DEPARTMENT OF TRANSPORTATION

Refining Return on Investment Methodology/ Tool for MnPASS

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16. Abstract (Limit: 250 words)

A refined return on investment (ROI) methodology is explored to supplement existing benefit-cost analysis (BCA) tools, data, and methodologies available to evaluate MnPASS managed lane projects. This would also facilitate more consistent and standardized measures for MnPASS system assessment and comparison. In this study, researchers investigated a more comprehensive set of factors, variables, and perspectives to include within the refined ROI analysis framework based on the limitations summarized in the current MnPASS BCA methodology; the major concerns identified from agency staff interviews; and available data resources. The selected cost components included initial capital costs, annual operating and maintenance costs, remaining capital value, and the potential benefit components consisted of travel time savings, vehicle operating cost savings, safety benefits, travel time reliability, transit benefit, induced traffic, emergency response, emissions impacts, and noise impacts. Tractable calculation methods were further explored for each cost and benefit measurement in order to facilitate use of the economic analysis tool. To verify the performance of the proposed methodology, the research team conducted a comparative demonstration, which produced a higher benefit-cost ratio than previous work. Furthermore, the contributions from additional benefit considerations highlighted the importance of integrating a wider range of project impact categories in the MnPASS ROI analyses.

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REFINING RETURN ON INVESTMENT METHODOLOGY/TOOL FOR MNPASS

FINAL REPORT

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EXECUTIVE SUMMARY

The implementation of MnPASS tolling lane projects has proven to be an effective way to relieve traffic congestion, manage increased travel demand, and maximize the benefit of limited public investments. With support for continued implementation of MnPASS-type facilities, MnDOT has been planning further expansion of MnPASS managed lanes in the Twin Cities metropolitan region to address estimated population increases and improve mobility in the region. As such, it is important to carefully select the next set of roadways to consider for managed lanes, to increase various public benefits in heavily congested areas with lower investment costs.

The evaluation and selection of alternative MnPASS corridors have traditionally been conducted through a series of geometric, operational, and financial viability assessments, for which cost estimates and performance measures have been collected to compare candidate options identified through travel demand forecasting. This allows the MnPASS system to operate in a fiscally responsible manner, and the goal of “lower costs and higher benefits” is beneficial for presenting quantifiable values to decision makers for implementation. While recommendations and results of prior studies have been generally considered reliable and accurate within their respective analysis scopes, each evaluation relied on different objectives and assumptions in achieving results. Further, the existing benefit-cost analysis tool used by MnDOT typically includes a restricted range of performance measures, which has achieved the highest degree of consensus among cost-benefit practitioners, specifically user benefits in the form of travel time savings, operating cost, and crashes. Potential inconsistency and limited consideration of benefits may impede the fair and thorough evaluation of candidates.

To better facilitate improved return on investment (ROI) assessment in MnPASS analyses, the objective of this project was to develop a refined, consistent, and standardized ROI methodology and tool. Taking into account the limitations summarized in the current MnPASS BCA methodology (Chapter 1), the major concerns identified from the agency interviews (Chapter 2) and available data resources, the research team identified a series of candidate cost and benefit components to develop the refined ROI assessment framework relating to MnPASS investments (Chapter 3). Typically, the main cost components included to estimate the direct cost of new investments in a MnPASS project were:

- Initial capital costs
- Operating and maintenance costs
- Remaining capital value

The primary impacts and user benefits selected to comprehensively evaluate the positive and negative performance of a MnPASS project include:

- Travel time savings
- Vehicle operation costs
- Crash cost savings
- Travel time reliability
- Freight benefits

- Transit benefits
- Induced traffic/travel
- Emergency response
- Emissions impacts
- Noise impacts

Tractable methodologies, data needs, adaptable tools, and estimation procedures were further refined (Chapter 4) for the measurement of each selected cost and benefit component. Researchers defined approaches for these measurements along with some necessary assumptions related to the calculation of cost and benefit values. The cost estimation focused on measuring the dollar costs generated in initial planning and construction and the costs associated with routine facility operation and maintenance; the benefit measurement addressed potential impacts directly attributable to highway users by comparing the Build (Improvement Case) to a No-Build (Base Case) scenario using the results of travel demand forecasting and other traffic modeling efforts.

In Chapter 5, a previous benefit-cost analysis on the I-35W North Managed Lanes project was selected to demonstrate the refined ROI framework. It also provided a comparison of the refined methods versus the original framework. The comparison results revealed that besides traditional traffic efficiency indicators (e.g., travel time savings, vehicle operating cost), several additional categories had a meaningful influence on the overall evaluation results. For example, travel time reliability and transit benefits contributed a substantial part of user benefits, while the negative emission and noise impacts produced smaller effects. After integrating a wider range of project impact categories, the benefit-cost ratio rose from 2.11 to 3.40 over the same 20-year analysis period, indicating that the MnPASS projects have more positive impacts on society and the economy than previously identified, and the new refined methodology is helpful in capturing these additional benefits of MnPASS.

CHAPTER 1: INTRODUCTION

The Minnesota Department of Transportation (MnDOT) operates MnPASS Express Lanes, which are a type of managed toll lane that provide a congestion-free alternative during peak rush hour periods for commuters. By providing dedicated lanes at no charge for high-occupancy vehicles (HOV), transit vehicles and riders, carpoolers, and motorcyclists, and charging a toll for single occupant vehicles (SOV), the strategy's aim is to enhance traffic operations through flow maximization, improve person throughput through increases in average vehicle occupancies and transit ridership, reduce incidents and crashes, and improve travel time reliability (Cambridge Systematics Inc, 2005). Two existing HOV corridors have been converted to MnPASS lanes: I-394, since 2005; and I-35W, since 2009, but then extended farther south in 2011. MnPASS lanes were most recently added to I-35E in two phases between 2015 and 2016 (see Figure 1). As a result, the implementation of MnPASS tolling lane projects has proven to be an effective way to relieve traffic congestion, manage increased travel demand, and maximize the benefit of limited public investments (Cambridge Systematics Inc, 2010, Cao et al., 2012, Cofiroute USA, 2013). It has been reported that the conversion of I-394 managed toll lanes has led to a considerable improvement in mobility:

- MnPASS lanes' peak hour volumes increased 9-33%;
- Total I-394 peak hour roadway volumes increased by up to 5%;
- 98% of time speeds in the MnPASS lanes are maintained above 50 miles per hour (mph);
- Travel speeds in the general-purpose lanes increased by 2 to 15%;
- Transit ridership and carpools levels increased; and
- There was a 45% reduction in crashes (Thompson, 2010a, Hourdos, 2015).

From April 2012 to March 2013, the MnPASS Express Lanes had a total of more than 2 million trips and generated $3.1 million dollars in toll revenue for both I-394 and I-35W express lanes (Cofiroute USA, 2013).

Figure 1. MnPass Express Lane System (Metropolitan Council 2040 Transportation Policy Plan)

With support for continued implementation of MnPASS-type facilities, MnDOT has been planning further expansion of MnPASS Express Lane projects in the Twin Cities metropolitan region since 2010 to address estimated population increases and improve regional mobility (e.g., the 2040 Transportation Policy Plan). Planning efforts for the next MnPASS system expansion are displayed in Figure 1.

MnPASS Express Lanes generally operate during peak rush hour periods. During peak periods, transit and carpools (two or more passengers) can use the MnPASS lanes for free, while solo motorists with a MnPASS transponder can choose to use the lanes by paying a fee that averages about $1.50 (Parsons Brinckerhoff, 2015). In this context, it is important to carefully select the next set of roadways to be considered for managed lanes to increase various public benefits in heavily congested areas with lower investment costs.

The evaluation and selection of alternative MnPASS corridors was conducted through a series of financial viability assessments, where cost estimation, benefit-cost analysis (BCA), and performance measures were evaluated to compare candidate options with the assistance of travel demand forecasting. This allows the MnPASS system to operate in a fiscally responsible manner, and the goal of "lower costs and higher benefits" is beneficial for presenting quantifiable values to decision makers for the final construction. While recommendations and results of prior studies were generally considered to be good, each analysis relied on different objectives and assumptions in achieving results. Further, the existing benefit-cost analysis tool used by MnDOT typically includes a fairly narrow range of performance measures, specifically user benefits in the form of travel time, operating costs, and crashes. Such inconsistency and limited consideration of benefits would be expected to hamper the fair evaluation of candidates.

Return on investment (ROI) analysis is widely applied in the field of transportation infrastructure development for evaluating the efficiency of an investment or comparing the efficiency of different investments. The objective of this project, therefore, is to develop and refine a consistent and standardized ROI methodology and tool for better assessing MnPASS programs and projects. The emphasis is to investigate a more comprehensive set of factors, variables and perspectives to include within the refined ROI analysis framework, such as transit impacts, travel time reliability, and environmental benefits (e.g., emission and noise reduction) that are not included within the existing economic analysis. Addressing the challenges of incorporating these concerns and impacts and proposing a consistent and standard evaluation framework will be key parts of the refined methodology. Ultimately, this project will identify existing best practices of ROI assessment for the MnPASS system and provide recommendations for conducting standardized ROI analysis to evaluate the financial effectiveness of MnPASS as a long-term regional mobility strategy. In terms of scope, the research team will estimate a level of effort for this expanded analysis by weighing it against the potential advantages of the expected improvements in investment guidance.

The proposed research plan was tailored to meet the research needs, specifically by refining the ROI methodology/tool for MnPASS by filling in current gaps and addressing challenges in the development of a framework. This was accomplished through the systematic and sequential series of tasks and approaches outlined below.

- Identify the limitations in the MnPASS BCA methodology through a review of related background studies and the development of a list of broader points to be considered for inclusion in the refinement process
- Conduct agency interviews with stakeholders to obtain MnPASS planning and operating agencies' objectives, experience, needs, related benefits and costs of the system, and necessary data to support the research
- Define typical ROI categories for MnPASS investments and establish a relationship diagram of these categories and their associated benefits and costs

- Adopt benefit cost analysis (BCA) and life-cycle cost analysis (LCCA) methods to estimate benefit-cost ratios of invested projects, and develop a refined ROI/BCA framework for MnPASS with an emphasis on the additional considerations

- Conduct a comparative demonstration of the revised methodology by using original and refined tools to develop recommendations

Consistent with the work plan, this “background review” task was completed to synthesize available background information on the existing ROI development and related financial evaluation from previous studies. It focuses on the adapted ROI and BCA methodologies for MnPASS system assessment, the main cost components considered in benefit-cost analysis, performance measurement criteria, and practices of the MnPASS system in recent years. Assumptions and limitations of the current economic evaluation methodology/tool for MnPASS tolling lanes and the overall MnPASS system were documented and summarized, which provided a foundation for subsequent tasks. This task also assembled the current pool of written knowledge relevant to ROI assessment for transportation systems and tolling road networks, and the use of BCA and life-cycle cost assessment (LCCA) in this related ROI research, which provided technical support for this study. Clear definitions of the differences between ROI, BCA, and LCCA were also developed to provide further clarification and guidance throughout the project.

1.1 BACKGROUND REVIEW ON MNPASS RELATED STUDIES

Over the past decade, MnDOT has administered a series of studies and projects to identify potential MnPASS priced managed lane systems and implement managed lanes on highways where traffic congestion has been a serious problem, e.g., I-394 and I-35W. The research team reviewed 11 representative research efforts on MnPASS system evaluation, selection, and pricing mechanisms to understand the present state and perspectives of the MnPASS system and to identify research needs and challenges that must be addressed to improve and extend the MnPASS Express Lane system. The initiatives include several state-level studies undertaken by different organizations; in addition, some of the projects are inter-related or a continuation of previous projects. Table 1 provides an overview of these research efforts through a summary of their objectives, funding sources, and respective emphases, as well as their key findings and results.

Most of the initiatives found in the literature evaluated alternative corridors for the purpose of providing recommendations for the deployment of MnPASS Express Lanes in the Twin Cities metropolitan region. For instance, the *MnPASS System Study Phase I and II* evaluated and reported relevant data concerning the impacts of deploying a MnPASS lane system in the Twin Cities metropolitan area by looking into regionally distributed segments to assess the geometric, operational, and financial viability of potential MnPASS corridors (Cambridge Systematics Inc, 2005, Cambridge Systematics Inc, 2010). The *I-35W North Managed Lanes Corridor Study* and *I-35E MnPASS Extension Study* focused on a given corridor to evaluate the conceptual alternatives for extending MnPASS (SRF Consulting Group Inc et al., 2013, Parsons Brinckerhoff, 2015). The *Benefit and Cost Analysis of the I-394 MnPASS Program*, *Additional Cost-Effectiveness Analysis of the I-35E MnPASS Lane*, and *Benefit-Cost Analysis for I-35W Urban Partnership Agreement Projects from Burnsville to Downtown Minneapolis* explored the benefits and costs associated with deploying express tolling lanes in the corridors, e.g. converting High Occupancy Vehicle (HOV) lanes to High Occupancy Toll (HOT) lanes, equipping a Priced Dynamic Shoulder Lane (PDSL) to operate as a MnPASS lane during peak periods, or constructing/adding new lanes, (SRF Consulting Group Inc, 2008, Cambridge Systematics Inc, 2012, Cao et al., 2012).

In addition to the typical economic analyses on MnPASS performance evaluation, the study of *I-394 MnPASS Technical Evaluation* included some other evaluation aspects: pre- and post-noise measurement and air quality in the I-394 MnPASS project area. The evaluation concluded that the operation of the MnPASS lane had no substantial impact on either the noise level or air quality in the project area (Cambridge Systematics Inc, 2006).

A recent study conducted by the University of Minnesota, *Evaluation of the Effect of MnPASS Lane Design on Mobility and Safety*, concentrated on the operational and design features of HOT lanes. This study presented an assessment of mobility and safety on the two current HOT facilities, I-394 and I-35W, building on the identification of the contradictive design philosophes between the two HOT facilities and the limitations of existing methodologies in designing access zones of MnPASS priced lanes (Stanitsas et al., 2014). There are also some studies concerning MnPASS operating issues (e.g., pricing mechanism); one example is *MnPASS Modeling and Pricing Algorithm Enhancement*, in which a microscopic traffic simulation-based model of HOT lanes was developed to carry out experimentation with other pricing strategies and price levels through a collection of field experiments, so as to understand and measure the value-of-time mechanism of MnPASS users (Hourdos, 2015).

To supplement the above project and program studies, the research team reviewed journal articles and identified another group of MnPASS related research studies. Consistent with the theme of performance evaluation, Buckeye (2012) confirmed the overall success of the I-394 MnPASS Express Lane project in regard to operational performance and customer satisfaction. After the opening of the MnPASS express lanes on the I-35W corridor, both Turnbull et al. (2013) and Buckeye (2014) examined the performance outcomes of the I-35W HOT lane conversion. In particular, Buckeye considered the following evaluation criteria for the performance measures: (1) change in vehicle and person trips as compared with the no-build condition; (2) change in travel speeds and trip time reliability; and (3) customer satisfaction. After a series of operational analyses, the positive performance of I-35W MnPASS express lanes in vehicle and person throughput, travel speed, travel time savings, and custom perception, etc., was verified in these studies. However, Buckeye's study also pointed out the difficulty in generalizing the same performance evaluation framework in view of the wide range of conditions and influences that may affect performance and the unique design and performance characteristics of each corridor.

Some studies presented a wider view of perspectives to investigate issues associated with the MnPASS system. Relevant examples are based partly on the behavior analysis of MnPASS users. Owen et al. (2014) conducted an investigation on the likelihood of a household having a subscription to the MnPASS system by investigating the factors contributing to such choice and establishing a prediction-oriented binomial logit model. In a similar approach, (Zmud et al., 2007) examined the range of MnPASS users' willingness to pay under conditions of stated preference (SP) experiments with "before and after" iterations; additionally, an initiative study concerning the evaluation of a

HOT lane project in Minnesota checked the applicability of panel design in the evaluation of such road pricing projects. Munnich Jr and Fure (2014) considered the public perception of the perceived “take-away” of general purpose lanes for implementing MnPASS managed toll lanes. Through a case study of an I-35E MnPASS managed lane extension project, the results indicated that the public would accept a “take-away” if well informed about the rationale of MnPASS lanes. In addition, the outreach and education efforts, careful operational design, prompt response to problems, and effective engagement strategies will provide a path leading to a successful project design and implementation.

The section below describes detailed information from these evaluations (Table 1) as well as other examples from the research literature.

