 4-foot buffer and reduce the buffer area around such isolated restrictions as bridge columns for short distances. Ideally such conditions are appropriately facilitated by varying the inside shoulder width to keep the lane alignment straight through the impediment. If continuous access is allowed, a single wide or double skip stripe placed around and within the buffer area is appropriate. If access is restricted, single or dual solid stripes are applied and broken wherever access is permitted.

**Figure 2: Concurrent Flow Buffer Separated Cross Sections**

Many candidate settings for concurrent flow lanes typically have bridges and related impediments that make widening to full design standards extremely difficult. In such cases, careful study of the proper trade-offs for lane, shoulder and buffer widths are warranted. These conditions are herein referred to as minimum designs, which often involve the removal or reduction in existing inside breakdown shoulders and perhaps slight reductions in some lane widths for the added lane. While trade-offs in each case will vary depending on site conditions, Figure 3 provides a reference of commonly applied priorities when trying to accommodate key design features in constrained settings.
Sequence | Cross Section Design Change
--- | ---
First | Reduce managed lane left lateral clearance to no less than 2 feet.
Second | Reduce freeway right lateral clearance (shoulder) from 10 feet to no less than 8 feet.
Third | Reduce buffer separation between the managed and general purpose lane to no less than 1.5 feet.
Fourth | Reduce managed lane width to no less than 11 ft. (Some agencies prefer reversing the fourth and fifth trade-offs when buses or trucks are projected to use the managed lane. The buffer markings may encroach on the 11-foot width.).
Fifth | Reduce selected mixed-flow lane widths to no less than 11 feet. (Leave at least one 12-foot outside lane for trucks).
Sixth | Transition barrier shape at columns to vertical face, or remove buffer separation between the managed lane and general purpose lanes.

**Figure 3: Suggested Sequence of Conceptual Trade-offs for Concurrent-Flow Lanes**

**Access Treatment**

Direct ramp treatments to major streets accessing downtown areas are facilitated by use of a grade separated flyover (goes over or under the mainlanes) or drop ramp (connects up or down from median to a connecting street). Such ramps are oriented within the median with left side entrance and exit ramps with the managed lanes and may be either two way or reversible to handle only the peak direction. They may be oriented in one or both freeway directions.

Any of these ramps will connect to a low speed roadway that may involve a traffic signal or other traffic control device at the ramp terminus. Accordingly, drop ramps require careful consideration in their respective design speed to take into account the sight distance that leads traffic from a high speed to low speed condition in a short distance, and vice versa. Drop ramps on concurrent flow lanes are typically two-way, with a barrier that transitions to an open buffer or curb section between opposing directions. An example layout is provided in Figure 4 and typical cross section in Figure 5.
A single directional or reversible ramp may be appropriate for very tight design settings. These generally follow the same guidelines for any other general purpose directional ramp on structure. If reversible, the orientation of the lane may be centered on a half shoulder (Figure 6). A wide variety of flyover and drop ramp examples exist in Seattle, Houston, Minneapolis, Atlanta, Hartford, Denver, Northern Virginia, Phoenix, Salt Lake City, and southern and northern California.
Active Traffic Management Components

The managed lane concepts under consideration in this study were determined to benefit from selective application of available active traffic management strategies, notably connector and ramp metering, lane control signals, queue warning, and speed harmonization. Ramp metering is already prevalent throughout the corridor and provides benefits in smoothing critical merge activity and in delaying the onset of congestion. But conditions outside the study limits, particularly the I-94 Lowry Hill Tunnel and the queues created by that bottleneck, adversely affect westbound traffic operations with queue formation extending back to the Cretin interchange and beyond. These queues ripple back during peak periods, particularly in the afternoon, creating increasing opportunities for crashes. A similar occurrence can be identified on the eastern end of the study limits where I-94 approaches the I-35E Capitol Interchange in St Paul (Figure 7).

Figure 6: Examples of Reversible Typical Sections

Figure 7: Speed Contours for Respective Peak Directions on I-94
The sudden and unexpected formation of queues on a regular basis can contribute to unstable flow, loss of throughput and higher incidence of crashes. These isolated segments in the respective peak periods would appear to be appropriate for the introduction of speed harmonization and queue warning to compliment ramp and connector metering and the lane control options being considered for mid-term and long-term horizons. Much like a similar application implemented along the I-35W Priced Dynamic Shoulder Lane (PDSL) project, speed harmonization and queue warning could increase efficiency and improve operational safety. Together, such systems provide a means of advising an approaching traffic slow-down and slowing traffic down gradually so that crashes and secondary incidents are avoided.

Desirable placement of gantries for mounting the speed harmonization and queue warning signing would be approximately every ¼ to ½ mile such that one is always in sight. If desired, use of the large number of overhead bridge structures to support the added signs could minimize the potential cost associated with installation of this strategy, although free-standing gantries would be acceptable. These costs are documented in Appendix C.
Candidate Conceptual Alternatives

The I-94 Managed Lane Study included an iterative process with input from both the Technical Committee and the Advisory Committee in the development of candidate conceptual alternatives. This process yielded two discrete future alternatives to augment the baseline. These candidates are referred to as the Minor Rehabilitation with ATM Alternative (“Concept 3” during the study) and the Full Reconstruction with Managed Lanes Alternative (“Concept 4”).

Baseline (“No Build”) Alternative

The No Build alternative was used in the study as the basis for comparison of the options being considered. The No Build returns the geometrics of I-94 to the conditions which existed prior to the I-35W bridge collapse and prior to the restriping of I-94 to meet the added traffic volumes during the emergency. In particular the “No Build” alternative restores the bus-only shoulders to reestablish the transit advantage in the corridor and eliminates the added general purpose lanes.

Minor Rehabilitation with ATM Alternative

The Minor Rehabilitation Alternative focuses on near term improvements to I-94, extending from the I-35W interchange in downtown Minneapolis to John Ireland Boulevard in St. Paul. Recognizing state and regional funding limitations, the Minor Rehabilitation Alternative has been developed to provide safety and capacity improvements within the operating constraints of the major bottlenecks imposed by the Lowry Tunnel to the west and the Capitol interchange to the east. Recognizing that the capital costs of major expansions of either of these bottlenecks is well beyond available budgets for decades, advanced traffic management systems will be included to preserve mobility and improve safety in these congested conditions.

Western Section (I-35W to TH 280)

The major changes in the current facility configuration are concentrated in the western section of the project area, between I-35W and TH 280. The basic elements of the Minor Rehabilitation Alternative will provide four (4) continuous lanes in each direction between the downtown Minneapolis access ramps at 5th Street Westbound (WB) and 6th Street Eastbound (EB) and the TH 280 interchange.

In the WB direction, 4 lanes will start at the Cretin/Vandalia interchange just to the east of TH 280 to carry the 4th lane through the TH 280 interchange rather than having a lane drop at the exit to NB TH 280. The WB left entrance ramp from TH 280 will enter with an acceleration lane, replacing the current add lane configuration to provide lane continuity for through traffic on I-94.

Between TH 280 and the Huron Boulevard interchange, emergency pull-offs will be added where possible without replacing overhead bridges and rebuilding retaining walls. The breakdown areas will be spaced approximately every ½ mile, consistent with the application on I-35W. These areas will be within the cone of lighting for the corridor, and, within viewing of traffic operations cameras. Signage will be incorporated indicating the intended use of the breakdown area.

Between the Huron entrance ramp and the Riverside Avenue exit, a fifth or auxiliary lane will be carried on the Dartmouth Bridge over the Mississippi River. Between the 25th Avenue entrance ramp and the Cedar Avenue exit, an auxiliary lane will be provided if sufficient horizontal clearance is available under the 20th Street and 28th Street overpasses. The Cedar Avenue exit will be widened at the ramp terminal to
provide for dual left turns. Throughout this section, the left shoulder will be reduced to 4 feet to permit the right lane to be widened to 13 feet for managed operations.

At the western limits of the study area, the ramps between I-94 and I-35W will be revised with acceleration and deceleration lanes replacing the current lane drops or adds to maintain lane continuity by maintaining three through lanes in each direction on I-94. At the downtown ramps, the WB exit to 5th Street will be a mandatory exit for the fourth or right lane to accommodate the heavy traffic flows exiting in peak periods, including the significant volume of Metro Transit buses exiting to downtown Minneapolis. Similarly in the EB direction, the entrance from 6th Street will be an added fourth lane to accommodate the heavy entering volume including several Metro Transit bus routes.

In the EB direction, 4 lanes will be provided between the 6th Street on ramp and the left hand mandatory exit to NB TH 280. A fifth or auxiliary lane will be provided between the Riverside entrance ramp and the Huron exit over the Dartmouth Bridge. The exit ramp to TH 280 will be realigned to accommodate a 55 mph design speed to avoid exiting traffic from slowing prior to exiting. Emergency pull-offs will be provide where feasible. A right shoulder will also be constructed between Franklin Avenue and Pelham Boulevard.

To improve safety and maintain mobility in this section of I-94, an extensive ATM system will be installed with overhead lane variable speed limit and lane control signs as well as queue warning signs between TH 280 and the Lowry Tunnel to advise WB motorists of back-ups from the Lowry Tunnel and to manage the right lane to preserve movement of the right lane for 35mph operations to the 5th Street exit. To improve the reliability of peak period operations particularly for the heavy volume of Metro transit buses, an in-road lighting system will also be installed in the right lane of WB I-94 between the Dartmouth Bridge at the 5th Street exit to manage access and egress to and from the right hand lane to assure reliable operations in the AM and PM peak periods. Similar ATM equipment and signing will be installed for the EB lanes of I-94 with a particular need for advance warning of queues at the curve east of the Huron entrance ramp.

To permit the lane adjustments and to avoid confusion to motorists from remnants of the current lane markings, this section of I-94 will be milled and overlaid with new finished pavement to permit the installation of the in-road lighting as well as added buried vehicle detection loops. Additional drainage inlets will be installed to meet current interstate standards.

![Figure 8: Rehabilitation Typical Section - 5th Street to Riverside](image-url)
For the section of I-94 east of the TH 280 interchange, the existing lane configuration will be retained. As discussed in the above description of the section west of TH 280, the WB roadway of I-94 will be modified west of the Cretin/Vandalia interchange to continue the four through lanes through the TH 280 interchange rather than having the right lane be a mandatory exit to NB TH 280. A queue management system is proposed for the WB entrance ramp from Cretin/Vandalia to I-94 to manage vehicles entering I-94. This would include adjustments to the local signal system to advise motorists of conditions approaching I-94 so that they could utilize alternates if needed. The exit ramps in both directions at the Snelling Avenue interchange will be modified to provide additional storage to avoid queues spilling back onto the I-94 mainline, impeding buses using the BOS lanes. This may include lengthening the decel lanes, widening the ramps for two lane operation, and providing added turn lanes at the ramp termini at Snelling, or combinations of all three treatments.

As in the section west of TH 280, ATM electronic systems will be installed with overhead lane control and variable speed limit signing, plus queue warning devices to advise EB traffic if queues are extending back from the Snelling Avenue interchange or the Capitol Interchange with I-35E. This section of I-94 will also be repaved using milling and an overlay of new finished pavement with new pavement markings. Existing overhead directional signs will be renewed together with the installation of the new overhead variable speed signs over each lane. Drainage systems and inlets will be expanded as part of the Minor Rehabilitation Alternative project to meet current Interstate standards.
The estimated capital cost for the Minor Rehabilitation Alternative in 2010 Dollars is $88.4 million, including a 35 percent risk factor/contingency and 3% escalation factor. Detailed in Appendix C, the summarized cost estimates are as follows:

<table>
<thead>
<tr>
<th>Type of Improvement</th>
<th>Total Cost Estimate (inc. 35% risk)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EB I-94 (Minneapolis to TH-280)</td>
<td>$12,280,000</td>
</tr>
<tr>
<td>WB I-94 (Minneapolis to TH-280)</td>
<td>$13,379,000</td>
</tr>
<tr>
<td>EB/WB I-94 (Lexington to St. Paul)</td>
<td>$18,340,000</td>
</tr>
<tr>
<td>ATM Infrastructure</td>
<td>$41,850,000</td>
</tr>
<tr>
<td>Escalation (3%)</td>
<td>$2,575,000</td>
</tr>
<tr>
<td><strong>TOTAL MINOR REHABILITATION ALTERNATIVE</strong></td>
<td><strong>$88,424,000</strong></td>
</tr>
</tbody>
</table>

**Figure 12: Minor Rehabilitation Alternative Cost Estimate (2010 Dollars)**

**Full Reconstruction Alternative (“Long Term Alternative”)**

The Full Reconstruction Alternative includes much more extensive long term improvements to I-94 extending from the I-35W interchange in downtown Minneapolis to John Ireland Boulevard in St. Paul. Recognizing that such a complete reconstruction of I-94 would likely be beyond state and regional funding capabilities for decades, the Full Reconstruction Alternative has been developed to identify a potential long range plan so that short term or interim measures will not preclude the ultimate
The major addition of the Full Reconstruction Alternative is a median HOT or managed lane in the median between Minneapolis and St. Paul with new direct access ramps to both downtown Minneapolis and downtown St. Paul. These direct access ramps would permit HOT lane traffic to enter and leave the median managed lanes in peak periods without the need to weave across the general purpose lanes. A limited number of access points would also be provided between the general purpose lanes and the managed lanes at intermediate points. The Full Reconstruction Alternative also includes the rebuilding of the I-94 interchange with TH 280 to eliminate the left hand ramps and to provide for continuing the median managed lanes through the interchange.

**Western Section (I-35W to TH 280)**

Four major geometric elements are included in the western section of the project area, between I-35W and TH 280. The basic elements of the Full Reconstruction Alternative will provide four (4) continuous general purpose lanes in each direction between the existing downtown Minneapolis access ramps at 5th Street Westbound (WB) and 6th Street Eastbound (EB) and the TH 280 interchange, and a fifth managed or HOT lane in each direction ending at a new reversible ramp in the median connecting to ramps leading to and from downtown Minneapolis. The fourth element of the Full Reconstruction Alternative is the reconstruction of the TH 280 interchange to replace the left hand ramps with right hand ramps permitting the median HOT lanes to continue through the interchange.

In both directions, collector-distributor (CD) roadways will be added between the Cretin/Vandalia interchange and the TH 280 interchange to have weaving movements occur on the CD roadways rather than on the I-94 main roadways. The WB lanes of I-94 will be realigned to parallel the EB lanes to accommodate the new structures over I-94 that will carry the EB exit to NB TH 280 and to replace the current left entrance ramp. Between TH 280 and the Huron Boulevard interchange, the parallel railroad spur would be removed along with the bridge carrying the spur over I-94 east of 27th Avenue. The bridges carrying 27th Avenue and Franklin Avenue as well as the ramp bridges in the Huron interchange would also be reconstructed and widened. Between the Huron WB entrance ramp and the Riverside Avenue exit, the five lanes at the Dartmouth Bridge over the Mississippi River will be reconfigured to carry four GP lanes and one HOT lane in the median. The Riverside Avenue, 25th Avenue and 20th Avenue structures over I-94 would be reconstructed and widened to accommodate the four lanes plus the HOT lane.

West of Cedar Avenue, the HOT lane will connect with a median reversible drop ramp as well as having a merge lane into WB I-94. The right (fourth) GP lane will be an exit only lane to the 5th Street exit. The reversible drop ramp will descend in the median to pass under the WB lanes of I-94 and pass over the Hiawatha LRT tracks to connect with the existing ramp to 5th Street. Throughout this section (except for the Dartmouth Bridge) the HOT lane will be separated from the four GP lanes by a 4 foot flush buffer. All travel lanes will be 12 feet in width, and a ten foot right shoulder will be provided. At the west limits of the study area, as with the Minor Rehabilitation Alternative, the ramps between I-94 and I-35W will be revised with acceleration and deceleration lanes, replacing the current lane drops or adds to maintain lane continuity by maintaining three through lanes in each direction.

In the EB direction, four (4) General Purpose lanes will be provided starting at the 6th Street on ramp. In addition, a median HOT lane will be added with a connecting ramp from EB I-94 and a connecting ramp from the reversible ramp to carry Metro Transit buses and HOT traffic from 6th Street. The EB roadway and structure carrying the EB lanes would be shifted to the south between TH 55 and Cedar Avenue to
provide room in the median for the reversible ramp. The four (4) GP lanes and the HOT lane will continue through the section to east of TH280. The five lanes over the Dartmouth Bridge will carry the four (4) GP lanes plus the HOT lane. The exit ramp to TH 280 will be reconstructed as a right hand exit. As in the WB direction, all travel lanes will be 12’ feet in width, and a ten foot right shoulder will be constructed. A four foot buffer would separate the GP lanes from the HOT lane except on the Dartmouth Bridge. An EB collector-distributor roadway would be carried through the TH 280 interchange so that traffic wishing to exit at Cretin/Vandalia would use the CD roadway eliminating weaving movements on the EB I-94 main roadway.

Since even with the full build-out of the Full Reconstruction Alternative, it is not likely that the bottlenecks at the Lowry tunnel and the Capitol interchange will be removed, to improve safety and maintain mobility in this section of I-94 an extensive ATM system similar to that proposed for the Minor Rehabilitation Alternative will be installed with overhead lane variable speed limit and lane control signs as well as queue warning signs between TH 280 and the Lowry Tunnel to advise WB motorists of back-ups from the Lowry Tunnel. Since the median HOT lane will serve Metro Transit buses and other permitted vehicles it will not be necessary to manage the right lane, obviating the need for the in-road lighting system planned in the Minor Rehabilitation Alternative.

![Figure 13: Reconstruction Typical Section – Dartmouth Bridge](image)

![Figure 14: Reconstruction Typical Section - I-35W to TH 280](image)

**Eastern Section (TH 280 to I-35E)**

For the section of I-94 east of the TH 280 interchange, the existing four GP lanes will be retained and a managed HOT lane will be added in the median. All travel lanes will be 12 feet in width. The HOT lane will
be separated from the GP lanes by a 4 foot buffer. The Snelling Avenue interchange will be reconstructed
to carry the four GP lanes through the interchange without lane drops. All the overhead bridges in this
section would have to be reconstructed to accommodate the through lanes plus the full shoulders of I-94.
As discussed in the above description of the section west of TH 280, collector-distributor roadways will be
constructed in both directions between the TH 280 interchange and the Cretin/Vandalia interchange to
eliminate the weaving movements on the I-94 roadways. The Snelling Avenue interchange will be
reconstructed to provide additional storage to avoid queues spilling back onto the I-94 mainline. All of the
closely-spaced interchange ramps between TH 280 and John Ireland Boulevard will be reconfigured to
reduce weaving on the I-94 main roadway and to relocate the weaves to the frontage roads where the
weaving movements can more safely be accommodated. The median managed lane will terminate west of
the I-35E Capitol interchange with a direct left hand exit ramp for Metro Transit buses and authorized
vehicles to access downtown St. Paul in the vicinity of St. Peter Street. The Managed lane traffic also will
merge into the EB GP lanes of I-94. The existing WB left hand entrance ramp from 6th Street will provide
access to the EB traffic from Downtown St. Paul, including Metro Transit buses, without the need to
weave across the general purpose lanes.

As in the section west of TH 280, ATM electronic systems will be installed with overhead lane control and
variable speed limit signing, plus queue warning devices to advise EB traffic if queues are extending back
from the Capitol Interchange with I-35E.

![Diagram of reconstruction typical section - TH 280 to Marion](image)

**Figure 15: Reconstruction Typical Section - TH 280 to Marion**

**Cost Estimates**
The estimated capital cost for the Full Reconstruction Alternative in 2010 Dollars is $484.9 million,
including a 35 percent risk factor / contingency. Detailed in Appendix C, the summarized cost estimates
are as follows:

<table>
<thead>
<tr>
<th>Type of Improvement</th>
<th>Total Cost Estimate (inc. 35% risk)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Eastbound (Minneapolis to TH 280)</strong></td>
<td></td>
</tr>
<tr>
<td>Direct access ramp (Minneapolis)</td>
<td>$30,105,000</td>
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<tr>
<td>Widen for HOT lane / buffer</td>
<td>$37,706,000</td>
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<tr>
<td>Widen Bridges (I-35W, LRT, Cedar)</td>
<td>$4,597,000</td>
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<tr>
<td>Replace Bridges (25th, Riverside, 20th)</td>
<td>$18,239,000</td>
</tr>
<tr>
<td>Realign SB Huron</td>
<td>$540,000</td>
</tr>
<tr>
<td>Remove Railroad Bridge (27th)</td>
<td>$507,000</td>
</tr>
<tr>
<td>Replace Bridge (Franklin)</td>
<td>$3,738,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$108,568,000</strong></td>
</tr>
<tr>
<td>Description</td>
<td>Cost</td>
</tr>
<tr>
<td>----------------------------------------------------------------------------</td>
<td>------------</td>
</tr>
<tr>
<td>New Ramp (I-94 to TH 280)</td>
<td>$2,700,000</td>
</tr>
<tr>
<td>ATM Infrastructure</td>
<td>$7,938,000</td>
</tr>
<tr>
<td>Replace Pedestrian Bridges</td>
<td>$2,498,000</td>
</tr>
<tr>
<td><strong>Westbound (Minneapolis to TH 280)</strong></td>
<td><strong>$55,854,000</strong></td>
</tr>
<tr>
<td>Realign Ramp (I-94 / TH 280)</td>
<td>$6,750,000</td>
</tr>
<tr>
<td>Widen for HOT lane / buffer</td>
<td>$37,706,000</td>
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<tr>
<td>Widen Cedar ramp</td>
<td>$760,000</td>
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<tr>
<td>Drop ramp to downtown Minneapolis</td>
<td>$1,080,000</td>
</tr>
<tr>
<td>ATM Infrastructure (to Lowry Hill Tunnel)</td>
<td>$9,558,000</td>
</tr>
<tr>
<td><strong>Eastbound (TH 280 to Lexington)</strong></td>
<td><strong>$121,156,000</strong></td>
</tr>
<tr>
<td>Widen for HOT lane / buffer</td>
<td>$37,706,000</td>
</tr>
<tr>
<td>Collector - Distributor ramp at TH 280</td>
<td>$6,727,000</td>
</tr>
<tr>
<td>Replace Railroad Bridge (Fairview)</td>
<td>$10,949,000</td>
</tr>
<tr>
<td>Replace Bridges (Vandalia, Cleveland, Fairview, Snelling, Pascal, Hamline)</td>
<td>$57,836,000</td>
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<td>ATM Infrastructure</td>
<td>$7,938,000</td>
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<tr>
<td><strong>Westbound (TH 280 to Lexington)</strong></td>
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<tr>
<td>Widen for HOT lane / buffer</td>
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<tr>
<td>Collector - Distributor ramp at TH 280</td>
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<td>ATM Infrastructure</td>
<td>$7,938,000</td>
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<tr>
<td><strong>Eastbound / Westbound (Lexington to St. Paul)</strong></td>
<td><strong>$135,477,000</strong></td>
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<tr>
<td>Widen for HOT lane / buffer</td>
<td>$52,326,000</td>
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<tr>
<td>Replace Bridges (Lexington, Pedestrian (3), Victor, Dale, Western, Marion, John Ireland)}</td>
<td>$58,419,000</td>
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<tr>
<td>ATM Infrastructure</td>
<td>$11,232,000</td>
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<tr>
<td>Egress ramp to St. Paul</td>
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<tr>
<td>Escalation (3%)</td>
<td>$14,125,000</td>
</tr>
<tr>
<td><strong>TOTAL FULL RECONSTRUCTION ALTERNATIVE</strong></td>
<td><strong>$484,064,000</strong></td>
</tr>
</tbody>
</table>

Figure 16: Full Reconstruction Alternative Cost Estimate (2010 Dollars)
Technical Evaluation of Concepts

Three technical evaluations were conducted of the Minor Rehabilitation Alternative and the Full Reconstruction Alternative: a regional traffic forecast analysis, a simulation of traffic operations on the corridor, and a benefit / cost analysis.

Regional Traffic Forecasts

The project team developed base year 2006 and forecast year 2030 average weekday daily and hourly auto and transit demand for the I-94 Managed Lanes Study. In addition to defining the features of the Minor Rehabilitation Alternative and the Full Reconstruction Alternative in the regional model, one of the key initial tasks in this study was to develop 2030 forecast travel demand for a no-build and build scenarios. This forecast had two primary purposes. First, the forecast was used to identify general demand in the corridor, including toll and HOV demand, as well as to provide an estimate for toll revenues. Secondly, the travel demand model output provided growth factors and ramp-to-ramp movements for use in the CORSIM traffic simulation model.

Methodology

The Twin Cities Regional Model (“the model”) was used to develop the travel demand forecasts for this study. The model was developed in the 2001-2003 timeframe as a part of the Twin Cities Travel Behavior Inventory (the 2000 TBI), and used information from the 2000 Census, the year 2000 Regional Home Interview Survey and a concurrent set of external surveys done as a part of the 2000 TBI. The model included the 7 core counties of the region, as well as a set of ring counties surrounding the core. A total of 1632 zones were included, with 1201 zones in the seven-county area.

The main inputs to the model included:

1. **Socioeconomic Data.** This included population, households, retail and non-retail employment by zone. Data for 2006 was obtained by interpolating 2000 and 2009 data from the Metropolitan Council. Special Generator Data for 2000, 2009 and 2030 were also provided by the Council and/or used from current studies. 2030 data used most recently for the Cedar Avenue Corridor Study was used with some minor reallocation of employment within Lakeville. Otherwise, the socioeconomic data was the same as used for the Central Corridor and SW corridor demand analyses.

2. **Networks.** A 2006 network set was supplied by the Metropolitan Council, and reflected roadway conditions in the region in 2006, including the pre-collapse configuration of I-35W, I-94 and TH280. The I-394 HOT lane was included. This network set included both highway and transit networks as reflected at that time. The Hiawatha Light Rail line was also included in the transit network. The associated transit accessibility file (i.e., percent of zone within 1/3 and 1 mile of a transit stop) was also included. The 2030 network set was obtained from the roadway and transit networks used for the Central and SW corridor Light Rail studies. As such, it included both the Central Corridor and SW corridor Light Rail lines, as well as the Northstar Commuter Rail Line. Washington Avenue was deleted just east of the Mississippi River Bridge on the University of Minnesota East Bank Campus, reflecting the plans of the Central Corridor. University Avenue between the two downtowns was assumed to have 2 lanes in each direction. Lane configurations on I-94 and TH280 were as they were prior to the I-35W bridge collapse. The 2030 networks are consistent with the regional policy plan of the Metropolitan Council. Transit route alignments and frequencies were verified by Met Council staff, and adjustments were made to reflect the current plans for transit in the corridor.
For each forecast year, the model was re-run in a full feedback mode, which included trip generation, distribution, mode choice, and morning/midday highway assignment. A multiple convergence test was used. The model was allowed to run in feedback mode until at least 90 percent of the average am peak hour volumes, times and speeds all changed by less than 10% from the previous iteration, and at least 90% of the OD-pairs of the am peak period trips change by less than 10% from the previous iteration. The same 2030 vehicle demand matrices were assigned to the no-build and each of the build alternatives. For each alternative, a ramp-to-ramp subarea trip table was developed which corresponded to the CORSIM network used for simulation. Adjustment factors were applied to each ramp and mainline entrance and exit, based on the 2005 count/2006 model estimated values at these ramp locations. The ramp-to-ramp matrix was then re-balanced to match the new target values, and re-assigned to the subarea network. From the subarea networks and associated trip tables, the information necessary for the demand inputs to CORSIM were supplied. Separate HOT lane demand matrices and link loadings were also supplied through this process.

The validation effort assessed mainline daily and peak hour volumes, comparing 2005 counts with 2006 model volumes for key mainline segments of I-94 in the corridor. Segments between TH55 and Marion Street compared favorably, with less than 6% difference between modeled and counts for the central study area for this project. The full Regional Forecasting report (Appendix D) contains more detailed results, including peak hour shares. For the key study sections, the overall 2006 model estimated volumes are 5% under the 2005 counts. The average AM peak hour modeled volumes are 6% higher than observed, while the average PM peak hour modeled volumes are 2% higher than observed. Average estimated peak hour directional splits for both am and pm peak hours are within 1% of observed.

An assignment-based routine was used to estimate toll and HOV demand for the HOT lane alternative. This is the same approach used in the I-35W Urban Partnership Agreement (UPA) analysis, and, used a dynamic toll demand estimation embedded within an equilibrium highway assignment. Willingness to pay parameters were based on actual local travel survey results. Note that this methodology does not have any sensitivity to transit mode shifts that might result from the alternatives. In support of the CORSIM modeling, a ramp-to-ramp demand matrix (peak hours) was generated using the subarea isolation procedures in Cube/Voyager. The standard assignment was used, with SOV, 2-person and 3+ person autos as demand markets in a multi-class assignment.

Regional Model Findings

Appendix D contains counts vs. estimated 2030 volumes and the modeled 2006 vs. the modeled 2030 base. The I-94 growth rate, both daily and peak hour, was minimal – about 2 percent growth. This growth is constrained by capacity on I-94 and by the capacity of the interchanges at both ends of the study area. The forecasting report shows the comparison of 2030 base to HOT lane demand.

The Minor Rehabilitation Alternative, utilizing conversion of shoulders to added travel lanes along with lane control technology, showed a 6 percent daily increase in I-94 traffic volume, with peak hour volume increases of 9 percent for the AM peak and 6 percent for the PM peak hours. The Full Reconstruction Alternative, utilizing a median HOT lane and major roadway widening and interchange revisions showed increases of 5 percent for daily traffic on I-94 in the corridor, with 12 percent for the AM peak and 10 percent for the PM peak. These percent changes were based on the sum of I-94 mainline segment volumes in the simulated network corridor.
The regional model assignments were developed for each hour of the day. From these, performance measures were developed that illustrate the overall system performance. Figure 17 shows these performance measures. As shown below, the Concepts 1, 2 & 3 alternatives, though attracting additional volume to the corridor itself, had a relatively small effect overall. The Full Reconstruction Alternative, the median HOT lane alternatives (with and without a direct EB connection to downtown St. Paul) had much more significant system-wide impacts, reducing delay by about 10 percent and increasing overall system speed by 0.7 miles per hour.

<table>
<thead>
<tr>
<th></th>
<th>No-Build</th>
<th>Concept 1, 2 &amp; 3</th>
<th>Concept 4 - HOT Lane</th>
<th>Concept 4 - HOT Lane-Alt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delay(veh-hrs)</td>
<td>1,169,000</td>
<td>1,155,400</td>
<td>1,047,900</td>
<td>1,047,100</td>
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<tr>
<td>VHT</td>
<td>3,571,100</td>
<td>3,556,500</td>
<td>3,361,500</td>
<td>3,360,600</td>
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<tr>
<td>VMT</td>
<td>104,912,000</td>
<td>104,882,000</td>
<td>101,145,000</td>
<td>101,137,000</td>
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<tr>
<td>Average Speed</td>
<td>29.4</td>
<td>29.5</td>
<td>30.1</td>
<td>30.1</td>
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**Change From NB**

<table>
<thead>
<tr>
<th></th>
<th>No-Build</th>
<th>Concept 1, 2 &amp; 3</th>
<th>Concept 4 - HOT Lane</th>
<th>Concept 4 - HOT Lane-Alt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delay(veh-hrs)</td>
<td>-13,600</td>
<td>-121,100</td>
<td>-121,900</td>
<td></td>
</tr>
<tr>
<td>VHT</td>
<td>-14,700</td>
<td>-209,600</td>
<td>-210,600</td>
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<tr>
<td>VMT</td>
<td>-30,000</td>
<td>-3,768,000</td>
<td>-3,775,000</td>
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**Percent Change From NB**

<table>
<thead>
<tr>
<th></th>
<th>No-Build</th>
<th>Concept 1, 2 &amp; 3</th>
<th>Concept 4 - HOT Lane</th>
<th>Concept 4 - HOT Lane-Alt</th>
</tr>
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<tbody>
<tr>
<td>Delay(veh-hrs)</td>
<td>-1.2%</td>
<td>-10.4%</td>
<td>-10.4%</td>
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<tr>
<td>VHT</td>
<td>-0.4%</td>
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<tr>
<td>VMT</td>
<td>-0.03%</td>
<td>-3.59%</td>
<td>-3.60%</td>
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</tr>
</tbody>
</table>

**Notes:**
All measures are calculated by summing all regional network link performance values for each hourly assignment.
Delay is computed by subtracting congested VHT from free-flow VHT.
VHT - Vehicle-hours of travel
VMT - Vehicle-miles of travel
Average Speed - VMT/VHT (expressed in miles per hour)
HOT Lane-Alt differs from the “HOT Lane” alternative only by the addition of a direct HOT lane ramp access to downtown St. Paul.

Figure 17: Year 2030 Performance Measures

**CORSIM Traffic Simulation**

Based on the high level travel demand analysis for the corridor and recommendations from project technical and advisory committees, the Minor Rehabilitation Alternative and the Full Reconstruction Alternative, along with the no build option, were selected for CORSIM simulation analysis of traffic operations. While conducting the simulation analysis, the capacity constraints in the two downtown areas (the Lowry Tunnel in Minneapolis and the Capitol Interchange in Saint Paul) showed significant negative effects on the operations on I-94 for extended sections of the study area. Therefore the two build concepts were tested under both constrained and unconstrained conditions in order to identify operational problems and to evaluate potential benefits in the project area which were otherwise masked by the traffic queues created by the congested end points. The Minor Rehabilitation Alternative is a moderate cost option for near term implementation including installation of ATM to improve the safety of operation...
within the present roadway envelope. The Full Reconstruction Alternative is a more extensive alternative with major widening and bridge reconstruction to provide continuous managed lanes in the median in both directions between the two downtowns.

**Methodology**

The CORSIM traffic models included the following system segments (shown on Figure 18):

- I-94 between TH 61 to the east and I-394 to the west
- I-35W between 31st Street and the Mississippi River Bridge
- I-35E between Kellogg Boulevard and Pennsylvania Avenue
- TH 280 between I-94 and University Avenue
- TH 65/I-94/I-35W interchange
- TH 55/I-94/I-35W interchange

![Figure 18: I-94 CORSIM Study Limits](image)

The CORSIM traffic model simulation and analysis for this study included the following step by step approach:

- Creation and calibration of an existing condition CORSIM model of traffic operations based on pre-bridge collapse conditions in 2005
- Future 2030 no-build CORSIM analysis with and without capacity constraints in the downtown areas using the same 2005 conditions with projected 2030 traffic volumes
- Future 2030 build CORSIM analysis for ‘base’ versions of the Minor Rehabilitation Alternative and the Full Reconstruction Alternative, both with and without capacity constraints in the downtown areas with 2030 traffic
- Creation of modeling scenarios to test geometric variations to the two base concepts
- Future 2030 modeling scenarios analysis with and without capacity constraints in the downtown areas
- Selection of detailed configurations for testing alternatives for the Minor Rehabilitation Alternative and the Full Reconstruction Alternative
- CORSIM analysis of preferred alternatives with capacity constraints in the downtown areas.
- CORSIM analysis of preferred alternative using existing traffic volumes
For the purposes of this study, it was determined that the pre-bridge collapse (2005) conditions should be considered as the baseline or existing conditions, including both the lane configuration and the hourly traffic volumes for ramps and main roadway segments. Due to the re-striping of I-94 between I-35W and TH 280 after the bridge collapse, the current configuration on I-94 is different from the 2005 existing condition in the study area. Therefore, the calibration and evaluation of the base condition for this project relied largely on driving experience, historical reports, and incident and traffic data obtained from Mn/DOT detectors prior to the bridge collapse.

Using the Mn/DOT incident database, a total of thirteen incident-free days were identified in May, September and October of 2005 and 2006 in the project area. The traffic patterns on I-94 from those dates were further explored to identify a typical day for the base CORSIM model calibration. As a result, May 3, 2005 was used as a “typical day”. All of the detector volume and speed data from this date were extracted and then balanced for the base CORSIM model calibration. To replicate the actual existing conditions in the CORSIM models, the calibration process required several adjustments of the model parameters. This resulted in the existing (2005) operations being effectively replicated at the start of simulation.

**CORSIM Simulation Findings**

The CORSIM modeling, using existing (2005 pre-collapse) and projected 2030 traffic volumes, revealed the following:

<table>
<thead>
<tr>
<th>Findings</th>
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<tbody>
<tr>
<td>1</td>
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<td>5</td>
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<td>6</td>
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<td>7</td>
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</tbody>
</table>
Adding HOT lanes on the left or median side of I-94 in both directions would accommodate traffic growth by 15% between the two downtowns. However, further improvements to the TH 280 interchange to eliminate the left ramps and to the HOT lane endpoints (where traffic would transition to the general purpose lanes) by adding median drop ramps would be necessary for the lanes to function effectively.

Figure 19: CORSIM Simulation Findings

Benefit / Cost Analysis

A benefit-cost analysis was conducted to quantify the relative benefits and costs of the final two build options for the I-94 corridor:

1. The Minor Rehabilitation Alternative, which includes ATM infrastructure, some capacity improvements, and improved BOS, and
2. The Full Reconstruction Alternative, which includes major infrastructure changes such as adding a center HOT lane in both directions, replacement of many restrictive overhead bridges, major interchange reconstruction to remove left-side ramps and HOT / express transit direct access ramps to and from the downtowns.

The monetary benefits for the project were only quantified in terms of reduced vehicle miles traveled (VMT), vehicle hours traveled (VHT), and estimated reduction in crashes over the analysis period between the No-Build and two Build option conditions. Estimated costs included roadway construction, bridges and structures, right-of-way, traffic management systems and engineering/project delivery costs. Remaining capital values of these roadway features at the end of the analysis period are subtracted from the total cost for each of the two concepts.

In this analytical approach, quantified benefits greater than or equal to the quantified costs (benefit-to-cost ratio greater than one) represent an economically viable project. Due to the planning level of detail involved in the calculations, the magnitudes of the benefit-cost ratios are not as important as the value being greater or less than one. These benefit-cost analysis results provide input for the comparison or ranking of the different alternatives.

For this project, all costs were evaluated in 2010 dollars, with the 20-year benefit period based on a 2011 day-of-opening through the year 2031. Daily VMT and VHT in the study area for the four scenarios (Existing 2006, 2030 No-Build, and 2030 Build Options) were directly obtained from the Twin Cities regional model, and daily VMT and VHT for years between 2011 and 2031 were calculated based on the linear growth method. For additional assumptions, refer to the I-94 Benefit-Cost Memo included in the Appendix.

The results of the Benefit-Cost analysis show that both Alternatives have a benefit-cost ratio greater than one, meaning each of the two alternatives would be a beneficial project. In other words, the VMT, VHT and crash reduction benefits for each Alternative are estimated to be greater than the costs associated with the construction of the project. The greatest relative benefits are seen in VMT and VHT values, as the added capacity and other improvements provided reduces congestion in the peak periods. Reductions in VMT and VHT reflect the ability of more drivers to use I-94 to reduce travel distance and trip times, and the reductions in crashes are the results of improved traffic management to provide drivers with better advance communication of changing road conditions.
Conclusions and Recommendations

Conclusions
The I-94 corridor connecting downtown Minneapolis and downtown St. Paul is a key link in the regional transportation network serving a broad range of trip purposes, through trips and local trips, and a significant number of truck and transit trips. The operational capacity and safety of the corridor are greatly impacted by the bottleneck conditions at the two ends of the study area: the Lowry Tunnel at the west end; and the Capitol Interchange at the east end. The congestion and queues resulting from these two bottlenecks greatly reduce the effectiveness of any concept to increase capacity on I-94 since the queues will persist because of the difficulty and impacts associated with reconstructing interchanges at the two bottlenecks. The study has focused on both short and long term opportunities to better manage the existing facility, to maintain mobility, to encourage use of transit and to improve safety.

Strengths of Each Concept
The Minor Rehabilitation Alternative improves traffic operations in the near-term by extending lane continuity on westbound I-94, continuing the four main lanes through the TH 280 interchange by: 1) making the entrance from southbound 280 to westbound I-94 an acceleration lane, 2) eliminating the lane drop at Riverside, and 3) making the exit to I-35W a deceleration lane rather than a mandatory exit. By managing the right lane between the Huron Boulevard interchange and the Sixth Street exit via dynamic overhead lane control signs and In Road Lighting (IRL), preference can be given to transit and traffic exiting at Sixth Street, thereby avoiding the queues extending back from the Lowry Tunnel. In the eastbound direction, adding the fourth through lane at the Sixth Street entrance ramp and continuing the four lanes to the TH 280 exit provides improved operations for the heavy volume of traffic entering from downtown Minneapolis, including a large number of Metro Transit buses. Widening the shoulder for enhanced BOS operations between TH 280 and downtown St. Paul will also permit higher bus operating speed in congested time periods. Provision of the overhead signs to manage speed and to warn of impending slowdowns for queues will provide important safety improvements and crash reductions, reducing delays from incidents.

The Full Reconstruction Alternative provides additional roadway and geometric improvements over a longer term by widening I-94 to allow for a continuous HOT managed lane in the median in each direction with connecting direct left hand entrance and exit ramps in both downtowns. The Full Reconstruction Alternative includes replacement of many of the overhead street and railroad bridges which restrict the ability to widen I-94 within available right-of-way in the near-term due to the associated high construction cost. The TH 280 interchange would be totally reconstructed to eliminate the left hand entrance and exit ramps, providing lane continuity, permitting the managed lanes to pass through that segment, and reducing the conflicts caused by vehicles weaving across the traffic lanes. Since the bottlenecks at both ends of the project would still be present, similar ATM would be required to manage speed as necessary and to warn drivers of queues ahead.

Weaknesses of Each Concept
The Minor Rehabilitation Alternative will require design exceptions from desirable geometric standards to stay within the existing physical envelope. Acceleration and deceleration lanes will not meet desirable lengths for many ramps and space is not available to extend the lanes without major added costs. The left
hand ramps at TH 280 will still result in traffic merging and diverging to and from the high speed lanes, undesirable weaving and lack of lane continuity. Shoulders will not be provided for disabled vehicles west of TH 280 due to restricted horizontal clearances at retaining walls and overhead bridges. Sight distances will also be limited on eastbound I-94 curves east of Huron and westbound I-94 west of TH 280. As traffic volumes continue to increase between the 2011-2012 (the anticipated opening date for completion of the Minor Rehabilitation Alternative), the queues from the two bottlenecks will extend further into the project from the two ends and will likely require further adjustments of ramp meter settings to limit traffic entering the freeway.

While the Full Reconstruction Alternative will provide managed lanes more appropriately oriented in the median for transit and HOVs and potentially for priced use by SOVs, the intermediate access points for the managed lanes may become congested with traffic attempting to merge into the congested general purpose lanes. The cost of the Full Reconstruction Alternative, in excess of $400 Million in 2010 dollars, will be a significant investment and will likely require many years of phased construction to complete. The bottlenecks at the Lowry tunnel and the Capitol Interchange would continue to exist.

Comparison to Purpose and Goals
Both Concepts 3 and 4 have been developed by focusing on the five goals set by Mn/DOT for the study:

- Better utilize existing infrastructure investments
- Preserve or enhance advantages for transit and carpoolers
- Preserve or enhance advantages for general traffic
- Provide a congestion-free choice for single occupant vehicles
- Preserve or enhance corridor safety

Both the near term improvements of the Minor Rehabilitation Alternative and the long-range elements of the Full Reconstruction Alternative are built around the present infrastructure. The Minor Rehabilitation Alternative can be constructed entirely within the existing right-of-way, while the Full Reconstruction Alternative may require some additional property for the replacement of some of the existing street and railroad overpasses. The Minor Rehabilitation Alternative improves BOS operations east of TH 280 and a DSL leading into downtown Minneapolis for a transit advantage. The median managed lanes of the Full Reconstruction Alternative would serve transit, carpools and could serve single occupant vehicles through dynamic pricing. The Minor Rehabilitation Alternative will provide improved lane continuity and added capacity in key segments for general traffic. The ATM systems, key to operational reliability of both the Minor Rehabilitation and Full Reconstruction concepts, are intended to enhance corridor safety as has been demonstrated in similar installations in Europe, in implementation on I-35W, and currently in development in a number of other states.

Recommendations
This study recommends a limited investment in managing the investment in the existing freeway, recognizing that 1) the limited availability of funds rules out major reconstruction and expansion of I-94 between Minneapolis and St. Paul, and 2) the impacts of the bottlenecks presented by the Lowry Tunnel to the west and the Capitol Interchange to the east will not disappear. To improve traffic flow for transit and general traffic and to enhance safety, limited spot improvements are proposed to provide four continuous lanes in each direction between I-35W and TH 280 together with an ATM system of variable
speed and queue warning signs along with in-road lighting for the WB right lane between the Dartmouth Bridge and the downtown Minneapolis exit to provide improved reliability for Metro Transit bus operations. Interchange ramps at I-35W and at TH 280 would be revised to eliminate lane drops and to provide lane continuity. Between TH 280 and downtown St. Paul, the roadways of I-94 would be reconstructed to provide wider BOS operations, the purpose of which is to permit 45 mph operations of buses. The Minor Rehabilitation Alternative, which included these short-term improvements, is estimated to cost $49 Million. This would include milling and overlaying the existing roadways to replace deteriorated pavement and to improve roadway drainage.

Looking to the long range, a continuous managed lane in each direction in the median of I-94 is recommended, together with direct connecting ramps to both downtown Minneapolis and downtown St. Paul. This would require the major reconstruction of the I-94 interchange with TH 280 to eliminate the left hand ramps. This widening and reconstruction would also require replacement of many of the overhead bridges which limit the space currently available for the I-94 roadways. This would include replacement of three railroad bridges over I-94. This total reconstruction of I-94 is estimated to cost $485 Million in 2010 dollars. This does not include any reconstruction of the Lowry Tunnel interchange or the Capitol Interchange, but does include the cost of an ATM system for the entire corridor to manage traffic operations and to improve safety.
Appendices

A: Special Use of Shoulders for Managed Lanes
B: ATM Assessment for Lowry Tunnel and Capitol Interchange
C: Cost Estimation
D: Regional Travel Demand Model Forecasting Methodology
E: CORSIM Traffic Model Simulation and Analysis
F: Aerial Layouts of Conceptual Alternatives
Special Use of Shoulders for Managed Lanes
Review of Practice and Research

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Texas Transportation Institute
7/13/2009

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SPECIAL USE OF SHOULDERS FOR MANAGED LANES

Review of Practice and Research

With congestion increasing and vehicle miles traveled outpacing population growth in almost every large city in the United States; major metropolitan areas are creatively addressing their approach to transportation infrastructure. Highway construction costs continue to grow, right of way is becoming more and more limited and traditional transportation funding sources have continually lost purchasing power. There is a growing acceptance that cities will be unable to build their way out of congestion.

Emerging technologies have allowed for the development and refinement of strategies to meet these challenges. Flexible operating strategies coupled with minimal roadway capacity improvements offer a means of addressing mobility needs and providing new travel options. The managed lanes concept is growing in popularity as an approach to effectively and efficiently use existing facilities, address community objectives and provide alternatives to congested roadways. Minnesota has led the nation in the consideration and implementation of managed lanes, including the implementation of I-394, the United States' fifth operational managed lane facility, in 2005.

The concept of managed lanes has evolved significantly over the past 30 years. The first iteration of managed lane corridors comprised exclusive-use facilities for buses in the 1970s. Over the years, these facilities adapted to allow for high occupancy vehicles (HOV), and recently, single occupant vehicles (SOV) that agree to pay a toll for access, such as on the I-394 high occupancy / toll (HOT) lane facility. Managed lanes not only include exclusive-lane facilities, but also involve an expansive use of pricing, eligibility, and management technology for enhancing the utilization of available capacity. Minnesota’s application of bus-on-shoulders (BOS) strategies comprises a different type of managed lane from that of I-394. BOS and other temporary shoulder use systems manage access to the capacity through vehicle eligibility, thereby satisfying a component of managed lanes. The ultimate purpose of managed lanes is the active management of traffic within designated systems of corridors and connecting facilities.

Of particular interest in the Twin Cities region are those managed lane applications that enhance traffic operations through flow maximization, improve average vehicle occupancies and transit ridership, reduce incidents, and improve travel time reliability. Recent experience on I-94 following the collapse of the Mississippi River bridge on I-35W with adapting BOS-operated shoulders for general purpose traffic indicate expanded use of shoulder lanes may partly satisfy these managed lane objectives. As a result, the Minnesota Department of Transportation (Mn/DOT) developed a series of managed lane alternatives for I-94 following the reopening of the Mississippi River bridge.

Managed lanes have many operational variants, including not only occupancy allowances, but also any application that involves system-management techniques such as time-of-day restrictions, vehicle-type restrictions, and value pricing. Whereas Minnesota has implemented BOS, HOT lanes, and (pending on I-35W) Priced Dynamic Shoulder Lanes (PDSL), Europe's approach has involved a system of active traffic management, which combines traffic and system management strategies to enhance throughput.

In order to better inform decisions regarding the short-term and long-term development of managed lanes on I-94 between Minneapolis and St. Paul, this technical memorandum has been prepared to highlight the existing body of knowledge regarding the implementation of managed lane facilities involving active use of shoulders.

MANAGED LANES: CONTEXT

Managed lanes have been in existence for nearly 30 years and represent a family of operational strategies
designed to address a wide array of transportation goals. The term itself is ambiguous and can mean different things to different stakeholders in the transportation industry. One key aspect that all managed lane facilities share in common is active demand and system management. Oftentimes, the development of managed lanes has come from the realization that demand on existing facilities necessitates the efficient management of those facilities. This holds especially true in situations where options for constructing new capacity are limited. Latent demand in moderate to severely congested corridors can quickly fill capacity that is not managed.

**MANAGEMENT TYPES**

Active management encompasses a range of strategies, with three principal elements: Eligibility, Access Control and Pricing.

**ELIGIBILITY**

Eligibility refers to the restriction of certain vehicles and vehicle types from accessing a given facility, which is most often based on occupancy or vehicle type. Restrictions based on occupancy generally stipulate that only vehicles carrying a certain number of occupants - usually 2 or greater - may enter a facility for free. In the case of traditional HOV lanes, single occupant vehicles (SOV) are barred completely from accessing such facilities, whereas in HOT lane applications, they are allowed to access facilities with the payment of a toll. Restrictions based on vehicle type generally bar certain types of vehicles from entering a facility, such as large commercial trucks, or provide free access for others, such as low emission vehicles or motorcycles.

Eligibility may also vary by time of day or change over the life of the facility in response to changing volumes of various vehicle classes. HOT lane facilities, for example, may experience growth in the volume of users such that congestion begins to occur and the level of service on the facility is degraded. As Figure 1 shows, a hierarchy of users is established, and eligibility requirements may be adjusted so as to price out lower priority users such as SOVs.

![FIGURE 1: LIFESPAN OF A HOT LANE, SWISHER 2003.](image)

**ACCESS CONTROL**

A common feature of managed lanes is the physical separation of vehicles on managed facilities from those on adjacent general purpose lanes. Access control is often accomplished by physically separating a managed lane facility from other facilities via barrier or buffer, such as those found on the I-394 HOT lane. In some situations, such as a bus-on-shoulder program in a confined urban area, right of way (ROW) may not be sufficient to construct a barrier or buffer, and a simple stripe has to suffice.

**PRICING**

The pricing aspect of managed lanes refers to the use of price controls for the purposes of controlling volumes and generating revenue on managed lanes facilities. Most contemporary managed lanes - such as HOV facilities, bus on shoulders, and other such facilities - do not feature a pricing component. However, many recent facilities do feature a pricing element that can be structured to accomplish any number of goals. Pricing may be fixed, with one flat rate being charged for all users during all times of the day; set on a variable schedule, where rates change pursuant to a pre-established schedule; or dynamic such as on I-394 and planned for I-35W, where the price for access increases during times of day when volumes are the highest. Dynamic pricing entails adjusting the price for facility access in real time in relation to the vehicular volume on the facility. As the
number of vehicles increases, so does the price to access the facility.

**OBJECTIVES OF MANAGED LANES**

Managed use lanes goals usually are comprised from operational, financial, and user objectives.

**OPERATIONAL OBJECTIVES**

Operational objectives seek to optimize the utilization of the managed lanes facility. However, optimal utilization may have different meanings to different agencies. If an agency seeks to optimize utilization through congestion management, then it will impose eligibility, access control and pricing policies that influence demand in given corridors so that fluctuations in traffic flows are minimal between peak and off peak periods of the day. Reliability for users is thus insured regardless of when they choose to travel. Objectives aimed at throughput maximization will ultimately lead to policies that maximize either the number of vehicles or the number of people traveling through a given corridor. Achieving operational efficiency objectives means maintaining both high levels of throughput as well as high operating speeds for vehicles on the facility.

**FINANCIAL OBJECTIVES**

Financial objectives are those that set targets for the level of revenue to be generated by a facility. In some cases, such as an HOV or BOS lane, there are no financial objectives, as the goal of the facility is to maximize person throughput on the corridor. Facility operators may choose to set pricing policies so that potential revenues are maximized or maintained at a specific level, generally one that allows that operator to meet operations and maintenance expenses, maintain debt service, and develop future projects. Operators may also choose to pursue economic efficiency with their pricing mechanism, wherein tolls are set at a level equal to the marginal economic cost imposed on the transportation system by each new user on a given facility.

**USER OBJECTIVES**

User objectives are those that improve a traveler’s experience on a given facility. This can be done by adopting policies that increase safety, improve reliability, or improve convenience. These objectives are generally lower priority and are subject to the constraints imposed by a facility’s financial and operational objectives.

**OPERATIONAL CONCEPTS FOR SHOULDER USE**

Although a variety of managed lane applications are available for corridor-wide pursuit, this report concentrates upon those that have the likeliest application for I-94 between Minneapolis / St. Paul. As the corridor has neither sufficient dominant peak directionality, nor the apparent ability to significantly expand the right of way envelope to accommodate widening, the managed lane strategies emphasized here make use of shoulders and lane narrowing. This discounts a variety of options, including reversible flow, contra-flow, and dual-dual facilities.

**DEDICATED SHOULDER LANES**

Since the 1950 publication of the Highway Capacity Manual and 1957 AASHTO Red Book, 12 ft shoulders have been the interstate design standard for urban freeways. Furthermore, a minimum of 4.5 ft lateral clearance is required, with 6 – 8 ft recommended in the vicinity of pier structures. However, by the 1980s in response to rising levels of congestion and a lack of right-of-way for contemporary expansion of capacity, many states adopted the use of dedicated shoulder lanes sometimes in conjunction with or instead of narrowed lane widths. By the 1990s, only four states had chosen to extensively use shoulders and/or narrow lanes on freeways: California (Los Angeles and Bay Area), Texas (Houston), Virginia (Fairfax County), and Washington (Seattle).
In dedicated shoulder lane operations, either general purpose or HOV-specific capacity has been added through the permanent conversion of shoulders. Most HOV applications use the interior lane for HOV operations while the exterior shoulder is used for general purpose traffic so as to maintain the same number of general purpose lanes as existed prior to implementation. A typical application would convert a three-lane freeway with 12 ft lanes, 10 ft exterior shoulder, and 8 ft interior shoulder to 11 ft general purpose lanes, 14 ft (including buffer striping) HOV lane, 5 ft exterior shoulder, and 2 ft interior shoulder.

In addition to HOV and general purpose capacity, additional existing uses of shoulders include: auxiliary lanes either between interchanges or in merge zones (particularly those that impede upstream traffic on the mainline), lane balancing requirements through bottlenecks, and creation of uniform lane widths.

In most cases, the shoulders have been converted to general purpose capacity, at least for a short distance. However, in a few applications, the implementing agency has attempted to recover use of the shoulder for refuge purposes during some portions of the day. On Massachusetts state highways 128 and 3 in the Boston area, all vehicles are permitted on shoulders in the peak periods only. Similarly, in Virginia on I-66, the shoulder carries general purpose traffic from 5:30 – 11 am (eastbound) and 2 pm – 8 pm (westbound); however, during this time, the interior general purpose lane is open to HOV traffic only. I-66 uses extensive traffic signals and signage in order to communicate the active times of service.

**FIGURE 2: CONVERTED SHOULDERS ON I-5 (CA)**

**FIGURE 3: I-66 HOV / SHOULDER LANE ADAPTATION**

**Bus on Shoulders**

Bus on Shoulders (BOS) programs, generally considered special-use applications of dedicated shoulder lanes, are most often implemented as a means of increasing the reliability of transit service in congested corridors in order to encourage increased use by the public. BOS was the established managed lane solution on the I-94 corridor prior to the Mississippi River bridge collapse on I-35W. It is generally a low cost and quick to implement solution that does not require costly expansion of highway right of way. They may be implemented on both highway and arterial corridors, but arterial BOS applications must often rely on additional operational treatments such as signal prioritization in order to maintain a time advantage over automobile travel.

Besides stand-alone BOS operations, BOS may also be implemented in conjunction with a separated managed lane facility. Bus lines running a station stopping operation along a median HOV or HOT lane may benefit greatly from the implementation of a BOS program. Such routes often make frequent stops at intervals of less than a mile between successive stops, which can pose significant problems with regards to weaving into and off of the HOV or HOT lane facility they access. This weaving can cause backups and disruptions on both the interior...
managed lane facility as well as the adjacent general purpose lanes. A BOS program ensures that buses can achieve significant travel time savings without the need to enter the interior managed lane facility and weave through general purpose traffic to enter or exit an interior managed lane.