Table 1. Overview of MnPASS system related studies

Study	Funding source	Overview	Key findings and results
MnPASS System Study (Phase I) (Cambridge Systematics Inc, 2005)	MnDOT	The report attempted to identify a potential Twin Cities Metropolitan Area MnPASS tolling lane system and to provide MnDOT and the Metropolitan Council with information on the cost, operational, revenue and system implications of that system. The intent was not to evaluate the benefits of tolled versus non-tolled capacity expansion, but rather to study a potential future system of express toll lanes.	• MnPASS lanes are a new transportation "product"; • Public investment is required since on average only 22% of the regional MnPASS system capital costs could be expected to be recovered from tolls; • The most financially viable segments to be built from scratch are not in the region's 25-year transportation policy plan; • The HOT lanes now under construction on I-394 and proposed on I-35W are expected to fill up with HOV traffic by 2030.
I-394 MnPASS Technical Evaluation (Cambridge Systematics Inc, 2006)	MnDOT	This study presented a comprehensive evaluation of the I-394 MnPASS deployment in the Twin Cities through the assessment of before and after conditions.	• MnPASS has been popular with users; • The toll schedule modifications implemented in January 2005 have resulted in an increase in revenue being collected and less volatility in rate changes at lower traffic levels; • The increased enforcement activities have had great success in curtailing illegal SOV use of the MnPASS lane in the I-394 corridor;

Study	Funding source	Overview	Key findings and results
			• Most transit providers have reported negligible impacts on operations as a direct result of MnPASS deployment.
Benefit-Cost Analysis for I-35W Urban Partnership Agreement Projects from Burnsville to Downtown Minneapolis (Memorandum) (SRF Consulting Group Inc, 2008)	MnDOT	This study conducted a BCA analysis (2010 – 2029) for the I-35W urban partnership agreement roadway modifications. The main components considered for BCA analysis include travel time/delay, operating costs, annual and periodic maintenance costs, remaining capital value and capital costs. Transit benefits are not considered.	• All three alternative project locations considered for roadway modifications had a B/C ratio greater than one and are more economically beneficial than No Build Alternative.
MnPASS System Study Phase II (Cambridge Systematics Inc, 2010)	MnDOT	This study was conducted to analyze and make recommendations for MnPASS managed lane projects in the Twin Cities metropolitan region. The study assumed that any additional MnPASS lanes would be developed from a smaller envelope (i.e., corridor width) utilizing the	• 8 corridors (out of 19 corridors) considered for the final analysis have considerable benefits in the short term (2 to 10 years); • Most corridors (with the exception of Corridor 2) will fully cover O&M costs with surplus revenue available to cover up to 25 percent of capital costs;

Study	Funding source	Overview	Key findings and results
		existing right-of-way footprint to the maximum extent possible.	• Corridors that are relatively long have higher B/C ratios due to large travel time benefits.
Metropolitan Highway System Investment Study (MHSIS) (Parsons Brinckerhoff, 2010)	MnDOT, Met Council	The study concentrated upon how active traffic management and managed lane components could be combined and implemented in the Twin Cities to provide a consistently congestion-free alternative throughout the regional highway system. For this study, only managed lane expansions were used for analysis.	• Overall performance rating (high, medium and low) was performed for the managed lane corridors, with respect to objectives of the MHSIS; • “High” and “Moderate” ratings are likely to correspond to MHSIS guidelines; • Some of the managed lanes found to have “low” ratings may work better in the long term (2030 to 2060) rather than the current short term analysis (2030).
I-394 Phase II Planning Study (Munnich Jr and Buckeye, 2010)	Federal Highway Admin., MNDOT	This study relied on a case study of I-394 MnPASS planning and evaluated four major study elements (transit, land use, infrastructure and telecommuting) and their relationships in a managed tolling urban corridor. The purpose is to improve the performance of corridors with multiple and diverse strategies.	• Land use, transit advantages and telecommuting are already being considered toward practical implementation and as important corridor enhancements; • Based on anticipated benefits and identifiable funding streams, infrastructure improvements, particularly conversion of the reversible section to bi-directional flow, are currently difficult to justify.

Study	Funding source	Overview	Key findings and results
Benefit and Cost Analysis of the I-394 MnPASS Program (Cao et al., 2012)	University of Minnesota	The study performed a benefits and costs analysis (BCA) associated with converting I-394 HOV lanes to HOT lanes (2006-2015). For economic analysis, benefits included were time savings, safety benefits (Empirical Bayes Method), and vehicle operating cost savings, and costs included were capital and annual operating costs.	• BCA ratio of 2.19 was observed, justifying the I-394 MnPASS program; • Travel time savings (3.23%) and travel time reliability (10.76%) are not the dominant sources of benefits; • Safety benefits (86.12%) dominate the total benefits, and these are important considerations for any future BCA analysis.
Additional Cost-Effectiveness Analysis of the I-35E MnPASS Lane (Memorandum) (Cambridge Systematics Inc, 2012)	MnDOT	The study conducted a BCA analysis to expand on a previous study about the effectiveness of the I-35E MnPASS Lane. Benefits for analysis include vehicle operating and maintenance benefits, travel time savings, reliability savings for MnPASS users, safety cost reductions, and emission cost reductions. Costs for analysis include capital costs, operating and maintenance costs, and salvage costs.	• MnPASS build alternative had a B/C ratio of 17.5; • Travel time savings, vehicle operating cost savings, safety savings, reliability savings, and emissions reductions each total 75%, 11%, 7%, 4% and 3%, respectively; • Negligible increase in vehicle occupancy across all trips; • Travel time savings is driven by the decrease in vehicle hours traveled (VHT); • Vehicle operating cost savings is driven by the decrease in vehicle miles traveled (VMT).
I-35W North Managed Lanes	MnDOT	The study was conducted to improve the traffic operations along a 25 mile I-35W north corridor,	• The traffic volume of I-35W north corridor would increase due to the introduction of a managed lane;

Study	Funding source	Overview	Key findings and results
Corridor Study (SRF Consulting Group Inc et al., 2013)		which has varying physical and traffic characteristics. The study identified and evaluated lower-cost/higher-benefit options for improving traffic operations along I-35W as well as options for providing a managed lane in the corridor. The results of the study would help the decision makers with possible options to resolve congestion issues and an implementation plan for the complete set of recommendations.	• Some segments of the I-35W north corridor would have a transit time savings (approx.7 minutes) resulting in 13% increase in ridership; • A future Bus Rapid Transit System (BRT) will benefit from a managed lane due to travel time savings resulting in increased ridership. However, ridership forecasts could be more dependent on the frequency of BRT service than the travel times; • A managed lane on the inside existing lanes in both directions was considered as a viable option from forecasted benefits; • It is estimated to cost approximately $550 million (2011 dollars) for total corridor investments; • The programmed and proposed build alternatives had a B/C ratio ranging from 0.7 to 2.9.
MnPASS Modeling and Pricing Algorithm Enhancement (Hourdos, 2015)	MnDOT	The study was conducted to develop and test a number of different pricing strategies for MnPASS express lanes (HOT lanes) and to develop a model for lane choice behavior of MnPASS users. The developed models were interfaced with the traffic simulation software	• Using only a travel time savings metric, drivers have a very high value of time; • Reliability is considered an important factor for drivers paying more, in addition to travel time savings; • A counterintuitive result is that both SOVs and HOVs increased usage of the MnPASS lanes with higher toll prices

Study	Funding source	Overview	Key findings and results
		and tested on MnPASS corridors of I-394 and I35W corridors.	as a result of drivers' likely assumption of downstream congestion and greater time savings.
Interstate 35E MnPASS Managed Lanes Extension: Little Canada Road to County Road 96 Pre-Implementation Study (Parsons Brinckerhoff, 2015)	MnDOT, FHA	This study will develop and evaluate conceptual alternatives for extending MnPASS from Little Canada Road to County Road 96 through the remaining bottleneck on I-35E north of I-694. The study will engage community stakeholders and corridor users in analyzing the design, operation, benefits, costs and public acceptability of each alternative, and identifying and evaluating methods for improving bus transit and carpool use in the MnPASS Express Lanes on I-35E.	• The Hybrid Concept is the preferred concept to address transportation needs of I-35E in the near and long term, with a highest BCA result of 3.16; • When implementing MnPASS through the I-35E corridor, continued outreach and education efforts were demonstrated to be beneficial; • Mixed land use is encouraged to build better connections for walking, biking and transit options and to move incrementally towards transit development.

1.2 PRICED MANAGED LANE SYSTEM STUDY OUTSIDE OF MINNESOTA

The information regarding priced managed lane systems outside of Minnesota is extensive. There are numerous publications regarding the different types of managed tolling lane systems and case studies where such strategies have been implemented, e.g., the I-95 Express Toll lanes in Maryland; the SR-91 HOT lanes in Orange County, California; the Katy Freeway Managed Lanes in Houston, Texas; and the I-85 Express Lanes in Atlanta, Georgia. The following survey of pertinent literature focuses on agencies that are implementing different types of priced managed lanes. Tools for selection of managed tolling lane types and candidate roadway sections are included, along with techniques for efficient operations and categories to use for benefit-cost analysis.

1.2.1 Selection of Roadways for Priced Managed Lane Implementation

A number of publications focused specifically on the methodology used in the selection of roadways for the implementation of managed tolling lanes and successful pricing strategies to encourage priced managed lane use. A report to the Florida Department of Transportation Research Center on *Deployment Strategies of Managed Lanes on Arterials* was recently published in February of 2015 (Yin et al., 2015). The purpose of the project was to "examine strategies for deploying managed lanes on arterials…and investigate ways to coordinate the deployment and operations of these lanes on arterials," with the intent of application to Florida transportation needs.

Within the report is a literature review of state and nationwide practices regarding priced managed lanes on both freeways and arterials, covering topics such as policies, practices, planning and implementation, design and regulations, public acceptance, environmental considerations, and traffic conditions and facility performance. A review of arterial managed lanes in the United States and Canada described the facility and findings with regard to the success and performance of managed lanes. From this review, strategies were developed to identify and select managed tolling lanes for implementation in Florida based on type, design and methods of implementation, and traffic management/control schemes. The report limited recommendations on design and implementation, traffic management schemes, and selection and screening process to HOV, bus-only, HOT, and Express Toll (ET) lanes due to the higher likelihood of implementation over truck only lanes and the similarity of bus-toll lanes to HOT lanes.

Four criteria were identified for priced managed lane selection. First, if an HOV lane already exists, a determination should be made as to whether or not the lane is being utilized to a pre-determined threshold. Conversion to a HOT lane is beneficial at 80% or lower capacity per the findings in *Optimal Dynamic Pricing Strategies for High-Occupancy/Toll Lanes* (Lou et al., 2011). If the HOV lane is congested, addition of another HOV lane or requiring higher vehicle occupancy may prove more effective. Second, an additional HOV lane can also be considered if demand is deemed sufficient. Literature suggests between 200 and 400 vehicles per hour per lane (VPHPL) for one-way lanes and between 80 to 160 VPHPL for reversible lanes. Third, addition of a bus-only lane should be considered if buses are already serving the candidate roadway and would benefit from enhanced performance. Lastly, sufficient distance between intersections provides for the implementation of a HOT or ET lane if accessibility and turning requirements are not substantially impinged.

The final section of the report focused on forecasting and valuation of potential impacts of the tolling lanes. Selection of arterial lanes for conversion to managed tolling lanes was based on the results of two procedures: the steepest decrease and pairwise interchange procedures. Both procedures relied on the use of an equilibrium problem to identify ideal arterials for managed tolling lane implementation based on the reduction of delay time that occurs when such a lane is implemented (Yin et al., 2015).

Further useful information on priced managed lane implementation was published in 2001. *Explaining High-Occupancy-Toll Lane Use* by Li (2001) utilized data originally collected through a survey performed by Cal Poly San Luis Obispo in the fall of 1996 on the SR91 HOT lanes in Orange County, California. The SR91 Express Lanes were implemented in late 1995 and were one of the first projects to deploy HOT lanes in conjunction with value pricing. The study sought to determine factors that influenced drivers' use of HOT lanes; Li hypothesized that the use of HOT lanes depended on three variables: travel characteristics of travelers, financial considerations, and demographics. After applying five logistic regression models, the study determined that "controlling for other variables, household income, vehicle occupancy, trip purpose, and age are important determinants of HOT lane use." However, in contrast to the results of a comprehensive study performed by E.C. Sullivan and his associates in the late 1990's, this analysis found that gender and trip length are not determining factors for HOT lane use. Perhaps the most important policy implications of Li's study were that affordable pricing is critical to HOT lane success while also promoting carpooling and that commuters were most likely to use HOT lanes. Thus, their driving habits should be considered accordingly when implementing new facilities. Finally, the findings provided helpful indicating factors for future HOT lane implementation, such as segments of roadway where congestion is particularly troublesome and variable tolls to accommodate changing HOT lane demand throughout the day and week (Li, 2001).

1.2.2 Methods and Tools for Evaluating Priced Managed Lane Performance

Further research has been performed on methods and tools to evaluate the performance of priced managed lanes. A 2006 Transportation Research Record article entitled, *Feasibility Assessment of Metropolitan High-Occupancy Toll Lane Network in Atlanta, Georgia* identified five performance measures that were used in the analysis of the HOT lane network in the area for Mobility 2030, the regional transportation plan. The study identified five performance measures used to gauge the efficacy of various HOT lane designs and pricing options. The first was "vehicle miles travelled" as an indicator for use of the managed tolling lane facilities. The second was "trip time savings," which was used to show the difference in travel time for roadway users in the general-purpose lanes and those who chose to utilize the HOT lane network. The third was "percentage of congested general purpose lanes, weekday" as a way to measure the impact of HOT lanes on the general-purpose lanes. The fourth performance measure was "vehicle and person trips on managed lanes, weekday," used to gauge the level of efficiency associated with given levels of utilization of the HOT lanes. The fifth and final performance measure identified was "revenues and costs," which accounted for the costs of HOT lane development, operation, and maintenance contrasted with that of general-purpose lanes (Meyer et al., 2006).

A portion of *Deployment Strategies of Managed Lanes on Arterials* sought to "identify tools for evaluating [managed tolling lane] performance," and included a review of planning tools for use in evaluating the "performance of a managed lane strategy." Three categories of evaluation tools were reviewed extensively followed by recommendations. First, several sketch planning tools were evaluated; the Mosaic Tool developed by the Oregon Department of Transportation was determined as the most comprehensive and with the greatest evaluation capability for various scenarios using the four-selected managed tolling lane types and the ability for calibration to location-specific conditions. Second, only one project planning tool was reviewed, the Florida Standard Urban Transportation Model Structure (FSUTMS). While the model can "reasonably accommodate different managed lane strategies," the report noted that future research was needed in order for the model to simulate certain situations such as bus only lanes and intersection behaviors. Third, two operations planning tools were evaluated and both were recommended due to unique intrinsic capabilities: (a) the CORSIM tool, originally developed by the FHWA, provides for the simulation of a variety of toll lanes and has enhanced features courtesy of the University of Florida to model HOT lane operations; (b) VISSIM is effective when strategizing bus-only lanes coupled with complex traffic signal behavior with the capability to use AutoCAD drawings and aerial photographs in network creation (Yin et al., 2015).

Another formative paper was prepared by the Texas Transportation Institute for the Texas Department of Transportation in conjunction with the FHWA. *Monitoring and Evaluating Managed Lane Facility Performance* is an extensive document that was published in November of 2005. The study addressed a wide variety of issues related to managed tolling lanes such as planning of facilities, design, and operation. A specific objective of the study was to "document reportable managed tolling lane benefits that may guide the development of 'benchmarks' for monitoring and evaluation."

Chapter 4 of the report outlined evaluation and performance strategies for six types of managed lanes: high-occupancy vehicle lanes, value-priced and high occupancy toll lanes, exclusive lanes, mixed-flow separation/bypass lanes, lane restrictions, and dual facilities. In the section on HOV lanes, a case study on Texas referenced a publication by Daniels and Stockton in 2002 that focused on the establishment of benefit-cost ratios for HOV lanes. "In brief, the study considered aggregated construction costs, traffic data, geometric data, maintenance, operation, and enforcement costs, accident data, and HOV lane operational data (including type of HOV lane, vehicle classifications and occupancies, hours of operation, and percentage of persons using the HOV lane) to develop benefit-cost ratios for various facilities in Texas." Results from the study showed that benefit-cost ratios varied significantly from corridor to corridor and were impacted by the type of HOV lane implemented and traffic. For value-priced and high occupancy toll lanes, estimated economic benefits included savings based on reduced travel time and vehicle operating costs, losses incurred due to trips not taken due to prohibitive cost, and minimization of cost variability due to trips not taken (Carson, 2005).

Another publication on using simulation tools identified that additional benefits can be realized by utilizing value pricing and allowing SOVs to utilize HOV lanes, effectively transitioning them into HOT lanes. In *Simulation-Based Investigation on High-Occupancy Toll Lane Operations for Washington*

State Route 167, Zhang et al. outlined the use of the VISSIM simulation tool to model the impacts of converting the underutilized capacity in HOV lanes to HOT lanes in the Seattle metropolitan area. The simulation resulted in clear benefits to roadway users such as increased speed in the GP lanes, higher vehicle throughput, and an overall decrease in travel time (Zhang et al., 2009). Further assessment of dynamic tolling was published in the 2010 issue of the Transportation Research Record in Chung and Choi's *Dynamic Toll Concept to Assess Feasibility of High-Occupancy Vehicle Lane on Kyungbu Freeway, South Korea* and resulted in similar benefits to Zhang's study. Again, using VISSIM, Chung and Choi analyzed the feasibility of converting an HOV lane on the Kyungbu Freeway in Seoul, South Korea to a HOT lane. Results indicated that the implementation of HOT lane facilities would result in higher vehicle throughput, reduced travel time, and higher average travelling speeds on the GP lanes (Chung and Choi, 2010).