**FIGURE 4: BUS ON SHOULDERS, MN/DOT 2006.**

BOS is the most common shoulder-lane application in the United States. Additionally, Minnesota has served as a continental leader in the state of the practice, both in the extent of application of BOS lanes as well as development of policies and authorizing legislation for BOS. Minnesota’s network is comprehensive, having established over 270 miles of BOS lanes throughout the Twin Cities since 1991. Like the current study for I-94, BOS applications were conceived following an emergency situation. In 1991, a flood closed major bridges along I-35W. Acting to improve downtown Minneapolis accessibility, the governor established a rapid-action task force among Mn/DOT and Metro Transit officials to brainstorm alternatives during flood drainage operations. Within one week, shoulder lanes were restriped and signage implemented creating BOS on SH-252 in Brooklyn Park. Having been well received, the task force formed a permanent group (expanded to include other entities) which created the current network of BOS lanes. Today, BOS operations are known to exist throughout the Twin Cities network, including long segments of I-694, I-35W, I-35E, I-94, I-494, US 169, SH 36, and US 10.

In addition to Minnesota, BOS lanes are operational in the following states (provinces) shown in Table 1:

**TABLE 1. BUS ON SHOULDER FACILITIES IN U.S.**

<table>
<thead>
<tr>
<th>State / Province</th>
<th>Facilities</th>
<th>Length (miles)</th>
<th>Year Started</th>
</tr>
</thead>
<tbody>
<tr>
<td>California</td>
<td>I-805, SR-52</td>
<td>4</td>
<td>2005</td>
</tr>
<tr>
<td>Delaware</td>
<td>DE-202 (southbound)</td>
<td>0.5</td>
<td>Unknown</td>
</tr>
<tr>
<td>Florida</td>
<td>FL-874, FL-878</td>
<td>4</td>
<td>2007</td>
</tr>
<tr>
<td>Georgia</td>
<td>GA-400</td>
<td>12</td>
<td>2005</td>
</tr>
<tr>
<td>Maryland</td>
<td>US-29, I-495, I-270</td>
<td>7+</td>
<td>Unknown</td>
</tr>
<tr>
<td>New Jersey</td>
<td>NJ-22, NJ-9</td>
<td>5+</td>
<td>Unknown</td>
</tr>
<tr>
<td>Ontario</td>
<td>Hwy-403, Hwy-417, Hwy 174</td>
<td>17</td>
<td>2003</td>
</tr>
<tr>
<td>Virginia</td>
<td>VA-267</td>
<td>1.3</td>
<td>Unknown</td>
</tr>
<tr>
<td>Washington</td>
<td>WA-520, WA-522</td>
<td>5+</td>
<td>1970s</td>
</tr>
</tbody>
</table>

Of all active BOS projects, only the Seattle region allows for HOV-3+ use of shoulders concurrent with buses (not including dynamically assigned HOV lanes, such as Virginia’s I-66).

**DYNAMIC SHOULDER LANES**

Dynamic (temporary) shoulder lanes is a congestion management strategy typically deployed in conjunction with complementary traffic management strategies - such as variable speed limits (speed harmonization) and/or ramp metering - to address capacity bottlenecks on the freeway network.
European implementers include The Netherlands, Germany, and Great Britain. The strategy provides additional vehicle-moving capacity during times of congestion and reduced travel speeds. The use of the exterior shoulder during peak travel periods has been used in Germany since the 1990s. When travel speeds are reduced, dynamic signs over or next to the shoulder indicate that travel on the shoulder is permitted.

A complete series of traffic signs indicate operations related to temporary shoulder use, including one with a supplemental speed limit indication (used when overhead gantries are not present). These signs and the overhead lane messages are blank when travel on the shoulder is not permitted. Temporary shoulder use is permitted only when speed harmonization is active and speed limits are reduced, thus providing an operating environment only when speeds are managed below posted levels. In addition to allowing temporary use of the right shoulder, the Dutch also deploy the use of traveling on a shoulder on the median side of the roadway, locally termed a “plus lane,” a narrowed extra travel lane (sometimes at a reduced width) provided by reconstructing the existing roadway while keeping the right hard shoulder open for travel use when traffic volumes reach levels that indicate congestion is growing.

Generally, implementation of dynamic shoulder use is at the discretion of the traffic management center operator, although traffic volumes help determine the need for the strategy. A typical installation in Europe incorporates a number of unique roadway features, which can include:

- Lightweight gantries,
- Lane control signals,
- Dynamic speed limit signals,
- Dynamic message signs,
- Digital enforcement technology,
- Closed-circuit television cameras,
- Enhanced lighting,
- Roadway sensors,
- Emergency roadside telephones,
- Advanced incident detection,
- Intensified incident management,
- Hard shoulder running, and
- Emergency refuge areas or pull-outs beyond the shoulder.

Operation of the system is handled by the regional control center, with operators on hand to monitor the system and initiate the modified operations as necessary. Specifically, operators use CCTVs mounted on lightweight sign gantries or separately to check for incidents and stalled vehicles in the shoulder before activating the system.

CONCEPTUAL APPLICATIONS

GENERAL PURPOSE ACCESS

Increasing general purpose capacity on a freeway by adding a lane of travel can be expensive, disruptive to the community, and may require an extended period of time. Roadway widening and right-of-way taking may be too costly to pursue a general purpose capacity expansion. However, additional general purpose capacity can be acquired by restriping the shoulders and (sometimes) narrowing other travel lanes. The resulting shoulder lane can be open to all traffic at all times – in essence, becoming an additional lane of general purpose capacity – or at partial times throughout the day (typically concurrent with peak periods). Besides time of day application, there are no other management tools implied concerning who may use a shoulder lane if it is open for general use.

REGULATED ACCESS

By comparison, regulation of access to the shoulder lane (or, capacity freed up on an interior lane by implementation of the shoulder lane) includes a management strategy.
**Regulation by Vehicle Class**

Regulation by vehicle class and occupancy, most commonly applied as High Occupancy Vehicle (HOV) lanes, are among the oldest applications of a managed lanes strategy. Their primary focus is the attainment of operational goals, namely the maximization of person throughput within the corridors in which they are developed. This is accomplished by increasing vehicle occupancy, improving transit operations and providing an attractive mobility choice outside of SOV travel for drivers in the corridor. Vehicle and occupancy eligibility requirements are enforced on these facilities as a means of regulating demand and ensuring that time savings are preserved for those utilizing HOV and transit options. There are currently three types of HOV facilities currently in use today: separated roadway, concurrent-flow lanes and contra-flow lanes. Given the directional split and available right-of-way, only concurrent-flow lanes are applicable to operations on I-94.

A concurrent-flow HOV lane is a lane that flows in the same direction as general purpose traffic and is not physically separated from the main lanes of a freeway. Such facilities are typically marked with a distinctive striping, either white (typical, including Minnesota) or yellow (California). Concurrent-flow HOV lanes may limit access, whereby the striping serves as a buffer (such as on I-394), or allow continuous access.

**Regulation by Pricing**

Pricing allows vehicles to access the lane with the payment of a toll. Multiple variations in pricing application (dynamic, variable, or flat fee) and access (occupancy, vehicle class, etc.) are found throughout the U.S.

Pricing differential by occupancy is most commonly applied as a High Occupancy / Toll (HOT) lane, such as on I-394 and pending on I-35W. These lanes are generally implemented as a means of improving lane utilization and selling unused lane capacity. In order for HOT lanes to be successful, the following assumptions should be present:

- HOT lanes should be incorporated with HOV lanes that are currently in existence or planned for construction
- There must be recurring congestion where the HOT lanes would help drivers avoid congestion by paying a toll
- HOT lanes should not take-away an existing main-lane in order to be created
- To date, HOT lanes are generally not self supporting

**Figure 5: Concurrent Flow HOV, Dart 2006.**

**Figure 6: I-394 HOT LANES, MN/DOT 2006.**

The key to success for HOT lanes is to manage the number of vehicles on the facility so that the use of the facility - by both HOV and SOV vehicles - is maximized without creating congestion. Modern
HOT lanes facilities accomplish this by incorporating a pricing element, which is most often either variable or dynamically set. Variable pricing, or fixed schedule pricing, can be adjusted by time of day or by vehicle type or both. The most common application of variable pricing on a HOT lane facility is pricing by time of day, with toll rates being set higher during peak periods of the day. Variable pricing by vehicle class may also be incorporated into this schedule, as in the case of the I-10 QuickRide HOT lanes facility in Houston, where HOV vehicles with only two occupants may access the facility for free up until the periods of heaviest congestion, after which they may only access the facility with the payment of a toll. In a dynamic pricing scenario, such as on I-394, volumes on a given facility are actively monitored and toll rates are adjusted in real time in response to changing conditions. If volumes increase rapidly, toll rates for access are increased so as to discourage additional users and ensure that facility maintains free flowing traffic speeds.

Express toll lanes are functionally equivalent to HOT lanes, with the notable exception that all vehicles are tolled. As a result, they tend to generate greater amounts of revenue and are not dependent upon an existing or planned HOV facility. These facilities generally do not feature eligibility requirements outside the common ban on commercial vehicles and do not offer pricing incentives for carpools and transit vehicles. Enforcement and pricing algorithms are simplified over their HOT lane cousins, as the operator need not be concerned with differential pricing and occupancy enforcement. Currently, no express toll facility is open in the United States, although many are planned in Texas and Maryland.

**Complementary Strategies**

European applications of the use of shoulder lanes typically are accompanied by a more holistic approach to freeway operations known as ‘active traffic management (ATM)’. ATM is the ability to dynamically manage traffic flow based on prevailing traffic conditions. Focusing on trip reliability, its goal is to maximize the effectiveness and efficiency of the facility under both recurring and non-recurring congestion as well as during capacity reductions involving incidents or road work. Through the flexible use of the roadway, it aims to increase system performance as well as traveler throughput and safety through the use of strategies that actively regulate the flow of traffic on a facility. ATM strategies can be automated, combined, and integrated to fully optimize the existing infrastructure and provide measurable benefits to the transportation network and the motoring public.

Active traffic management consists of a combination of operational strategies that, when implemented in concert with dynamic shoulder lanes, fully optimize the existing infrastructure and provide measurable benefits to the transportation network and the motoring public. These strategies include but are not limited to speed harmonization, junction control, and dynamic signing and rerouting.

**Speed Harmonization**

Speed harmonization helps manage traffic by posting speed limits on a roadway or over each lane on an advisory or regulatory basis in real time, sometimes referred to as variable speed limits in the U.S. This approach has been in use in Germany since the 1970s and is oriented toward improving traffic flow based on prevailing conditions. Similar installations are in operation in The Netherlands and Great Britain on various roadway sections with high traffic volumes. A typical installation of speed harmonization monitors traffic volumes and weather conditions along the roadway. If sudden disturbances occur in the traffic flow – such as with an incident or building congestion – the system modifies the speed limits upstream accordingly, providing users with the quickest possible warning that roadway conditions are changing. The deployment of the speed harmonization is automatic and begins immediately upstream of the congestion point; it does not require remote operator intervention. The system incrementally decreases speeds upstream in a
cascading manner often in increments of 10 to 20 km/h to smooth the deceleration of the traffic and help ensure more uniform flow to offset what would otherwise by sudden queues emanating from the incident.

JUNCTION CONTROL
A variation of dynamic shoulder lanes—known as junction control in Germany—involves dynamic lane assignment. Typically, the concept is applied at entrance ramps or merge-points where the number of downstream lanes is fewer than upstream lanes. The typical U.S. application to this geometric condition would be a lane drop for one of the outside lanes or a forced merge of two lanes, both of which are static treatments. The German dynamic solution is to install lane control signals over both upstream approaches before the merge, and provide downstream lane priority to the higher volume and dynamically post a lane drop to the lesser volume roadway or approach. This is particularly effective when implemented with dynamic shoulder use at on-ramp locations where bottlenecks frequently form.

DYNAMIC SIGNING AND RE-ROUTING
The practice involves utilizing dynamic overhead message signs or other changeable roadway signs and route markers (such as rotational prism guide signs) that dynamically change the primary routing of a major thoroughfare to an alternate route where capacity is available, in response to changing with traffic conditions. If an incident occurs downstream, operators at the TMC deploy alternate guide sign information combinations that provide alternate route information to roadway users. Similar information is also provided on full-matrix DMS installed on other roadways. On facilities that employ speed harmonization combined with dynamic shoulder use, the signs change so that the information displayed for the operational lanes is appropriate. Regional coordination is often a key component of this operational strategy to ensure that alternate routes are not overloaded with diverted traffic.

PERFORMANCE

OPERATIONS
NCHRP 369 provided a comparative benchmark analysis methodology of eleven corridors in six states, using in-corridor comparisons of “unaltered” segments (full shoulders with 12 ft lanes) and “altered” segments (use of shoulders with or without
narrow lanes). The evaluation hypothesis postulated that the lack of shoulders and/or use of narrow lanes would result in different operating conditions.

**Effects**

When isolated by level of service categorizations, travel speeds on segments with use of shoulders / narrow lanes were not significantly different from their interstate standards brethren in low-volume and high-volume applications. However, there was a minor difference in speeds in medium-volume applications:

- **Level of Service A/B.** With volumes less than 1,600 vehicles per hour per lane (vphpl), speeds were identical between altered and unaltered facilities.
- **Level of Service C/D.** A slight decrease (less than five miles per hour) in average travel speeds were found in altered facilities when volumes ranged between 1,600 vphpl and 2,000 vphpl. This was the only statistically significant difference.
- **Level of Service E/F.** Like LOS A/B, there was no difference in speeds between altered and unaltered facilities at volumes higher than 2,000 vphpl.

At LOS C or worse, there was no significant difference in the choice of lanes (shoulder vs. static lanes) by travelers. However, at LOS A or B, the use of shoulder lanes were significantly less prevalent, especially if the surface of the shoulder was different from the travel lanes. It should be noted that on part-time shoulder facilities (such as Massachusetts routes 3 and 128 and I-66 in Virginia), if traffic remains slow and the time is outside the operational shoulder-lane time period, drivers will ignore the shoulder-use restriction and use the lanes anyway. This complicates the ability of the operating agency to recapture the shoulder as a refuge area.

In addition to the difference in average speeds, altered facilities exhibit a greater range of speeds in LOS C/D conditions (30 - 70 miles per hour) than unaltered LOS C/D conditions (50 - 70 mph). This finding provides an interesting implication for Priced Dynamic Shoulder Lanes (PDSL), as the explicit purpose of PDSL is to maintain reliable travel speeds at LOS C/D. If narrow / shoulder lanes complicate this matter, then the pricing management system must be sufficiently robust to respond to speed swings.

Lateral clearance effects of altered facilities did have an impact on drivers, causing them to shy away from the barrier. The percent of traffic within a foot of the interior lane line (regardless of lane) was lower at altered sites than unaltered ones. As would be expected, inadvertent lane-line crossings per hour increased significantly with altered sites compared with unaltered ones.

**Safety**

Initial safety reviews in the 1980s of shoulder lane usage indicated that projects implemented for short distances to address specific problems often yielded a decline in accident rates. However, the NCHRP Report 369 introduced an alternate methodology to examine accident severity, time of day, type of accident, and characteristics to validate the initial findings. Corridors examined were: I-395 (Virginia), I-5 (Washington), I-5 (California), I-85 (Georgia), and I-10 (California).

Statistical analysis indicates that, in aggregate across the study corridors, there was no significant difference between altered and unaltered segments. However, significant increases in accidents (up to 36% more in some segments on I-5) occurred in one specific alteration: a combination of use-of-shoulders and narrow lanes for greater than one mile in length. Under these conditions, accident frequency increased significantly, as did sideswipe, nighttime, and truck accidents.

On I-66 in Virginia, investigators found no significant impact of the combined managed lane (HOV) and shoulder lane (General Purpose) operations on traffic...
crash frequency. Authors hypothesized that advanced incident identification and clearance, and, enhanced dynamic messaging signs contributed to the lack of evidence that the system increased crashes.

Overall, although accident rates may be higher for certain altered facilities, if the selection of appropriate sites considers lane balancing and continuity concerns, the reduction in accident severity from such alterations may be greater than the increased rate as observed.

MAINTENANCE

The implementation of shoulder lanes has yielded higher costs of and more difficult maintenance activities. Maintenance-related issues as identified by the NCHRP Report 369 included:

- Under altered conditions, highway appurtenances such as signage, barriers, drains, and lights were closer to traffic, and resulting damaged more often and more severely than under unaltered conditions.
- In order to conduct regular maintenance, additional personnel and equipment is needed to close lanes and provide adequate work area protection.
- Most incidents, from minor to major, require some action by personnel that involves shoulders, which in turn requires shoulders remain closed until the incident is cleared, items are removed, or other action is completed. Estimates by personnel indicate that clearance time for incidents doubles with shoulder lane use.
- As emergency vehicles use shoulders to access scenes of accidents, delays in arriving on scene have consequent increases in periods of congestion, secondary accidents, and clearance time.

GUIDANCE

NCHRP Report 369 provided basic guidance for shoulder lane project development, based upon the results of research and experiences of implementing agencies. No elements of AASHTO design / geometric standards or MUTCD signage standards were changed in the guidance.

DESIGN GUIDELINES

Geometric guidance included the following highlights in applying AASHTO standards:

- Minimizing impacts in transition zones. Slowdowns occurred most frequently in transition areas, which affected operations. The recommendation included at least 2,000 ft be maintained between the transition area and the next upstream ramp, and, that the transition also be located in an area where there are no crossing structures, retaining walls, or other roadside appurtenances.
- Carefully consider ramp ingress / egress. The elimination of an exterior shoulder can reduce acceleration / deceleration distances at ramps. This may require improvements to the ramps, especially if sight distances for entering traffic are severely impacted by the shoulder lane operations.
- Where possible, construct refuge areas. Emergency refuge areas should be considered and constructed so as to provide some means of accident and breakdown clearance. Although emergency personnel should be involved in location selection, turnouts should be provided every 1,500 ft. If necessary, railings and other barriers should be moved or eliminated to accommodate.
- Review horizontal sight distances. Retaining walls, concrete medians, and other physical barriers may reduce sight distances.
with the elimination of shoulders. Sight distances will be critical along curves and at ramps.

OPERATIONAL GUIDELINES

Operational guidelines as suggested by NCHRP Report 369:

- **Prohibit truck use of shoulders.** Shoulder use by heavy trucks can more quickly degrade the quality of pavement on the shoulders, increase accidents, and affect braking / slowdown in areas of shorter sight distances. As such, trucks should be restricted from using the shoulder lane, except within 1,500 ft of ingress / egress ramps. In these situations, pavement structure should be augmented to accommodate trucks. Use of shoulders and narrow lanes are NOT recommended when truck proportion of peak period volume exceeds 10 percent.

- **Identify opportunities to resolve lane balance and continuity issues.** As lane balancing and continuity opportunities provided the greatest net benefit to corridor performance and safety, similar opportunities should be sought out for shoulder lane implementation.

- **Proactive signage and traffic control should be implemented.** Advance warning signage of shoulder lane usage should be provided 0.5 miles in advance, and repeated at 1-mile intervals throughout the altered segments. Emergency refuge zone availability should be signed 1,000 ft in advance and striped to indicate such use.

NORTH AMERICAN TRIGGERS FOR BUS ON SHOULDER OPERATIONS

Mn/DOT is the only state DOT to establish explicit thresholds for the establishment of bus-use of shoulders:

- Predictable congestion delays, with congestion occurring one or more days per week
- BOS operations may commence once general purpose lane speeds have declined to less than 35 mph during peak periods
- Buses may operate in the shoulder at a maximum of 15 mph faster than the adjacent general purpose lanes, with a maximum speed of 35 mph
- A minimum of 6 buses per day must use the corridor in order to activate the shoulder for BOS
- The expected time savings must be more than 8 minutes per mile per week
- Roadway must have continuous shoulder width of at least 10 feet (12 foot shoulder preferred)

Other states have applied different approaches to BOS operations, as illustrated in Table 2. Although the criteria are not as comprehensive as Minnesota’s, the general approach is informative.

In general, according to unpublished works in progress for TCRP D-13, Guidelines for Bus on Shoulder Operations, most contemporary applications of BOS have accepted Mn/DOT guidance as accepted practice. This includes active periods defined as when general purpose lane speeds decline below the 35 mph threshold, 15 mph max speed differential, and 35 mph max speed. Legacy BOS, though, typically do not have stated controls on speeds or active periods.

Furthermore, it should be noted that recent implementations in Atlanta, Miami, and San Diego have all indicated BOS operations are interim strategies, to be used until such a time that full managed lane operations can be designed, built, and implemented in the corridors.
TABLE 2. BUS ON SHOULDER THRESHOLDS.

<table>
<thead>
<tr>
<th>State / Province</th>
<th>Threshold / Approach to BOS</th>
</tr>
</thead>
<tbody>
<tr>
<td>California</td>
<td>GP speeds less than 30 mph; 10 mph max speed differential; max speed of 35 mph</td>
</tr>
<tr>
<td>Delaware</td>
<td>All day BOS operations; no stated max speed differential</td>
</tr>
<tr>
<td>Florida</td>
<td>GP speeds less than 35 mph; no stated max speed differential; max speed of 35 mph</td>
</tr>
<tr>
<td>Georgia</td>
<td>GP speeds less than 35 mph; 15 mph max speed differential; max speed of 25 mph</td>
</tr>
<tr>
<td>Maryland</td>
<td>Regular hours of operation (6 – 9 am, 3 – 8 pm); no stated max speed differential</td>
</tr>
<tr>
<td>New Jersey</td>
<td>Regular hours of operation; no stated max speed differential</td>
</tr>
<tr>
<td>Ontario</td>
<td>Toronto: GP speeds less than 38 mph; 12 mph max speed differential; Ottawa: All day operations; buses may travel at posted speed limit (62 mph)</td>
</tr>
<tr>
<td>Virginia</td>
<td>Regular hours of operation (4 – 8 pm); max speed of 25 mph</td>
</tr>
<tr>
<td>Washington</td>
<td>All day BOS + HOV-3+ operations; no stated max speed differential</td>
</tr>
</tbody>
</table>

BRITISH TRIGGERS FOR DYNAMIC SHOULDER USE

In Great Britain, the national Highways Agency has developed operational guidance for the use of dynamic shoulder lanes (coined, Managed Motorways with Dynamic Hard Shoulder Lanes - MM-DHS for short). The implementation of MM-DHS is dependent upon the concurrent use of speed harmonization within a corridor, as the decision to open the shoulders is made based upon a dynamic algorithm. This algorithm incorporates a reduction in variable speed limits (and volume change as appropriate), anticipated peak period volumes (based upon historical trends), and established research showing an increase of 7-9% maximum theoretical flow when MM-DHS is implemented with speed harmonization.

The process established for activating MM-DHS is as follows:

1. Initially, at low volumes, the corridor speed limit will be signed at its posted maximum speed (typically, 60 mph). This speed will be maintained until the algorithms anticipate immediate flow breakdown.

2. In order to delay the onset of flow breakdown and increase vehicular throughput on the corridor, the variable mandatory speed limits will be decreased to 55 and 50 mph in stages. The speeds limits are enforced by video-based camera detection systems in the corridor, and are signed as such.

3. Once 50 mph speeds are maintained, a “conditioning” period is established for opening the shoulders. The furthest downstream link is opened first at 50 mph, followed by each successive upstream link, all signed at 50 mph in concurrence with the general purpose lanes.

4. If an incident occurs or if significant queues form at 50 mph, all lanes are mandatorily set at 40 mph (including the shoulders) and queue warning messaging is provided upstream.

Interestingly, the reduction in speeds through speed harmonization and queue warning, whereas effective on their own, have been shown to be significantly more effective in reducing accidents when implemented with MM-DHS. Research has shown up to 15% reduction in accidents with MM-DHS as opposed to without MM-DHS.

Of significant note: the British implementation of dynamic shoulder lanes does not carry with it any presumptions regarding travel time benefits for transit or HOV vehicles. As a result, corridor flow rates are highest with general-purpose use of the
lanes, but there is no speed advantage for users of the shoulder lanes versus the general purpose lanes. Hence, there are no established speed differential or maximum speeds for the shoulder lanes, as there are for most BOS implementations.

MAINTENANCE AND ENFORCEMENT GUIDELINES

Where shoulders have been eliminated, maintenance and enforcement operations become more difficult and costly. NCHRP Report 369 offered the following suggestions for improving the outcome of these efforts:

- Establish staging areas for maintenance crews. Staging areas may be located at emergency refuge areas, but these should be maintained open as much as possible. Additionally, coordinated activities for maintenance should be conducted, so as to minimize disruption to travel lanes.
- Replace items and landscaping with low maintenance equivalents. The elimination of maintenance visits should be a priority within the treatment area.
- Provide alternative access. If equipment or landscape areas can be accessed from surface streets or other locations outside the freeway, alternative access should be created.
- Provide high visibility for enforcement. If the shoulder lanes are to be restricted use, enforcement is key. However, the lack of shoulders makes actual enforcement intercepts more difficult. Increased visibility of patrols may be necessary to establish appropriate violation thresholds. Additionally, signage should be considered that informs the public to acknowledge an intercepting officer and then proceed to next turnout or exit for enforcement stops.
- Consider enforcement-by-mail options. As implemented in Virginia on I-66, HOV violators can be ticked by mail. This allows patrols to observe traffic from safe locations.

INCIDENT RESPONSE AND MANAGEMENT GUIDELINES

The lack of shoulders constrains the capabilities of incident response, but it also underscores the importance of conducting efficient and effective incident management. Suggested considerations for incident response and management include:

- Provide frequent facility crossovers. Strategic development of facility crossovers will allow for response teams to approach the site from opposing directions. If downstream contra-flow response may be necessary on the facility, incident management route maps should be prepared in advance of implementation.
- Fully cover the facility with Closed Circuit TV. Camera coverage should be complete for the treatment zone, making precise location of incidents known to responders.
- Increase motorist aid and safety patrols. Removing breakdowns and minor incidents is critical to the success of a shoulder lane treatment facility. Increasing courtesy patrols should be done so as to more quickly remove impediments to flow.
- Consider signage to guide public. Without shoulders, drivers may be uncertain how to clear space for responders. Signage may be used to inform drivers of the correct procedure to use in the case of an upstream responder making way through traffic.

ANALYSIS

The findings from the literature review indicate that the use of shoulders and narrow lanes reduces speeds in favor of maintaining adequate flow at high volumes. For a managed corridor, either through the
implementation of managed lanes or through active traffic management techniques in conjunction with shoulder lanes, travel time reliability should be the key metric.

Reducing the variability of speeds is a necessary component to reliability and maintaining traffic flow. Furthermore, variability has a negative impact upon accidents, especially near ingress / egress ramps in medium-to-high volume situations. Additionally, truck volumes must be considered in these situations, both as a contributor to degraded flow in stop-and-go situations, and, to accident severity when involving a passenger vehicle.

Already, Mn/DOT restricts entering volumes to I-94 through the system’s extensive ramp metering program. As volumes are managed, the next variable to consider is speed limits - speed harmonization may be considered as a necessary complement to shoulder lanes. Europe’s experience with combining speed harmonization with dynamic shoulder lanes indicates a positive outcome may result. However, the research conducted in NCHRP Report 369 did not indicate a reduction in speed limit would have a positive effect. Perhaps for dedicated shoulder lanes with a static eligibility policy, the subject of the NCHRP study, the need for speed harmonization would not be justified.

The guidance provided for sight distance may indicate an appropriate consideration for queue warning, especially if shoulder lane operations impede “morning glare” or curve-related sight distances.

REFERENCES
CASE STUDY: THE NETHERLANDS, TEMPORARY SHOULDER USE AND SPEED HARMONIZATION

OVERVIEW

**Facility:** Various throughout the Netherlands

**Operator:** National Traffic Control Center and regional control centers

**Years of Operation:** 1981-current

**Operating Strategy Overview**

- Advanced queue warning systems that utilize flashing lights and variable speed limit signs alert drivers of recurrent congestion, lane closures, and incidents
- Requires extensive technological investment and monitoring activities
- Deployment is automated based on field data and is initiated automatically based on an assessment algorithm, requiring no intervention by an operator
- Only operates during time periods of congestion or when incidents occur along instrumented roadways

**Number of Lanes:** Applied to an entire corridor, encompassing all lanes

**Length:** 1,000 kilometers (620 miles) of roadway
PROJECT NARRATIVE

THE AREA
The Netherlands is home to over 16.2 million residents, 6.9 million cars, with 155 million vehicle miles traveled (VMT) each day across its network. It covers an area of roughly 16,000 square miles. Traffic operations are controlled by a series of five regional traffic control centers which are in turn coordinated by a national traffic control center.

MANAGED LANES CONCEPT APPLIED
Active traffic management, in the form of speed harmonization, has been deployed on most major roadways throughout the Netherlands. Speed harmonization works to reduce speeds in congested conditions in order to improve traffic flows and reduce the likelihood of traffic incidents. Such systems require significant technological development, as traffic speeds must be continually monitored and information must be continually transmitted throughout the entire corridor. The Netherlands’ speed harmonization system works through the motor control and signaling system (MCSS), an advance queue warning system that utilizes flashing lights and variable speed signs to alert drivers of congestion and lane closures.