One of the leading publications on managed tolling lane assessment, the National Cooperative Highway Research Project (NCHRP) 03-91, summarized an analysis of managed tolling lanes on freeway facilities, which resulted in the publication of a web-only document for project managers. The report outlines the development of guidelines to be used when evaluating the performance of managed tolling lanes, particularly those that are adjacent to general-purpose lanes. The developed framework is effective in determining which lanes would provide benefits (reduced travel time, increased throughput, higher average speeds on managed and GP lanes) to drivers. The project developed the "FREEVAL-ML computational engine," an Excel-based tool that can be utilized for analyzing managed tolling lane performance, which can be found here: http://sites.kittelson.com/hcqs-fwy(Wang et al., 2012).

1.2.3 Benefit-Cost Relationships on Priced Managed Lanes

The afore mentioned study, *Monitoring and Evaluating Managed Lane Facility Performance*, concluded with a number of important points on benefit-cost relationships. First, the dynamic pricing and HOT lanes are sources of revenue, thus maximizing revenue whether or not they encourage changes in driving habits. Second, HOV lanes often compare the travel-time savings benefits to those of the inherent costs of the lanes such as operation, maintenance, and initial infrastructure costs. However, safety benefits should not be overlooked, despite the significant time investment for accurate quantification. Third, value priced HOT lanes advocate travel time savings as the greatest benefit while encouraging higher occupancy rates in vehicles, while still allowing SOVs and HOVs not meeting the criteria to utilize the lanes for an increased fee (Carson, 2005).

The Atlanta, Georgia feasibility study mentioned above utilized a steering committee comprised of transportation officials and practitioners from agencies in the greater Atlanta metropolitan area. One of the first tasks the steering committee undertook was the identification of discreet benefits that could be realized by the implementation of a HOT lane network in the area. These benefits were: enhanced transportation options including the increased reliability of travel times and decreased congestion, enhanced efficiency, guaranteed trip reliability for transit vehicles, revenue generation that could subsidize transportation improvements, and funding to cover the costs of operation and maintenance of the HOT lane network. Stakeholders that were identified by the steering committee as possible beneficiaries of the enhanced HOT lane network were those travelers who utilized the area transit system, participated in van and carpools, and were willing to pay a fee to realize the benefits of the HOT lanes. The new lanes would also improve operations for local government agencies such as police, fire and emergency responder vehicles (Meyer et al., 2006).

Pricing is also an important tool in encouraging managed tolling lane use and realizing benefits for roadway users. In 2010, Loudon, Synn, and Miller published *Consideration of Congestion Pricing and Managed Lanes in Metropolitan Transportation Planning* in the Transportation Research Record that explored the concept of congestion pricing for managed tolling lanes and incorporation into transportation planning for metropolitan areas. The paper reviewed existing and planned managed tolling lane projects with congestion pricing elements, including those in the Minneapolis-St. Paul, Minnesota metro area; Atlanta, Georgia; Dallas-Fort Worth, Texas; Los Angeles-Orange County, California; Kansas City, Missouri; Phoenix, Arizona; San Francisco-Oakland-San Jose, California; Seattle, Washington; Washington D.C.; and Miami, Florida. Additionally, the measurement and evaluation of the benefits of congestion pricing or establishment of managed tolling lanes were defined using discrete performance measures from three categories: (a) travel time, delay, and level of service; (b) net revenue generated; and (c) distribution of cost impacts and travel time benefits across the population.” The paper notes that some studies referenced therein identified other categories such as environmental benefits and the impact of pricing variability on alternate means of transportation. The metropolitan areas of Washington D.C., Dallas-Fort Worth, and Miami utilize proprietary models to analyze and conduct benefit-cost studies with travel time and level of service assessment, while others (e.g., Minneapolis-St. Paul, San Francisco-Oakland-San Jose, Seattle, and Washington D.C.) employ a micro simulation model. Conclusions from the ten metropolitan areas reviewed for this paper indicated that the interest in managed tolling lanes and congestion pricing has increased, and strategic support for these implementation efforts is critical to ongoing success and in furthering the practice. Of particular importance is the continued assessment of various alternatives, development of evaluation benchmarks, collaboration between Departments of Transportation and metropolitan planning agencies, and continued research support through various funding channels (Loudon et al., 2010).

1.3 ECONOMIC ANALYSIS METHODOLOGIES FOR MNPASS SYSTEM EVALUATION

As one of the justifications for screening potential MnPASS corridors and tolling lanes, a series of economic assessment measures were conducted (e.g. BCA), to provide MnDOT, the Metropolitan Council and associated agencies with information on the cost, operational, revenue and system implications of alternatives, and to rank their priorities for MnPASS system design and implementation. For example, benefit-cost analysis was performed for *Benefit-Cost Analysis for I-35W Urban Partnership Agreement Projects from Burnsville to Downtown Minneapolis* and the *Benefit and Cost Analysis of the I-394 MnPASS Program* projects. In the former study, a sketch-level benefit-cost analysis was conducted for relative comparison of the roadway modification projects along I-35W (three alternatives) to the base or “no-build” scenario (SRF Consulting Group Inc, 2008). For the latter, a comprehensive BCA analysis was performed to justify the net societal benefits and costs associated with the I-394 MnPASS program (Cao et al., 2012).

In most cases, the financial viability of candidates for next MnPASS facilities across a given analysis timeframe was evaluated based on methodologies used for travel demand forecasting and toll revenue forecast. After that, taking a candidate corridor as an example, user benefits in the form of travel time savings, operating costs, and crashes by severity were typically used to capture the effects of economic improvement of tolling lanes. Initial capital cost (e.g. construction cost), operation and maintenance cost, and salvage cost were used for cost estimation (Cambridge Systematics Inc, 2010, Parsons Brinckerhoff, 2010, Cao et al., 2012, SRF Consulting Group Inc et al., 2013).

Of the eleven studies summarized in Table 1, only six of them were focused on the evaluation of potential MnPASS systems and corridors through financial assessment, e.g., cost estimation, benefit accountings, and performance measures. The following is a summary of the cost and benefit components and performance indicators being used in the six studies to evaluate the financial viability and performance of MnPASS program alternatives. The purpose here is to show the relevant referable information on parameter considerations under similar planning objectives, and to provide the necessary foundation for the refined and standard ROI methodology/tool to be developed in this project.

1.3.1 Cost Estimation

The cost estimation methodology applied in the six studies (as listed in Table 2) covered the different philosophies of financial cost accountings, as a result of the various project background and assumption settings. For example, as an early screening effort, *MnPASS System Study Phase I* completed two rounds of technical analysis to capture the financial and system performance of different timeframe designs. Round 1 only considered traffic levels expected in year 2030, and Round 2 had forecasts for both 2010 and 2030 analysis years. To provide two different perspectives on building MnPASS lanes, the system of potential MnPASS segments was further divided into two concepts in Round 2, referred to as Concept A-1 and Concept A-2. In Concept A-1, the costs of building MnPASS lanes "from scratch" were treated as "MnPASS cost" (in most cases, the MnPASS lanes were assumed to be added without reconstructing existing lanes); while under Concept A-2, the incremental cost of converting a Transportation Policy Plan (TPP) lane-addition project to a MnPASS lane (gantries, striping, additional buffer zones, etc.) was assumed to be the "MnPASS cost." The *MnPASS System Study Phase II* drew on MnDOT's experience with using a priced dynamic shoulder lane (PDSL) in the I-35W managed lane and assumed to use a smaller envelope (i.e., corridor width) to develop MnPASS corridors, so as to avoid the need for costly road widening and right-of-way acquisitions. In the *Metropolitan Highway System Investment Study*, the configuration of managed lanes in the form of dedicated and dynamic shoulder lane use was considered. Under these scenarios, the main components being used to calculate the total cost of MnPASS candidates can be inferred from Table 2.

From Table 2, it is clear that among these studies, total costs consisted mostly of capital cost and operating cost. Based on the summary, the capital cost may include roadway construction, bridge structures, roadway connection, advanced traffic management, right-of-way, project delivery, risk, and similar components. The operational cost may be dominated by electronic toll collection, back office operation, payment enforcement, roadway maintenance, and other expenses. Some projects could include salvage cost in their cost estimation, e.g., *MnPASS System Study Phase II* and *Additional Cost-Effectiveness Analysis of the I-35E MnPASS Lane*, but there were also assumptions about the exclusion of operations and maintenance costs in the cost estimation based on the assumptions that operations and maintenance costs could be offset (by policy and practice) with toll revenue, e.g. *MHSIS*. Even in the same category, the inclusion of specific sub-level cost components largely depended on the setup of project scenarios, as shown in Table 2, where "$\sqrt{}$" means the positive consideration of a component in each project, and "×" reveals the clear exclusion in that project. In light of the different definitions and grouping methods for sub-level cost components in these studies, and to facilitate the building of Table 2, this section further provided an explicit classification and related definitions for sub-level cost components covered in the list of capital cost and operational cost. These details are presented in Appendix A. Any further expansion and amendment of this study could be made based on these two Tables.

1.3.2 Benefit Calculations

Benefits considered in these analyses are generally calculated for the Build and No-build scenarios or the existing and future year conditions, and valued as the annualized benefit of selected metrics related to user, agency, and environmental considerations. All the metrics being used in the six studies may be classified as one of the following:

- Travel time saving benefit (VHT savings)
- Vehicle operating benefit (VMT savings, travel delay reduction)
- Operational benefit (minus O&M costs)
- Safety benefit (VMT shifts between different facility types, crash reduction)
- Environmental benefit (Emission and noise reduction)

Table 3 presents a summary of the benefit accountings being considered in the six studies to estimate the project benefits toward the calculation of benefit/cost ratio and comparison of MnPASS alternatives.

In general, travel time savings and vehicle operating benefits seem to be the most widely adopted considerations for benefit measurement. The travel time benefit includes vehicle hours traveled (VHT) savings and travel time reliability. Almost all of the six studies have taken into account such benefits in their planning phases, except *MnPASS System Study Phase I*. The vehicle operating benefit is included in all studies, and these metrics are largely focused on the vehicle miles traveled (VMT) savings, average speed savings, and travel delay reduction. VMT shifts and fuel reduction also appear to be common vehicle operating benefit metrics. The safety benefit that followed the above two categories is mainly linked to crash reduction, which is found in the studies of *Benefit and Cost Analysis of the I-394 MnPASS Program* and *Additional Cost-Effectiveness Analysis of the I-35E MnPASS Lane*. Environmental measures, captured by emission reduction, are seen only in the *Additional Cost-Effectiveness Analysis of the I-35E MnPASS Lane*. Operational indicators do not seem to be in wide use either. The *MHSIS* Study is the only initiative with operational benefit considerations, captured by net operational benefit (minus operational cost), and revenue mostly is assumed to be offset by operating and maintenance cost.

1.3.3 Performance Measures

In all six initiatives, five of them focused on the planning phase study before the real-build scenarios, while only the study of *Benefit and Cost Analysis of the I-394 MnPASS Program* focused on the after-phase performance evaluation. Taking a broad view of these studies, the measurements reveal that performance evaluation should be done from the perspectives of both transportation and financial interests, jointly engaging stakeholders in building their vision of the evaluation structure. For instance, in *MnPASS System Study Phase I*, the transportation performance of potential MnPASS segments and systems was addressed at three levels: road network, MnPASS system, and segment. Some basic cost and revenue metrics (for Round 1) plus a few additional metrics (for Round 2), e.g. cost recovery ratio and funding gap, were listed as financial performance evaluation criteria. In the *MHSIS* study, the indicators were categorized by the potential effects of MnPASS candidate projects. In addition to different grouping rules, the definitions of indicators in these studies also contribute to the differences in structure of evaluation criteria. To sort out these performance indicators and metrics, this section continues to adopt the performance categories in the *MHSIS* study, as shown in Table 4, and categorizes the performance evaluation criteria of each study into one of the following groups:

- Increase the people-moving capacity of the metropolitan highway system
- Manage and optimize, to the greatest extent possible, the existing system
- Reduce future demand on the highway system
- Implement strategic and affordable investments

Performance evaluation criteria are crucial for developing the most effective evaluation system for a MnPASS agency at the local, State, or national levels. They are also effective mechanisms for comparing candidate corridors and alternatives and promoting progress toward cost-effectiveness goals. Generally, the performance evaluation endeavors in the five studies were selected to be consistent with MnDOT's long-range transportation plan; some principles were also adopted to provide guidance in the evaluation process, e.g. an example from MHSIS, showing that "a lower-cost/high-benefit approach [that] may be an effective way to address specific problems and that pricing can provide an alternative for managing congestion". In Table 4, indicators with respect to the improvement of the existing transportation system present a wider adoption and consensus. Almost all of the five studies take VMT, VHT, average speed, and travel time related metrics (e.g., travel time reliability) as the main indicators. In addition to the concern for user travel efficiency, increasing the throughput of the whole target road network is also a high-ranking consideration (e.g., MnPASS System Study Phase II, MHSIS, and I-35 W) through the indicators of both person throughput and vehicle throughput in peak hours. In these same three studies, transit-related indicators that link to reducing future demand on the road system are also found. Although each study has a different statement describing specific indicators, there is a common theme related to increasing the transit ridership and improving the operation of the transit system. Financial indicators are not frequently used, and MnPASS System Study Phase I, MHSIS, and I-35 W are the only initiatives with any economic indicators in their domain. Additionally, all listed indicators appear to revolve around the calculation of MnPASS candidates' cost-effectiveness, expressed by a benefit/cost valuation (e.g., MHSIS), ratio of annual net revenue/annualized capital cost, or some other metrics.

After the deployment of the I-394 and I-35W MnPASS tolling lanes, MnDOT implemented some comprehensive evaluation efforts to assess the practical performance of the MnPASS system. As a supplement, we further examined the performance criteria structure built for the post-project phase, as listed in Table 5, through the study of *Benefit and Cost Analysis of the I-394 MnPASS Program*. It was found that compared with the evaluation criteria structure summarized in Table 5, more extensive perspectives and robust branch indicators were established. For example, in addition to the conventional concerns about travel efficiency (e.g., throughput, travel time reduction, travel speed, etc.), and transit improvement (e.g., mode share, vehicle speed, etc.), the operation of revenue collection, access violations, impact on the adjacent network, and safety and environmental impacts were also strongly represented in the structure. This comprehensive framework, which was mainly designed to serve the post-project scenarios, could also be adapted to provide relevant information for the performance evaluation study in the pre-project planning phase.

Table 2. Cost components used for cost estimation in the six initiatives (where "√" means the positive consideration of a component in each project, and "×" reveals the clear exclusion in that project).

		MnPASS System Study Phase I		MnPASS System Study Phase II	MHSIS Study	I-35W North Managed Lanes Corridor Study	Benefit and Cost Analysis of the I-394 MnPASS Program	Additional Cost-Effectiveness Analysis of the I-35E MnPASS Lane
		Round-1	Round-2					
Capital Cost							√	√
Roadway construction	New lane construction							
	Additional lane construction (Widen to inside/outside)	√	√	√		√		
	Pavement construction			√	√	√		√
	Interchange ramp realignment			√				
	Utility relocation	×	√	√	√	√		√

	Median barrier			√	√			
	Retaining wall	×	√		×	√		
	Miscellaneous			√	√	√		
Advanced traffic management (ATM)	ATM equipment		√	√	√			√
	MnPASS equipment	√	√	√	√			√
Bridge structures	Bridge widening		√	√	√			
	Bridge replacement	√	√	√	√	√		
Roadway connection		√	√	√		√		
Transit system construction			×					
Right-of-way		×	√		×	√		

Project delivery		√		×			
Risk		√	√	√	√		
Operational cost							
Electronic toll collection	√		√	√	√		√
Payment enforcement	×		√		√	√	√
Back office operation				√			√
Roadway maintenance	×			√	√	√	
Incident management	×				√		
Traffic management	×				√		
Travel information cost	×						

Postage					√	
Operation contract					√	
Verifone					√	
Salvage cost		√				√

Table 3. Benefit accounting considered in the six initiatives (where "√" means the positive consideration of a component in each project, and "×" reveals the clear exclusion in that project).