The entire system monitors traffic speeds in the corridors it is implemented in. Should the system detect large drops in overall speed within a certain area, it notifies other travelers of the impending slow down and lowers the speed limit in incremental stages as displayed on variable speed signs for traffic approaching the congested area, as shown in Figure 9. This alleviates the “shock” that can be caused by a sudden reduction in speed, improves traffic flow and reduces the number of traffic incidents as a result of congested conditions. Speed harmonization is often employed during severe weather conditions and in environmentally sensitive areas to reduce pollutants.
The standard speed limit is 120 km/h (75 mph) on the motorways, but posted speeds can drop to 90 km/h (55 mph), 70 km/h (44 mph), or as low as 50 km/h (31 mph) if a shock wave or speed-drop is detected. These conditions are normally due to high volumes or incidents and incidents occurring on the facility. As of 2007, the MCSS system has been implemented on over 1,000 km (620 miles) of roadway in the Netherlands and 61 km (38 miles) more are planned. The MCSS was first deployed in 1981.

The Netherlands implemented temporary right shoulder use – also known as hard shoulder running or the rush hour lane – in 2003 as part of a larger program to improve use of the existing infrastructure. As Figure 10 shows, a gantry with lane control signals indicates when the shoulder is available for use. Where a shoulder lane passes through a junction and at the end of a hard shoulder running section, guidance information will change according to lane use.
In addition to allowing temporary use of the right shoulder, the Dutch also deploy the use of traveling on a dynamic lane on the median side of the roadway. As Figure 11 shows, the left lane – also known as the plus lane, or a narrowed extra lane provided by reconstructing the existing roadway while keeping the hard shoulder – is opened for travel use when traffic volumes reach levels that indicate congestion is growing.
FIGURE 11: PLUS LANE IN THE NETHERLANDS.

PROJECT CONCEPTUALIZATION AND PLANNING
Speed harmonization is only one element of the overall transportation system for the Netherlands. The Ministry of Transport, Public Works and Water Management (Rijkswaterstaat) manages over 2,000 miles of the Netherlands mainline roadways and operates the country's numerous regional traffic control centers in addition to the National Traffic Control Center. The primary focus for Rijkswaterstaat is on maintaining high levels of customer service and ensuring trip reliability, which has led the agency to establish the following benchmarks:

- 95 percent of trips are completed on time
- Trips in urban areas do not take more than twice as long in congested conditions as they do in normal conditions
- Trips on all other roads do not take more than 1.5 times as long in congested conditions as they do in normal conditions

Speed harmonization works towards both goals of customer service and trip reliability, as it keeps travelers informed of current conditions and manages roadway conditions so as to maximize throughput and reduce travel time variability. Temporary shoulder use complements speed harmonization to better utilize roadways and improve trip reliability. The Ministry of Transport, Public Works and Water Management manages 2,000 miles of the Netherlands mainline roadways and operates the country’s numerous regional traffic control centers in addition to the National Traffic Control Center.
Facility Management
In the Netherlands' national approach to congestion management, information is a primary resource in the overall traffic management architecture, including speed harmonization. Information is the backbone behind all traffic and demand management strategies in the control scheme. The National Traffic Control Center (NTCC) coordinates the activities of and gathers traffic-related data from the five regional traffic control centers that center on major cities and operate 24 hours a day, 7 days a week. The regional traffic control centers are responsible for the daily operation of the congestion warning and speed harmonization systems. The NTCC, which also operates 24-7, is the focal point for national traffic operations. It establishes national guidelines and procedures on traffic management, coordinates emergencies, communicates with other European national centers, and collects management information from around the country. The NTCC fosters cooperation between the national and regional governments to direct road users for optimal roadway performance.

Technologies Deployed
The Netherlands has used speed harmonization for many years. Some deployments have been implemented to promote safer driving during adverse weather conditions (such as fog), while others have been used to create more uniform speeds. Most recently, the Netherlands' MCSS has been used to reduce speed in a densely populated and environmentally sensitive area to reduce polluting elements. The posted speed limit of 80 km/h (50 mph) is further effectuated by an automated speed enforcement system, which measures average speed over a section of the highway, normally 2 to 3 km long. Temporary shoulder use is a more recent implementation of active traffic management, having been first implemented in 2003. Additional technologies and facilities are always implemented along with temporary shoulder use to help mitigate any adverse safety consequences the operational strategy may create, including the following:

- Overhead lane signs and full matrix signs;
- Emergency refuge areas with automatic vehicle detection
- Variable route signs at junctions
- Advanced incident detection
- CCTV surveillance
- Intensified incident management
- Public lighting

Performance of System
Highway System Performance
It is estimated that facilities under the MCSS system have seen throughput increase between four and five percent. Primary accidents decreased by 15 to 25 percent and secondary incidents decreased by 40 to 50 percent between 1983 and 1996. It is estimated that speed harmonization has reduced collisions by about 16 percent and increased throughput by three to five percent, and reduced the cost of work zone traffic control. Regarding temporary shoulder use, assessment of this strategy reveals that its implementation has increased overall capacity 7 to 22 percent (depending on usage levels) by decreasing travel times from 1 to 3 minutes and increasing traffic volumes up to 7 percent during congested periods.
SAFETY AND INCIDENTS
The Dutch have seen a reduction in incidents on facilities with temporary shoulder use, as shown in Figure 12. Additional safety benefits may include fewer queues and shock waves, lower travel speeds with harmonization, better monitoring, and swifter incident response. As in Germany, temporary shoulder use is allowed only when speed harmonization is in effect.

![Figure 12: Incident Reductions with Temporary Shoulder Use, The Netherlands.](image)

FIGURE 12: INCIDENT REDUCTIONS WITH TEMPORARY SHOULDER USE, THE NETHERLANDS.

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CASE STUDY: GERMANY, TEMPORARY HARD SHOULDER USE AND SPEED HARMONIZATION

OVERVIEW

Facility: Various

Operator: Federal Ministry of Transport and regional traffic management centers

Years of Operation: 1996-current

Operating Strategy Overview:

- Variable speed limit signs alert drivers to reduce speeds as a result of recurrent congestion, lane closures, and incidents to address bottlenecks on the freeway network caused by these conditions.
- Temporary shoulder use designated by sign gantries with variable message signs and shoulder-mounted diagrammatic signs to indicate availability for use; operational when traffic volumes are high and the hard shoulder is strong and wide enough for use.
- Temporary hard shoulder use only deployed with speed harmonization (line control) when maximum allowable speed limits is 100 km/h (62 mph) and if dynamic message signs are used for lane control.
- Deployment of variable speed limits is automated based on field data and is initiated automatically based on an assessment algorithm, requiring no intervention by an operator.
- Operates both between junctions and through junctions.

Number of Lanes:

Applied to an entire corridor, encompassing all lanes.

Length: Over 200 km of roadway currently in congested corridors across the country.
PROJECT NARRATIVE

THE AREA
Germany is home to an estimated 82 million inhabitants and covers an area of about 138,000 square miles. Its federal motorway network is about 7,500 miles spread across 10 states. Most of these major highways are four to six lane facilities that carry average daily traffic volumes of about 49,000 vehicles. Overall demand on the German transportation network is expected to increase by 16 percent for passenger transport and 58 percent for freight transport by 2015. Officials hope to accommodate this growth with the construction of over 1,000 miles of new roadways, widening 1,300 miles of existing roadway and constructing 717 bypasses.

MANAGED LANES CONCEPT APPLIED
Temporary shoulder use is a congestion management strategy typically deployed in conjunction with speed harmonization to address capacity bottlenecks on the freeway network. The strategy, known in Germany as temporary hard shoulder use, provides additional capacity during times of congestion and reduced travel speeds. The use of the right shoulder during peak travel periods has been used in Germany since the 1990s, with the first deployment on the A4 near Cologne in December 1996. Today, nearly 125 miles of temporary hard shoulders are in operation around the country. This temporary shoulder use is one of several traffic control systems developed by the Federal Ministry of Transport and used in various locations in the country. When travel speeds are reduced, signs indicate that travel on the shoulder is permitted, as Figure 13 shows. This installation is located on the Autobahndirektion Südbayern (South Bavaria) and has had the official signs added digitally for illustrative purposes. Figure 14 shows the complete series of signs indicating operations related to temporary shoulder use, including one with a supplemental speed limit indication (used when overhead gantries are not present). These signs and the overhead lane messages are blank when travel on the shoulder is not permitted. Temporary shoulder use is permitted only when speed harmonization is active and speed limits are reduced.
FIGURE 13: RIGHT SHOULDER USE WITH SPEED HARMONIZATION, GERMANY.

FIGURE 14: TEMPORARY HARD SHOULDER USE SIGNS, GERMANY.
Temporary shoulder use in Germany can either end or continue through interchanges depending on the bottleneck locations and overall characteristics of the corridor. Figure 16 and Figure 17 illustrate the signing and marking used when temporary hard shoulder use continues through an interchange. Figure 18 and Figure 19 illustrate those signs and markings used when temporary hard shoulder use terminates at an interchange.

**FIGURE 15: SIGNS AND MARKINGS FOR TEMPORARY HARD SHOULDER USE CONTINUATION THROUGH INTERCHANGE, GERMANY.**
FIGURE 16: CONTINUATION OF TEMPORARY HARD SHOULDER USE THROUGH AN INTERCHANGE, GERMANY.
FIGURE 17: SIGNS AND MARKINGS FOR TEMPORARY HARD SHOULDER USE TERMINATION AT INTERCHANGE, GERMANY.
FIGURE 18: TERMINATION OF TEMPORARY HARD SHOULDER USE AT INTERCHANGE, GERMANY.

PROJECT CONCEPTUALIZATION AND PLANNING

In response to the growing demand on its roadways, the Federal Ministry of Transport, Building, and Urban Affairs established a Federal Transport Infrastructure Plan to upgrade the road network by 2015 through major construction projects. This plan includes constructing 1,074 miles of new motorways, widening 1,340 miles of existing motorways, and constructing 717 bypasses across the country. In addition, the ministry has a comprehensive 5-year Programme for Traffic Control on Federal Motorways, which is oriented toward overall management of the federal motorway network. This program's objectives are to (1) increase by 745 miles the length of motorways equipped with traffic control systems, (2) increase by 1,500 miles the length of motorways with dynamic diversion possibilities, and (3) increase by 15 the number of traffic control centers across the country. Both federal initiatives illustrate a national movement to upgrade and actively manage the motorway network for efficient operations and to enhance the mobility of the country's citizens. Temporary hard shoulder use and speed harmonization are critical components of this management program.

The German federal government also has a policy on telematics and transport, with a primary emphasis on public-private cooperation. The intent is to define specific responsibilities that are best handled by the public sector, those that are best handled by the private sector, and those that can best be accomplished by public-private partnerships. This policy recognizes the strengths of the private sector in some arenas and acknowledges that some activities can be undertaken only by governmental agencies and should remain under public control. The
federal government owns the federal motorways and highways and finances their construction, maintenance, and telematic infrastructure deployment, while the individual states are responsible for maintenance, operations, traffic safety, traffic regulations, and financing the planning and operational activities for the network.

**FACILITY MANAGEMENT**

At the regional level, German states establish freeway operation programs for their motorway networks with two primary objectives. The first objective is to maintain or increase safety by harmonizing traffic flow, providing hazard warnings to motorists, and providing dynamic in-vehicle information on traffic conditions to users. The second objective is to maintain and improve mobility, which is achieved through the optimal use of the existing network capacity and the use of various operational strategies to temporarily increase road capacity.

Regional traffic management centers, like the Traffic Center Hessen, have established a proactive traffic management approach. This approach is a comprehensive framework that encompasses benchmarking of network performance; deploys and maintains various traffic management strategies to meet the aforementioned objectives; incorporates data management, traffic analysis, and forecasting to evaluate and assess the impacts of those strategies; and facilitates the implementation of innovations to enhance mobility. Temporary use of hard shoulders and line control are two tools in this proactive congestion management toolbox.

**TECHNOLOGIES DEPLOYED**

Components typically installed with the required regulatory signs include:

- Overhead gantries;
- Dynamic speed limit displays;
- Dynamic message signs;
- Roadway sensors; and
- Closed Circuit Television (CCTV) cameras.

**PERFORMANCE OF SYSTEM**

**HIGHWAY SYSTEM PERFORMANCE**

Overall, Germany has seen considerable benefits from the deployment of temporary hard shoulder running and speed harmonization. These benefits include a travel time reduction up to 20 percent, a temporary increase in freeway capacity of up to 25 percent, and a high motorist acceptance of variable traffic signs given reasonable speed limits are displayed for speed harmonization. Temporary shoulder use affords congested motorways with higher throughput, as shown in Figure 19. The addition of the third lane in the form of temporary shoulder use, while slightly decreasing speed and initially reducing volumes on the motorway, actually delays the onset of congestion and breakdown and increases the overall throughput on the facility. Similar operational improvements are realized as a result of speed harmonization, with breakdown flow under breakdown conditions being reduced, as shown in Figure 20.
FIGURE 19: SPEED-VOLUME RELATIONSHIP OF TEMPORARY SHOULDER USE, GERMANY.
SAFETY AND INCIDENTS

The safety benefits realized through the use of speed harmonization are significant. Facilities with speed harmonization have seen a reduction in accidents with personal damage up to 29 percent, a reduction in accidents with heavy material damage up to 27 percent, and a reduction of accidents with light material damage up to 3 percent.
FIGURE 21: SAFETY BENEFITS OF SPEED HARMONIZATION, GERMANY.

REFERENCES

- Pilz, A. “Presentation of the Traffic Centre Hessen.” Hessian Ministry of Economy and Transport, Frankfurt, Germany, Presentation to PCM Scan Team, June 2006.

**CASE STUDY: GREAT BRITAIN, TEMPORARY SHOULDER USE SYSTEM**

**Overview**

**Facility:** M42 Motorway (J3A to J7)

**Operator:** Highways Agency

**Years of Operation:** 2006-current

**Operating Strategy Overview**

- Variable speed limit signs alert drivers to reduce speeds as a result of recurrent congestion, lane closures, and incidents
- Temporary shoulder use designated by sign gantries with dynamic message signs to indicate availability for use
- Temporary shoulder use only deployed when speed limits are reduced (initially to 50 mph)
- Deployment of variable speed limits is automated based on field data and is initiated automatically based on an assessment algorithm, requiring no intervention by an operator
- Only operates 1) during time periods of congestion or when incidents occur along instrumented roadways, and, 2) between junctions, requiring users to exit at each junction and reenter the roadway beyond
- Emergency Refuge Areas provided for use when vehicles break down

**Number of Lanes:** Applied to an entire corridor, encompassing all lanes

**Length:** 11 miles of roadway currently with plans to expand to other congested corridors.
PROJECT NARRATIVE

THE AREA
As with other countries across Europe, the United Kingdom (UK) now faces a number of new challenges regarding transportation and mobility. Trends in traffic growth predict that volumes will increase by 29 percent by the year 2010, and with increased volumes comes increased congestion on the transportation network. Estimates are that non-recurrent congestion in the form of incidents (25 percent) and construction (10 percent) account for 35 percent of this congestion.

MANAGED LANE CONCEPT APPLIED
Introduced in 2001 by the Minister of Transport, the M42 active traffic management pilot is a new operational strategy intended to provide reliable journeys, reduced recurring and non-recurring congestion, and enhanced information to drivers. It is a direct response to the road users’ demands for better service within the realistic limitations of widening and expanding the roadway network. Building on advancements in technology and experience from across the globe, this pilot project works to make the best use of the existing capacity on the segment of M42 between Junctions 3A and 7. The ATM pilot also provides additional capacity during periods of congestion or incidents. The pilot project combines the strategies of speed harmonization and temporary shoulder use. To ensure safe operations of the temporary shoulder use, emergency refuge areas are spaced at 1,640 ft intervals along the shoulder (as shown in Figure 22), and emergency call boxes are provided at each refuge area (as shown in Figure 23).
FIGURE 22: EMERGENCY REFUGE AREA ON FACILITY WITH ACTIVE TRAFFIC MANAGEMENT, ENGLAND
The roadway provides traditional information to travelers as seen on other motorways across the region. Under such conditions, all normal rules apply. However, information provided to travelers changes during periods of recurring congestion or incidents depending on whether or not the hard shoulder is open for travel. In both cases, gantries with lance control signals and dynamic message signs indicate reduced speed limits and the availability of the hard shoulder for travel use rather than only for emergency refuge. Overall benefits include increased capacity, enhanced journey reliability, driver stress reduction, a reduction in the number and severity of crashes, reductions in traffic noise, emissions, fuel consumption, and improved driver behavior.

**Project Conceptualization and Planning**

In 2004, the Department for Transport established a long-term strategy for a modern, efficient, and sustainable transport system that is supported by high level of investment. Acknowledging that transportation is vital to the economy and quality of life, the strategy focuses on providing a 2030 transportation network that can meet the challenges of a growing economy and an increasing demand for travel while achieving our environmental objectives. Three themes support this strategy, including (1) a sustained investment in the transportation network over the long term; (2) continued improvements in transportation management to maximize the benefits of public spending;
and (3) planning for the future and considering new and innovative approaches to improving transportation. Underlining these themes is the objective to balance the need to travel with the need to improve quality of life. Active traffic management is a key component of the agency's approach to meeting its long-term strategy for its transportation network.

A primary goal for improving transportation across the UK is related to safety – which is an acknowledged contributor to roadway congestion. The national goal, which has been in place since 2000, is to maintain the network in a safe and serviceable condition. A continuous review of measures to improve roadway safety and that of work zone personnel through engineering and design improvements are key activities related to this goal. Specific numbers that the Highways Agency is working to meet include a 33 percent reduction in the number of deaths or severe injuries in motor-vehicle related accidents, a 10 percent reduction in the right of minor injuries – both of which will contribute to a 50 percent reduction in child casualties.

**FACILITY MANAGEMENT**

The national focal point for congestion management in England is the National Traffic Control Center (NTCC). At this information hub, NTCC staff monitor a network of over 1,730 CCTV cameras and 4,450 traffic sensors 24 hours a day, 365 days a year. They review the network and deliver vital information to the news media and other operational partners including the police and the Highways Agency traffic officer service. They also display real-time messages on the 350 DMS placed strategic points on the motorway network.

The NTCC coordinates and is interconnected with seven regional control centers across the country. These centers monitor and maintain the roadway network within their jurisdiction and are the first line of control regarding congestion management. If minor incidents occur, the regional centers initiate appropriate responses related to incident and congestion management and report information to the NTCC regarding the incident. For major incidents, actions are coordinated with the NTCC as needed to optimize the remaining capacity and to minimize the duration and impact of the incident on the entire motorway network and the adjacent local road system. The West Midlands Traffic Control Center in Birmingham is responsible for operating the ATM system on the M42 as part of its overall duties.

**TECHNOLOGIES DEPLOYED**

The ATM project on the M42 has numerous technological components that ensure its successful operation. In addition to the traffic sensors, CCTV cameras, and DMS deployed on the roadway network as part of the regional traffic control center, the completed system includes the installation of the following:

- lightweight gantries,
- lane control signals,
- dynamic speed limit signals,
- dynamic message signs,
- digital enforcement technology,
- closed circuit television cameras,
- enhanced lighting,
- roadway sensors,
- emergency roadside telephones, and
- emergency refuge areas.

**PERFORMANCE OF SYSTEM**
HIGHWAY SYSTEM PERFORMANCE
Overall, traffic conditions on the M42 have become smoother and more consistent since the implementation of ATM. Weekday travel times have reduced in variability by 27 percent and capacity has increased by an average of 7 to 9 percent when hard shoulder running is in effect. Travel times have improved by 24 percent in the northbound direction 9 percent in the southbound direction during peak periods as a result of the speed harmonization deployment. Moreover, the travel time variability has been reduced by 22 percent to 32 percent since deployment, allowing drivers to more accurately predict their journey times. These trends are shown for both winter and summer seasons despite the increase in demand experienced during the summer season. Additionally, the ATM on the M42 improved the distribution of traffic across the travel lanes and has not had an adverse affect on traffic in the surrounding areas.

SAFETY AND INCIDENTS
Overall, traffic operations on the M42 have improved with traffic congestion and the speed differential between lanes being reduced. Furthermore, there is a higher occurrence of free flow conditions with headways greater than 5 seconds. During the first year of operation, a limited crash analysis indicates that accidents along the corridor in the ATM section decreased from 5.08 per month to 1.83 per month.

OTHER IMPACTS
Initial vehicle emission and air quality measurements indicate that vehicle emissions for carbon-monoxide, particulate matter, carbon-dioxide, and oxides of nitrogen have dropped between 4 and 10 percent and fuel consumption has dropped by 4 percent since deployment. Noise reduction along the corridor has also been measured between 1.8 dB(A) and 2.4 dB(A).

REFERENCES
- “M42 Active Traffic Management Results – First Six Months”, Highways Agency, Department of Transport, United Kingdom, October 2007.
- “4-Lane Variable Mandatory Speed Limits – 12 Month Report (Primary and Secondary Indicators), Highways Agency, Department of Transport, United Kingdom, June 2008.
CASE STUDY: VIRGINIA, I-66 TEMPORARY SHOULDER AND HOV LANES

Overview

**Facility:** I-66 (U.S. 50 to I-495)

**Operator:** Virginia Department of Transportation

**Years of Operation:** 1995 - current

**Operating Strategy Overview**

- Use of rightmost shoulders by general purpose traffic during peak periods only (Eastbound, 5:30 am - 11:00 am; Westbound, 2:00 pm - 8:00 pm)
- Adaptation of leftmost general purpose lane to HOV-2 lane concurrent with opening of shoulder lane (Eastbound, 5:30 am - 9:00 am; Westbound; 3:00 pm - 7:00 pm)
- Advance signage and traffic control signaling provide travelers information of operations, including large signs alerting drivers to nine emergency refuge areas
- Opening of the shoulder lane during traffic incidents / construction

**Number of Lanes:** One HOV-2 lane, captured from interior-most general purpose lane, operational concurrent with opening of exterior shoulder for use by general purpose traffic

**Length:** 6.5 miles of dual HOV/SL operations
PROJECT NARRATIVE

THE AREA
As the primary highway conduit connecting Washington, DC (population 600,000) and Northern Virginia (population 2,400,000), I-66 suffers heavy traffic throughout the Fairfax County section. Although the corridor features concurrent metro-rail service (Washington Metro Orange Line, operating between Vienna and western Arlington County), the freeway's three lanes in each direction are often overtaxed.

MANAGED LANE CONCEPT APPLIED
Built in 1964, the segment of I-66 between U.S. 50 and I-495, where the case study HOV / Shoulder Lane combination is operational, includes three main-lanes in each direction. Starting in 1994, the shoulder was opened to peak-period, peak-direction general purpose traffic, allowing the leftmost lane to operate as an HOV lane. This lane provides continuity to HOV lanes which continue on I-66 west of U.S. 50, for an additional 15 miles to VA-234. The cross section west of U.S. 50 includes a static HOV lane (interior) and three general purpose lanes (exterior), as shown in Figure 24.

In the combined HOV / Shoulder Lane segment (hereafter referred to as HOV/SL), three travel lanes and one shoulder are present for the entire segment with a posted speed limit of 55 mph. When shoulder lanes are active, four emergency refuge areas (eastbound) and five refuge areas (westbound) provide accommodation for breakdowns and enforcement activities. Additionally, collector/distributor roads (barrier separated from main lanes) provide access to and from the corridor’s three ingress / egress ramps (eastbound) and four ingress / egress ramps (westbound). The shoulder lanes and C/D roads can be seen in Figure 25. As shown in the cross section Figure 26 and Figure 27, the general purpose lanes are 12 ft wide, interior shoulders are 8 to 12 ft wide, and exterior shoulders are 11 ft wide.
FIGURE 24: I-66 HOV LANES, WEST OF HOV/SL PORTION
FIGURE 25: I-66 HOV/SL PORTION
Special Use of Shoulders for Managed Lanes

FIGURE 26: I-66 HOV/SL LANE PROFILE

FIGURE 27: I-66 HOV/SL TYPICAL CROSS SECTION
PROJECT CONCEPTUALIZATION AND PLANNING

I-66 has a storied history. Originally conceived in 1956 and designed in the 1960s, I-66 was one of the initial highway construction projects to be successfully sued on the grounds of lacking an environmental impact statement (despite the approval and design occurring prior to the enactment of the National Environmental Policy Act). The HOV/SL segment was constructed prior to this lawsuit, but in 1972, the U.S. Court of Appeals required the US Department of Transportation to halt construction and conduct an EIS, specifically for the portion east of I-495. The end result was a 4-lane freeway (2 in each direction) between Washington, DC and I-495, with HOV-2+ required for the peak period / peak-direction portion of the freeway between I-495 and Rosslyn (although, SOV travel to/from Dulles airport is permitted). This cross section allows the HOV/SL portion to have an interesting design - two separate ramps to I-495 from I-66 directly accessible from both the HOV lane and the shoulder lane, as shown in Figure 28. Lane balancing is not an issue, given the constrained design within the beltway.

![Image of I-66 and I-495](image.png)

**FIGURE 28: I-495, VIEWING DUAL ENTRANCE RAMPS FROM I-66**

FACILITY MANAGEMENT

Whereas the shoulder lanes are open to general purpose traffic, the HOV lane is open all vehicles meeting either two-person restrictions or permitted hybrid vehicles. An overhead sign enables a downward pointing green arrow
when the SL is active, and a red X appears when the shoulder has been recovered, as seen in Figure 29. To respond to the need for incidents and breakdowns, emergency refuge areas have been constructed since the implementation of the facility.

Furthermore, the operational hours of the shoulder lanes have changed since 1995 to respond to changing traffic conditions. Peak period conditions often extended beyond the original 10:00 am eastbound threshold, and, prior to the 3:00 pm westbound initialization. As a result, VDOT extended the operational times to 11:00 am and 2:00 pm, respectively.

![Image of shoulder lane control signal]

**FIGURE 29: I-66 SHOULDER LANE CONTROL SIGNAL**

**Performance of System**

**Highway System Performance**

In 2007, typical traffic volumes during the eastbound HOV/SL hours range from 19,500 to 27,000 vehicles; with 21,000 to 25,000 vehicles westbound. These compare with 190,000 AADT for the corridor in this segment. Truck volumes are low (approximately 2-3 percent) as are bus volumes (1 percent) within the HOV/SL portion of I-66. Within the HOV/SL segment, morning volumes to capacity ratios fell between 0.90 and 1.00 (eastbound), indicating at capacity, heavy volume usage. In the westbound direction, LOS F conditions typically resulted, with
V/C ratios between 0.83 and 1.01 (suggesting the backward-bending portion of the V/C curve, whereby saturated conditions depress both volumes and speeds).

SAFETY AND INCIDENTS
Based on a safety analysis using negative binomial regression models and crash data from 2002 to 2004, it was concluded that there was no evidence that the HOV/SL managed lane strategy during peak hours had a statistically significant effect on crash frequency. As the authors of the study commented, “A typical factor, high AADT volume, and a natural causal factor, light conditions, especially combined with motorist’s aggressive lane change behaviors in merging and diverging areas, are presumably major factors influencing crashes in the study area”, and not the effect of the SL operations directly.

REFERENCES
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Overview

During recent meetings of the I-94 Managed Lanes Project Technical Team and Advisory Committees, a common perspective expressed from members was that improvements to I-94 between Minneapolis and St. Paul may have marginal value, reason being that primary problems seem to occur at the Lowry Hill Tunnel and the Capitol Interchange. The Lowry Hill Tunnel, located on the southwest side of downtown Minneapolis and shown in Figure 1 and Figure 2, is a key bottleneck that creates congestion on both sides of the tunnel as it essentially acts as a quarter-mile underpass with limited right-of-way.
The Lowry Hill Tunnel is part of I-94 located between the freeway interchanges with I-394 and I-35W.

Figure 1. Lowry Hill Tunnel Entrance – Minneapolis, MN (1).
The Lowry Hill Tunnel is part of I-94 located between the freeway interchanges with I-394 and I-35W.
The Capitol Interchange in St. Paul, as displayed in Figure 3, is an equally restrictive bottleneck. It is a common section of I-94 and I-35E with complex ramps connecting the I-94 and I-35E freeways and includes local ramp connections to downtown St. Paul.

Figure 2. Lowry Hill Tunnel Location – Minneapolis, MN (2).

Figure 3. Capitol Interchange Location – St. Paul, MN (2).
In the 2030 CORSIM analysis for the I-94 managed lanes, queues from the Lowry Hill Tunnel bottleneck extend all the way to the Mississippi River, negating many of the benefits of managed lanes on I-94. Despite the severe impact on congestion, it is highly unlikely any capacity expansion would occur at the tunnel over the next 50 years.

Recognizing that capacity expansion in the corridor is unlikely, active system management appears to be the only realistic alternative for the Lowry Hill Tunnel and Capitol Interchange. Given that I-35W will have speed harmonization (and, thus, control software already implemented) and I-94 is moving in the direction of speed harmonization with queue warning from downtown Minneapolis to SH-280, future conditions may provide other opportunities. For example, opportunities and benefits may be gained from deploying Active Traffic Management (ATM) at the Lowry Hill Tunnel and Capitol Interchange.

The intent of this technical memorandum is to assess a number of issues related to the possible deployment of ATM at the Lowry Hill Tunnel and Capitol Interchange. Specific issues to be addressed include the following:

- Identify ATM and/or pricing strategies that have been deployed for similar situations;
- Identify potential congestion reduction benefits;
- Identify any efforts to model and simulate the effects of ATM using CORSIM and related tools; and
- Identify packages – from basic to aggressive – that could be loosely aggregated for improving traffic operations through this key bottleneck and list the likely range of benefits that might be realized from those packages.

### Similar Experiences

Several ATM operational strategies discussed previously have the potential to address the congestion problems at both the Lowry Hill Tunnel and the Capitol Interchange. Those strategies that are possible alternatives include speed harmonization, dynamic merge control, dynamic rerouting and traveler information, queue warning, congestion pricing, and congestion pricing with dedicated HOV lanes.

Various agencies across the United States have applied some form of active traffic management to address bottleneck conditions similar to those along I-94 at the Lowry Hill Tunnel and the Capitol Interchange. Not all of the feasible strategies noted above have been deployed in the U.S., but those that have are discussed in the following sections.

### Speed Harmonization

The European deployment of ATM operational strategies was well-documented in the previous technical memorandum. However, one deployment that addresses a restricted capacity situation that was not described is the use of speed harmonization on the M3 Motorway around Copenhagen.
The operational strategy was deployed to manage congestion during a major reconstruction project that involved the widening of the corridor. The Road Directorate of the Danish Ministry of Transport and Energy decided to deploy speed harmonization as part of work zone traffic management strategies for the multiyear widening of the M3. Using traffic detection systems, closed circuit television (CCTV) cameras, and dynamic message signs (DMS), control center staff in the region monitor traffic and reduce speeds when congestion begins to build. This active management strategy has been deemed a success by Road Directorate and project staff. As a result of the speed harmonization shown in Figure 4, incidents on the motorway have not increased during the reconstruction project, while the existing two lanes have been maintained at a narrower-than-normal width and no entrance ramps, exit ramps, or bridges have been closed (3). Furthermore, the equipment used to implement speed harmonization will be a permanent installation on the completed facility, which is being constructed with the expectation that the right shoulder will be used as a temporary lane when congestion warrants it in the future. The agency acknowledges that this will most likely be the last opportunity to widen this corridor so future use of the shoulder was included in the design to provide capacity in the future as well as to minimize the costs of that shoulder use by installing the needed infrastructure now.

Figure 4. Speed Harmonization – Copenhagen, Denmark.

**Dynamic Merge Control**

Several states, including Minnesota, have deployed the dynamic lane merge system (DLMS) to address congestion at bottleneck locations. This strategy, which has a similar intent as the junction control used in Europe, works to increase capacity at merge points. Minnesota’s initial DLMS use
addressed the problems associated with queues extending beyond the farthest advanced warning signs at merge points (4). Typically used in work zones, the setup illustrated in Figure 5 provides guidance to motorists on proper lane usage, helping to reduce the amount of capacity that goes unused at merge points when drivers merge early into the through lane, leaving the terminating lane empty for a significant distance.

Figure 5. Dynamic Late Merge System - Minnesota (4).

MnDOT has found this treatment to be successful, with typical queue lengths being reduced by 40%, lane occupancy in the terminating lane increasing to near equal lane occupancy upstream.
of the merge point, less driver confusion, more uniform driver behavior, and reduced aggressive driving (4). A current deployment of this strategy is in use on I-35 in the northern Twin Cities Metro region associated with resurfacing work in conjunction with portable changeable message signs to encourage alternate route usage (5). While this strategy is not identical to the European concept of junction control, it has the similar objective of increasing capacity and reducing queues. Other states have experimented with the operational strategy with positive results.

**Congestion Pricing**

Pricing has been used successfully in various locations to address high congestion levels at system bottlenecks. The examples noted herein involve variable pricing schemes at toll bridges and similar facilities to work to adjust traffic volumes to ease congestion.

**Cape Coral & Midpoint Memorial Bridges - Lee County, Florida**

The Lee County variable pricing project was an early FHWA Value Pricing project begun in the mid-1990’s. The project has had various formats over the years. The current program provides financial incentives for travelers on the Cape Coral Bridge and Midpoint Memorial Bridge – both of which are toll bridges in Lee County. On these facilities – as mapped in Figure 6 – drivers paying electronically with a prepaid LeeWay account receive a 25% discount on their tolls during off-peak hours, Monday through Friday, excluding holidays (6). This pricing scheme has been effective at shifting of approximately 10% of eligible peak-period drivers to travel in off-peak times (7).

![Figure 6. Cape Coral Bridge and Midpoint Memorial Bridge – Lee County, FL (2).](image-url)
**Tappan Zee Bridge - Westchester County, New York**
The Tappan Zee Bridge is a major toll facility on I-87 that connects Rockland and Westchester Counties, New York, crossing the Hudson River as shown in Figure 7. The Tappan Zee Bridge has seven lanes including a reversible lane. A moveable barrier is used to convert one lane to eastbound operation in the AM, and to reverse that lane to westbound operation in the PM. Tolls are collected only in the eastbound or south direction. Cash tolls are $5.00 for passenger cars, with a toll of $4.75 for EZPass users. While commercial vehicle tolls are variable with the highest toll between 7 and 9 AM, no similar incentive tolls are offered for passenger cars. In fact commuter discounts are offered ($60/month or $3 each based on 20 crossings) and a further discount is offered for carpools of 3 or more ($10/month or $.50 per crossing).

![Tappan Zee Bridge](image)

**Figure 7. Tappan Zee Bridge – Westchester County, NY (8).**

**Congestion Pricing with HOV Lanes**
Several facilities combine congestion pricing with HOV lanes to manage congestion at network bottlenecks. The following examples are locations where the combination of increased prices with priority access by HOV and transit manage congestion and provide more travel alternatives.

**Lincoln Tunnel**
The Lincoln Tunnel, shown in Figure 8, is a major artery between New Jersey and Manhattan and offers four different incentives for travelers when crossing into the city. For example, travelers using EZPass transponders to pay for electronic tolls get a $2.00 discount off the $8.00 cash price in...
the off-peak hours. Additionally, vehicles with 3 or more people using E-ZPass pay only $2.00 for their trip, regardless of whether it is during peak or off-peak hours (9). Carpools do not get the discount if they pay cash. Also, during the week-day morning peak, the Port Authority of New York and New Jersey operates an exclusive bus lane (XBL) from New Jersey Route 3 and from the New Jersey Turnpike to the Lincoln Tunnel to provide a direct route to the tunnel bypassing rush hour traffic (10). The travel time savings for transit users using the XBL into the tunnel are 15-20 minutes. Finally, tunnel users who drive eligible low-emission vehicles receive a $4.00 discount off the $8.00 peak period toll when using E-ZPass and traveling in the off-peak hours. They are not allowed to pay cash and receive the discount. All of these tolls are collected when entering New York, with no tolls being collected when entering New Jersey. Similar toll schedules and incentives are offered at the other Port Authority entrances to New York City, including the George Washington Bridge, the Holland Tunnel, the Goethals Bridge, the Outerbridge Crossing, and the Bayonne Bridge.

San Francisco-Oakland Bay Bridge
The San Francisco-Oakland Bay Bridge is one of the most heavily traveled corridors in the country. It connects San Francisco to the East Bay and is operated by the California Department of Transportation (11). This facility offers several options to travelers in an effort to ease congestion on the facility, with pricing being varied only for select vehicles. As shown in Figure 9, the bridge has 4 lanes designated for transit and carpools. Carpools with three or more persons may cross the bridge toll-free during peak travel periods: 5 a.m. – 10 a.m. and 3 p.m. – 7 p.m. Furthermore, any motorcycle, bus, or vehicle designated by the manufacturer to be occupied by no more than two
persons and carrying two persons, may cross for free during the same hours. Inherently-low-emission vehicles (ILEV) with appropriate decals may also travel for free during the peak travel period. Commute buses may cross the bridge for free at any time in designated lane(s) (12). All other vehicles pay a flat toll based on the number of axles. The San Francisco-Oakland Bay Bridge also accepts electronic payment for tolls using FasTrak. It is also important to note that traffic exiting the toll plaza is metered to ensure the smooth merge of exiting vehicles. Similar incentives are offered to car pools on other facilities in the region, including the Antioch, Benicia-Martinez, Carquinez, Richmond-San Rafael, Dumbarton, and San Mateo-Hayward bridges, though peak periods may vary.

![San Francisco-Oakland Bay Bridge Toll Plaza](image_url)

**Figure 9. San Francisco-Oakland Bay Bridge Toll Plaza - San Francisco, CA (13).**

### Possible Benefits

Table 1 lists the potential benefits of each of the aforementioned ATM operational strategies. As to be expected, the experiences from across Europe and in the U.S. vary considerably according to application and facility, yielding varying benefits. Thus, it is difficult to pinpoint exactly what level of benefits might be achieved with specific applications. Modeling of applications may yield benefits that are more specific than the general ones listed. Additionally, the following sections list specific benefits that have been reported from some of the applications in Europe and domestically, though not every strategy is represented. Not every country has documented benefits for every application, though these sections provide an idea of what might be expected from ATM deployments.
Table 1. Potential Benefits of Active Traffic Management Strategies (Adapted from 14).

<table>
<thead>
<tr>
<th>ATM Strategy</th>
<th>Potential Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Increased Throughput</td>
</tr>
<tr>
<td>Speed Harmonization</td>
<td>X</td>
</tr>
<tr>
<td>Dynamic Merge Control</td>
<td>X</td>
</tr>
<tr>
<td>Dynamic Rerouting and Traveler Information</td>
<td>X</td>
</tr>
<tr>
<td>Queue Warning</td>
<td>X</td>
</tr>
<tr>
<td>Congestion Pricing</td>
<td>X</td>
</tr>
<tr>
<td>Congestion Pricing with HOV Lanes</td>
<td>X</td>
</tr>
</tbody>
</table>

**Speed Harmonization**

- Germany
  - 3% reduction in light property damage crashes;
  - 27% reduction heavy material damage crashes;
  - 30% reduction in personal injury crashes (14);
  - Reduction in travel time costs;
  - Reduction in operational costs; and
  - Nominal reduction in 1% environmental costs.
The Germans have conducted extensive modeling of the road network in Munich of speed harmonization. Using VISSIM, the modeling has predicted a 7-10% capacity increase using this strategy. Furthermore, the modeling predicted a capacity increase with dynamic route guidance. A similar model of dynamic route guidance on the Hessen freeway network helped identify bottlenecks.

- **Denmark**
  - No increase in accidents as a result of narrowed lanes through construction zone; and
  - No need to close ramps and/or bridges during reconstruction.

- **The Netherlands**
  - 16% reduction in collisions; and
  - 3-5% increase in throughput.

- **England**
  - 18% reduction in incidents; and
  - 27% reduction in travel time variability and 24% improvement in travel times when combined with hard shoulder running.

### Dynamic Merge Control
- **Minnesota**
  - 40% reduction in queues

### Dynamic Rerouting and Traveler Information
- **The Netherlands**
  - Under normal conditions, 8-10% motorists adhere to revised route information, providing an overall network performance increase up to 5%

### Queue Warning
- **The Netherlands**
  - 4-5% increase in throughput;
  - 15-25% decrease in primary incidents; and
  - 40-50% decrease in secondary incidents.

### Congestion Pricing
- **Florida**
  - 10% shift in travelers to the off-peak period.

### Congestion Pricing with HOV Lanes
- **New York/New Jersey**
  - 15-20 minute time savings for transit users.
ATM Packages

The various ATM operational strategies discussed previously have potential to improve operations along I-94 at the two bottlenecks of the Lowry Hill Tunnel and the Capitol Interchange. The following sections list possible applications and packages that might help with the congestion challenges of these two locations. Anticipated benefits for these strategies can be gleaned from Table 1, though not all combinations might make sense for the bottlenecks. It is important to note that the benefits when combining strategies may not necessarily compound accordingly. Furthermore, the limited benefit information available for these strategies within the domestic context makes it difficult to pinpoint specific benefits and their order of magnitude in the absence of detailed modeling. Also, as strategies are combined, economies of scale can be realized as some strategies necessitate like infrastructure needs that can serve dual purposes.

Basic Applications

- Speed Harmonization
- Dynamic Merge Control at Upstream Merge Points
- Dynamic Rerouting and Traveler Information
- Queue Warning
- Congestion Pricing at Lowry Hill Tunnel

Basic Plus Applications

- Speed Harmonization + Dynamic Merge Control at Upstream Merge Points
- Speed Harmonization + Dynamic Rerouting & Traveler Information
- Speed Harmonization + Queue Warning
- Speed Harmonization + Congestion Pricing at Lowry Hill Tunnel
- Dynamic Rerouting & Traveler Information + Queue Warning
- Dynamic Merge Control at Upstream Merge Points + Queue Warning

Advanced Applications

- Speed Harmonization + Dynamic Merge Control at Upstream Merge Points + Dynamic Rerouting & Traveler Information
- Speed Harmonization + Dynamic Merge Control at Upstream Merge Points + Queue Warning
- Speed Harmonization + Dynamic Merge Control at Upstream Merge Points + Congestion Pricing
- Speed Harmonization + Dynamic Rerouting & Traveler Information + Queue Warning
- Speed Harmonization + Dynamic Rerouting & Traveler Information + Congestion Pricing
- Speed Harmonization + Queue Warning + Congestion Pricing at Lowry Hill Tunnel

Aggressive Applications
Speed Harmonization + Dynamic Merge Control at Upstream Merge Points + Dynamic Rerouting & Traveler Information + Queue Warning

Speed Harmonization + Dynamic Merge Control at Upstream Merge Points + Dynamic Rerouting & Traveler Information + Congestion Pricing at Lowry Hill Tunnel

Speed Harmonization + Dynamic Rerouting & Traveler Information + Queue Warning + Congestion Pricing at Lowry Hill Tunnel

**Final Remarks**

ATM operational strategies have the potential to manage congestion in corridors where capacity expansion is not possible. As experience with these strategies increases in the U.S., agencies can gain knowledge about their relativity to the American freeway network and driving population as well as identify facilities where applications may work to ease congestion. Minnesota is on the cutting edge of this deployment and has a unique situation where these strategies may help with problem bottlenecks and enhance mobility in the Twin Cities region.

**References**


Concept 3 - Modified

**Minn DOT I-94 Conceptual Estimate**  
**September 23, 2009 FINAL DRAFT**  
(Revised at Bottom Line 10-09-09 to Reflect 2010 Dollars)

### Minneapolis to T.H. 280 - L= 14,700 LF

#### Eastbound:

1. Restripe to 4 lanes, TH 280 to 6th Street; reduce left shoulder to 4 ft. to maximize right shoulder width. Mill and overlay with added drainage inlets. No widening of existing roadway required. Full depth shoulder reconstruction and lighting improvements.

<table>
<thead>
<tr>
<th>Description</th>
<th>LF</th>
<th>$</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>14,700 LF</td>
<td></td>
<td></td>
<td>$5,145,000</td>
</tr>
<tr>
<td><strong>TOTAL 1. EB</strong></td>
<td></td>
<td></td>
<td>$5,145,000</td>
</tr>
</tbody>
</table>

2. 4-12 ft. lanes plus a 12 ft. auxiliary lane across Dartmouth Bridge with 4 ft. outside shoulder and 2 ft. buffer  
   NOTE: No widening of bridge required.

<table>
<thead>
<tr>
<th>Description</th>
<th>SF</th>
<th>$</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>300' L x 12' W x 1 side</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Detours/MOT</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL 2. EB</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3. Construct 10 ft. shoulder along I-94 EB between Huron entrance and exit ramps

<table>
<thead>
<tr>
<th>Description</th>
<th>LF</th>
<th>$</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>550 LF</td>
<td></td>
<td></td>
<td>$302,500</td>
</tr>
<tr>
<td><strong>TOTAL 3. EB</strong></td>
<td></td>
<td></td>
<td>$302,500</td>
</tr>
</tbody>
</table>

4. Realign SB Huron to EB I-94 ramp that has substandard acceler. Lane to increase to 418 ft.

<table>
<thead>
<tr>
<th>Description</th>
<th>LF</th>
<th>$</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>418 LF</td>
<td></td>
<td></td>
<td>$158,840</td>
</tr>
<tr>
<td><strong>TOTAL 4. EB</strong></td>
<td></td>
<td></td>
<td>$158,840</td>
</tr>
</tbody>
</table>

5. Construct 10 ft. shoulder along EB I-94 east of Franklin to Pelham Blvd., and add noise wall

<table>
<thead>
<tr>
<th>Description</th>
<th>LF</th>
<th>$</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>2,400 LF</td>
<td></td>
<td></td>
<td>$1,320,000</td>
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<tr>
<td>Noise wall</td>
<td>1 LS</td>
<td>$1,500,000</td>
<td>$1,500,000</td>
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<tr>
<td><strong>TOTAL 5. EB</strong></td>
<td></td>
<td></td>
<td>$2,820,000</td>
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</table>

6. Realign EB I-94 to NB T.H. 280 ramp to increase design speed

<table>
<thead>
<tr>
<th>Description</th>
<th>LF</th>
<th>$</th>
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</tr>
</thead>
<tbody>
<tr>
<td>750 LF of new ramp - 24 ft. width</td>
<td>750</td>
<td>$760</td>
<td>$570,000</td>
</tr>
<tr>
<td><strong>TOTAL 6. EB</strong></td>
<td></td>
<td></td>
<td>$570,000</td>
</tr>
</tbody>
</table>

7. 3-12 ft. lanes from lane drop to NB T.H. 280 to left add lane from SB T.H. 280 to EB I-94 - No Widening Required

<table>
<thead>
<tr>
<th>Description</th>
<th>all</th>
<th>$</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 ALL</td>
<td></td>
<td>$100,000</td>
<td>$100,000</td>
</tr>
<tr>
<td><strong>TOTAL 7. EB</strong></td>
<td></td>
<td></td>
<td>$100,000</td>
</tr>
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</table>

**TOTAL EASTBOUND - MINNEAPOLIS TO T.H.280**

<table>
<thead>
<tr>
<th>Description</th>
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</thead>
<tbody>
<tr>
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<td>$9,096,340</td>
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**TOTAL EASTBOUND - MINNEAPOLIS TO T.H.280**

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<tr>
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<td>$3,183,719</td>
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**TOTAL EASTBOUND - MINNEAPOLIS TO T.H.280**

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<thead>
<tr>
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<th>Total Cost</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>$12,280,059</td>
</tr>
</tbody>
</table>

**TOTAL EASTBOUND - MINNEAPOLIS TO T.H.280**
Westbound:

1. Restripe to 4 lanes, TH 280 to 5th Street, and mill and overlay existing pavement with added drainage inlets. No widening of existing roadway required.
   - 14,700 LF $350 $5,145,000
   - TOTAL 1.WB $5,145,000 $1,800,750 $6,945,750

2. Continue 4 - 12 ft. lanes on I-94 bridge over SB T.H. 280 ramp
   - Say 100' span, widened by 12 feet
   - 1,200 SF $175 $210,000
   - Detour/MOT 1 LS $50,000 $50,000
   - TOTAL 2. WB $260,000 $91,000 $351,000

3. SB T.H. 280 to WB I-94 becomes a left merge onto I-94 with possible metering, and Move I-94 -WB 10-15 ft. to the south-Assume Full Width, Full-Depth Replacement, and moving wingwall. Purpose is to eliminate existing sag curve and improve sight distance.
   - Say 1000 ft. for I-94 WB Relocation
   - 1,000 LF $1,800 $1,800,000
   - Say 500 ft. of New 24 ft. wide Ramp with Metering at entrance
   - 500 LF $760 $380,000
   - TOTAL 3. WB $2,180,000 $763,000 $2,943,000

4. Construct emergency pullout east of Franklin Ave.
   - Say 300 ft. long x 24 ft. wide (Say same as new Ramp)
   - 300 LF $760 $228,000
   - TOTAL 4. WB $228,000 $79,800 $307,800

5. Construct 10 ft. shoulder along WB I-94 between Huron Blvd. entrance and exit
   - Say 10-12 ft. widening
   - 700 LF $550 $385,000
   - TOTAL 5. WB $385,000 $134,750 $519,750

6. 4-12 ft. lanes plus a 12 ft. auxiliary lane across Dartmouth Bridge with 4 ft. outside shoulder and 2 ft. buffer
   - NOTE: No widening of bridge required.

7. Construct emergency pullout west of 25th Street
   - Say 300 ft. long x 24 ft. wide (Say same as new ramp)
   - 300 LF $760 $228,000
   - TOTAL 7. WB $228,000 $79,800 $307,800

8. Construct 10 ft. wide shoulder along WB I-94 between Cedar Avenue off-ramp and the bridge over Hiawatha and LRT
   - 500 LF $550 $275,000
   - TOTAL 8. WB $275,000 $96,250 $371,250

9. Widen Cedar Avenue off ramp to include 2 left turn lanes to Cedar Avenue
   - Widen 1 Lane @ Grade
   - 1,500 LF $550 $825,000
   - TOTAL 9.WB $825,000 $288,750 $1,113,750

10. Construct In-Road Lighting Between west end of Dartmouth Bridge and 5th Street
    - 4,800 LF $80 $384,000
    - TOTAL 10. WB $384,000 $134,400 $518,400

TOTAL WESTBOUND - MINNEAPOLIS TO T.H.280 $9,910,000 $3,468,500 $13,378,500
### T.H. 280 to Lexington Ave., Lexington Ave. to St. Paul - L=25,100 LF

**Eastbound and Westbound**

4-12 ft. lanes and a 12 ft. bus-only shoulder, full depth shoulder reconstruction and drainage and lighting improvements, from SB T.H. 280 to St. Paul (except for 4200 ft. long section at Snelling between the ramps (25,100’ - 4200’)

<table>
<thead>
<tr>
<th>Description</th>
<th>Length (LF)</th>
<th>Cost ($1,000)</th>
<th>Total Cost ($1,000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. 4-12 ft. lanes and a 12 ft. bus-only shoulder, full depth shoulder</td>
<td>20,900</td>
<td>650</td>
<td>13,585,000</td>
</tr>
<tr>
<td>reconstruction and drainage and lighting improvements</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Note: WB ATM improvements extend to the Lowry tunnel, and assumes existing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>bridges can be used for some signing.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL 1. EB &amp; WB</strong></td>
<td></td>
<td></td>
<td>13,585,000</td>
</tr>
</tbody>
</table>

**Eastbound and Westbound - Entire Project**

ATM infrastructure (lane control signals, queue warning system, and speed harmonization system) throughout the entire corridor for both I-94 EB and WB

<table>
<thead>
<tr>
<th>Description</th>
<th>Length (LF)</th>
<th>Cost ($1,000)</th>
<th>Total Cost ($1,000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. ATM infrastructure (lane control signals, queue warning system, and</td>
<td>40,000</td>
<td>750</td>
<td>30,000,000</td>
</tr>
<tr>
<td>speed harmonization system) throughout the entire corridor for both I-94</td>
<td></td>
<td></td>
<td>10,500,000</td>
</tr>
<tr>
<td>EB and WB Note: WB ATM improvements extend to the Lowry tunnel, and assumes</td>
<td></td>
<td></td>
<td>40,500,000</td>
</tr>
<tr>
<td>existing bridges can be used for some signing.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Install Ramp Controls/Queue Management at Cretin/Vandalia Interchange</td>
<td>1</td>
<td>1,000,000</td>
<td>1,000,000</td>
</tr>
<tr>
<td>3 closure gates, 3 VMS, 2 blankout signs, 2 cctv cameras</td>
<td></td>
<td></td>
<td>350,000</td>
</tr>
<tr>
<td><strong>TOTAL 1. EB &amp; WB - ENTIRE PROJECT</strong></td>
<td></td>
<td></td>
<td>31,000,000</td>
</tr>
</tbody>
</table>

**TOTAL PROJECT COST - CONCEPT 3 - 2009**

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost ($1,000)</th>
<th>Total Cost ($1,000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTAL PROJECT COST - CONCEPT 3 - 2009</td>
<td>63,591,340</td>
<td>$85,848,309</td>
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<tr>
<td>3% Escalation</td>
<td>1,907,740</td>
<td>$2,575,449</td>
</tr>
<tr>
<td><strong>TOTAL PROJECT COST - CONCEPT 3 - 2010</strong></td>
<td>65,499,080</td>
<td>88,423,758</td>
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</table>
## Minn DOT I-94 Conceptual Estimate
### September 23, 2009 FINAL D R A F T
(Revised at Bottom Line 10-09-09 to Reflect 2010 Dollars)

### Concept 3 - Modified

#### ADDITIONAL IMPROVEMENT OPPORTUNITIES

<table>
<thead>
<tr>
<th>Number</th>
<th>Description</th>
<th>Risk Factor</th>
<th>Total Cost 2009</th>
<th>Total Cost 2010</th>
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<tbody>
<tr>
<td>1</td>
<td>Remove existing railroad bridge E. of 27th Ave.</td>
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<td>$300,000</td>
<td>$306,250</td>
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<td></td>
<td>Demo Existing Bridge</td>
<td>12,000 SF</td>
<td>$25</td>
<td>$75,000</td>
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<tr>
<td></td>
<td>Detours/MOT</td>
<td>1 ALL</td>
<td>$75,000</td>
<td>$75,000</td>
</tr>
<tr>
<td></td>
<td>TOTAL 1</td>
<td></td>
<td>$375,000</td>
<td>$506,250</td>
</tr>
<tr>
<td>2</td>
<td>Replace Bridges on 25th, Riverside and 20th</td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Replace Bridge On 25th.</td>
<td>13,500 SF</td>
<td>$20</td>
<td>$270,000</td>
</tr>
<tr>
<td></td>
<td>Demo. Existing Bridge</td>
<td></td>
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<tr>
<td></td>
<td>Construct New Bridge</td>
<td>13,500 SF</td>
<td>$175</td>
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<td></td>
<td>Detours/MOT</td>
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<td>$500,000</td>
<td>$500,000</td>
</tr>
<tr>
<td></td>
<td>TOTAL 2</td>
<td></td>
<td>$3,132,500</td>
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<tr>
<td></td>
<td>Replace Bridge at Riverside</td>
<td>21,000 SF</td>
<td>$20</td>
<td>$420,000</td>
</tr>
<tr>
<td></td>
<td>Demo. Existing Bridge</td>
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</tr>
<tr>
<td></td>
<td>Construct New Bridge</td>
<td>21,000 SF</td>
<td>$175</td>
<td>$3,675,000</td>
</tr>
<tr>
<td></td>
<td>Detours/MOT</td>
<td>1 ALL</td>
<td>$500,000</td>
<td>$500,000</td>
</tr>
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<td></td>
<td>TOTAL 3</td>
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<td>$4,595,000</td>
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<tr>
<td>3</td>
<td>Replace Franklin Ave. Bridge.</td>
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</tr>
<tr>
<td></td>
<td>Demo Existing Bridge</td>
<td>10,800 SF</td>
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<td>Construct New Bridge</td>
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<td>Detours/MOT</td>
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<td>$500,000</td>
<td>$500,000</td>
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<td></td>
<td>TOTAL 3</td>
<td></td>
<td>$2,506,000</td>
<td>$3,383,100</td>
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<td>4</td>
<td>Additional 12 ft. wide lane EB &amp; WB through the Snelling interchange</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Exit to Entrance both sides, EB &amp; WB - 24 ft, total widening, assume no bridge work required and milling/overlay included elsewhere</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4,200 LF</td>
<td>$850</td>
<td>$3,570,000</td>
<td></td>
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<tr>
<td>5</td>
<td>ATM Infrastructure for I-94 EB - John Ireland Boulevard west to Kellogg Boulevard</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>500 LF</td>
<td>$400</td>
<td>$200,000</td>
<td>$270,000</td>
</tr>
<tr>
<td>6</td>
<td>ATM Infrastructure for I-94 WB - St. Paul east to Mounds Boulevard</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4,000 LF</td>
<td>$400</td>
<td>$1,600,000</td>
<td>$2,160,000</td>
</tr>
<tr>
<td>7</td>
<td>ATM Infrastructure for I-35 E - University Avenue to St. Claire Avenue</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>12,000 LF</td>
<td>$400</td>
<td>$4,800,000</td>
<td>$6,480,000</td>
</tr>
<tr>
<td>8</td>
<td>ATM Infrastructure for I-35 W - Franklin to University Avenue (Note: For costs, assumed no signing allowed on bridges; all on new gantries.)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>10,000 LF</td>
<td>$400</td>
<td>$4,000,000</td>
<td>$5,400,000</td>
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<tr>
<td></td>
<td>TOTAL 5 - 8</td>
<td></td>
<td>$10,600,000</td>
<td>$14,310,000</td>
</tr>
</tbody>
</table>