	Travel time benefit		Vehicle operating benefit					Safety benefit	Environmental benefit	Operational benefit	
	VHT savings	Travel time reliability	VMT savings	Average speed savings	Travel delay reduction	VMT shifts	Fuel reduction	Crash reduction	Emission reduction	Net operational benefit	Revenue
MnPASS System Study Phase I				√							
MnPASS System Study Phase II	√		√								
MHSIS Study	√				√					√	×
I-35W North Managed Lanes Corridor Study	√		√			√					
Benefit and Cost Analysis of the I-	√	√					√	√			

394 MnPASS Program											
Additional Cost-Effectiveness Analysis of the I-35E MnPASS Lane	√		√	√				√	√		

Table 4. Indicators and metrics for performance evaluation of MnPASS project alternatives in the planning phase (Five initiatives)

	Increase the people-moving capacity of the metropolitan highway system	Manage and optimize, to the greatest extent possible, the existing system	Reduce future demand on the highway system	Implement strategic and affordable investments
MnPASS System Study Phase I		Road network/MnPASS system • Vehicle miles of travel (VMT) • Vehicle hours of travel (VHT) • Average speed (VMT/VHT) Segment Length of segment Travel time (minutes) and vehicle hours Travel time savings (minutes and percent)		Round 1: Basic cost and revenue metrics • Estimated annual debt service on a 30-year bond • Annual operating cost • Annual gross toll revenue • Annual net revenue (gross revenue minus operating cost) • Ratio of annual net revenue/annualized capital cost Round 2: Basic cost and revenue metrics, plus: • Cost recovery ratio

	Increase the people-moving capacity of the metropolitan highway system	Manage and optimize, to the greatest extent possible, the existing system	Reduce future demand on the highway system	Implement strategic and affordable investments
				• Funding gap
MnPASS System Study Phase II	Throughput	• Travel-time reliability • Travel-time reduction • Change in congested vehicle-miles traveled	Transit suitability: • Total number of daily bus trips • Total number of peak-period bus trips • Existing bus-only shoulder (BOS) facilities • Number of short bus trips (impact of BOS usage) • Future planned transit facilities (park-and-ride, bus rapid transit, and express bus) • Future planned BOS facilities	
MHSIS Study	• Daily new vehicular trips per lane mile • Daily new person trips per lane mile	• Daily reduction in congested VMT • Daily reduction in peak hours of delay per trip	• Change in transit mode share • Change in corridor attractiveness for SOV trips	• Cost effectiveness, calculated as a benefit / cost valuation • Standard deviation in cost effectiveness

	Increase the people-moving capacity of the metropolitan highway system	Manage and optimize, to the greatest extent possible, the existing system	Reduce future demand on the highway system	Implement strategic and affordable investments
		• Daily reduction in average travel time per trip		• Investment opportunity rating • Investment parity rating
I-35W North Managed Lanes Corridor Study	• Increase person throughput (peak hour) • Increase vehicle throughput (peak hour)	• Improve travel time reliability • Vehicle miles of travel (VMT) • Vehicle hours of travel (VHT)	• Increase transit ridership • Reduce transit travel time	• Capital cost • Operations and maintenance cost • Annual revenue
Additional Cost-Effectiveness Analysis of the I-35E MnPASS Lane		• Vehicle miles of travel (VMT) • Vehicle hours of travel (VHT) • Average speed		

Table 5. Indicators and metrics for performance evaluation of MnPASS system in the operation phase (An example from I-394 MnPASS Technical Evaluation)

Category	Indicators and metrics
Improve efficiency	• Increase in vehicle throughput in the corridor • Increase in person throughput in the corridor • Increase in vehicle speeds in the general purpose lanes • Decrease in average person travel time in the corridor
Maintain free-flow speeds for transit and carpools	• No decrease in vehicle speeds in the HOV/HOT lanes • No increase in travel time for transit vehicles • No increase in vehicle speed variability in the HOV/HOT lanes • No change in mode share in the corridor • No increase in illegal SOV usage of the HOV/HOT lanes
Improve highway and transit in corridor with revenue generated	• Documented planned improvements • Documented MnPASS revenues
Electronic toll collection and ITS technologies	• Documented system downtime • Documented system error rates • Documented MnPASS revenues
Assess safety impacts	• No increase in the number of crashes occurring in the corridor • No increase in crash rate in the corridor • Decrease in the speed differential between HOV/HOT lanes and general purpose lanes
Assess enforcement issues	• No increase in illegal SOV usage of the HOV/HOT lanes

	• Documented number of issued HOV lane violations • Documented number of issued double-line crossing violations
Assess impact to adjacent bottleneck locations	• No increase in vehicle throughput at the bottleneck locations
Assess environmental impact	• No increase in corridor noise levels • No increase in corridor emission levels

1.3.4 Findings and Implications

In the summaries described above, the studies focusing on the MnPASS system and individual corridor studies generally adopt different objectives, considerations, and working plans, and utilize different assumptions and value settings (e.g. timeframes, parameter values) in estimating the benefits and costs of project alternatives, which introduces inconsistency among the results. For instance, the *Metropolitan Highway System Investment Study* and the *MnPASS System Study Phase II* concurrently studied a collection of potential MnPASS corridors, but they presented four different areas when performing cost estimation (Cambridge Systematics Inc, 2010, Parsons Brinckerhoff, 2010).

The cost components used in the evaluation studies included the following: capital/construction cost, operating and maintenance cost, and salvage/remaining cost. Some or all of these components could be used in different studies to express the estimated total cost of a certain candidate deployment. Capital cost if a common and dominant factor in the total cost calculation, and its value generally varies depending on the category of construction line items included within each study. Operating and maintenance costs linked to collecting tolls were sometimes assumed to be offset by the revenue; and salvage costs and remaining costs were only involved in a few reviewed studies.

The synthesis of benefit accountings in Table 3 reveals that the benefits of the MnPASS tolling system currently are largely being captured more by transportation effectiveness and efficiency indicators; and, to a lesser extent by safety, environmental and economic indicators. Similarly, the main indicators and metrics used most often in the transportation performance measures of the MnPASS system and corridor evaluation are also centered on quantifiable or measurable transportation indicators, e.g., increased network throughput, vehicle operating and maintenance savings, and travel time reduction. Transit system and financial indicators are infrequently identified as important considerations.

The review and synthesis of the projects and literature on the MnPASS system and corridor evaluation reveal a number of important findings:

- There is no consistent economic analysis framework for MnPASS system comparison. The conventional framework including some or all of the typical indicators in the domain of cost estimation, benefit accountings, and performance measures cover the main considerations of economic analysis for a MnPASS system study. However, the point should be made that analyses of these indicator systems were conducted based on the respective background assumptions and methodologies established at the beginning of the project. Therefore, actual components and indicators selected for calculating the final benefit-cost ratio or ROI index may vary between projects, and the final outputs of these studies tend to present different results, even using the same group of candidate projects.

- In addition to the inconsistency that occurred in the selection of typical indicators, the present status of economic analysis of MnPASS candidates shows some common elements: a higher focus on the effectiveness and efficiency of transportation system operation as well as measurable financial considerations, and less of a focus on a wider range of social and environmental impacts. This finding may raise another issue in the development of a standard and referable economic analysis tool. A more comprehensive analysis of traffic, revenue, cost and financial structures should be developed and performed in future studies, in order to better support project financing. Additional factors that should be evaluated for inclusion in the refined MnPASS ROI/BCA methodology could include transit impacts, travel time reliability, emission and noise reduction, and safety impacts.

- Some broader factors that are not included within the existing economic analysis (e.g., social and environmental impacts mentioned above) are arguably integral components of any systematic initiative to move toward a standard and comprehensive economic analysis tool. Nonetheless, there is a lack of guidance and clarity on how to measure these factors. To develop a refined MnPASS ROI/BCA methodology for economic analysis and evaluating progress, there would be value in not only providing guidance on their measurement, but also measuring how effective these components are for project comparison.

The goal of MnPASS ROI/BCA efforts is to create a tool that produces consistent and comparable results, in order to provide valid recommendations for the next generation of MnPASS system projects. The contradiction in the current “various results but same goal” pattern therefore reinforces the idea that developing a standardized and consistent ROI/BCA methodology/tool is a critical element for MnDOT and the agencies that plan and operate the MnPASS systems. The end goal is to conduct better assessments and communicate why MnPASS is a financially effective long term strategy for addressing mobility and congestion issues.

1.4 LITERATURE REVIEW ON ROI, BCA AND LCCA METHODOLOGIES

1.4.1 ROI, BCA and LCCA Methodologies

The term Return on Investment (ROI), adapted from the private sector, effectively measures a firm's profits for an investment or compares the profits of different investments. In transportation applications, ROI determines if an investment promotes sufficient transportation and economic productivity benefits. Benefit-Cost analyses (BCA) are another type of economic analysis, which helps to determine if an investment yields a positive return by comparing the quantifiable direct benefits to the direct costs for a defined period of time. In transportation applications, BCA would focus on comparing the net changes between improvement case (with project or program) and base case (no build, or without project or program) (Horst, 2011). BCA differs from ROI analysis by including broad sets of benefits such as environmental benefits (e.g., emissions) and societal benefits (e.g., safety) and are widely used in public sector projects.

Increasingly, ROI has been widely used but largely non-standardized in the public sector for economic analysis. The main difference between public and private sector ROI is in the estimation of benefits. In the private sector, ROI benefits exclusively focus on the tangible income generated by investment for the private agency. In the public sector, a benefit could include factors that do not directly generate income for the public agency. For example, in a toll project led by a public agency, the personal time savings may well be considered as a major benefit for economic analysis. However, a private firm would not consider the personal time savings as a benefit, as they do not directly generate income to the private firm. Instead, they would focus on the future toll revenues for making decisions. Applications of ROI for public sector analysis essentially become identical to BCA. The difference in estimating the benefits between private and public sectors led to the use of ROI for the private sector and BCA for the public sector, although the terms are sometimes used interchangeably (Cambridge Systematics Inc, 2008).

In recent times, analysts are increasingly using life-cycle cost of a project's investment as the accurate cost for all economic analysis. Life-cycle cost analysis (LCCA) is a tool that determines all the future costs associated with a project's usable life and helps to determine the most cost-effective option. LCCA analyzes three major components for economic analysis: initial agency costs (e.g., capital/constriction costs), future agency costs (e.g., operating and maintenance costs) and accounting for uncertainty costs (Cambridge Systematics Inc, 2008). Also, LCCA differs from ROI and BCA by assuming that benefits across different project alternatives remain the same. For example, having asphalt and concrete pavement on a gravel road could help to increase the level of service (a kind of benefit measure) for users, but asphalt and concrete may have a different cost associated with construction, repairs and usable life.

An ROI calculation could include other concepts for economic analysis. The traditional BCA approach used for the public sector cannot be used, especially if a public project generates revenues such as toll road networks. Recent studies used both BCA and LCCA concepts to serve as a foundation for developing a ROI methodology for transportation related projects (Cambridge Systematics Inc, 2008, Smart Growth America, 2013).

1.4.2 Other Economic Analysis Methods

In addition to ROI, BCA and LCCA, there are other methods that can be used for economic analysis of a project or an investment, such as Internal Rate of Return (IRR), Net Present Value (NPV) and Equivalent Uniform Annual Costs (EUAC).

IRR is primarily used in private industry, representing the discount rate necessary to make discounted cost and benefits equal. IRR is generally applied when budgets are constrained by the same initial investment for all projects; in general, the project with highest IRR will be considered best. Net Present Value (NPV) measures the difference between the sum of the present values of future benefits (incoming cash flows) and sum of costs (outgoing cash flows) over a period of time. NPV is commonly used for expansion and replacement projects. EUAC is typically used when budgets are allocated on an annual basis. It calculates the NPV and assumes that it occurs uniformly for each year throughout the analysis period. The inputs required to produce these measures are typically included as part of a traditional BCA.

For the MnPASS system evaluation, the ultimate issue is how to best define the benefits and costs of potential corridors and alternatives, and IRR, NPV and EUAC may not be the best indicators for these performance measures. Since MnPASS express toll lanes are public projects, it is therefore important to include all economic, environmental and societal benefits and costs in the financial viability assessment. IRR, NPV and EUAC are typically used in private industry and may not necessarily include all these factors for economic analysis. Thus, ROI along with BCA and LCCA could all be considered suitable methods for evaluating alternative MnPASS corridors/lanes and further developing a refined economic assessment framework.

1.4.3 ROI Assessment for Transportation Systems and Other Tolling Road Networks

ROI has been applied in several areas for economic assessment. In particular, it is widely used for evaluating transportation systems before making any long-term investments. In some cases, transportation systems (such as toll road networks) have been evaluated using methods that are similar to ROI, but with variations in assessment procedures and metrics. This section will summarize examples of ROI assessment and similar studies in transportation systems. Metrics to compare and evaluate alternatives in these studies will also be gathered.

Itasca in Minnesota conducted an ROI study on expansion of the transit system in the Minneapolis area (ITASCA project, 2012). The project considered three scenarios for economic assessment: (1) A built-out regional transit system (2030 Regional Plan); (2) A built-out regional transit system by 2023 (Accelerated Regional Plan); and (3) a 2030 plan with more growth near stations.

In order to assess their economic impacts, the study analyzed six kinds of direct impacts:

- Vehicle operating costs
- Travel times and travel reliability
- Shipping and logistics costs
- Emissions
- Safety costs
- Road pavement conditions

It should be noted that this study used both environmental (emissions) and societal (safety) metrics for a comprehensive economic assessment. This study also assumed a discount rate of 2.8% for analysis. However, it did not include the short-term impacts such as economic activity and jobs tied to the transit construction period (ITASCA project, 2012).

Munroe et al. (2006) provided another example of analyzing the economic benefits of toll roads operated by transportation corridor agencies. The main purpose of the study was to evaluate and explore the economic benefits of toll roads when compared to non-toll highways and interstates. Regional traffic data were primarily used for data analysis. Parameters such as 1) reduced travel time and 2) improved fuel efficiency were primarily considered. The study also mentioned additional benefits (not included for analysis) such as increased value for properties that have access to toll roads and additional benefits for nearby businesses (Munroe et al., 2006).

In another ROI study conducted for MnDOT's state highway program, a broader set of benefits were used for economic analysis. In addition to traditional transportation benefits, various factors within social benefits (safety, health, noise), economic benefits (travel time reliability, vehicle operating costs, life cycle costs, loss of agricultural land) and environmental benefits (emissions, wetland effects, runoff) were used for each investment option (Smart Growth America, 2013).

The Oregon DOT developed a framework and process for economic assessment of the Portland metro region for potential "congestion pricing" (tolling schemes) (Economic Development Research Group Inc and Parametrix Inc, 2010a). Congestion pricing generally refers to imposing some kind of toll (or fee) on a congested area, to promote the efficient use of available road capacity and reduce congestion. However, congestion pricing may have negative economic consequences for some neighborhoods, sectors of the economy and socioeconomic groups. The objective of the study was to 1) eliminate the regions which have undesired or unacceptable local consequences due to congestion pricing and 2) recommend actions of implementation (for regions not eliminated) for congestion pricing based on total cost and regional-level economic and environmental impacts. In this model, a local economic impact assessment for each tolling scheme was developed to screen the regions that had negative impacts on the economy. The factors considered for local economic impact assessment included:

- Direct impact on local travelers
- Direct impact on route reliant businesses

- Direct impact on broader market access and connectivity
- Unintended consequences on spatial patterns of economic impact

Based on the outcome of the screening from local economic impact assessment, an optional refinement of tolling schemes was developed. Finally, tolling schemes that passed the screening and refinement were selected for complete analysis for long-term impact and benefit assessment (Economic Development Research Group Inc and Parametrix Inc, 2010a).

1.4.4 Application of BCA and LCCA in the Field of Transportation Systems, Specifically Tolling and Similar Areas

BCA and LCCA are typical economic analysis methodologies that have a wide application in the field of transportation systems in terms of their flexible evaluation frameworks and demand-oriented working procedures. The research team found a large body of research that provided the definitions, indicators and metrics considered in various assessments; this section focuses on how these assessments worked in the roadway tolling system and similar areas.

A benefit-cost analysis assessment was developed by the Oregon DOT for evaluating proposed highway tolling and pricing options (Economic Development Research Group Inc and Parametrix Inc, 2010b). In order to perform BCA analysis, a realistic base case (benchmark) was first defined to analyze the potential benefits and cost of alternatives. The study suggested measuring the capacity cost for each alternative and base case, including property acquisition, engineering and design, grading and drainage, wet lands replacements, paving/road construction, transport structures (bridges), vehicles, tolling electronics and other equipment, operations and maintenance, and rehabilitation/safety improvements. For the benefit part, the study measured the changes of the following parameters between alternative and base case.

- Vehicle occupancy
- Value of time
- Vehicle operating costs
- Safety benefits (Reduction in property damage, personal injury and fatality)
- Environmental benefits (emission reductions)
- Congestion and travel time variability and reliability
- Residual value (after analysis period – controversial for public projects)
- Diversion (Changes in congestion on nearby roads or in adjacent lanes)

The study also performed a risk analysis to incorporate the uncertainty associated with all predictions by using Monte Carlo methods, sensitivity analysis, and Scenario-based methods (low, medium and high). Finally, other non-qualified benefits that could be difficult/expensive to measure, e.g. health, noise and certain environmental benefits other than emissions were suggested to be considered as part of the BCA.

BCA was also used for road pricing in downtown Seattle (Danna et al., 2012). In this study, it was assumed that driving to downtown Seattle could produce social costs other than private cost to the driver, e.g., decreased reliability and increased travel time, traffic accidents, and emissions from fuel consumption. To measure the benefits of road pricing compared to base scenario (no road pricing), the following parameters were measured:

- Reduced travel time
- Increased travel time reliability
- Reduced emissions (air pollutants and greenhouse gases)
- Reduced traffic accidents

To calculate the costs of road pricing compared to "no road pricing" situations, the study considered three components: 1) capital and operating cost of toll collection system, 2) cost associated with the increase in transit ridership due to the diverted vehicle trip, and 3) both direct and indirect financing costs. As necessary supplements, a series of other factors were also considered, such as the potential changes in retail sales in the downtown area, reduced competitiveness of the freight industry and change in land use patterns for economic assessment, some long-term effects (e.g., the increase in volume of traffic as travelling public became accustomed to paying toll), and changes in government revenues due to reduced revenues from parking and gas tax for the state and federal government (Danna et al., 2012).