### TOTAL - ADDITIONAL IMPROVEMENT OPPORTUNITIES - 2009

- $29,703,500
- $10,396,225
- $40,099,725

### TOTAL - ADDITIONAL IMPROVEMENT OPPORTUNITIES - 2010

- $30,594,605
- $14,418,112
- $45,012,717

### 3% Escalation

- $891,105
- $311,887
- $1,202,992
Minn DOT I-94 Conceptual Estimate - September 23, 2009 - FINAL DRAFT
(Revised at Bottom Line 10-09-09 to Reflect 2010 Dollars)

Concept 4

Minneapolis to T.H. 280 - L= 14,700 LF

<table>
<thead>
<tr>
<th>RISK FACTOR - 35%</th>
<th>TOTAL COST</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Eastbound:**

1. Reconstruct EB roadway to provide for median on ramp to HOT lane, from 5th, & 6th, or 7th & 8th St.

   - 1 Lane Aerial Structure to 5th, & 6th, or to 7th & 8th St.
     - 22,000 SF $175 $3,850,000
   - 1 Lane Aerial Structure to connect to Mainline
     - 22,000 SF $175 $3,850,000
   - 1 Lane Aerial
     - 22,000 SF $175 $3,850,000
   - Detours/MOT
     - 1 LS $1,500,000 $1,500,000

   **TOTAL 1. EB** $13,050,000 $4,567,500 $17,617,500

2. Construct ramps from downtown to HOT lane.

   - Say 2 Ramps at 1000’x25’=50,000 sf
     - 22,000 SF $175 $8,750,000
   - Detours/MOT
     - 1 LS $500,000 $500,000

   **TOTAL 2. EB** $9,250,000 $3,237,500 $12,487,500

3. Provide 4-12 ft. lanes, 1-12 ft. HOT lane (with 2ft. Buffer on each side) and a 10 ft. shoulder, including retaining walls

   - 14,700 ft $1,900 $27,930,000

   **TOTAL 3. EB** $27,930,000 $9,775,500 $37,705,500


   - Widen Existing I-94 Bridge Over I-35W
     - 9,500 SF $175 $1,662,500
   - Widen I-94 Bridge Over Hiawatha LRT
     - 4,400 SF $175 $770,000
   - Widen I-94 Bridge Over Cedar Ave.
     - 2,700 SF $175 $472,500
   - Detours/MOT
     - 1 ALL $500,000 $500,000

   **TOTAL 4. EB** $3,405,000 $1,191,750 $4,596,750

5. Replace Bridges on 25th, Riverside and 20th

   - Replace Bridge On 25th.
     - Demo. Existing Bridge
       - 13,500 SF $20 $270,000
     - Construct New Bridge
       - 15,400 SF $175 $2,695,000
     - Detours/MOT
       - 1 ALL $500,000 $500,000

   **TOTAL 5. EB** $3,465,000

   - Replace Bridge at Riverside
     - Demo. Existing Bridge
       - 21,000 SF $20 $420,000
     - Construct New Bridge
       - 24,000 SF $175 $4,200,000
     - Detours/MOT
       - 1 ALL $500,000 $500,000

   **TOTAL 6. EB** $5,120,000

   - Replace Bridge at 20th
     - Demo. Existing Bridge
       - 20,000 SF $20 $400,000
     - Construct New Bridge
       - 23,000 SF $175 $4,025,000
     - Detours/MOT
       - 1 ALL $500,000 $500,000

   **TOTAL 7. EB** $4,925,000

6. Realign SB Huron to EB I-94 ramp to standard 600 ft. acceleration lane

   - 1,000 LF $400 $400,000

   **TOTAL 8. EB** $13,510,000 $4,728,500 $18,238,500

   **TOTAL** $83,993,000 $28,575,750 $112,568,750
7. Remove existing railroad bridge E. of 27th Ave.

<table>
<thead>
<tr>
<th>Description</th>
<th>Quantity</th>
<th>Area</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demo Existing Bridge</td>
<td>12,000</td>
<td>$</td>
<td>$25</td>
</tr>
<tr>
<td>Detours/MOT</td>
<td>1</td>
<td>$75,000</td>
<td>$75,000</td>
</tr>
<tr>
<td><strong>TOTAL 7. EB</strong></td>
<td></td>
<td></td>
<td><strong>$375,000</strong></td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th>Description</th>
<th>Quantity</th>
<th>Area</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demo Existing Bridge</td>
<td>10,800</td>
<td>$20</td>
<td>$216,000</td>
</tr>
<tr>
<td>Construct New Bridge</td>
<td>12,300</td>
<td>$175</td>
<td>$2,152,500</td>
</tr>
<tr>
<td>Detours/MOT</td>
<td>1</td>
<td>$400,000</td>
<td>$400,000</td>
</tr>
<tr>
<td><strong>TOTAL 8. EB</strong></td>
<td></td>
<td></td>
<td><strong>$2,768,500</strong></td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th>Description</th>
<th>Quantity</th>
<th>Area</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construct New Bridge</td>
<td>10,000</td>
<td>$175</td>
<td>$1,750,000</td>
</tr>
<tr>
<td>Detours/MOT</td>
<td>1</td>
<td>$250,000</td>
<td>$250,000</td>
</tr>
<tr>
<td><strong>TOTAL 9. EB</strong></td>
<td></td>
<td></td>
<td><strong>$2,000,000</strong></td>
</tr>
</tbody>
</table>

10. Develop queue warning system and speed harmonization system for entire corridor.

<table>
<thead>
<tr>
<th>Description</th>
<th>Quantity</th>
<th>Area</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Queue warning system, speed</td>
<td>14,700</td>
<td>$400</td>
<td>$5,880,000</td>
</tr>
<tr>
<td>harmonization system, and signing.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL 10. EB</strong></td>
<td></td>
<td></td>
<td><strong>$5,880,000</strong></td>
</tr>
</tbody>
</table>

11. Replace two pedestrian bridges

<table>
<thead>
<tr>
<th>Description</th>
<th>Quantity</th>
<th>Area</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demo. Pedestrian Bridge</td>
<td>6,000</td>
<td>$15</td>
<td>$90,000</td>
</tr>
<tr>
<td>Re-Construct Pedestrian Bridge</td>
<td>6,800</td>
<td>$150</td>
<td>$1,020,000</td>
</tr>
<tr>
<td>Demo. Pedestrian Bridge</td>
<td>7,500</td>
<td>$15</td>
<td>$112,500</td>
</tr>
<tr>
<td>Re-Construct Pedestrian Bridge</td>
<td>8,500</td>
<td>$150</td>
<td>$1,275,000</td>
</tr>
<tr>
<td><strong>TOTAL 11. EB</strong></td>
<td></td>
<td></td>
<td><strong>$2,497,500</strong></td>
</tr>
</tbody>
</table>

**TOTAL EASTBOUND - MINNEAPOLIS TO T.H.280**

<table>
<thead>
<tr>
<th>Description</th>
<th>Quantity</th>
<th>Area</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td><strong>$81,066,000</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Description</th>
<th>Quantity</th>
<th>Area</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td><strong>$28,373,100</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><strong>$109,439,100</strong></td>
</tr>
</tbody>
</table>
Westbound:

1. Realign I-94 and replace left hand ramp with a right hand ramp from SB T.H. 280 to W.B. I-94
   
<table>
<thead>
<tr>
<th>Realign I-94</th>
<th>1</th>
<th>ALL</th>
<th>$5,000,000</th>
<th>$5,000,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTAL 1. WB</td>
<td></td>
<td></td>
<td>$5,000,000</td>
<td>$1,750,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$6,750,000</td>
<td></td>
</tr>
</tbody>
</table>

2. Provide for 4-12 ft. lanes, a 12 ft. HOT lane (with 2 ft. buffers on each side) and a 10ft. Shoulder, including retaining walls, from T.H. 280 to 5th. St.
   
<table>
<thead>
<tr>
<th>Provide for 4-12 ft. lanes, a 12 ft. HOT lane (with 2 ft. buffers on each side) and a 10ft. Shoulder, including retaining walls, from T.H. 280 to 5th. St.</th>
<th>14,700</th>
<th>1,900</th>
<th>$27,930,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTAL 2. WB</td>
<td></td>
<td></td>
<td>$9,775,500</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$37,705,500</td>
</tr>
</tbody>
</table>

   Remove existing railroad bridge E. of 27th. Ave.
   Replace existing bridges at 25th, Riverside, and 20th
   Replace two pedestrian bridges

   Replacing bridges is same as shown under the EB - Costs included there.

4. Widen Cedar Ave. ramp to allow for 2 left turn lanes to Cedar Ave.
   
<table>
<thead>
<tr>
<th>Widen 1 Lane @ Grade</th>
<th>1,500</th>
<th>LF</th>
<th>$375</th>
<th>$562,500</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTAL 4. WB</td>
<td></td>
<td></td>
<td>$196,875</td>
<td>$759,375</td>
</tr>
</tbody>
</table>

5. Construct drop ramp from W.B. HOT lane to Downtown Minneapolis on 5th, 6th, 7th or 8th St.
   
<table>
<thead>
<tr>
<th>Construct drop ramp from W.B. HOT lane to Downtown Minneapolis on 5th, 6th, 7th or 8th St.</th>
<th>1,000</th>
<th>LF</th>
<th>$800</th>
<th>$800,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTAL 5. WB</td>
<td></td>
<td></td>
<td>$280,000</td>
<td>$1,080,000</td>
</tr>
</tbody>
</table>

6. Develop queue warning system and speed harmonization system for entire corridor.
   (Cost assumes no signing on bridges; all on new gantries.)
   
<table>
<thead>
<tr>
<th>Develop queue warning system and speed harmonization system. Extends to Lowry Tunnel</th>
<th>17,700</th>
<th>LF</th>
<th>$400</th>
<th>$7,080,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTAL 6. WB</td>
<td></td>
<td></td>
<td>$2,478,000</td>
<td>$9,558,000</td>
</tr>
</tbody>
</table>

TOTAL WESTBOUND - MINNEAPOLIS TO T.H.280

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTAL WESTBOUND - MINNEAPOLIS TO T.H.280</td>
<td>$41,372,500</td>
<td>$14,490,375</td>
<td>$55,852,875</td>
<td></td>
</tr>
</tbody>
</table>
## T.H. 280 to Lexington Ave. - L=14,700 LF

### Eastbound

1. **Reconstruct roadway to allow for 4-12 ft. lanes, a 12 ft. HOT lane with 2 ft. buffers on each side and a 10 ft. shoulder, including retaining walls.**

<table>
<thead>
<tr>
<th>Description</th>
<th>LF</th>
<th>$</th>
<th>$</th>
</tr>
</thead>
<tbody>
<tr>
<td>14,700 LF</td>
<td>1,900</td>
<td>$27,930,000</td>
<td></td>
</tr>
</tbody>
</table>

   **TOTAL 1. EB**

   |                               |     | $9,775,500 | $37,705,500 |

2. **Construct a CD ramp from SB T.H. 280 to E.B. I-94 which requires a new bridge over EB and WB I-94.**

<table>
<thead>
<tr>
<th>Description</th>
<th>SF</th>
<th>$</th>
<th>$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construct New Bridge</td>
<td>8,700</td>
<td>175</td>
<td>1,522,500</td>
</tr>
<tr>
<td>1-Lane @ Grade</td>
<td>400</td>
<td>800</td>
<td>320,000</td>
</tr>
<tr>
<td>2-Lane @ Grade</td>
<td>2,000</td>
<td>920</td>
<td>1,840,000</td>
</tr>
<tr>
<td>1-Lane @ Grade</td>
<td>1,000</td>
<td>800</td>
<td>800,000</td>
</tr>
<tr>
<td>Detours/MOT</td>
<td>1</td>
<td>500,000</td>
<td>500,000</td>
</tr>
</tbody>
</table>

   **TOTAL 2. EB**

   |                               |     | $1,743,875 | $6,726,375 |

3. **Replace existing railroad bridge near Fairview Ave. but reduce the tracks from three to two.**

<table>
<thead>
<tr>
<th>Description</th>
<th>SF</th>
<th>$</th>
<th>$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demo Existing RR Bridge Near Fairview Ave.</td>
<td>30,000</td>
<td>25</td>
<td>750,000</td>
</tr>
<tr>
<td>Re-Construct RR Bridge Near Fairview Ave.</td>
<td>30,000</td>
<td>200</td>
<td>6,000,000</td>
</tr>
<tr>
<td>Remove and Replace Trackwork and Switches</td>
<td>1,200</td>
<td>300</td>
<td>360,000</td>
</tr>
<tr>
<td>Detours/MOT</td>
<td>1</td>
<td>1,000,000</td>
<td>1,000,000</td>
</tr>
</tbody>
</table>

   **TOTAL 3. EB**

   |                               |     | $2,838,500 | $10,948,500 |

4. **Replace bridges at Vandalia, Cleveland, Prior, Fairview, Snelling, Pascal and Hamline.**

<table>
<thead>
<tr>
<th>Description</th>
<th>SF</th>
<th>$</th>
<th>$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demo. Bridge at Vandalia</td>
<td>24,000</td>
<td>20</td>
<td>480,000</td>
</tr>
<tr>
<td>Re-Construct Bridge at Vandalia</td>
<td>27,400</td>
<td>175</td>
<td>4,795,000</td>
</tr>
<tr>
<td>Demo. Bridge at Cleveland</td>
<td>17,500</td>
<td>20</td>
<td>350,000</td>
</tr>
<tr>
<td>Re-Construct Bridge at Cleveland</td>
<td>19,900</td>
<td>175</td>
<td>3,482,500</td>
</tr>
<tr>
<td>Demo. Bridge at Prior Ave.</td>
<td>19,600</td>
<td>20</td>
<td>392,000</td>
</tr>
<tr>
<td>Re-Construct Bridge at Prior Ave.</td>
<td>22,300</td>
<td>175</td>
<td>3,902,500</td>
</tr>
<tr>
<td>Demo. Bridge at Fairview Ave.</td>
<td>24,800</td>
<td>20</td>
<td>496,000</td>
</tr>
<tr>
<td>Re-Construct Bridge at Fairview Ave.</td>
<td>28,300</td>
<td>175</td>
<td>4,902,500</td>
</tr>
<tr>
<td>Demo. Bridge at Snelling Ave.</td>
<td>66,000</td>
<td>20</td>
<td>1,320,000</td>
</tr>
<tr>
<td>Re-Construct Bridge at Snelling Ave.</td>
<td>75,200</td>
<td>175</td>
<td>13,160,000</td>
</tr>
<tr>
<td>Demo. Bridge at Pascal St.</td>
<td>19,800</td>
<td>20</td>
<td>396,000</td>
</tr>
<tr>
<td>Re-Construct Bridge at Pascal St.</td>
<td>22,500</td>
<td>175</td>
<td>3,937,500</td>
</tr>
<tr>
<td>Demo. Bridge at Hamline</td>
<td>14,500</td>
<td>20</td>
<td>290,000</td>
</tr>
<tr>
<td>Re-Construct Bridge at Hamline</td>
<td>16,500</td>
<td>175</td>
<td>2,887,500</td>
</tr>
<tr>
<td>Detours/MOT</td>
<td>1</td>
<td>2,000,000</td>
<td>2,000,000</td>
</tr>
</tbody>
</table>

   **TOTAL 4. EB**

   |                               |     | $14,994,525 | $57,836,025 |

5. **Develop queue warning and speed harmonization systems throughout the corridor.**

   *(Cost assumes no signs on bridges; all on new gantries.)*

<table>
<thead>
<tr>
<th>Description</th>
<th>LF</th>
<th>$</th>
<th>$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Queue warning system and speed harmonization system, and signing</td>
<td>400</td>
<td>$5,880,000</td>
<td></td>
</tr>
</tbody>
</table>

   **TOTAL 5. EB**

   |                               |     | $2,058,000 | $7,938,000 |

**TOTAL EASTBOUND - T.H. 280 TO LEXINGTON AVENUE**

|                               |     | $31,410,400 | $121,154,400 |

### Westbound

1. **Reconstruct roadway to allow for 4-12 ft. lanes, a 12 ft. HOT lane with 2 ft. buffers on each side and a 10 ft. shoulder.**

<table>
<thead>
<tr>
<th>Description</th>
<th>LF</th>
<th>$</th>
<th>$</th>
</tr>
</thead>
<tbody>
<tr>
<td>14,700 LF</td>
<td>1,900</td>
<td>$27,930,000</td>
<td></td>
</tr>
</tbody>
</table>

   **TOTAL 1. WB**

   |                               |     | $9,775,500 | $37,705,500 |
2. Replacing bridges is same as shown under the EB - Costs included there.

<table>
<thead>
<tr>
<th>Description</th>
<th>Quantity</th>
<th>Unit</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>At-Grade Roadway 2-Lane</td>
<td>1,600</td>
<td>LF</td>
<td>$1,600,000</td>
</tr>
<tr>
<td>At-Grade Roadway 1-Lane</td>
<td>600</td>
<td>LF</td>
<td>$480,000</td>
</tr>
<tr>
<td>At-Grade Roadway 1-Lane</td>
<td>400</td>
<td>LF</td>
<td>$320,000</td>
</tr>
</tbody>
</table>

**TOTAL 2. WB** $2,400,000

3. Construct a CD ramp from WB I-94 to NB 280.

<table>
<thead>
<tr>
<th>Description</th>
<th>Quantity</th>
<th>Unit</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>At-Grade Roadway 2-Lane</td>
<td>1,600</td>
<td>LF</td>
<td>$1,600,000</td>
</tr>
<tr>
<td>At-Grade Roadway 1-Lane</td>
<td>600</td>
<td>LF</td>
<td>$480,000</td>
</tr>
<tr>
<td>At-Grade Roadway 1-Lane</td>
<td>400</td>
<td>LF</td>
<td>$320,000</td>
</tr>
</tbody>
</table>

**TOTAL 3. WB** $2,400,000

4. Develop a queue warning and speed harmonization systems throughout the corridor.

<table>
<thead>
<tr>
<th>Description</th>
<th>Quantity</th>
<th>Unit</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Queue warning system and speed harmonization system.</td>
<td>14,700</td>
<td>LF</td>
<td>$5,880,000</td>
</tr>
</tbody>
</table>

**TOTAL 4. WB** $5,880,000

**TOTAL WESTBOUND - T.H. 280 TO LEXINGTON AVENUE** $36,210,000

Lexington Ave. to Downtown St. Paul - L=10,400 LF

**Eastbound & Westbound**

1. Reconstruct roadway to allow 4-12 ft. lanes, a 12 ft. HOT lane with 2 ft. buffers on each side and a 10 ft. shoulder, including retaining walls.

<table>
<thead>
<tr>
<th>Description</th>
<th>Quantity</th>
<th>Unit</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demo. Lexington Parkway Bridge</td>
<td>30,000</td>
<td>SF</td>
<td>$600,000</td>
</tr>
<tr>
<td>Re-Construct Lexington Parkway Bridge</td>
<td>34,200</td>
<td>SF</td>
<td>$5,985,000</td>
</tr>
<tr>
<td>Demo. Pedestrian Bridge</td>
<td>6,000</td>
<td>SF</td>
<td>$90,000</td>
</tr>
<tr>
<td>Re-Construct Pedestrian Bridge</td>
<td>6,800</td>
<td>SF</td>
<td>$1,020,000</td>
</tr>
<tr>
<td>Demo. Victor St. N. Bridge</td>
<td>11,200</td>
<td>SF</td>
<td>$224,000</td>
</tr>
<tr>
<td>Re-Construct Victor St. N. Bridge</td>
<td>12,700</td>
<td>SF</td>
<td>$2,222,500</td>
</tr>
<tr>
<td>Demo. Pedestrian Bridge</td>
<td>7,500</td>
<td>SF</td>
<td>$112,500</td>
</tr>
<tr>
<td>Re-Construct Pedestrian Bridge</td>
<td>8,500</td>
<td>SF</td>
<td>$1,275,000</td>
</tr>
<tr>
<td>Demo. North Dale St. Bridge</td>
<td>12,200</td>
<td>SF</td>
<td>$244,000</td>
</tr>
<tr>
<td>Re-Construct North Dale St. Bridge</td>
<td>13,900</td>
<td>SF</td>
<td>$2,432,500</td>
</tr>
<tr>
<td>Demo. Pedestrian Bridge</td>
<td>5,250</td>
<td>SF</td>
<td>$78,750</td>
</tr>
<tr>
<td>Re-Construct Pedestrian Bridge</td>
<td>6,000</td>
<td>SF</td>
<td>$900,000</td>
</tr>
<tr>
<td>Demo. Western Ave. Bridge</td>
<td>17,400</td>
<td>SF</td>
<td>$348,000</td>
</tr>
<tr>
<td>Re-Construct Western Ave. Bridge</td>
<td>19,800</td>
<td>SF</td>
<td>$3,465,000</td>
</tr>
<tr>
<td>Demo. Marion St. Bridge</td>
<td>38,700</td>
<td>SF</td>
<td>$774,000</td>
</tr>
<tr>
<td>Re-Construct Marion St. Bridge</td>
<td>44,100</td>
<td>SF</td>
<td>$7,717,500</td>
</tr>
<tr>
<td>Demo. Ramp</td>
<td>23,400</td>
<td>SF</td>
<td>$468,000</td>
</tr>
<tr>
<td>Re-Construct Ramp</td>
<td>26,600</td>
<td>SF</td>
<td>$4,655,000</td>
</tr>
<tr>
<td>Demo. John Ireland Blvd. Bridge</td>
<td>25,800</td>
<td>SF</td>
<td>$516,000</td>
</tr>
<tr>
<td>Re-Construct John Ireland Blvd. Bridge</td>
<td>29,400</td>
<td>SF</td>
<td>$5,145,000</td>
</tr>
<tr>
<td>DETOUR/MOT</td>
<td>1</td>
<td>ALL</td>
<td>$5,000,000</td>
</tr>
</tbody>
</table>

**TOTAL 2. EB & WB** $43,272,750

3. Develop queue warning and speed harmonization system throughout the corridor.

<table>
<thead>
<tr>
<th>Description</th>
<th>Quantity</th>
<th>Unit</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Queue warning system and speed harmonization system.</td>
<td>10,400</td>
<td>LF</td>
<td>$8,320,000</td>
</tr>
</tbody>
</table>

**TOTAL 3. EB & WB** $8,320,000

4. Construct egress to and from St. Paul from HOT lane.

<table>
<thead>
<tr>
<th>Description</th>
<th>Quantity</th>
<th>Unit</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allow for egress ramps to and from St. Paul</td>
<td>1</td>
<td>AL</td>
<td>$10,000,000</td>
</tr>
</tbody>
</table>

**TOTAL 4. EB & WB** $10,000,000

**TOTAL EB & WB - LEXINGTON AVE. TO DOWNTOWN ST. PAUL** $100,352,750

**TOTAL PROJECT COST - CONCEPT 4 -2009** $348,745,250

3% Escalation

<table>
<thead>
<tr>
<th>Description</th>
<th>Quantity</th>
<th>Unit</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>3% Escalation</td>
<td>10,462,358</td>
<td>$3,661,825</td>
<td></td>
</tr>
</tbody>
</table>

**TOTAL PROJECT COST - CONCEPT 4 -2010** $359,207,608
Memorandum To: Jim Henricksen, MnDOT
From: Steve Ruegg, PB
Copy to: Wayne Norris, MnDOT
        Brian Isaacson, MnDOT
        Mark Filipi, Met Council
Date: March 17, 2009
      Updated: August 26, 2009
      Updated: October 27, 2009
Subject: I-94 Managed Lanes Study, Travel Demand Forecasting Methodology (Final DRAFT)

Introduction:
This memorandum describes the assumptions made and approach used to develop base year 2005 and forecast year 2030 average weekday daily and hourly auto and transit demand, in support of the I-94 Managed Lanes Study. The I-94 Managed Lanes Study (the “study”) is a project conducted to develop a future vision plan for the management of I-94, roughly between the Minneapolis and St. Paul CBDs. Alternatives that are anticipated for study include the use of a Dynamic Shoulder Lane (“DSL”) and a High-Occupancy/Toll (HOT) lane for all or part of the corridor. One of the key initial tasks in this study is to develop 2030 forecast travel demand for a no-build and build scenarios. This forecast will have two primary purposes. First, the forecast was used to identify general demand in the corridor, including toll and hov demand, as well as provide an estimate for toll revenues. Secondly, the travel demand model output will provide growth factors and ramp-to-ramp movements for use in the CORSIM simulation model.

General Methodology:
The Twin Cities Regional Model (“the model”) was used to develop the travel demand forecasts for this study. The model was developed in the 2001-2003 timeframe as a part of the Twin Cities Travel Behavior Inventory (the 2000 TBI), and used information from the 2000 Census, the year 2000 Regional Home Interview Survey and a concurrent set of external surveys done as a part of the 2000 TBI. The model includes the 7 core counties of the region, as well as a set of ring counties surrounding the core. A total of 1632 zones are included, with 1201 zones in the seven-county area. The model is executed on a TP+ software platform, and makes use of several stand-alone FORTRAN programs used for trip generation, mode choice and external station choice.
The main inputs to the model include:

1. **Socioeconomic Data.** This includes population, households, retail and non-retail employment by zone. Data for 2006 was obtained by interpolating 2000 and 2009 data from the Metropolitan Council for this study, and reflects current conditions. Special Generator Data for 2000, 2009 and 2030 were also provided by the Council and/or used from current studies. Data for 2030 was the 2030 data used most recently for the Cedar Avenue Corridor Study, and includes some minor reallocation of employment within Lakeville, as requested by that city. Otherwise, the socioeconomic data is the same as used for the Central Corridor and SW corridor demand analyses, and reflects the most recent forecasts of the Metropolitan Council. Table 1 shows a summary of the 7-county totals for these datasets.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Year 2000</th>
<th>Year 2006</th>
<th>Year 2030</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area (sq mi)</td>
<td>2,970</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Avg HH Income (2000$)</td>
<td>$71,220</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Population</td>
<td>2,642,056</td>
<td>2,861,970</td>
<td>3,636,041</td>
</tr>
<tr>
<td>Households</td>
<td>1,021,454</td>
<td>1,129,524</td>
<td>1,503,331</td>
</tr>
<tr>
<td>Retail Employment</td>
<td>171,272</td>
<td>266,448</td>
<td>373,154</td>
</tr>
<tr>
<td>Non-Retail Employment</td>
<td>1,391,561</td>
<td>1,448,638</td>
<td>1,775,424</td>
</tr>
<tr>
<td>Total Employment</td>
<td>1,562,833</td>
<td>1,715,086</td>
<td>2,148,578</td>
</tr>
</tbody>
</table>

2. **Networks.** A 2006 network set was supplied by the Metropolitan Council, and reflects roadway conditions in the region in 2006, including the pre-collapse configuration of I-35W, I-94 and TH280. The I-394 HOT lane is included. This network set included both highway and transit networks as reflected at that time. The Hiawatha Light Rail line was also included in the transit network. The associated transit accessibility file (i.e., percent of zone within 1/3 and 1 mile of a transit stop) was also included.

The 2030 network set was obtained from the roadway and transit networks used for the Central and SW corridor Light Rail studies. As such, it includes both the Central Corridor and SW corridor Light Rail lines, as well as the Northstar Commuter Rail Line. The Washington Avenue roadway was deleted just east of the Washington Avenue Mississippi River Bridge on the University of Minnesota East Bank Campus, reflecting the latest plans of the Central Corridor. On University Avenue between the downtowns, 2 lanes in each direction for autos are assumed, even with the Central Corridor LRT (parking removed). Lane configurations on I-94 and TH280 are represented as they were prior to the I-35W bridge collapse. The 2030 networks are consistent with the regional policy plan of the Metropolitan Council. Route alignments and frequencies in the corridor were checked and verified by Met Council staff, and adjustments were made to...
reflect the current plans for transit in the corridor. Figure 1 shows the 2030 highway network in the study area, color coded and annotated by number of one-way lanes.

Other model parameters remain unchanged from standard model practice. These include:

- Trip generation Rates and Special Generators
- Trip distribution parameters and k-factors
- Model choice parameters (note that both LRT and Commuter rail modes were turned “on” as appropriate for the year of analysis).
- Gas price is $1.474 in $2000 dollars, which is about $1.81 in 2009 dollars.
- Parking and fare Costs
- Income (remained constant)
- Volume-Delay functions and associated parameters
- Diurnal Factors
**Model Execution:**

For each forecast year, the model was re-run in a full feedback mode, which included trip generation, distribution, mode choice and am/midday highway assignment. A multiple convergence test was used. The model was allowed to run in feedback mode until at least 90 percent of the average am peak hour volumes, times and speeds all changed by less than 10% from the previous iteration, and at least 90% of the OD-pairs of the am peak period trips change by less than 10% from the previous iteration. The overall AM peak VMT and VHT percent changes were also tracked. Table 2 shows this convergence for 2006 and 2030.

<table>
<thead>
<tr>
<th>Year 2006, percent with 10% change, and overall VMT &amp; VHT Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iteration</td>
</tr>
<tr>
<td>-----------</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Year 2030, percent with 10% change, and overall VMT &amp; VHT Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iteration</td>
</tr>
<tr>
<td>-----------</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4*</td>
</tr>
</tbody>
</table>

*An additional feedback run was done after deleting the Washington Ave link, EB U of M*

The same 2030 vehicle demand matrices were assigned to the no-build and each of the build alternatives. For each alternative, a ramp-to-ramp subarea trip table was developed which corresponded to the CORSIM network used for simulation. Adjustment factors were applied to each ramp and mainline entrance and exit, based on the 2005 count/2006 model estimated values at these ramp locations. The ramp-to-ramp matrix was then re-balanced to match the new target values, and re-assigned to the subarea network. From the subarea networks and associated trip tables, the information necessary for the demand inputs to CORSIM were supplied. Separate HOT lane demand matrices and link loadings were also supplied through this process.

**Model Validation Checks:**

Table 3 shows a listing of mainline daily and peak hour volumes, comparing 2005 counts with 2006 model volumes for key mainline segments of I-94 in the corridor. Segments between TH55 and Marion Street compare favorably with less than 6% difference between modeled and counts for this, the central study area for this project. Appendix A contains more detailed results, including peak hour shares. For the sections shown in Table 3, the overall model estimated volumes are 5% under the count. The average AM peak hour modeled volumes are 6% higher than observed, while the average PM peak hour modeled volumes are 39% higher than observed. The high model estimate for PM peak hour demand, in light of the relatively close daily demand comparison, is primarily
a result of the use of a fixed diurnal share within the regional model, and the constrained capacity and severe congestion within the corridor. The delays that result from this congestion, particularly due to incidents and upstream queues, are not reflected in the regional travel demand model. While the PM peak hour demand shows approximately the same peak share as for AM based on counts, the regional model shares, derived for the entire region, show a significantly higher PM peak share when compared with the AM Peak share. This model property is accurate on a global basis, but does not apply in a congested corridor such as this section of I-94 for reasons of incident and queue delay mentioned above. In addition, the fixed diurnal shares are not sensitive to peak spreading, which may have a significant effect on demand within this corridor, especially during the PM peak hour period when there is a greater proportion of non-work, discretionary trips. Average estimated peak hour directional splits for both am and pm peak hours are within 1% of observed.
Table 3: Daily Count/Model Comparison By I-94 Mainline Segment

<table>
<thead>
<tr>
<th>Freeway Segment</th>
<th>To</th>
<th>Lanes</th>
<th>2005 Counts</th>
<th>2006 Modeled</th>
<th>Pct diff</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broadway Ave</td>
<td>I-394</td>
<td>10</td>
<td>123,800</td>
<td>112,600</td>
<td>-9%</td>
</tr>
<tr>
<td>I-394</td>
<td>Hennepin Ave (Tunnel)</td>
<td>6</td>
<td>174,200</td>
<td>145,200</td>
<td>-17%</td>
</tr>
<tr>
<td>Hennepin Ave</td>
<td>TH 65/I-35W South</td>
<td>8</td>
<td>221,800</td>
<td>181,900</td>
<td>-18%</td>
</tr>
<tr>
<td>TH 65/I-35W South</td>
<td>TH 55 (Common)</td>
<td>8</td>
<td>157,000</td>
<td>136,600</td>
<td>-13%</td>
</tr>
<tr>
<td>TH 55</td>
<td>Cedar Ave</td>
<td>6</td>
<td>159,000</td>
<td>161,800</td>
<td>+2%</td>
</tr>
<tr>
<td>Cedar Ave</td>
<td>Riverside Ave</td>
<td>8</td>
<td>174,500</td>
<td>177,000</td>
<td>+1%</td>
</tr>
<tr>
<td>Riverside Ave</td>
<td>Huron Blvd</td>
<td>8</td>
<td>171,200</td>
<td>163,700</td>
<td>-4%</td>
</tr>
<tr>
<td>Huron Blvd</td>
<td>TH 280</td>
<td>6</td>
<td>174,500</td>
<td>167,800</td>
<td>-4%</td>
</tr>
<tr>
<td>TH 280</td>
<td>Cretin Ave</td>
<td>8</td>
<td>180,600</td>
<td>177,800</td>
<td>-2%</td>
</tr>
<tr>
<td>Cretin Ave</td>
<td>Snelling /Hamline Ave</td>
<td>8</td>
<td>185,000</td>
<td>180,400</td>
<td>-2%</td>
</tr>
<tr>
<td>Snelling /Hamline Ave</td>
<td>Lexington Ave</td>
<td>8</td>
<td>172,700</td>
<td>168,200</td>
<td>-3%</td>
</tr>
<tr>
<td>Lexington Ave</td>
<td>Dale St</td>
<td>8</td>
<td>184,100</td>
<td>172,900</td>
<td>-6%</td>
</tr>
<tr>
<td>Dale St</td>
<td>Marion St</td>
<td>8</td>
<td>185,500</td>
<td>175,500</td>
<td>-5%</td>
</tr>
<tr>
<td>Marion St</td>
<td>I-35E South</td>
<td>6</td>
<td>148,200</td>
<td>138,800</td>
<td>-6%</td>
</tr>
<tr>
<td>I-94 &amp; I-35E Common</td>
<td></td>
<td>10</td>
<td>211,600</td>
<td>206,100</td>
<td>-3%</td>
</tr>
<tr>
<td>I-35E North</td>
<td>TH 52</td>
<td>6</td>
<td>167,400</td>
<td>171,000</td>
<td>2%</td>
</tr>
<tr>
<td>TH 52</td>
<td>6th St</td>
<td>6</td>
<td>143,600</td>
<td>138,600</td>
<td>-3%</td>
</tr>
<tr>
<td>6th St</td>
<td>Mounds Blvd</td>
<td>6</td>
<td>125,100</td>
<td>120,800</td>
<td>-3%</td>
</tr>
<tr>
<td>Mounds Blvd</td>
<td>TH 61</td>
<td>10</td>
<td>138,600</td>
<td>128,600</td>
<td>-7%</td>
</tr>
<tr>
<td>TH 61</td>
<td>White Bear Ave</td>
<td>6</td>
<td>117,800</td>
<td>116,000</td>
<td>-2%</td>
</tr>
</tbody>
</table>
Toll and HOV Forecasting Approach:
An assignment-based routine was used to estimate toll and HOV demand for the HOT lane alternative. This is the same approach used in the I-35W UPA analysis, and uses a dynamic toll demand estimation embedded within an equilibrium highway assignment. Willingness to pay parameters are based on actual local travel survey results. Note that this methodology does not have any sensitivity to transit mode shifts that might result from the alternatives.

In support of the CORSIM modeling, a ramp-to-ramp demand matrix (peak hours) was generated using the subarea isolation procedures in Cube/Voyager. The standard assignment was used, with SOV, 2-person and 3+ person autos as demand markets in a multi-class assignment.

Year 2030 Forecasts:
Appendix B contains counts vs. estimated 2030 volumes, and Appendix C shows the modeled 2006 vs. the modeled 2030 base. The 2030 volumes are count-adjusted. The I-94 growth rate, both daily and peak hour, is minimal, about 2 percent. This growth is constrained by capacity on I-94. Appendices D and E show the comparison of 2030 base to 2030 Concepts 1 and 3 (HOT lane) demand.

Concept 1, utilizing lane control technology and shoulder lane conversion, showed a 6 percent daily increase in I-94 traffic volume, with peak hour increases of 9% for the AM peak and 6% for the PM peak hours. Concept 3, utilizing a median HOT lane showed increases of 5% for daily traffic on I-94 in the corridor, with 12% for the AM peak and 10% for the PM peak. These percent changes were based on the sum of I-94 mainline segment volumes in the simulated network corridor.

The regional model assignments were developed for each hour of the day. From these, performance measures were developed that illustrate the overall system performance. Table 4 shows these performance measures. As shown below, the Concept 1 alternative, though attracting additional volume to the corridor itself, has a relatively small effect overall. The HOT lane alternatives (with and without a direct connection to St. Peter Street) have a much more significant system-wide impact, reducing delay by about 10% and increasing overall system speed by 0.7 miles per hour.
Table 4: Year 2030 Performance Measures

<table>
<thead>
<tr>
<th></th>
<th>No-Build</th>
<th>Concept 1</th>
<th>HOT Lane</th>
<th>HOT Lane-Alt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delay(veh-hrs)</td>
<td>1,169,000</td>
<td>1,155,400</td>
<td>1,047,900</td>
<td>1,047,100</td>
</tr>
<tr>
<td>VHT</td>
<td>3,571,100</td>
<td>3,556,500</td>
<td>3,361,500</td>
<td>3,360,600</td>
</tr>
<tr>
<td>VMT</td>
<td>104,912,000</td>
<td>104,882,000</td>
<td>101,145,000</td>
<td>101,137,000</td>
</tr>
<tr>
<td>Average Speed</td>
<td>29.4</td>
<td>29.5</td>
<td>30.1</td>
<td>30.1</td>
</tr>
</tbody>
</table>

Change From NB

<table>
<thead>
<tr>
<th></th>
<th>No-Build</th>
<th>Concept 1</th>
<th>HOT Lane</th>
<th>HOT Lane-Alt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delay(veh-hrs)</td>
<td>-13,600</td>
<td>-121,100</td>
<td>-121,900</td>
<td></td>
</tr>
<tr>
<td>VHT</td>
<td>-14,700</td>
<td>-209,600</td>
<td>-210,600</td>
<td></td>
</tr>
<tr>
<td>VMT</td>
<td>-30,000</td>
<td>-3,768,000</td>
<td>-3,775,000</td>
<td></td>
</tr>
</tbody>
</table>

Percent Change From NB

<table>
<thead>
<tr>
<th></th>
<th>No-Build</th>
<th>Concept 1</th>
<th>HOT Lane</th>
<th>HOT Lane-Alt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delay(veh-hrs)</td>
<td>-1.2%</td>
<td>-10.4%</td>
<td>-10.4%</td>
<td></td>
</tr>
<tr>
<td>VHT</td>
<td>-0.4%</td>
<td>-5.9%</td>
<td>-5.9%</td>
<td></td>
</tr>
<tr>
<td>VMT</td>
<td>-0.03%</td>
<td>-3.59%</td>
<td>-3.60%</td>
<td></td>
</tr>
</tbody>
</table>

Notes:
All measures are calculated by summing all regional network link performance values for each hourly assignment.
Delay is computed by subtracting congested VHT from free-flow VHT
VHT – Vehicle-hours of travel
VMT – Vehicle-miles of travel
Average Speed – VMT/VHT (expressed in miles per hour)
HOT Lane-Alt differs from the “HOT Lane” alternative only by the addition of a direct HOT lane ramp access to St. Peter Street in downtown St. Paul.
Appendix A

2005 Count vs. 2006 Modeled Volume Comparisons
Appendix B

2005 Count vs. 2030 Modeled Volume Comparisons
Appendix C

2005 Modeled vs. 2030 Modeled Volume Comparisons
Appendix D

2030 Modeled NO-Build vs. 2030 Modeled Concept 1 Volume Comparisons
Appendix E

2030 Modeled NO-Build vs. 2030 Modeled Concept 3 (with HOT Lanes) Volume Comparisons
CORSIM Traffic Model Simulation and Analysis

I-94 Managed Lanes Study

Between TH 55 in Downtown Minneapolis and John Ireland Boulevard in Downtown St Paul

SEH No. 106816

November 12, 2009
Executive Summary

Project Overview

As one of the tasks for the I-94 Managed Lanes Study which extended along the I-94 corridor from TH 55 in Downtown Minneapolis to John Ireland Boulevard in Downtown St Paul, CORSIM model simulation and analysis was undertaken to test two build alternatives (Concept 3 and Concept 4) that were selected from a number of concepts developed in the preceding project tasks.

Findings

The CORSIM models, using existing and projected 2030 traffic volumes, revealed the following:

1. Due to capacity constraints in the two downtown common areas (the Lowry Tunnel in Minneapolis and the Capitol Interchange in Saint Paul), the 2030 traffic models showed that the projected traffic is not able to pass through the study area. To better understand the impacts and/or benefits of the various concepts within the study area, it was concluded that the models should include scenarios with and without the capacity constraints in the two downtown areas.

2. There are some deficiencies with the current configuration of I-94 in the study area, especially on westbound I-94 between the TH 280 interchange and southbound I-35W exit ramp. The lane-drops (one at the exit ramp to Riverside Avenue on the right and the other at the exit ramp to the southbound I-35W on the left), create turbulence and poor levels of service for both AM and PM peak hours.

3. In the TH 280 interchange area, the modeling scenario of four westbound through lanes with a regular acceleration lane from the southbound TH 280 entrance ramp would provide better operations than the scenario of three through lanes with a fourth lane added from the southbound TH 280 entrance ramp.

4. A continuous fourth lane on westbound I-94 between Riverside Avenue and 5th Street would provide benefits to both passenger vehicles and bus users in the near term.

5. An eastbound I-94 lane drop at the exit ramp to Huron Boulevard, with a eastbound I-94 lane add at the entrance ramp from Huron Boulevard causes severe operational problems (if the left-most lane downstream is designated as an exit only lane to northbound TH 280).


7. Adding a continuous fourth lane through the Snelling Avenue Interchange for I-94 in both directions without any other capacity improvements would create merging problems in the downstream entrance ramp areas.

8. Adding High-Occupancy-Toll (HOT) lanes on the left for I-94 in both directions would accommodate traffic growth by 15% between the downtowns. However, further studies on improvements to the TH 280 interchange and HOT lane end points (where they would transition to general purpose lanes) are necessary.
1.0 Project Overview

1.1 Introduction

Providing access to the Central Business Districts (CBD) of Minneapolis and St. Paul, as well as to through interregional trips, the I-94 corridor between the downtowns is a critical link on Minnesota’s Interstate system. After the collapse of the I-35W Mississippi River Bridge in August 2007, Mn/DOT created a detour to redirect traffic around the closed portion of I-35W to a section of both eastbound and westbound I-94 between I-35W and TH 280. Capacity was added by restriping the existing lanes and shoulders in each direction of I-94 to accommodate the 20-percent increase in traffic along the detour route. While they eliminated the bus-only shoulders between I-35W and TH 280, these system improvements were successful in returning the congestion levels on I-94 to pre-collapse conditions.

Following the opening of the new I-35W bridge in September 2008, Mn/DOT completed an interim restriping project (completed October 12 and 13, 2008) that included safety and the restoration of some transit advantages. The fourth lane on westbound I-94 between Riverside Avenue and 25th Avenue was eliminated to allow for bus-only shoulder operation and provide a refuge for stalled vehicles, while in the eastbound direction; the 2-lane exit to TH 280 was reverted back to a single lane exit. With traffic volumes on I-94 returning to pre-collapse levels, Mn/DOT recognized a study opportunity to ensure that the I-94 lanes were used to provide the greatest benefits to all commuters. The I-94 Managed Lanes Study examined a variety of short and long-term managed lane alternatives in the I-94 corridor, both within the limits of the previously restriped shoulder (Highway 280 to I-35W) and expanded to include the entire corridor between downtown Minneapolis and downtown St Paul. These alternatives included High-Occupancy-Vehicle (HOV) lanes, High-Occupancy-Toll (HOT) lanes, Priced-Dynamic-Shoulder Lanes (PDSL), Dynamic Shoulder Lanes (DSL), and several hybrid alternatives.

Based on the high level travel demand analysis for the corridor and recommendations from project technical and advisory committees, two future build concepts (Concept 3 and Concept 4), along with the no build option, were selected for CORSIM simulation analysis. While conducting the simulation analysis, it was realized that the capacity constraints in the two downtown areas (the Lowry Tunnel in Minneapolis and the Capitol Interchange in Saint Paul) had significant effects on the operations in the study area. Therefore, it was determined that the build concepts would be tested under both a constrained and unconstrained condition in order to reveal problems and/or benefits in the project area.
The traffic models created for this study included following freeways:

- I-94 between TH 61 and I-394
- I-35W between 31st Street and the Mississippi River Bridge
- I-35E between Kellogg Boulevard and Pennsylvania Avenue
- TH 280 between I-94 and University Avenue
- TH 65/I-94/I-35W interchange
- TH 55/I-94/I-35W interchange

Figure 1-1 illustrates the study area and the CORSIM model limits for this study.

**Figure 1.1 – I-94 Managed Lanes Study and Model Areas**

1.2 CORSIM Modeling Approach

The CORSIM Traffic Model Simulation and Analysis for this study included the following step by step approach:

- Creation and calibration of an existing condition CORSIM Model based on pre-bridge collapse conditions in 2005
- Future 2030 no-build CORSIM analysis with and without capacity constraints in the downtown areas
- Future 2030 build CORSIM analysis for ‘base’ versions of Concept 3 and Concept 4, both with and without capacity constraints in the downtown areas
- Creation of modeling scenarios to test geometric variations to the two base concepts
- Future 2030 modeling scenarios analysis with and without capacity constraints in the downtown areas
- Selection of a preferred alternative for Concept 3 and Concept 4
- Preferred alternative CORSIM analysis with capacity constraints in the downtown areas.
- Preferred alternative CORSIM analysis using existing traffic volumes
- Creation of a final memorandum summarizing the CORSIM modeling procedure and results
1.3 Level of Service Criteria

The following criteria for Freeway Level of Service from the Highway Capacity Manual (HCM) were used to evaluate I-94 freeway mainline operations for this study:

**Table 1.1 – Freeway Measures of Effectiveness (MOEs)**

<table>
<thead>
<tr>
<th>Level of Service (LOS)</th>
<th>Description</th>
<th>Density (pc/mi/ln)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Free flow operations where free flow speeds and operating speeds are the same. Vehicles are unimpeded in their ability to maneuver.</td>
<td>≤ 10.00</td>
</tr>
<tr>
<td>B</td>
<td>Free flow speeds are generally maintained. Vehicle’s ability to maneuver is only slightly restricted.</td>
<td>&gt; 10.0 – 20.0</td>
</tr>
<tr>
<td>C</td>
<td>Free flow speeds are generally maintained. Freedom to maneuver is noticeably restricted. Queues may be expected to form behind any significant blockage.</td>
<td>&gt; 20.0 – 28.0</td>
</tr>
<tr>
<td>D</td>
<td>Speeds begin to decline with increased traffic. Freedom to maneuver is more noticeably restricted. Queues can be expected to form behind any minor incident.</td>
<td>&gt; 28.0 – 35.0</td>
</tr>
<tr>
<td>E</td>
<td>The lower boundary of LOS E is considered at capacity. Operations are very volatile with extremely limited room to maneuver. Any disruption such as lane changing or vehicle entering from a ramp can cause a breakdown and extensive queuing.</td>
<td>&gt; 35.0 – 43.0</td>
</tr>
<tr>
<td>F</td>
<td>Total breakdown in vehicular flow. Traffic is under stop and go conditions.</td>
<td>&gt; 43.0</td>
</tr>
</tbody>
</table>

2.0 Existing Conditions and CORSIM Model Calibration

2.1 Overview

An accurate existing CORSIM model is necessary to reliably simulate future traffic operations under both No-Build and Build conditions. The existing traffic model results can be compared against known operating conditions, whether field observed or measured. Adjustments to traffic model parameters are made to match as closely as possible to the known traffic operations, and these parameters are used in the models for future build options to produce reliable results and analysis.

For the purposes of this study, it was determined that the pre-bridge collapse (2005) condition should be considered as the baseline or existing condition. Due to the re-striping of I-94 between I-35W and TH 280, the current configuration on I-94 is different from the 2005 existing condition in the study area. Therefore, the calibration and evaluation of the base condition for this project largely relied on driving experience, historical reports, and incident and traffic data obtained from Mn/DOT detectors prior to the bridge collapse.

2.2 Existing Model Calibration

Using the Mn/DOT incident database, a total of thirteen incident-free days were identified in May, September and October of 2005 and 2006 in the project area. The traffic patterns on I-94 from those dates were further explored to identify a typical day for the base CORSIM model calibration. As a result, May 3, 2005 was identified as a “typical day”. All of the detector volume and speed data from this date was extracted and then balanced for the base CORSIM model calibration. Figure 2-1 in the appendix are based on the detector data and shows the areas with congestion (speeds below 45-mph) and areas with severe congestion for I-94 both directions during AM and PM periods. It is worth noting that the westbound I-94 speeds between Cretin Avenue and the Lowry Hill Tunnel were 30-MPH or less for the majority of the three hour PM peak period. The westbound I-94 PM peak period started at 2:00PM and ended at 7:00PM.
To replicate the actual existing conditions in the CORSIM models, the calibration process required several adjustments of the model parameters. Research showed that the over-congested conditions like I-94 during the PM peak required different parameters than the AM peak. This rational assumes motorists would drive differently (more aggressively) during over congested conditions. After a discussion with Mn/DOT, it was decided the AM and PM peak models should be calibrated separately provided that the corresponding calibrated parameters are carried over for the future year AM and PM models. In general, to replicate the initial congested conditions for westbound I-94 during the PM peak, the initial time period was extended and a higher demand volume was used for that period. This resulted in the existing operations being effectively replicated at the start of simulation.

2.3 Existing Operational Issues

CORSIM models for the 2005 existing conditions identified many well-known bottlenecks and operational deficiencies along the I-94 corridor within the model limits. These locations are discussed in detail below.

A. Eastbound and Westbound I-94/ Lowry Tunnel/I-394 ramps area
The Lowry Tunnel is a 1/3-mile-long cut-and-cover land bridge structure that provides three traffic lanes in each direction along I-94. The tunnel contains a curved segment, which limits speed and sight distance. On surface above, the tunnel defines the right-of-way for the convergence of major city streets — Lyndale Avenue and Hennepin Avenue. Further compounding the tunnel-related congestion are the ramps for I-394 on the west side of the tunnel. In the eastbound I-94 direction, the I-94 mainline narrows from 5 lanes to only two through lanes at the exit to westbound I-394. Downstream of this location, traffic enters from TH 55 via an acceleration lane, and a third lane is gained at the eastbound I-394 entrance to I-94 just west of the tunnel. The two-lane segment and the curve through the Lowry Hill tunnel result in congestion that extends from a point ½ mile upstream of the westbound I-394 exit through the tunnel to the Hennepin Avenue entrance to eastbound I-94.

In the westbound I-94 direction, traffic desiring to exit onto westbound I-394 must maneuver into the left lane in the tunnel creating additional friction in the right two lanes through the tunnel’s curved section. This results in peak hour densities of over 55 vehicles per lane/per mile/per hour. The queue extends across the I-94/I-35W downtown commons to the TH 280 interchange area during the PM peak.

B. Eastbound I-94 at 6th Street
The weave section on eastbound I-94 between the 6th Street entrance ramp and the Cedar Avenue entrance ramp is short at 570 feet. The distance between the Cedar Avenue entrance ramp and the Riverside Avenue exit is 1,400-feet. The high entering volumes from 6th Street create congestion on both the freeway mainline and the HOV bypass ramp.

C. Eastbound I-94 at Huron Boulevard
The curve along mainline I-94 east of Huron Boulevard limits sight distance causing eastbound I-94 traffic to slow to speeds below 45-MPH during the PM peak as it approaches the Mississippi River Bridge upstream of the curve. During the AM peak it has also been stated that traffic occasionally slows due to a low-rising sun on the horizon.

D. Eastbound I-94 at TH 280
Left hand exit and entrance ramps for TH 280 create some spot congestion through this area during PM peak due to the overloading of the left lane exit for northbound TH 280 and the weave across I-94 for traffic entering from southbound TH 280 destined for the right-hand Snelling Avenue exit.

E. Eastbound I-94 at Snelling Avenue
High traffic demand from Snelling Avenue enters I-94 creating a weave in the auxiliary lane between Snelling Avenue and Lexington Avenue. The weave between these two ramps creates a congested condition through this area during the PM peak.
F. Eastbound I-94 in Downtown St. Paul  
Vehicle back-ups occur near the Capitol interchange due to the lane drop east of John Ireland Boulevard and the weaving demand volumes through the I-94/I-35E common segment.

G. Westbound I-94 east of Downtown St. Paul  
During the AM peak there is a high demand volume headed westbound on I-94 exceeding the capacity of the three lane section of I-94 from the Mounds Boulevard exit to the NB I-35E exit.

H. Westbound I-94 at Cretin Avenue and TH 280 exit  
The volume demand through this area during the AM peak is at capacity for both the four and three lane sections provided along this segment of I-94.

I. Westbound I-94 at TH 280 entrance  
Under the 2005 conditions, the entrance ramp from southbound TH 280 enters westbound I-94 on the left hand side as a ramp with a regular acceleration lane. This left side entrance creates additional friction through the adjacent three-lane section by entering on the left side and adding 700 VPH to the 6,300 VPH in the adjacent lanes during the AM peak. These volumes well exceed the typical capacity of 2,000 vehicles per lane.

J. Westbound I-94 at the Riverside Avenue/25th Avenue Interchange  
Under 2005 conditions, the right lane in the interchange area gets overloaded due to high exiting demand at Cedar Avenue and 5th Street during the AM peak.

3.0 CORSIM Models Analysis

3.1 Overview  
A number of build concepts were developed for the I-94 corridor. These concepts included general purpose lanes, Dynamic Shoulder Lanes (DSL) and High-Occupancy-Toll (HOT) lanes. Based on the high level traffic demand analysis and recommendations from the project technical and advisory committees, two build concepts (Concept 3 and Concept 4), along with the no build scenario, were selected for further CORSIM traffic model analysis. Figures 3-1 and 3-2 illustrate the I-94 freeway mainline base lane configuration and modeling variations for the two build concepts in the study area.

The preliminary CORSIM analysis revealed that the capacity constraints in the two downtown areas had significant effect on the operations in the study area between the downtowns. It was decided that the build concepts needed to be tested under both constrained and unconstrained conditions in order to expose real problems in the project area.

A number of CORSIM modeling alternatives and scenarios were developed for the two base concepts to test different geometric variations at a number of locations. Preferred alternatives were selected based in part on the analysis. The preferred alternatives were then modeled using existing traffic volumes.

3.2 Assumptions for Removal of Capacity Constraints  
The purpose for modeling without capacity constraints was to develop a hypothetical, non-congested condition for the boundaries of the I-94 Managed Lanes Study so that any deficiencies associated with the proposed concepts between the downtowns could be identified using the CORSIM models. It was an iterative process to create such a condition. Two basic principles were followed in the process:

- Upstream - it was considered "without constraints" if the forecasted volumes could pass through into the I-94 Managed Lanes Study area.
- Downstream - it was considered "without constraints" if the queues didn't back up from the downstream segments into the I-94 Managed Lanes Study area.
To achieve the “—without constraints” conditions, the following capacity improvements were assumed in the 2030 Build CORSIM models within both downtown commons sections and the TH 280/Franklin Avenue interchange area:

- **Downtown Minneapolis:**
  - On eastbound I-94:
    - The eastbound I-394 entrance ramp is expanded to a two-lane ramp with the second lane drop occurring 600’ beyond the merge with eastbound I-94.
    - The Hennepin Avenue entrance ramp was expanded to a two-lane ramp.
    - A lane is added between the Hennepin Avenue Entrance ramp and 5th Avenue entrance ramp.
  - On westbound I-94:
    - The 11th Street exit only ramp is changed to a regular exit ramp with the 4th lane extended by 1100 feet to drop under the TH 65 Bridge.
    - The northbound I-35W/4th Avenue ramp is expanded to a two-lane ramp.
    - A lane is added between the northbound I-35W entrance ramp and the westbound I-394 exit ramp through the Lowry Tunnel.

- **Downtown St Paul:**
  - On eastbound I-94:
    - A lane is added between the northbound I-35E slip entrance ramp and Jackson Street entrance ramp.
    - The acceleration lane from the southbound I-35E entrance ramp is extended by 1000 feet to drop after the southbound TH 52 exit ramp.
    - A lane is added between the northbound TH 52 entrance ramp and the Mounds Boulevard entrance ramp. The Mounds Boulevard ramp is reduced to a single lane.
  - On westbound I-94:
    - A lane added is between the southbound I-35E slip entrance ramp and the Marion Street exit ramp.
  - On I-35E:
    - A lane is added between the Pennsylvania Avenue exit ramp and the Maryland Avenue exit ramp for both directions.
  - TH 280/Franklin Avenue interchange (this assumption was made to all 2030 models):
    - Franklin Ave/eastbound I-94 ramp intersection was signalized.