In another study conducted in State Route (SR-91) express lanes (10 miles) in California, BCA was used for obtaining the incremental societal costs and benefits for a variable pricing project (Sullivan and Burris, 2006). In order to perform BCA or benefit-cost analysis, a base case and two alternatives were considered.

- Base Case—construct two new general purpose lanes (GPLs) in each direction
- Alternative 1—construct two variable toll express lanes in each direction (actually happened)
- Alternative 2—construct two high-occupancy vehicle (HOV 2+) lanes in each direction

For estimating the costs, the study used the incremental initial investment and facility operating costs. The initial investment costs included construction cost, additional structures associated with SR 55/91 connectors, construction of special enforcement zones, and acquisition/installation of electronic toll collection system and acquisition/installation of traffic management system. For estimating the benefits, the study used travel time savings, fuel use and change in emissions (Sullivan and Burris, 2006).

The same research team conducted a very similar study for the QuickRide high occupancy/toll (HOT) lanes in Texas (Burris and Sullivan, 2006). In this study, a base scenario assumed that Houston continues to operate HOV lanes and the alternative scenario compared was the implementation of proposed HOT lanes. The study used travel time savings, fuel savings and emission savings for estimating the benefits. Start-up costs and operation and maintenance costs were used for estimating the costs (Burris and Sullivan, 2006). In both studies conducted for Texas and California, travel time savings contributed to the majority of the benefits. The study highlights the importance of travel time savings and suggests additional research for value of time (VOT), especially for locations where toll varies by time of day.

Another comprehensive study relating to various transportation cost and benefit estimation methods was carried out by Victoria Transport Policy Institute in Canada (Litman, 2009). This study included and analyzed a wider range of potential impacts due to various costs and benefits for different transportation systems. Table 6 presents all of the twenty-three cost strategies that were included in the report. It can be noted that cost and benefit estimation included a comprehensive consideration of environmental and societal impacts. For instance, on the environmental front, the study included the costs associated with the change in air pollution, greenhouse gas pollution, noise, water pollution and waste; on the societal front, the study covered the costs associated with achieving health benefits for travelers and society. Each cost component was further organized into three categories: 1) internal (borne by users) vs. external (imposed on non-users), 2) variable (related to the amount of travel) vs. fixed, and 3) market (involving goods regularly traded in competitive market) vs. non-market. Based on such placement, the study calculated the dollars per passenger-mile for different modes of transport (e.g., compact car, bus, bicycle etc.,) and travel conditions (e.g., urban, rural etc.). The framework developed in this study could be applicable to various planning activities for transportation policy analysis, transportation pricing, investment policies, transportation equity analysis, and transportation demand management analysis (Litman, 2009).

Table 6. Transportation Cost Categories (Litman, 2009)

Cost	Description
Vehicle Ownership	Fixed costs of owning a vehicle.
Vehicle Operation	Variable vehicle costs, including fuel, oil, tires, tolls and short-term parking fees.
Operating Subsidies	Financial subsidies for public transit services.
Travel Time	The value of time used for travel.
Internal Crash	Crash costs borne directly by travelers.
External Crash	Crash costs a traveler imposes on others.
Internal Activity Benefits	Health benefits of active transportation to travelers (a cost where foregone).
External Activity Benefits	Health benefits of active transportation to society (a cost where foregone).
Internal Parking	Off-street residential parking and long-term leased parking paid by users.
External Parking	Off-street parking costs not borne directly by users.
Congestion	Congestion costs imposed on other road users.
Road Facilities	Roadway facility construction and operating expenses not paid by user fees.
Land Value	The value of land used in public road rights-of-way.
Traffic Services	Costs of providing traffic services such as traffic policing, and emergency services.

Transport Diversity	The value to society of a diverse transport system, particularly for non-drivers.
Air pollution	Costs of vehicle air pollution emissions.
Greenhouse Gas Pollution	Lifecycle costs of greenhouse gases that contribute to climate change.
Noise	Costs of vehicle noise pollution emissions.
Resource Externalities	External costs of resource consumption, particularly petroleum.
Barrier Effect	Delays that roads and traffic cause to non-motorized travel.
Land Use Impacts	Increased costs of sprawled, automobile-oriented land use.
Water Pollution	Water pollution and hydrologic impacts caused by transport facilities and vehicles.
Waste	External costs associated with disposal of vehicle wastes.

LCCA calculates the overall life cycle cost of an alternative, under the pre-assumption that the benefits of all alternatives are the same or have acceptable levels of service. A study from California DOT described an example of LCCA application, in which a LCCA procedure manual was developed using "*RealCost Version 2.5CA*" for pavement investment selection (Caltrans, 2013). In this manual, two types of costs were taken into account for analysis: agency cost and user cost. The former covered the initial construction cost, maintenance cost, rehabilitation cost and future project support costs, and the latter covered costs associated with maintenance and rehabilitation activities, and public traveling delays that occurred during the construction period. Remaining service life of pavements after final rehabilitation was also a part of LCCA assessment (Caltrans, 2013).

Compared to previous reliance on traditional deterministic-based LCCA approaches, recent studies are transitioning to a comprehensive probabilistic-based LCCA approach. An example of such efforts was found in a pavement type selection study conducted by South Carolina Department of Transportation (SCDOT) (Rangaraju et al., 2008). This study developed a probabilistic-based LCCA approach based on various LCCA input parameters obtained from a survey taken by the respondents from U.S. and Canada. Due to the unavailability of reliable cost data associated with traffic volume and the organizational structure of SCDOT, the study separated user cost from agency cost for further LCCA analysis. In terms of agency construction cost, the study suggested a probabilistic input in the analysis rather than a deterministic input. An analysis period of 40 years (instead of 30 years) and triangular probability distributions (75% minimum and 125% maximum of the mean value) were utilized for the analysis year and the initial and rehabilitation service lives, respectively.

An NCHRP study was performed to develop a comprehensive LCCA procedure for bridge project evaluation (Hawk, 2003). This study separated the total cost into three categories: agency cost, user cost and vulnerability cost. (The use of vulnerability cost distinguished this study from others identified for this review.) Table 7 shows the costs considered in each category of LCCA.

Table 7. Cost components considered in each category: agency cost, user cost and vulnerability cost (Hawk, 2003)

Agency Cost	User Cost	Vulnerability cost
• Design, engineering, and regulatory • Acquisitions, takings, and other compensation • Construction, Maintenance and repair • Demolition, removal, and remediation • Inspections • Site and administration services • Replacement and rehabilitation • Miscellaneous agency actions	• Traffic congestion costs • Traffic detours and delay-induced diversions • Highway vehicle damage • Environmental damage • Business effects • Miscellaneous routine user actions	• Load-related structural damage • Collision damage, Earthquake-related damage • Flood-related damage • Scour-related damage • Obsolescence

1.4.5 Literature Review Conclusions

In general, ROI, BCA and LCCA are all sound methodologies for economic assessment, and many common themes and considerations could be found in these studies. The differences among them center on their respective working focuses. For transportation applications, ROI assessment has its emphasis on analyzing investment effectiveness for generating a profit in varying currency such as tax dollars, tax collections, and nonmonetary benefits; BCA focuses on cost effectiveness of a selected alternative compared to a base case (no-build); and LCCA is predominantly used for projects that have the same benefits or acceptable level of service from different alternatives, e.g., making a selection between different pavement and bridge designs. Researchers noted that ROI assessment used in transportation systems and tolling road networks mainly focused on the direct benefits such as reduced travel time, fuel efficiency, and travel reliability, and some assessments overlooked the environmental and societal factors for analysis. Whereas BCA can cover a wider range of concerns, such as safety and environmental perspectives (emission reduction, improved safety, noise and pollution, etc.,) than ROI studies, it can be difficult to estimate the fiscal benefits and costs for safety and environmental factors. Additionally, in BCA, achieving a break-even point of investment can be considered as a benefit if a particular alternative has substantial safety and environmental benefits. LCCA can calculate the cost of each alternative over the entire usable life, which provides a helpful supplement for an ROI assessment study. As such, in this project, these methods were used as needed in the process of element measurements, e.g., cost estimation and benefit calculation (Task 5), after establishing a standard indicator and metrics system (Task 4) towards building a refined ROI assessment framework for the MnPASS priced managed lane system.

1.5 CONCLUSIONS

Given the growing interest in expanding the MnPASS system in the Minneapolis and St. Paul metropolitan area, developing a refined, consistent and standardized ROI methodology and tool for better assessing MnPASS programs and projects becomes an indispensable component to support such expansion activities. With this goal in mind, the objective of this task was to synthesize available background information on existing MnPASS related studies, priced managed lane system studies outside of Minnesota, and financial evaluation methods from previous studies. The purpose was to examine cost and benefit components and performance indicators being used in the current managed lane system studies, and to characterize the financial evaluation framework of the MnPASS system and how the economic desirability of alternatives is measured. In addition, the research team gathered and reviewed the current pool of written knowledge relevant to typical economic analysis methodologies that are suitable for financial viability assessment in transportation systems and tolling road networks, with a focus on ROI, BCA, and LCCA, in order to provide technical support for this project.

The team reviewed a selection of MnPASS related initiatives over the past 15 years. The findings indicate that there is no standard and consistent economic analysis framework and tool for MnPASS system comparison. Different methodologies and assumptions have been adopted and used in prior studies to meet their respective background and target settings. In addition, the desirability of a potential MnPASS corridor is largely being evaluated by transportation effectiveness measures and efficiency indicators, as well as financial metrics. A more comprehensive framework could be developed to incorporate a wider range of transportation, social and environmental factors, such as transit impacts, travel time reliability, emission and noise reduction, and safety impacts. Providing guidance and clarity on the measurements of these broader factors would add another level of value in the development of a refined MnPASS ROI/BCA methodology. In general, there are numerous opportunities to refine the vision and capabilities of a financially viable evaluation framework, which support progress toward an enhanced MnPASS service system.

CHAPTER 2: AGENCY RESPONSE MEMORANDUM

This chapter summarizes the agency interview task. The research team conducted agency interviews with stakeholders to obtain MnPASS planning and operating agencies' objectives, experience, needs, related benefits and costs of the system, and necessary data to support the research. This chapter details schedule and structure of the interviews, input received from participants, and considerations for specific topics that should be addressed in the subsequent research efforts. The comments described in this chapter reflect input from agency staff who participated in the interviews. Further consideration of topics discussed at the agency interviews is expected to continue throughout the project.

Return on investment (ROI) analysis is widely applied in the field of transportation infrastructure development as a way to quantitatively convey the benefits of a potential project. The objective of this project is to develop a refined, consistent, and standardized ROI methodology and tool for better assessing MnPASS programs and projects. The emphasis is to investigate a more comprehensive set of factors, variables, and perspectives to include within the refined ROI analysis framework, such as transit impacts and weekend benefits (traditional methods of using the travel demand model are limited to weekdays, but weekend benefits, such as event traffic, could be included) that are not included within the existing economic analysis, and incorporate broader benefits from MnPASS system operations (i.e. travel time reliability, managed network connectivity and accessibility). Addressing the challenges of incorporating these concerns and impacts, and proposing a consistent and standard evaluation framework will be key parts of the refined methodology. Ultimately, this project will identify best practices of ROI assessment for the MnPASS system, and provide recommendations for conducting standardized ROI analysis to evaluate the financial effectiveness of MnPASS as a long-term regional mobility strategy. This will be accomplished through a systematic and sequential series of tasks and approaches outlined below.

- Identify the limitations in the MnPASS benefit-cost analysis (BCA) methodology through a review of related background studies and the development of a list of broader points to be considered for inclusion in the refinement process.
- Conduct agency interviews with stakeholders to obtain MnPASS planning and operating agencies' objectives, experience, needs, related benefits and costs of the system, and necessary data to support the research.
- Define typical ROI categories for MnPASS investments and establish a relationship diagram of these categories and their associated benefits and costs.
- Adopt benefit-cost analysis (BCA) and life-cycle cost analysis (LCCA) methods to estimate benefit-cost (B/C) ratios of proposed projects, and develop refined ROI/BCA framework for MnPASS with an emphasis on the additional considerations.
- Conduct a comparative demonstration of the revised methodology by using original and refined tools to develop recommendations.

2.1 AGENCY INTERVIEW STRUCTURE

The agencies and staff represented at each agency interview are shown in Table 8.

Table 8: Agency Interview Staff

MnDOT Metro District (May 1, 2015)	MnDOT Central Office (May 5, 2015)	Metropolitan Council (May 6, 2015)	MnDOT RTMC (May 12, 2015)
Jim Henricksen	Ken Buckeye	Jonathan Ehrlich	Brian Kary
Brian Isaacson	Philip Schaffner	Steve Peterson	Morrie Luke
Brad Larsen	John Wilson	Brad Utecht	

The discussion items presented to the staff at each interview are listed in Figure 2.

DISCUSSION AGENDA

- Shortcomings of existing methodology
  - VMT/VHT from regional travel demand model does not fully capture benefits
  - Transit and reliability measures not considered
  - Inconsistency between system/corridor studies and design projects
  - Cost estimation techniques have not always produced reasonable results
- Expectations for refined methodology
  - Technical questions to be answered
    - User impacts, tool set/analysis tools
  - Potential users
    - MnPASS corridor and system studies
    - Other: transitway studies, non-MnPASS managed lane studies
  - Level of effort
    - What is the expected outcome/future use?
    - What elements are agencies willing to compromise (i.e. cost estimates, operations analysis, etc.)
- Specific elements to be included in refined methodology
  - Transit
    - Ridership increases, benefits to riders and operators
  - Carpools

      - Changing the mode distribution, encouraging greater number of HOV’s
  - Person throughput
  - Travel time reliability
      - Travel time benefits for non-recurring factors
  - Improved cost estimates
      - Review previous project construction costs
- Consideration of other economic factors
  - 20-year time horizon generally used – consider modifying
  - Other standard MnDOT parameters
      - Discount rate, value of time
- Unique elements of alternatives
  - Non-MnPASS managed lanes
      - BRT dedicated guideway, direct connections
- Investment categories and plans
  - Return on investment categories within the practical investment options for MnPASS
- Other comments

Figure 2: Agency Interview Discussion Topics

NOTE: THE TEXT IN FIGURE 1 REPRODUCES THE DISCUSSION LIST PROVIDED TO INTERVIEW PARTICIPANTS VERBATIM. ACRONYMS NOT PREVIOUSLY DEFINED INCLUDE VEHICLE-MILES TRAVELLED (VMT), VEHICLE-HOURS TRAVELLED (VHT), HIGH-OCCUPANCY VEHICLE (HOV), AND BUS RAPID TRANSIT (BRT).

2.2 AGENCY REPONSES

Responses from the four agency interviews are summarized below. This summary is a synthesis of statements made throughout the interviews. Statements have not been verified for accuracy, but rather represent the opinions expressed by interview participants.

2.2.1 Background Experience

MnDOT Metro staff identified issues and lessons learned from four of the existing and potential MnPASS corridors. From past MnPASS projects, it has been observed that a MnPASS implementation is unlikely to happen in isolation, which makes it difficult to determine the impacts exclusively from a MnPASS lane. In addition, when a MnPASS lane is added to a corridor with an existing HOV lane, staff members are able to observe the increase in SOV toll payers, but are unable to make any conclusion about the number of HOV trips generated.

2.2.2 MnPASS Case Studies

The following case studies were identified by agency interview staff:

- I-35W Urban Partnership Agreement (UPA) Project: This project was completed concurrent with other mobility improvements, and it is difficult to distinguish which benefits are coming from the MnPASS lane versus other enhancements along the corridor during the analysis.
- I-35W North: Spot improvements were separated out by measuring what could be improved with MnPASS versus what could be improved with small improvements along the corridor. Each incremental improvement was accounted for during analysis (possible in planning context).
- I-94: This is a high cost project, and it is difficult to convey how many of the benefits are coming from MnPASS versus preservation. For example, it is unlikely that an improvement would be undertaken in the absence of other preservation activities. It is far less common that preservation activities would be accelerated to coordinate with other investments.
- I-35E: MnDOT Regional Transportation Management Center (RTMC) staff noted that this MnPASS corridor was not the highest priority, but due to the Cayuga bridge replacement, the MnPASS lane construction was accelerated. In this example, the synergy of preservation led to the managed lane.

2.2.3 Potential Tool Refinement Topics

Two of the challenges that led to this study are the concerns about cost estimation techniques not providing reasonable results and determining what is reasonable to be included in BCA for MnPASS lanes (MnDOT Metro). Up to this point, reliability benefits of MnPASS lanes have been measured qualitatively, and an objective of the ROI research is to quantitatively measure benefits when comparing a MnPASS lane to a general-purpose lane (Metropolitan Council).

MnDOT staff indicated that measures of VMT and VHT from the regional travel demand model (TDM) were perhaps overestimating benefits. There are several reasons for this:

- TDM is taking trips from the entire region and allocating them to a subarea.
- VMT and VHT from regional TDM capture even the smallest of changes and quantifies them based on, what MnDOT staff considers, unrealistic or inestimable user costs. Participants described an example where a travel time savings of a few seconds per user applied to many users may result in significant benefits. Counting these individual small benefits may be unrealistic.
- Existing VMT and VHT in the BCA do not account for vehicle operating costs in the BCA tool, which are out of pocket expenses for the user (gas, vehicle upkeep, etc.).

Another challenge currently facing users of the existing BCA tool is that benefit-cost calculations vary widely from a system level analysis versus a project or corridor analysis. While users can compare BCA calculations from project to project (providing that consistent factors are used for all projects), an issue arises when performing a “traditional” BCA (determining if a project is cost-effective using a threshold of benefit-cost ratio greater than 1.0 for a specific project). Often, the ratio is much greater than 1.0 because the benefits used in the calculations are, according to interviewees, “imaginary”, meaning that the benefits are dispersed among many users making it challenging to measure and nearly impossible to demonstrate, while the costs are real (MnDOT Metro). The lack of consistency (variation in range of costs and benefits) makes it difficult to compare a no build versus build alternative for a project, or among different projects (MnDOT Central Office). Other necessary refinement categories include travel time reliability, safety, and transit.

2.2.4 Costs and Benefits to be Included in New Tool

One of the main issues identified during the agency interviews was determining which costs and benefits should be used in BCA calculations for MnPASS lanes. For decision making purposes, the new tool and methodology should clearly define what is being compared between projects, or between alternatives for a single project. Most of the cost and benefit categories already have established tools. The following costs and benefits were identified by the agencies as areas of interest:

- User benefits
- Operating benefits and costs
- Coordination with Maintenance Activities
- User costs during construction
- Incident management benefits and costs
- Enforcement cost
- Emissions cost

The following sections present the key points that agencies identified about potential benefits and costs that should be included in the updated tool.

2.2.5 User Benefits

The construction of MnPASS lanes will provide benefits to both users and non-users. These include: travel time reliability benefits, health benefits, and system coverage and connectivity benefits.

2.2.5.1 Travel Time Reliability Benefits

By taking users out of the general purpose lane, there is a travel time benefit that can be applied for general purpose traffic. The congestion-free option of the MnPASS lane will provide travel time reliability and savings to users. While travel time reliability is not captured as a quantitative measure by the existing tool, including reliability benefits in the new tool could potentially make the construction of MnPASS lanes more defensible to decision makers. Quantitative travel time reliability benefits could be more meaningful than incremental benefits (the ability to capture the value of consistently reliable travel times may be worth more than small increases in average travel times) in the BCA for MnPASS. Further discussion of travel time reliability is provided in a subsequent section.

2.2.5.2 Health Benefits

In addition to the time savings benefit, the agencies expressed interest in the monetization of healthcare benefits from MnPASS. Potential healthcare savings include stress reduction and physical benefits from spending less time in a vehicle.

2.2.5.3 Coverage and Connectivity Benefits

Coverage and connectivity user benefits should also be included in the new tool. For example, a new MnPASS lane attracts users from a general-purpose lane, which now has a better capacity to attract trips from a non-freeway parallel route. As the MnPASS network expands, users will also have access to MnPASS lanes on five or more facilities (instead of two) with the purchase of a single transponder, and connect directly to other MnPASS lanes. Data may not be available for this and could be investigated through analysis of regional travel patterns and review of managed lane networks in other metropolitan areas.

2.2.6 Operating Benefits and Costs

Incremental costs are typically included in BCA, along with general maintenance costs. While the MnPASS lane provides increased travel time reliability and less congestion, there are external costs associated with MnPASS highway expansions that are not included in the existing tool. Various staff (Metropolitan Council) felt that costs such as storm water should be included in the new tool.

2.2.7 Coordination with Preservation Activities

Preservation costs and benefits may occur for a project, regardless of a proposed improvement. Including or excluding these benefits may have a large impact on results. Marginal benefits resulting from preservation activities should be excluded from the BCA, to ensure that benefits that the agency is not paying for are not included in the analysis. In addition, the project's benefits do not need to justify preservation costs, as the costs would be present without the proposed improvement. For example, if a portion of a project's cost is due to preservation activities and a portion comes from the proposed improvement, the tool needs to be able to take this into account. The existing tool cannot separate preservation costs and benefits from the overall project costs and benefits.

2.2.8 User Costs during Construction

Existing tools do not generally include user costs during construction in the BCA. Currently, this criterion is evaluated separately, but is sometimes considered in the decision-making process. The agencies made it clear that this is an evaluation criterion that needs to be considered, but is not included in the current ROI calculation. For example, a project may have an ultimate benefit-cost ratio greater than 1.0, but the construction could impact users (travel-time and congestion) to the point that the project is no longer feasible. The consensus was that these costs need to be considered when developing a benefit-cost ratio for all projects.

2.2.9 Incident Management

MnPASS lanes present both benefits and costs relating to incident management.

MnPASS lanes will, to some degree, provide free-flow conditions that can be utilized by emergency vehicles. By using the MnPASS lane, emergency response vehicles will have more reliability and shorter travel time. Agency representatives expressed that this seems like a significant benefit that should be captured by the tool, but there is no way to do so in the existing tool.

In addition to the benefits provided by the MnPASS lane, there are additional incident management costs that must be considered. The tool should be able to quantify the added risk to emergency vehicles, and the added costs of constructing an extra refuge area (shoulder lost to MnPASS lane). The tool should also account for additional costs to educate the public and emergency professionals about how the MnPASS lane should or should not be utilized by emergency response vehicles.

2.2.10 Enforcement Cost

Additional costs for enforcement are included in BCA for MnPASS alternatives (included as part of the annual recurring costs). However, agencies questioned whether or not it is fair to assign all enforcement costs to the MnPASS operation, because enforcement should be present for all alternatives. This may vary depending on the use of the analysis, for example: whether MnDOT is considering internal financial outlays versus overall public costs.

2.2.11 Emission Cost

The MnDOT Central Office placed a strong emphasis on including the cost of emissions in the BCA tool. The first challenge with including emissions in the BCA calculations is to monetize the cost of emissions. MnDOT Central Office staff referenced the TIGER BCA Resource Guide, stating that it provides direction on how to calculate several factors (i.e. social cost of carbon, local pollutants, and health impacts) that are used in the EPA's model to produce a cost per mile for cars and trucks (separately). The agency would like to incorporate a factor similar to this in the new tool for future BCA calculations, so that future decisions could include the intersection of the benefits from increased reliability (reduced congestion) with the repercussions of increased emissions.

2.2.12 Travel Time Reliability

Improved travel time reliability is the core purpose for MnPASS lanes. However, capturing and measuring travel time reliability is an emerging area of analysis and has not been adopted for mainstream use at this time. Additionally, there are a limited number of projects that include travel time reliability. The Strategic Highway Research Program (SHRP 2) provides guidance on how to understand, measure, and represent the reliability of a facility in BCA, but many questions still remain.

2.2.12.1 Value of Time/Value of Reliability

Monetizing travel time reliability will be a key aspect of the refined methodology. To do this, a value of time must be developed. From a travel demand model perspective, value of time only makes a difference when individuals have different values of time, or else everyone would always make the same route choice. Drivers make route choices based on multiple attributes and how much their time is worth. Individual's varying preferences for values of time, reliability, and other travel choices result in varying distributions that produce different route decisions.

Research is exploring the value of reliability over and above the value of time (SHRP 2 tools, for example). As results of this research become more widely published and accepted, this should be incorporated in MnDOT's planning tools. This research has not yet produced a consensus on these topics, but MnDOT should stay up to date on the progress of this research.

2.2.12.2 Measuring Value of a Congestion Free Trip

MnPASS lanes are designed to provide a congestion free trip at no cost for the users who qualify to use it (carpoolers and transit) and for single drivers who choose to pay for it. Measuring the value of some drivers having a congestion free trip some of the time is a challenge that needs to be addressed with the new tool. The reason the toll works is because people have a qualitative measure of their travel time savings, and it is important that this is captured by the tool.

Travel time reliability appears to be very valuable according to the *MnPASS Modeling and Pricing Algorithm Enhancement – Draft Final Report* prepared by the University of Minnesota in December 2014. According to this report, users are willing to pay higher rates for increased reliability.

2.2.12.3 System vs. Local Value of Time and Value of Reliability

A key strength of MnPASS is the reliability of trip time, and this is why toll payers choose to pay a premium value to use the lane (MnDOT Central). However, this may vary between corridors, and throughout the state. The new tool should consider whether reliability is corridor specific and should be treated locally, or if it is acceptable to have a statewide value of time that is used in calculations.

2.2.12.4 Planning Time Index/Planning Time Savings

One possible approach to quantifying travel time reliability is calculating the planning time index or planning time savings. Planning time index calculations are fairly specific and may be difficult to replicate from project to project. MnDOT Metro staff noted that many users may be using the 95th percentile travel time (willing to be late every one out of twenty days) to make commute decisions. If this is the case, it was suggested that costs should be applied over the planned travel time, or even applied to a different threshold. For example, a commuter who regularly uses the general-purpose lane and must plan for a 30 minute commute instead uses the MnPASS lane and only needs to plan for a 15 minute commute. The MnPASS user is saving 15 minutes of planned travel time (50%), but with the current process there will be no benefits applied to these savings.

2.2.12.5 Financial Impact of Being Late

The Metropolitan Council staff indicated that the financial impacts of being late should be explored, and that quantifying the impact of unreliable travel on time sensitive activities such as catching a flight, daycare pickup, and shift jobs should be explored. It was suggested that the financial impacts of being late may be more related to occupation than income, but a survey might be necessary to understand what types of occupational tolerance to lateness exist, and if the tolerance is regionally or temporally specific.

2.2.12.6 Health Impacts of Unreliable Travel

Quantifying the impact of unreliable travel time on health (stress), and the corresponding costs, is an area of future research identified by the agencies during the interviews. In addition to physiological impact of unreliable travel, agencies also expressed interest in determining the physical impacts of unreliable travel (i.e. back or neck pain from extra time spent in a car due to congestion).

2.3 ON TIME PERFORMANCE

In addition to monetizing the value of travel time reliability for drivers, the agencies expressed interest in monetizing the benefits of increased travel time reliability for transit, emergency vehicles, and freight.

2.3.1 Reliability for Transit Service

A shortcoming of the existing methodology is that the absolute travel time savings for private cars and trucks are captured, but buses and other transit modes are not included. With the addition of MnPASS lanes, the agencies expect that transit trips will become more reliable, and that operating costs will be decreased; a faster, more reliable bus line will require fewer busses and operators, and there should be a cost savings for this. Agency representatives recommend that the refined process incorporates these savings and benefits in the future BCA.

MnDOT Metro staff noted that there are two types of transit reliability that could be incorporated in the tool: service reliability and passenger experience reliability. This may be difficult to capture because transit ridership is variable throughout the day, but warrants further consideration.

2.3.2 Emergency Vehicles

Emergency vehicles will have the opportunity to use MnPASS lanes to decrease response times. This benefit is not included in the existing process, but should be incorporated in the updated tool.

2.3.3 Freight

The development of labor costs for freight vehicles should be explored with the development of the refined process, and the benefits that MnPASS could potentially offer to freight operations. Depending on applicability, a better understanding of value of time of shippers would improve the process and allow for better evaluation. The potential opening of MnPASS lanes to additional shippers and heavy vehicles could be a future area of research.

2.4 NON-RECURRING CONGESTION

Another objective of the updated tool is to understand the impact that MnPASS lanes have on travel time reliability on days with non-recurring congestion. Tools developed through SHRP 2 and corridor evaluations in Minnesota are emerging to provide these results. It will be important to understand if the unreliable travel time is due to atypical conditions (weather, crash, incident, etc.) or capacity issues. Currently, the planning time and travel time savings from MnPASS during non-recurring congestion are not included in the BCA.

2.4.1 Weather Impacts

The agencies expressed interest in determining the benefits to travel time reliability (if any) that can be attributed to MnPASS on days with snow or other weather events. In addition, the agencies are interested in understanding the relationship between non-recurring congestion and MnPASS use and revenue. For example, on days with a snow event does the number of MnPASS users increase, and are those users willing to pay a higher toll to have a less congested (and more reliable) travel option? During these times, could the toll be increased to more than eight dollars?

2.4.2 Crashes and Incidents

A MnPASS lane will offer different clearance characteristics for crashes and incidents than a general-purpose lane. In addition, when using the VMT/VHT methods for BCA, vehicles switching from non-freeway roads to freeways will be assigned additional safety benefits. Some unanswered questions remain regarding effects from changes in vehicle occupancy among users of MnPASS lanes and other vehicle throughput factors.

2.4.3 Safety

2.4.3.1 Are Safety Benefits a Goal of Expanding MnPASS System?

MnPASS is only under consideration for existing roadways where capacity improvements are needed, so safety benefits are unlikely to impact the decision to construct a MnPASS lane. Metropolitan Council staff stated that if MnPASS cannot be justified based on policy, the project will not be built, so safety benefits are irrelevant. MnDOT staff also raised the question of whether or not safety benefits are a goal of expanding the MnPASS system. There are many facets to safety considerations in the planning and design of MnPASS facilities. These include user perceptions, lane access locations, and congestion related crashes. Broadening evaluation of safety impacts should continue to be explored.

Some participants felt that safety benefits are not a goal of expanding the MnPASS system, however this point was not universally agreed upon.

2.4.4 Crash Rates

If safety benefits from MnPASS will be used by future decision makers, it will be important that the updated tool accounts for different facility types and the crash rates with corresponding VMT (freeway versus non-freeway). This process will need to be detailed without being burdensome, and will need to be applied to MnPASS as well.

2.4.5 Data Availability

One challenge with including safety benefits due to MnPASS will be compiling statistically meaningful data showing the difference in crashes on MnPASS lanes compared to general purpose lanes (are the MnPASS lanes more or less safe than general purpose). To do this, crash data would have to be tracked by lane on the MnPASS facilities. Another way to try to determine the safety benefits of MnPASS would be to calculate the rate of crashes before and after the construction of MnPASS along a corridor.

Participants made note that the I-394 report (*Benefit and Cost Analysis of the I-394 MnPASS Program)*, which documented significant safety benefits when a MnPASS lane was added.

2.5 TRANSIT

As noted previously, the existing tool does not apply benefits and costs associated with transit in the VMT/VHT process; the agencies agreed that the degree to which this impacts the current process is significant, and this needs to be addressed in the tool refinements. The agencies identified the following areas of improvement.

- Increase Throughput without Increasing Congestion
  - MnDOT metro staff expressed interest in exploring how MnPASS can attract additional transit users without increasing congestion.
- Quantifying Time Savings for Transit User Base
  - Understanding the benefits to transit becomes difficult because the benefits must be quantified systematically and consistently with data from the region. This is particularly challenging with transit since the model is different.
- Including Transit in BCA Calculations
  - There is still some uncertainty about how transit will be included in the BCA calculations. There may be a need to move away from VMT/VHT and toward more person-based

measures, as BCA monetization is done at the per-person level, after the application of average vehicle occupancy rates.

2.6 TRAVEL BEHAVIOR CONSIDERATIONS

Several behavioral issues were brought up throughout the agency interviews. These topics include the influence of MnPASS on carpool habits, price sensitivity, and evaluation methodology.

2.6.1 MnPASS Influence on Carpool Habits

There was an interest in understanding the influence (if any) that MnPASS lanes have on the formation of new carpools and attracting existing carpoolers to the corridor. MnDOT staff suggested that it would be helpful to include studies about the influence of HOV/HOT lanes on carpool formation in the literature review, or include a case study (such as the Central Minnesota Area Commuter Study). They are skeptical that the addition of MnPASS lanes would increase carpoolers, and speculated that most people would rather pay the toll than ride in a carpool.

The conversion of the I-394 and I-35W HOV lanes to HOT lanes resulted in no net increase in carpools, but simply additional users who purchased transponders. However, there are no remaining HOV lane conversions, so any additional MnPASS lanes will be new HOT lanes. MnDOT RTMC staff believes that this will provide another, fairly significant, incentive for users to carpool in addition to the other incentives to carpool, and that this is an important factor to try to include in the benefits.

The regional travel demand model has the ability to capture this, and a better understanding of carpool formation would provide more confidence in these calculations.

2.6.1.1 Capturing Change in Occupancy

There are a number of factors that have to occur for effective carpooling, including: home location, work location, and consistent schedule, which limit the potential for new carpool formations. This is an area for review of findings from other metro areas and future research.

2.6.2 Price Sensitivity

Field observations and completed studies suggest counterintuitive price elasticity. When the price for SOVs using MnPASS increases, drivers are using it as a proxy for the condition of general purpose lanes. As a result, MnPASS pricing is not as effective as it should be at limiting flow of MnPASS. More information is needed for customers to make a rational economic decision about using MnPASS, for example, providing the travel time or travel time savings (indication of value of time savings) to users in general purpose lanes.

2.6.2.1 Limiting Use of MnPASS to Ensure Reliable Travel

MnDOT metro staff identified a list of actions that could potentially be taken in the future (if necessary) to limit the number of paying SOVs to ensure reliable travel time in MnPASS lanes. The first step would be to accelerate price increases (rather than increase the maximum price). Next, access spacing could be adjusted. This could be done by either opening up additional access, or reducing existing access to limit shorter trips. The third step would be to raise the maximum toll, or increase segmentation (e.g. implement segments where users pay up to eight dollars per segment, but no more than 12 dollars total). The final step would be conversion pricing from HOV 2+ to HOV 3+ such that users would have to pay a toll when there are fewer than three passengers.