### 3.3 Geometric Configurations for Base Modeling Options

The base geometric configurations for the CORSIM models are as follows:

- **Base existing conditions within the I-94 CORSIM model limits (Modeling Scenario #1.0)**
  - 2005 (pre-bridge collapse)

- **Base 2030 no build conditions within the I-94 CORSIM model limits (Modeling Scenario #2.0)**
  - Base existing conditions described above, with the following:
    - New I-35W Mississippi River bridge (as constructed in 2008)
    - NB I-35W HOT lane to Downtown Minneapolis (as proposed in the UPA project)
The base build concepts developed and subjected to the CORSIM modeling are as follows:

- **Concept 3 V1 (Modeling Scenario #3.0)**
  - Four continuous general purpose lanes for eastbound I-94 between the 6th Street entrance ramp and the northbound TH 280 exit ramp
  - Four continuous general purpose lanes for westbound I-94 between the northbound TH 280 exit ramp and the Riverside Avenue exit ramp
  - An additional lane for I-94 in both directions under the Snelling Avenue bridge

Figure 3-1 in the appendix illustrates the I-94 freeway mainline lane configurations for Concept 3 V1 between downtown Minneapolis and downtown St Paul.

- **Concept 4 V1 (Modeling Scenario #5.0 and #7.0)**
  - Four general purpose lanes + HOT lane for eastbound I-94 between 6th Street and the Marion Street exit
  - Four general purpose lanes + HOT lane for westbound I-94 between the John Ireland entrance ramp and the Riverside Avenue exit ramp
  - Intermediate HOT/General Purpose lanes ingress/egress points between TH 280 and Huron Boulevard, between Cretin Avenue and Snelling Avenue, and between Lexington Avenue and Dale Street
  - New reversible left-hand HOV ramp from/to Downtown Minneapolis
  - New TH 280 interchange with right-hand exit/entrance ramps and Collector-Distributor (CD) Roads between TH 280 and Cretin Avenue

- **Concept 4 V1 (Revised for last CORSIM model run) (Modeling Scenario #7.1)**
  - Concept 4 V1 as described above, with the following modifications:
    - Three general purpose lanes between the CD roads and TH 280 for I-94 in both directions, with a one lane mandatory exit ramp from westbound I-94 to northbound TH 280, and a two-lane entrance ramp from the southbound TH 280 CD road to eastbound I-94 (one lane drops prior to the Cretin Avenue entrance)
    - Full auxiliary lane between Cretin Avenue and Snelling Avenue for eastbound I-94

Figure 3-2 in the appendix illustrates the I-94 freeway mainline lane configurations for Concept 4 V1 between downtown Minneapolis and downtown St Paul.

### 3.4 Concept 3 Variations and Modeling Scenarios

The configurations for Concept 3 V1 were described in the previous section. The project team, in coordination with Mn/DOT, proposed the following variations at specific locations to Concept 3 V1 for further modeling analysis.

- **Concept 3 V0:** Variation to Concept 3 V1 on westbound I-94 with the 4th lane addition starting from the 25th Avenue entrance on the right and terminating in a lane drop at the southbound I-35W exit (current configuration in 2009).
- **Concept 3 V2:** Variation to Concept 3 V1 on westbound in the TH 280 interchange area with the 4th lane drop at the exit ramp to northbound TH 280 on the right and then adding back a 4th lane from the southbound TH 280 entrance ramp on the left.
- **Concept 3 V3:** Variation to Concept 3 V1 on westbound with the 4th lane continuing through the Riverside Avenue Interchange to drop at 5th Street exit ramp.
- **Concept 3 V4**: Variation to Concept 3 V1 on eastbound with the 4th lane terminating in a lane drop at the Huron Boulevard Exit and adding the 4th lane back from the Huron Boulevard Entrance Ramp.
- **Concept 3 V5**: Variation to Concept 3 V1 on eastbound with a new exit ramp to Pascal St.

Figure 3-1 in the appendix graphically illustrates these options.

One or more of the above geometric variations, along with different assumptions on traffic and capacity constraints conditions, were incorporated into the Concept 3 V1 option to produce various modeling scenarios for the final CORSIM analysis. Those modeling scenarios for the Concept 3 variations are described as follows:

<table>
<thead>
<tr>
<th>Modeling Scenario</th>
<th>Concept</th>
<th>Constraint Conditions</th>
<th>Year of Traffic Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>#3.0</td>
<td>Concept 3 V1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>#3.1</td>
<td>Concept 3 V2+V0</td>
<td>With Constraints</td>
<td>2005</td>
</tr>
<tr>
<td>#3.2</td>
<td>Concept 3 V3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>#4.1</td>
<td>Concept 3 V3</td>
<td>With Constraints</td>
<td>2030</td>
</tr>
<tr>
<td>#6.0</td>
<td>Concept 3 V1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>#6.1</td>
<td>Concept 3 V2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>#6.2</td>
<td>Concept 3 V3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>#6.3</td>
<td>Concept 3 V2+V3</td>
<td>Without Constraints</td>
<td>2030</td>
</tr>
<tr>
<td>#6.4</td>
<td>Concept 3 V2+V3+V4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>#6.5</td>
<td>Concept 3 V2+V3+V5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**3.5 Concept 4**

The configurations for Concept 4 V1 were described in Section 3.3. Based on earlier preliminary modeling analysis results, the project team, in coordination with Mn/DOT, proposed adding a new left-hand eastbound HOV ramp to St. Peter Street in Downtown St Paul for further modeling analysis.

Figure 3-2 in the appendix graphically illustrates this option as “Option for the New Left-Hand St. Peter Street HOV Ramp”.

**3.6 CORSIM Modeling Results**

All future CORSIM models were built based on the existing models to reflect the proposed geometry for the different concepts and scenario variations. The calibrated parameters in the existing models were carried forward.

Table 3-1 in the appendix summarizes the westbound I-94 freeway model results for all Concept 3 modeling scenarios using 2030 AM and PM traffic projections with and without the capacity constrained conditions. For comparative purposes, the results for 2030 no build are also included in the table.

Table 3-2 in the appendix summarizes the eastbound I-94 freeway model results for all Concept 3 modeling scenarios using 2030 AM and PM traffic projections with and without capacity constrained conditions. For comparative purposes, the results for 2030 no build are also included in the table.

Table 3-3 in the appendix summarizes the westbound I-94 freeway model results for the preferred Concept 3 modeling scenarios using existing AM and PM traffic volumes. For comparative purposes, the results for calibrated existing models are also included in the table.
Table 3-4 in the appendix summarizes the eastbound I-94 freeway model results for the preferred Concept 3 modeling scenarios using existing AM and PM traffic volumes. For comparative purposes, the results for calibrated existing models are also included in the table.

Table 3-5 in the appendix summarizes the westbound I-94 freeway model results for Concept 4 modeling scenarios using 2030 AM and PM traffic projections with and without capacity constrained conditions. For comparative purposes, the results for 2030 no build are also included in the table.

Table 3-6 in the appendix summarizes the eastbound I-94 freeway model results for Concept 4 modeling scenarios using 2030 AM and PM traffic projections with and without capacity constrained conditions. For comparative purposes, the results for 2030 no build are also included in the table.

3.7 Findings
The analysis based on the modeling results reveals following findings:

3.7.1 Concept 3
Concept 3 V0
Concept 3 V0 represents the current configuration in 2009 for westbound I-94 between the Riverside Avenue exit ramp and the southbound I-35W exit ramp. By comparing the results of Modeling Scenario #3.1 and Modeling Scenario #1 (existing pre bridge collapse conditions) in Table 3-1, it was found that this option created a bottleneck at the westbound I-94/Riverside Avenue interchange area. The AM model results show that the westbound queue backed up from the bottleneck into the TH 280 interchange area. The two lane-drops, one at the exit ramp to Riverside Avenue on the right and the other at the exit ramp to southbound I-35W on the left, created turbulence and poor levels of service for both AM and PM peak hours. It is worth noting that the detector data in May 2009 verified the CORSIM modeling results for this modeling scenario.

In summary, the modeling results showed that Concept 3 V0 was not a preferable option.

Concept 3 V1
Concept 3 V1 is the base option for Concept 3. For eastbound I-94, this option provides four continuous lanes between the 6th Street entrance ramp and the northbound TH 280 exit ramp in Minneapolis, and between the southbound TH 280 entrance ramp and the 5th Street exit ramp in St. Paul by adding a fourth lane between Huron Boulevard and TH 280, as well as under the Snelling Avenue Bridge. For westbound I-94, this option provides four continuous lanes between the John Ireland Boulevard entrance ramp in St. Paul and the Riverside exit ramp in Minneapolis by adding a fourth lane under the Snelling Avenue bridge and between TH 280 and Huron Boulevard.

The results from Modeling Scenario #3.0 and Modeling Scenario #1 show that the freeway operations for eastbound I-94 improve substantially, especially during the PM peak, due to the removal of the bottleneck at the eastbound I-94/northbound TH 280 exit ramp by adding the fourth lane between Huron Boulevard and TH 280. In addition, the westbound I-94 freeway operations under the Concept 3 V1 conditions were better than those under pre-bridge collapse conditions (see results from Modeling Scenario #3.2 and Modeling Scenario #1 in Table 3-3 in the appendix).

In summary, while the modeling results showed that Concept 3 V1 improved the traffic operations in the corridor, further refinements were considered as discussed in the following text.

Concept 3 V2
Concept 3 V2 represents the current (2009) configuration in the westbound I-94/TH 280 interchange area. The westbound I-94 right lane drops on the right at the northbound TH 280 exit ramp, while the westbound I-94 entrance ramp from southbound TH 280 becomes a full fourth lane on the left. By comparing the results from Modeling Scenarios #6.0 (Concept 3 V1, 2030 traffic) and #6.1 (Concept 3 V2, 2030 traffic) in Table 3-1, it is found that the freeway operations for the latter scenario would become worse, especially during the
2030 AM peak hour. This finding was verified by comparing the results from Modeling Scenarios #6.2 (Concept 3 V3, 2030 traffic) and #6.3 (Concept 3 V3+V2, 2030 traffic), also shown in Table 3-1.

In summary, the modeling results showed that Concept 3 V2, without a fourth westbound I-94 lane through the TH 280 interchange, would create turbulence and poor levels of service in the area.

Concept 3 V3
Concept 3 V3 includes a new variation for westbound I-94 between the Riverside Avenue exit ramp and the southbound I-35W exit ramp. In this concept, the fourth lane continues through the westbound I-94/Riverside Avenue interchange and terminates in a lane drop at the 5th Street exit ramp. This means that this concept would include a regular deceleration lane to the southbound I-35W exit ramp (as in the pre-bridge collapse configuration).

By comparing the results of Modeling Scenarios #6.0 (Concept 3 V1, 2030 traffic) and #6.2 (Concept 3 V3, 2030 traffic) in Table 3-1, it is found that this option removed the bottleneck at the westbound I-94 Riverside Avenue exit ramp. This finding was validated based on the results from the Modeling Scenarios #3.0 (Concept 3 V1, existing traffic) and #3.3 (Concept 3 V3, existing traffic) as shown in Table 3-3.

Based on the analysis of the various unconstrained scenarios with 2030 traffic, this Concept 3 V3 was selected as a preferred alternative and was then evaluated using capacity constrained conditions. The results from Modeling Scenario #2 (no build pre-bridge collapse condition, 2030 traffic) and Modeling Scenario #4.2 (Concept 3 V3, capacity constrained with 2030 traffic) in Tables 3-1 and 3-2, show that the I-94 freeway operations for the build option would become worse than those for the no build option, especially for westbound I-94 during the PM peak hour. The explanation for this is that under build conditions, the traffic forecasts were 8% higher than under no-build. This additional traffic resulted in longer queues from the bottleneck at the Lowry Tunnel into the project area.

Since this concept would benefit parallel corridors, an analysis with a broader influence area from the regional model was conducted to fully evaluate it. The analysis indicated that the capacity constraints in the two downtown areas would have significant impacts on operations in the study area, especially in the PM peak hour when the corridor is normally over-congested.

As mentioned previously, this concept was analyzed using existing traffic volumes and compared with pre-bridge collapse and current configuration scenarios. The results showed it would improve the operations in the corridor substantially.

In summary, the modeling results showed that Concept 3 V3, with a continuous fourth lane on westbound I-94 through the Riverside Avenue/25th Avenue interchange, would improve traffic operations significantly in the study area, especially in the near term.

Concept 3 V4
Concept 3 V4 includes a new variation for the eastbound I-94/Huron Boulevard interchange. Under this concept, the fourth lane drops at the Huron Boulevard exit ramp and is added back with the entrance ramp from Huron Boulevard. By comparing the results from Modeling Scenario #6.3 (Options V2+V3, 2030 traffic) and Modeling Scenario #6.4 (Options V2+V3+V4, 2030 traffic) in Table 3-2, it is determined that this option would create a significant bottleneck for eastbound I-94 during both the AM and PM peak hours.

In summary, the modeling results showed that the Concept 3 V4, without a fourth lane on eastbound I-94 through the Huron Boulevard Interchange, is not a preferred option.

Concept 3 V5
Concept 3 V5 includes a new variation for the eastbound I-94/Snelling Avenue interchange by adding a new exit ramp at Pascal Street. By comparing the results from Modeling Scenario #6.3 (Concept 3 V2+V3, 2030 traffic) and #6.4 (Options V2+V3+V4, 2030 traffic) in Table 3-2, it is determined that this option would create a significant bottleneck for eastbound I-94 during both the AM and PM peak hours.

In summary, the modeling results showed that the Concept 3 V5, without a fourth lane on eastbound I-94 through the Snelling Avenue interchange, is not a preferred option.
traffic) and Modeling Scenario #6.5 (Concept 3 V2+V3+V5, 2030 traffic) in Table 3-2, this new exit ramp would make operations on the I-94 mainline slightly worse in the TH 280 and Snelling Avenue area.

In summary, the modeling results showed that Concept 3 V5, adding a new exit ramp at Pascal Street, is not a preferred option.

**Continuous 4th lane on I-94 under Snelling Avenue**

All 2030 Concept 3 modeling scenarios assumed a continuous fourth lane through the Snelling Avenue Interchange for I-94 in both directions. Therefore, it was not possible to evaluate the advantages or disadvantages of this option for future year modeling scenarios. Under existing conditions, however, Modeling Scenario #1, which reflects the pre-bridge collapse condition (without the fourth lane under Snelling Avenue), was compared to Modeling Scenario #3.1 (Concept 3 V1, existing traffic) in Tables 3-3 and 3-4. This comparison shows that the operations for Concept 3 V1 near the exit ramps to Snelling Avenue improved slightly while the operations in the Snelling Avenue entrance ramp areas downstream became a little worse for I-94 in both directions during the AM and PM peak hours.

In summary, the existing modeling scenario results show that the option of adding a fourth lane for I-94 under the Snelling Avenue Bridge would need to be further studied using a broader influence area.

### 3.7.2 Concept 4

**Concept 4**

As described previously, this concept introduces a new HOT lane in the median of I-94 in both directions. It designates certain locations where traffic is allowed to enter/exit the HOT lane from/to the general purpose lanes. A new I-94/TH 280 interchange with CD roads between Snelling Avenue and Vandalia Street/Cretin Avenue is incorporated into the concept as an attempt to eliminate current weaving problems in the area. Additionally, a new reversible HOV ramp (open for I-94 westbound exiting traffic to downtown in AM peak while for I-94 eastbound entering traffic from downtown in PM peak) is proposed to align the HOT lanes with the current 5th Street and 6th Street ramps.

The results of Modeling Scenario #7.0 in Tables 3-5 and 3-6 indicate that this concept would operate well with the exception of some areas, including the TH 280 and Dale Street interchanges for eastbound I-94 and the Riverside Avenue interchange for westbound I-94, considering that the build option traffic demands would be about 15% higher than the no build option in the corridor.

**New St. Peter Street HOV Ramp**

This option considered a new left-hand eastbound HOV ramp St. Peter Street in downtown St. Paul to eliminate weaving problems in the I-94/HOT Lane Access/Dale Street interchange area. In Base Concept 4 without the new ramp, the eastbound HOT traffic destined to downtown St. Paul would have to weave across four general purpose lanes to exit at the Marion Street Ramp or the 5th Street Ramp, creating turbulence and poor levels of service in the area. By comparing the modeling results from Modeling Scenario #7.0 (Base Concept 4) and Modeling Scenario #7.1 (Base Concept 4 with New St. Peter Street HOV Ramp) in Table 3-6, it is found that the freeway operations in the weaving area improved significantly in the PM peak. However, the freeway operations in the area were still at unacceptable levels of service E or F.

**Capacity Constrained Conditions**

Similar to the no build and Concept 3, the results from Modeling Scenario #5 under capacity constrained conditions (shown in Tables 3-5 and 3-6) indicates that the I-94 freeway operations would continue to deteriorate, especially in the westbound direction during the PM peak. The bottlenecks in the two downtown areas have tremendous impacts on the effectiveness and efficiency of capacity improvement projects within the study area.
4.0 Bus Only Shoulders Analysis

Authorized buses are allowed to run on the outside shoulders within the I-94 corridor between the downtowns to avoid congestion on the mainline. The general rules for bus only shoulder lanes are twofold. First, the maximum speed for buses on the shoulder is 35 mph. Second, the speed of the buses on the shoulder is limited to no more than 15 mph above the speed of the adjacent general traffic.

One of the goals for this project is to preserve or enhance advantages for transit. All previous CORSIM modeling analysis was conducted for general traffic as, due to their unique operations, the freeway bus-only shoulders were not included in the CORSIM models. Therefore, the Measures of Effectiveness (MOEs) for buses weren’t available from model outputs. To analyze bus operations for different modeling scenarios, the output for speeds by lane and freeway segment distance were used to calculate the average running speeds based on the assumption that buses would run either on the right lane or shoulder lane. Therefore the speed for buses on any freeway segment could be calculated as follows:

- For the freeway segments where bus-only shoulders were not available, the right lane speeds were used for buses.

- For the freeway segments where bus-only shoulders were available, the bus speed would be the right lane speed if it was greater than 35 mph; 35 mph if the right lane speed was between 35 mph and 20 mph; or the right lane speed plus 15 mph when the right lane is less than 20 mph.

The bus operations along the westbound I-94 freeway segment between the TH 280 interchange and the 5th Street exit varied in different modeling scenarios. Due to right-of-way constraints, bus-shoulder lanes on some segments had to be removed to fulfill some options for Concept 3.

Figure 4-1 in the appendix illustrates the bus operations for three conditions: pre-bridge collapse, Concept 3 V1 and Concept 3 V3. As shown in the figure, buses would operate during the AM peak hour most favorably in Concept 3 V3, and operate the worst in Concept 3 V1 (due to the bottleneck at the Riverside Avenue exit ramp). In Concept 3 V1, the queue would back into the TH 280 interchange area, where the bus-only shoulders are not available between TH 280 and Huron Boulevard to bypass the queue. In the PM peak hour, buses operate the best under the pre-bridge collapse condition because buses could take full advantage of bus-only shoulders during congested conditions. The diagrams also show that the general traffic would operate much worse under Concept 3 V1.

Figure 4-2 in the appendix illustrates the bus operations for Concept 3 V3 and the pre-bridge collapse conditions in 2030. The results show that by 2030 or even earlier, the buses under pre-bridge collapse conditions would take advantage of the shoulder lanes in both the AM and PM peak hours. As analyzed before, the corridor in Concept 3 V3 would become over congested in both the AM and PM peak hours due to the queue back-up from the Lowry Hill Tunnel.

In summary, the modeling results show that Concept 3 V3 is not favorable for buses in either the existing PM peak hour or the 2030 AM and PM peak hours, even though it is the best for general traffic, compared to pre-bridge collapse conditions. A more comprehensive cost/benefit analysis including total person delays, throughputs and compatibility with long-term planning policies along the corridor will need to be conducted to determine the final option for implementation.

5.0 Conclusions

Based on the CORSIM analysis of the concepts developed and described above, Concept 3 V3 and Concept 4 V1 (with the HOV exit ramp to St. Peter Street) were presented to the project technical team as the near-term and long-term recommended alternatives for the I-94 corridor, respectively.
Appendix:

Figure 2-1 (I-94 Freeway Existing Peak Period Speed Contours)
Figure 3-1 (I-94 Lane Schematics for Various Concept 3 Options)
Figure 3-2 (I-94 Lane Schematics for Concept 4 Options)
Table 3-1 (I-94 Westbound Freeway Peak Hour Operations Comparison 2030 Volumes, Concept 3 Scenarios)
Table 3-2 (I-94 Eastbound Freeway Peak Hour Operations Comparison 2030 Volumes, Concept 3 Scenarios)
Table 3-3 (I-94 Westbound Freeway Peak Hour Operations Comparison 2005 Volumes, Concept 3 Scenarios)
Table 3-4 (I-94 Eastbound Freeway Peak Hour Operations Comparison 2005 Volumes, Concept 3 Scenarios)
Table 3-5 (I-94 Westbound Freeway Peak Hour Operations Comparison No-Build and Concept 4 Scenarios)
Table 3-6 (I-94 Eastbound Freeway Peak Hour Operations Comparison No-Build and Concept 4 Scenarios)
Figure 4-1 (I-94 By Lane Peak Hour MOE and Bus Operation Comparisons – 2005 Traffic Conditions)
Figure 4-2 (I-94 By Lane Peak Hour MOE and Bus Operation Comparisons – 2030 Traffic Conditions)
I-94 Managed Lanes Study

Between Downtown Minneapolis and Downtown St Paul

I-94 Freeway Existing Peak Period Speed Contours

Figure 2-1
I-94 Managed Lanes Study
Between Downtown Minneapolis and Downtown St Paul

Base Concept 3 V1: I-94 between Downtown Minneapolis and Downtown St Paul

Concept 3 V0: WB I-94 Exit Only to SB I-35W
Concept 3 V2: WB I-94 three through lanes at TH 280
Concept 3 V3: WB I-94 four through lanes to drop at 5th Street Exit
Concept 3 V4: EB I-94 Lane Drop at Huron Exit
Concept 3 V5: EB I-94 New Exit Ramp at Pascal Street

Note:
1) The base Concept 3 V1 shows the lane schematics for all the corridor in the study area.
2) Other concept 3 options illustrate variations to the base option at specific locations.
Base Concept 4 Option: I-94 between Downtown Minneapolis and Downtown St Paul

Concept 4 Option for the New Left-hand St Peter Street HOV ramp
### Table 3-1 I-94 Westbound Freeway Peak Hour Operations Comparison (2030 Volumes_Concept 3 Scenarios, CORSIM Model Results)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Mode</th>
<th>Lane Config.</th>
<th>Volumes</th>
<th>Density (veh/ln</th>
<th>Speed (mph)</th>
<th>Comments</th>
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<td>V1</td>
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<tr>
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<td>AM</td>
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<td>7,000</td>
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</table>

1. Bottleneck in the Riverside exit, queue backed to TH 280.
2. Bottleneck in the Riverside exit, queue backed to TH 280.
4. Bottleneck in the Riverside exit, queue backed to TH 280.
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97. Bottleneck in the Riverside exit, queue backed to TH 280.
98. Bottleneck in the Riverside exit, queue backed to TH 280.
100. Bottleneck in the Riverside exit, queue backed to TH 280.
### Table 3-2 I-94 Eastbound Freeway Peak Hour Operations Comparison (2010 Volumes_Concept 3 Scenarios, CORSIM Model Results)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>AM</th>
<th>PM</th>
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<tbody>
<tr>
<td><strong>V1</strong></td>
<td><strong>V2</strong></td>
<td><strong>V3</strong></td>
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<tr>
<td><strong>Density (vplph)</strong></td>
<td><strong>Counts (vph)</strong></td>
<td><strong>Speed (MPH)</strong></td>
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<tr>
<td>AM</td>
<td>92</td>
<td>99</td>
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</tbody>
</table>

**Notes:**
- **V1** refers to the baseline scenario.
- **V2**, **V3**, **V4**, and **V5** represent various concept scenarios.
- **LOS C** indicates a level of service that is considered satisfactory.
- **LOS D** indicates a level of service that may lead to incidents.
- **LOS E** indicates a level of service that may lead to severe delays.
- **LOS F** indicates a level of service that may lead to gridlock.

*This is a table that compares the Eastbound peak hour operations for various scenarios, focusing on key metrics such as density, counts, and speeds.*
<table>
<thead>
<tr>
<th>Scenario</th>
<th>Peak Hour AM</th>
<th>Speed (MPH)</th>
<th>Density (vplph)</th>
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<tr>
<td>#3</td>
<td>58</td>
<td>13</td>
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</table>

**Comments**

1) Bottlenecks at Downtown St Paul, TH280 and the Lowry Hill Tunnel/Downtown MPLS area, similar to pre-bridge collapse condition, validated with detector data.

2) Minor problem between the Snelling and Vandania Tunnel/Downtown MPLS area, similar to pre-bridge collapse condition, validated with detector data.

3) Huge bottleneck in the Lowry Hill Tunnel/Downtown MPLS area, similar to pre-bridge collapse condition, validated with detector data.

4) The queue from the Tunnel/Downtown MPLS area was getting worse between 25th Ave and TH280, compared to #1. The queue built up from Riverside exit ramp.

5) No major problem between SB 8th and TH 280.

6) The queue from the Tunnel/Downtown MPLS area was getting worse.

7) The queue from the Tunnel/Downtown MPLS area was getting worse.

8) No major problem between SB 8th and TH 280.

9) The queue from the Tunnel/Downtown MPLS area was getting worse.
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<tr>
<th>Table 3-4</th>
<th>I-94 Eastbound Freeway Peak Hour Operations Comparison (2005 Volumes_Concept 3 Scenarios, CORSIM Model Results)</th>
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### Table 3-5 I-94 Westbound Freeway Peak Hour Operations Comparison (Nobuild & Concept 4 Scenarios, CORSIM Model Results)

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<th>Scenario</th>
<th><strong>Entering</strong></th>
<th><strong>Leaving</strong></th>
<th><strong>General Purpose Lanes</strong></th>
<th><strong>HOT Lanes</strong></th>
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<td>Density(vplph)</td>
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**Comments:**
- 1) Free flow, i.e. delay = 0.
- 2) Bottleneck at the Riverside Freew. due to a queue buildup.
- 3) Bottleneck at the St. Paul Freeway Interchange.
- 4) Bottleneck at the I-90/I-94 Overpass.
### Table 3-6 I-94 Eastbound Freeway Peak Hour Operations Comparison (Nobuild & Concept 4 Scenarios, CORSIM Model Results)

<table>
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<tr>
<th>Concept</th>
<th>General Purpose Lanes</th>
<th>High Speed Lanes</th>
<th>Remarks</th>
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- **General Purpose Lanes**
- **High Speed Lanes**
- **Remarks**

**Modeling Scenario**

- **AM (7:00-8:00AM)**
- **PM (4:30-5:30PM)**

**Entrance**

- **Entrance**
- **Entrance**
- **Entrance**
- **Entrance**
- **Entrance**

**Entrance**

- **Entrance**
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- **Entrance**

**Remarks**

- **Remarks**
- **Remarks**
- **Remarks**
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- **Remarks**

**Density (vplph)**

- **Density (vplph)**
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- **Density (vplph)**

**Speed (MPH)**

- **Speed (MPH)**
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- **Speed (MPH)**
- **Speed (MPH)**

**Demands (vph)**

- **Demands (vph)**
- **Demands (vph)**
- **Demands (vph)**
- **Demands (vph)**
- **Demands (vph)**

**LOS**

- **LOS**
- **LOS**
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- **LOS**

**CORSIM Model Results**

- **CORSIM Model Results**
- **CORSIM Model Results**
- **CORSIM Model Results**
- **CORSIM Model Results**
- **CORSIM Model Results**
Vol. Density Speed
[43, 222] 35 43
LOS E
x
AM transit ridership: 1100
PM transit ridership: 360
Free Flow Speed: 80 MPH

Vol. Density Speed
[112, 222] 28 35
x
x
x
x
x

Regular Traffic Occupancy: 1.414

Table 4-1:

<table>
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<tr>
<th>Time Period</th>
<th>Total Transit Person Delay (Minutes)</th>
<th>Total Regular Traffic Person Delay (Minutes)</th>
<th>All Person Delays (Minutes)</th>
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<td>1,135</td>
<td>3,857</td>
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<tr>
<td>PM</td>
<td>7,463</td>
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<td>9,568</td>
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**Legend & Notes**

- **Bus Average Speed** between TH 280 and 5th St (MPH):
  - **43** for Concept 3_V1 AM
  - **38** for Concept 3_V1 PM
  - **31** for Concept 3_V3 PM

**I-94 Bylane Peak Hour MOE and Bus Operation Comparisons (2005 Traffic Conditions)**

(CORSIM model results, options for prebridge, concept 3 V1 and V3)
Legend

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Vol. Density Speed

- Regular Traffic Occupancy: 1.414
- All-transit occupancy: 0.16

Free Flow Speed: 60 MPH

I-94 Bylane Peak Hour MOE and Bus Operation Comparisons (2030 Traffic Conditions)

(CORSIM model results, prebridge configuration and concept 3_V3)

Figure 4-2

SB TH 280 Entrance

Most right lane speeds in V3 lower than 35 MPH, advantage to bus only shoulder concepts

V3 right lane speeds less than 30 MPH, advantage to bus only shoulder concept