2.7 FINDINGS AND CONCLUSIONS

The input obtained through the agency interviews will be highly valuable in guiding the research to refine the return on investment tools for evaluating MnPASS. The participants representing the agencies that plan and operate MnPASS facilities were extremely helpful in offering their input to the process, and demonstrated that they share in the investment to improve upon currently available tools. The information presented in this chapter describes the interview format, summarizes the range of topics discussed, and describes the recommendations gleaned from this process.

An updated evaluation methodology will become necessary to incorporate the tool refinements and behavioral topics identified by the agencies throughout the interviews. To aid in the development of new evaluation methodology, a spectrum of evaluation components was developed.

2.7.1 Spectrum of Evaluation Components

The agency interviews produced a wealth of input toward the refinement of ROI tools for evaluating future MnPASS investments. This input covered an immense variety of topics and their applicability to a refined toolset, and in some cases, contradictory assessments. The research team has attempted to distill this input into distinct categories and postulate how they may fit into the subsequent steps of refining the MnPASS evaluation methods.

A spectrum consisting of two axes was devised to organize the topics relative to one another based on feedback obtained through the agency interviews (Figure 3). The y-axis indicates the level of maturity status for each evaluation topic. This is a largely objective measure based on industry capabilities, because the availability of applicable tools can be readily identified. Items closer to the top of the chart have methodologies that are well established, while items near the bottom are less understood.

The x-axis is a largely subjective measure based on the cumulative responses from the agency interviews and illustrates the extent to which each element may be expected to fit into the refined MnPASS evaluation tools. The left-hand side shows topics that participants were essentially certain will be included in the tools, whereas the right-hand side includes topics that may not fit into the evaluations due to technical limitations or applicability.

Together, these spectra helped to create a framework for the subsequent research tasks, with items in the upper left representing the "low-hanging fruit" and items in the bottom right as "beyond the scope" of this work. Items found in the lower left and upper right will require additional consideration to weigh the tradeoffs for inclusion.

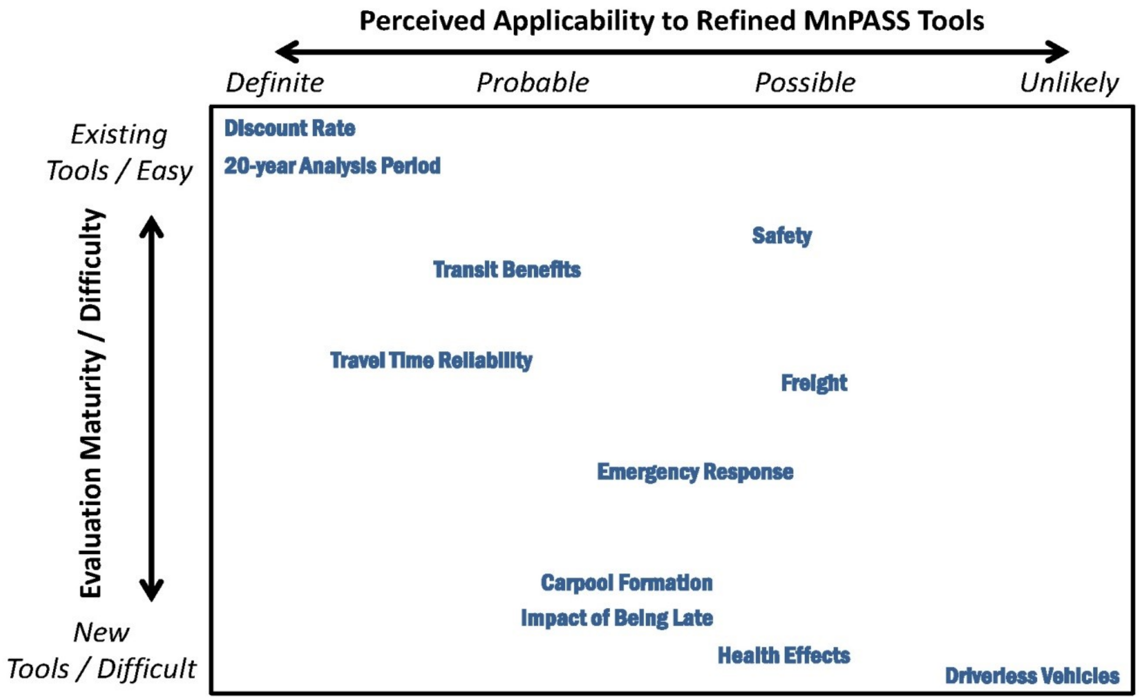

Figure 3: Spectrum of Potential Tool Components

2.7.2 Recommendations

2.7.2.1 Discount Rate

The discount rate is currently set using a formula based on thirty-year treasury notes. It was recognized that the discount rate is an essential component of benefit-cost and other economic analysis, and that it has the potential to influence evaluation results. In this context, interview participants believed it was critical to tie it to a widely recognized benchmark rate, and that the treasury rate was a reliable source and does not need to be reconsidered at this time.

Action: Continue using discount rate with current methods.

2.7.2.2 20-Year Analysis Period

MnDOT has utilized a twenty-year analysis period for benefit-cost analysis. Historically, it has been used because it corresponds to the region's long-range transportation planning horizon. Agency representatives recognized that a longer period would capture a greater proportion of the service life of infrastructure investments. There was concern that due to the accuracy limitations of current forecasting tools and methods, interest in lengthening the analysis period is limited.

Action: Continue using a 20-year analysis for economic evaluation of MnPASS investments.

2.7.2.3 Transit Benefits

Inclusion of transit benefits was consistently viewed as one of the critical needs to refine current methods for evaluating MnPASS. Tools to analyze transit benefits are widely available and understood, but simply need to be applied consistently. While additional effort is required compared to more basic approaches, there was broad consensus that transit benefits should be included.

Action: Incorporate transit benefits into refined evaluation tools by defining a consistent methodology.

2.7.2.4 Travel Time Reliability

The goal of a congestion-free choice is the touchstone of the MnPASS system's functionality and operating principles. Previously, however, there have been limitations to evaluating and expressing the reliability benefits of MnPASS. Travel time reliability tools are now emerging as an indispensable complement in the traffic evaluation toolbox, and were widely seen as necessary for capturing and communicating the role of MnPASS in the regional network.

Action: Incorporate travel time reliability into refined evaluation tools as reliability methods continue to mature.

2.7.2.5 Safety

Economic safety impacts have been included in benefit-cost analysis for many years using general methods that rely on shifts in VMT among various roadway types. While these may be appropriate for major projects like capacity expansion, freeway conversion, and new alignments, many expressed doubts about whether these methods are appropriate for managed lanes. Traditional methods of evaluating traffic shifts between arterial and freeway facilities focus on safety at the facility level, whereas considering MnPASS safety from a design context may be a more applicable approach. As a result, the continued use of safety impacts in future tools should be scrutinized.

Action: The applicability and influence of safety considerations in MnPASS evaluation must continue to be explored to determine how it is implemented in refined analysis tools.

2.7.2.6 Freight

The role and impacts of freight movements on the metropolitan area's highway network are escalating, and more robust performance information is desired. Some tools exist to evaluate freight movements, but a large opportunity for enhancement was observed. There was uncertainty, however, concerning how MnPASS interacts with freight. It was generally felt that freight deserved additional consideration in MnPASS evaluation, but there was little consensus on how this would be accomplished or the effects it may have.

Action: Explore the overlap between freight performance and MnPASS facilities to determine whether there is sufficient evidence to support incorporation into refined evaluation tools.

2.7.2.7 Emergency Response

Emergency responders are an under-represented group of beneficiaries of MnPASS facilities. This segment arguably has the highest value of time among all roadway users and stands to benefit greatly from expansion of the MnPASS system. There was little awareness of efforts to engage these users and develop a framework to capture their benefits from MnPASS. While some upfront effort will be required to involve this stakeholder, many suggested that this be explored further as a component of MnPASS evaluation.

Action: Explore emergency response impacts at a high level to determine whether they are meaningfully significant for MnPASS facilities to support incorporation into refined evaluation tools.

2.7.2.8 Carpool Formation

There was extensive discussion about the role and effectiveness of MnPASS on influencing carpooling behaviors. Some suggested that facilities providing HOV advantages have a large influence, while others maintained that they have little to none. Objective research on these effects is clearly needed, and is unlikely to be available for inclusion in tools developed as part of the current effort. While conducting this research represents an effort beyond the scope of the study, it is likely within MnDOT's capabilities and would provide substantial payback in terms of improved evaluation methods and MnPASS marketing approaches.

Action: Review literature for studies addressing the influence of managed lane facilities on carpool formation or consider future MnDOT-led research on this topic. Utilize results of this investigation to determine if knowledge is adequate for use in refined tools.

2.7.2.9 Impact of Being Late

While evaluation of travel time reliability performance at the facility level will likely be incorporated into MnPASS evaluations, a host of related topics remain in their infancy. Among these are financial impacts of being late and defining the value of reliability. There was intense interest in these topics as they were repeatedly viewed as critical to MnPASS evaluation. Unfortunately, the state-of-the-science on these measures is not mature enough to seriously consider their inclusion in a refined methodology at this time.

Action: Review literature and ongoing research on impacts of being late and value of reliability, but current knowledge is not adequate to include these components in tools.

2.7.2.10 Driverless Vehicles

The refinement and proliferation of automated and driverless vehicles are rapidly permeating the consciousness of transportation professionals, and are expected to have far-reaching impacts on operations, facility design, and evaluation techniques. This evolution remains relatively distant at this point, however, and imminent changes to MnPASS evaluation tools would not be warranted until these vehicles achieve a critical fleet share in the range of five to ten percent.

Action: Monitor advances in driverless vehicles and reconsider inclusion as fleet proportion grows in the future.

CHAPTER 3: IDENTIFICATION OF MNPASS ROI INVESTMENT CATEGORIES

Similar to a state highway program that contains different investment components (e.g. pavement preservation, bridge replacement, highway safety, highway reconstruction, etc.), MnPASS investment also consists of a variety of programs and projects associated with each component of MnPASS construction. In other words, MnPASS is a bundle of various investment/infrastructure components, rather than a discrete category of its own. The state highway program adopted a method for developing a composite return on investment based on the relative benefits generated by each investment/infrastructure components, in light of the diversity of investment/infrastructure components. However, the MnPASS program generates its benefits through the operation of the whole system, not the tolling lane segment itself, and every investment component is inseparable from the realization of a functional MnPASS system.

Currently, there are no remaining high-occupancy vehicle (HOV) lane conversions, so any additional MnPASS lanes will be new high-occupancy toll (HOT) lanes. As a result, major improvements and changes to these MnPASS lanes (to both the road itself as well as the auxiliary utilities) may involve full-depth pavement and additional width, bridge structure, lane reconfigurations, new shoulders, changes in access points, new medians and green space, reconstructed sidewalks, new lighting, drainage relocation, and other modifications. To maintain consistency with the potential construction needs of the MnPASS system, the following elements have been identified as the major investment options for a single MnPASS project. These elements collectively play a role in the improved roadway network:

- Roadway construction to accommodate MnPASS lanes in the existing road segment;
- Bridge construction to support the operation of a continuous MnPASS system;
- Roadway connection to realize the connection of MnPASS lanes, or MnPASS lanes and general purpose lanes;
- Advanced traffic management to install and operate MnPASS equipment;
- Transit system construction to incorporate transit facilities in the updated network;
- Utility deployment and relocation to provide auxiliary service (e.g., overhead sign relocation)

Detailed descriptions of the investment components and potential ROI categories are provided in Table 9.

Table 9. Investment Component and ROI Categories of MnPASS System

Investment Component		Scenario	Application
Roadway construction	Pavement reconstruction	Addition of MnPASS lanes in the median of the freeway segment	Standard design corridors with sufficient median width to accommodate MnPASS lanes
		Reconstruction and widening of shoulders to accommodate traffic	Other standard design and priced dynamic shoulder lane (PDSL) corridors requiring lane alignment shifts extending onto the existing right shoulder
	Resurface existing pavement	Mill and overlay of the full roadway cross section	When lanes will be shifted and potentially narrowed to accommodate the addition of MnPASS lanes
Bridge structures	Bridge widening	Standard design corridors	For existing bridges assumed to be suitable for widening
	Bridge replacement	Local road overpasses with insufficient horizontal clearance or freeway overpasses with designs incompatible with widening	When widening is not practical and the entire structure must be replaced
Roadway connection	New Segment connections	Connections of MnPASS lanes and general purpose lanes	Developed for each location individually based on a review of design concepts and site characteristics

Investment Component		Scenario	Application
	Ramp realignment	Modification of ramp alignments due to lane alignment shifts	PDSL and other corridors where lanes will be shifted affecting ramps within the corridor
Advanced traffic management (ATM)	ATM and MnPASS equipment	Tolling equipment, signs, sign structures, and communication infrastructure	For corridors with dedicated full-time MnPASS lanes
	MnPASS equipment only	Tolling equipment for MnPASS equipment only	For corridors with existing ATM in place
Transit system construction	Transit accommodation facility	Bus-only shoulder facility, etc.	Due to additional bus station design in the updated transit network
Utility deployment and relocation	Grading and drainage	Grading and drainage system adjustment	Due to additional pavement width and potential lane alignment shifts
	Overhead sign relocation	Overhead sign deployment	Due to shifting of signs to potential new ATM sign structures or relocation due to increased roadway width
	Median barrier	Addition of a concrete median barrier to corridors with no barrier in place	Standard design corridors with sufficient median width to accommodate MnPASS lanes
	Refuge area	Emergency vehicle shoulder facility	Due to shoulder lost to MnPASS lane

Investment Component		Scenario	Application
	Retaining wall	Retaining wall construction	Due to the geographic need of construction site
Miscellaneous	Other auxiliary utilities	Noise walls, additional ponding/drainage, etc.	When additional utilities are needed in some special construction sites

Investment in an actual MnPASS project will depend on the construction requirements in the candidate corridor. Some, or all, of the identified investment options and ROI categories could be covered in the new project. Due to the diversity of investment options and ROI categories, the overall cost of the project will vary among different combinations, which provide different alternatives for the investment decisions.

3.1 BENEFITS AND COSTS OF MNPASS PROGRAM

In accordance with the economic analysis methodology as recommended by the U.S. DOT in the guide to preparing ROI analyses for transportation improvement projects, a benefit-cost analysis (BCA) or Life-cycle Cost Analysis (LCCA) based ROI analysis is expected to be used to evaluate, rank, and select candidate MnPASS projects.

Theoretically, benefit-cost analysis (and ROI assessment) has the goal of providing a “full-cost” evaluation framework which tries to cover and measure all the impacts of new investment, and then generate a comparable index number (e.g., B/C ratio) for policymakers. However, in practice, it is always very complicated and difficult to enumerate and quantify all impacts. The complexities may exist in:

- Multiple impacts: not only on the visual improvement of traffic situation (e.g. congestion relief, speed increase, and shortened travel distance, etc.), but also on the surrounding environment (e.g., emissions and noise), social economic development (through the improvement of accessibility), and many other not readily noticeable but concerned aspects.
- Various beneficiaries: including not only road network users in the project affected region by auto, transit, truck, emergency vehicle, and other modes, but also the whole society that shares the impacts of new investment.
- Long-time accruement: of both cost and benefit components with uncertain changes in the whole life span assumption of new programs.

This project does not intend to concentrate on such a “full-cost” evaluation for future MnPASS programs. The main reason for constructing MnPASS managed tolling lanes in the Twin-city metropolitan area is to improve the performance of the travel system to alleviate increasing congestions. Therefore, it should be reasonable to estimate benefit and cost components that are typically related to the consequences of travel system improvement and direct cost of new investment in the economic analysis framework.

Based on the identification of potential investment options and ROI categories in the previous section, the following process tries to group cost and benefit components that occur in these new investments of MnPASS programs. The components identified in this section don’t cover all the impacts of a MnPASS project, but they are mostly derived according to the following rules: (1) accepted commonly as the direct impacts of an MnPASS program, (2) represent multiple aspects of project impacts and the measurements are not overlapping, and (3) measurable and the arithmetical methods are technically sound.

The following section provides a detailed overview of each component and associated feasible approach for the next step measurement. A summary of all valuations and methodologies to be used in the refined ROI framework for each impact component will be discussed in CHAPTER 4: .

3.2 ECONOMIC COST COMPONENTS

In a typical economic analysis, costs are defined as the resources (e.g. land, labor, and material) and expenditures required for implementing and maintaining the investments related to a certain project. Since these cost components generally represent goods or services that can be quantified with monetary value, it is generally easier and more convenient to value costs than benefits. The summary of BCA on the Transportation Research Board website lists the typical cost components that are included in a transportation improvement project: initial and capital costs, operating and maintenance costs, and remaining capital value.

3.2.1 Initial and Capital Costs

A project’s initial costs mainly occur in the process of project design and construction. For an MnPASS project, initial investment costs could include some or all of the following:

- Planning, preliminary engineering and project design
- Environmental impact report and ROI evaluation
- Project-related staff training
- Final engineering
- Land acquisition
- Construction costs for MnPASS lane addition, including improvements to existing facilities
- Construction equipment and vehicle rentals/purchases

- ATM equipment required for MnPASS managed tolling lane operation

MnPASS System Study Phase I provided a relevant method for estimating the annual initial/capital costs: multiplying the unit cost of each generic typical cross section by the number of miles in each segment. The cost per mile for each typical road section may include all the basic items that go along with road design and construction. For the connecting bridges and interchanges, the evaluation could be done individually as a part of the annual initial/capital cost estimation. MnDOT has designed a standard LWD (length, width, depth) cost estimating method for simplified, reliable and early estimates in the planning phases that could be used in the new tool.

3.2.2 Operating and Maintenance Costs

The cost of operating and maintaining a proposed MnPASS project is another indispensable part of total cost estimation. Operations and maintenance activities apply to several assets and produce continuing costs when a project is completed and in use. These costs may include the following items.

- Operations
    - Traffic management, toll collection, and bus operations.
    - Respond to specific conditions such as crashes and adverse weather.
- Preservation/Rehabilitation
    - Routine service to maintain and preserve the condition of tolling lanes.
    - Major repairs of facilities, such as lane resurfacing and bridge repair.

The background review of previous MnPASS studies relating to the operations and maintenance cost estimation identified some categories and their coverages considered in practice, as shown in Table 10. Although the resulting cost estimation of MnPASS operation contains many aspects, there is a strong connection between the existing MnPASS system and the further expansions in operations and maintenance cost estimation, e.g., shared administrative and back office functions, the same operation and management modes, and so on. Using the data from previous representative projects to estimate an approximate operations and maintenance cost could be an option for new MnPASS expansion projects, which would eliminate the need to conduct complicated analysis of many operation elements.

Table 10. Operations and Maintenance Categories and Cost Coverage Considered in Previous MnPASS Studies

Category	Description
Electronic toll collection	Toll collection services (e.g. device and equipment)
Payment enforcement	Enforce the payment of tolls
Back office system	Collect and process payments, record keeping etc.

MnPASS lane maintenance	Regular and winter maintenance activities
Incident management	Keep the lanes free of stalled vehicles
Traffic management	Monitor traffic levels
Travel information	Provide dynamic message signs to display current toll rates

3.2.3 Remaining Capital Value

At the end of the analysis period, there may be MnPASS infrastructure facilities that are not completely worn out, and will continue to provide benefits into the future. These future benefits can be captured in the remaining capital value. Previous studies indicated that 10 years after initial construction, the initial costs of some MnPASS components will be spent, e.g. electronics. Additionally, MnDOT staff indicated that some of the MnPASS utilities, e.g., overhead signs, need to be replaced in 10 years. Therefore, even though the analysis period for benefit-cost analyses put in place by the MnPASS project is up to 20 years (the recommendation in CHAPTER 2:), a shorter 10-year analysis period could be considered to include possible remaining capital value so as to provide a more conservative benefit-cost estimate.

In addition to these typical cost considerations, the following concerns were identified in CHAPTER 2: as components that should be added in the new tool and methodology for a refined MnPASS ROI assessment.

3.3 ECONOMIC BENEFIT COMPONENTS

In theory, the impact of a new transportation investment is a comprehensive expression of all aspects of its performance in real operation, and it's difficult to separate the new investment impacts into individual categories. In this task, the research group make the choice to select typical benefit components that are highly related with the characteristics and effects of the MnPASS system to capture the primary impacts of MnPASS lane construction and operation.

Traditionally, the evaluation of transportation system efficiency is the focus of BCA for most transportation improvement projects. Efficiency is expressed in terms of direct changes related to travel time, vehicle operating cost, and crash rate, based on prior MnPASS projects. In recent years, broader measures of social and environmental benefits have gained more attention, and they are being added as a value to the comprehensive BCA (e.g. social and environmental factors). To facilitate the calculation, MnDOT has established valuable guidance, “Benefit-Cost Analyses for Transportation Projects”, for conducting tractable and effective benefit-cost analysis. The consulting firm Parson Brinkerhoff created an analysis tool called PRISM that has also been applied by agencies around the country to determine benefits and costs within the five categories required by the federal TIGER grant program, such as State of good repair, Economic competitiveness, Livability, Sustainability, and Safety. To date, BCA studies have been implemented with the PRISM tool by jointly integrating the following social, economic and environmental factors (Table 11).

Table 11. Benefit-Cost Factors of PRISM

Social/Health	Economic/ Transportation	Environmental
• Safety • Bicycle/Pedestrian health effects • Noise	• Travel time • Travel time reliability • Vehicle operation costs • Life cycle costs • Loss of agricultural land • Induced economic activity • Access to jobs	• Emissions (CO_2 + criteria pollutants) • Wetland effects • Runoff

3.3.1 Traditional Benefit Considerations

3.3.1.1 Travel Time Savings

For a congestion relief project, travel time savings is often the principal benefit of a transportation improvement project. For projects like MnPASS that add a new lane to the existing road network, changes in traffic speeds and travel delays on both the new lane and parallel general purpose lanes will contribute to significant travel time savings benefit.

3.3.1.2 Vehicle Operating Cost

A MnPASS project could alter transportation and infrastructure characteristics, such as vehicle miles traveled (VMT), traffic speed and delay, roadway surfaces, and even roadway geometry, which will directly affect travelers' vehicle operating costs. Estimating changes in total VMT, vehicle travel speeds, as well as some fuel and non-fuel-related costs is a common way to calculate an approximate cost estimation.

3.3.1.3 Crash Cost

Crash cost reduction is a primary part of the safety benefit considered in the economic analysis. The change in traffic crash rates (also called crash or collision rates), e.g. frequency and severity, is mostly used for estimating the total economic value of safety improvement through the comparison of "Build" and "No-build" scenarios.

3.3.2 Additional Benefit Components

The MnPASS project, as a demonstrated effective measure to improve mobility within the Twin Cities, can benefit multiple stakeholders besides commuters. In particular, the effects on mobility improvement can contribute to broader indirect effects on the society and environment. These effects generally are difficult or impossible to monetize, and the difficulties in their quantification and inclusion in the new tool usually fall into two categories: how to understand and represent the effects with measurable changes and how to apply an appropriate dollar value for such changes. In terms of data availability and the effect of the MnPASS system in practice, the following impact categories could be added into the refined ROI assessment framework along with the tractable transportation measurements.

3.3.2.1 Travel Time Reliability

The goal of a congestion-free choice is the touchstone of the MnPASS system's functionality and operating principles. However, in the past there have been limitations to evaluating and expressing the reliability benefits of MnPASS. Travel time reliability tools are now emerging as an indispensable complement in the traffic evaluation toolbox, and are widely seen as necessary for capturing and communicating the role of MnPASS in the regional network.

3.3.2.2 Transit User Benefits

Inclusion of transit benefits was consistently viewed as one of the critical needs to refine current methods for evaluating MnPASS. Generally, transit benefits are realized when the perceived travel costs of transit users are reduced. MnPASS lanes provide free use for transit vehicles, which could greatly reduce transit users' travel time and travel delay, especially in the peak periods. These benefits can be calculated by identifying travel time savings and applying the savings to ridership on existing transit routes.

3.3.2.3 Freight User Benefits

The role and impacts of freight movements on the metropolitan area's highway network are escalating, and more robust performance information is desired. Some tools exist to evaluate freight movements, but the research team identified opportunities for enhancement. However, there was uncertainty concerning how MnPASS interacts with freight. It was generally felt that freight deserved additional consideration in MnPASS evaluation, but there was little consensus on how this would be accomplished or the effects it may have.

3.3.2.4 Induced Traffic

The MnPASS project could potentially increase vehicle travel speeds and reduce travel cost in both general purpose and managed tolling lanes, and as a result, it could induce and attract additional vehicle travel from other facilities and parallel corridors. The induced traffic may include:

- New users (e.g. SOVs) that make trips they previously would not have made due to the lower travel cost in both general purpose and HOT lanes
- More trips on transit or in HOVs in the HOT lanes

The factor could be measured as the sum of the change in consumer surplus that induced users take from the MnPASS construction.

3.3.2.5 Emergency Response

Emergency responders are an under-represented group of beneficiaries of MnPASS facilities and arguably have the highest value of time among all roadway users, and stand to benefit greatly from expansion of the MnPASS system. There was little awareness of efforts to engage these users and develop a framework to capture their benefits from MnPASS. While some upfront effort will be required to involve these stakeholders, many suggested that this be explored further as a component of MnPASS evaluation.

3.3.2.6 Emission Impact

The MnPASS project will produce environmental and sustainability impacts relating to air pollution resulting from automobile, commercial truck, and bus travel. Several forms of emissions could be identified, measured and monetized in terms of per-mile emissions rates, but the result will be highly dependent on available data support. For the Build and No-Build scenarios, further investigation is needed to determine whether the new transportation improvement is beneficial for emission reductions.

3.3.2.7 Noise Impact

Since MnPASS has the potential to attract traffic to the surrounding area, a traffic noise analysis may be needed to determine whether the impact of new improvement is significant or whether it’s beneficial for noise reduction. The costs of noise abatement measures could increase the total estimation of initial/capital cost, but potential noise reduction could be a benefit with a certain economic value.

All of the determined elements factor multiple economic, social, and environmental variables of the MnPASS system; they are then acting together to calculate either net benefit (benefit minus cost) or benefit-cost ratio. As a result of the diversity of potential project impacts, the data requested for calculating a benefit-cost ratio can vary among benefit and cost components. Table 12 summarizes the identified benefit and cost components and the data used to measure each item.

Table 12. Potential Data Needs for Impact Measurement of MnPASS Program

Data needs	Travel time savings	Vehicle operation costs	Crash cost	Emissions	Noise	Transit	Travel time reliability	Induced travel	Freight	Emergency response
Vehicle miles traveled		√	√	√	√	√		√	√	
Vehicle hours traveled	√						√		√	√
Annual number or rate of crashes			√							
Average speed		√		√	√		√		√	√
Throughput						√	√	√	√	
Annual average daily traffic					√			√		
Average bus headways	√					√	√			
Average bus occupancy	√					√	√			

3.4 SUMMARY

In accordance with the research requirement to explore broader benefit and cost factors of a refined MnPASS ROI assessment tool, this task specifically focused on three issues for in-depth investigation and valuation.

- **Definition of typical ROI categories relating to MnPASS system construction**. For new HOT lanes, researchers identified the following major investment options for a single MnPASS project: roadway construction (primarily addition of new lanes), bridge construction, roadway connection, toll equipment installation, transit system construction, and utility deployment and relocation. Different combinations of these investment options may lead to various alternatives, and specific geographic and site requirements may determine actual ROI categories. Assuming a constant level of benefits for one single MnPASS project, alternatives can be compared on a lifecycle cost basis.

- **Determination of cost components**. Based on the identification of major investment options for the MnPASS program, this task is trying to estimate all the direct cost of new investment in the economic analysis framework, i.e., initial and capital costs, operating and maintenance costs, and remaining capital value. The occurrence of all cost components within a project lifecycle is shown in Figure 4.

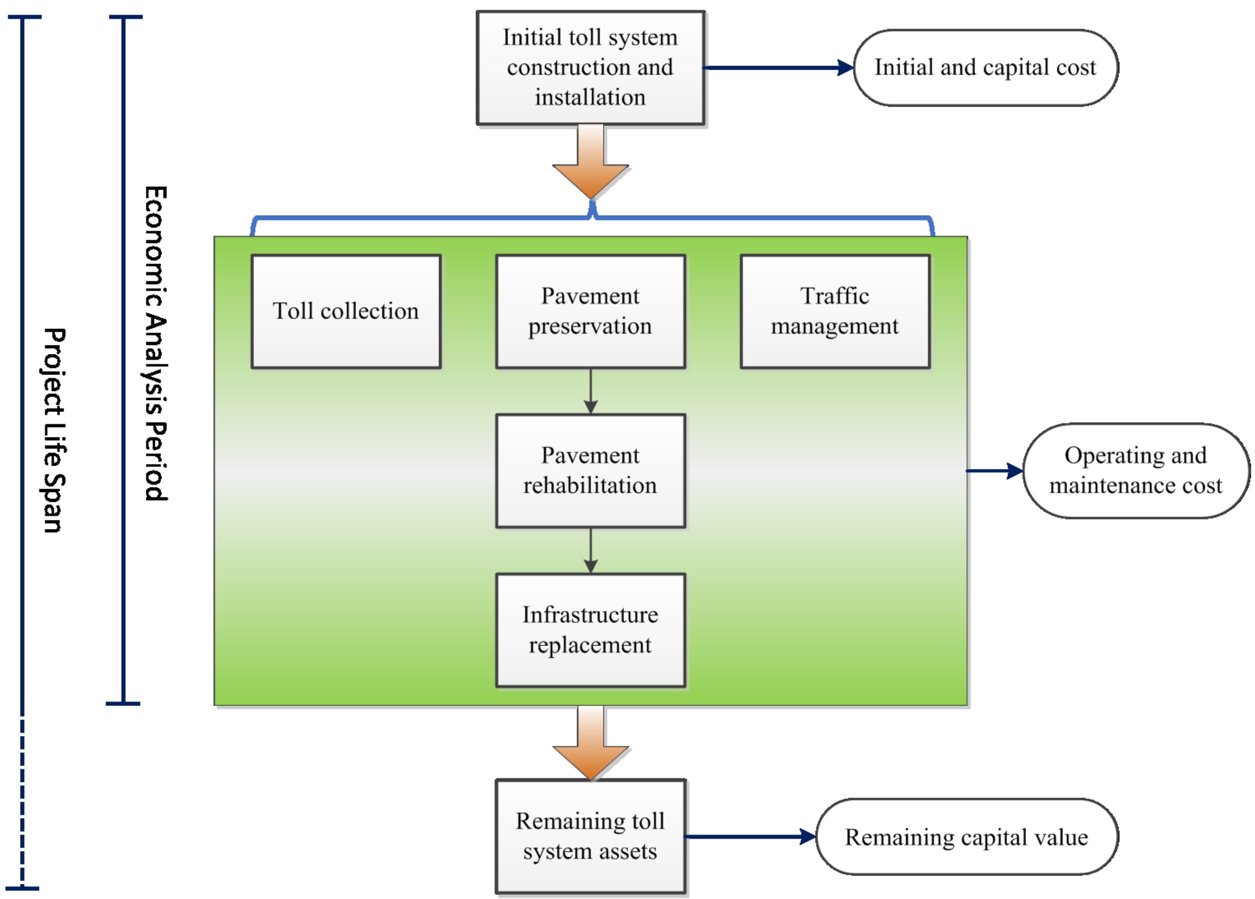

Figure 4. The Occurrence of Cost Components within a MnPASS Project Lifespan

- Incorporation of benefit components. Capturing the broader factors and assumptions that are not included within the existing economic analysis is the main focus of this research. Given the complexity of a MnPASS project, the benefits that include both transportation measures, social, and environmental factors can be hard to quantify. This task tries to synthesize the primary impact components that are accepted commonly as the direct impacts of a MnPASS program (as shown in Table 13), as well as accessible data needs for measurement. During this process, major concerns identified from MnDOT agency interviews (Chapter 2), limitations identified in the MnPASS BCA methodology (Chapter 1), and available data support were used as the primary basis for the determination of these factors.

Table 13. Identified Benefit Components for the Development of Refined ROI Assessment Tool

Social/Health	Economic/ Transportation	Environmental
• Safety/Crash costs • Noise	• Travel time savings • Vehicle operation costs • Travel time reliability • Induced traffic • Transit • Freight • Emergency response	• Emissions

CHAPTER 4: REFINEMENT FRAMEWORK OF ROI METHODOLOGY FOR MNPASS

The objective of this task was to develop a refinement of the framework of ROI methodology for MnPASS projects. Traditionally, the desirability of a potential MnPASS corridor is largely evaluated by transportation effectiveness measures and efficiency indicators, as well as financial metrics. A more comprehensive framework could be developed to incorporate a wider range of transportation, social and environmental factors, such as transit impact, travel time reliability, induced traffic, emergency response, emission and noise impacts, and safety factor, so as to capture more positive and negative effects of MnPASS projects on roadway users and local economy.

This task is a core step of the whole project and fully built upon the previous foundational steps. The steps for implementing a full ROI/BCA assessment of MnPASS projects followed the general logic of all policy evaluations and are shown in Figure 5.

In addition, despite the complexity of summarizing and calculating all the impacts of the MnPASS projects, policy decision makers need a simple and tractable methodology/tool for practical use in future economic analysis. In an effort to balance the ideal desire to implement a "full-cost" evaluation and the practical needs of an easy-to-use BCA (or ROI) tool, the research group made the choice in the previous tasks to select typical benefit components that are highly related with the characteristics and effects of the MnPASS system to capture the primary impacts of MnPASS lane construction and operation. The purpose is to find an appropriate balance between identifying sufficient costs and conducting a feasible analysis for the final MnPASS ROI assessment. The identified cost and benefit components are shown in Table 14 to Table 16. As a subsequent section, the research group continued to work on the measurement of identified impacts, as shown in the green square in Figure 5.

In the refined framework, necessary assumptions and simplifications were applied, and tractable calculation methods are presented for each cost and benefit measurement so as to make the economic analysis tool easy to follow. This process is expected to add separate calculations for each component to the total cost and benefit values.

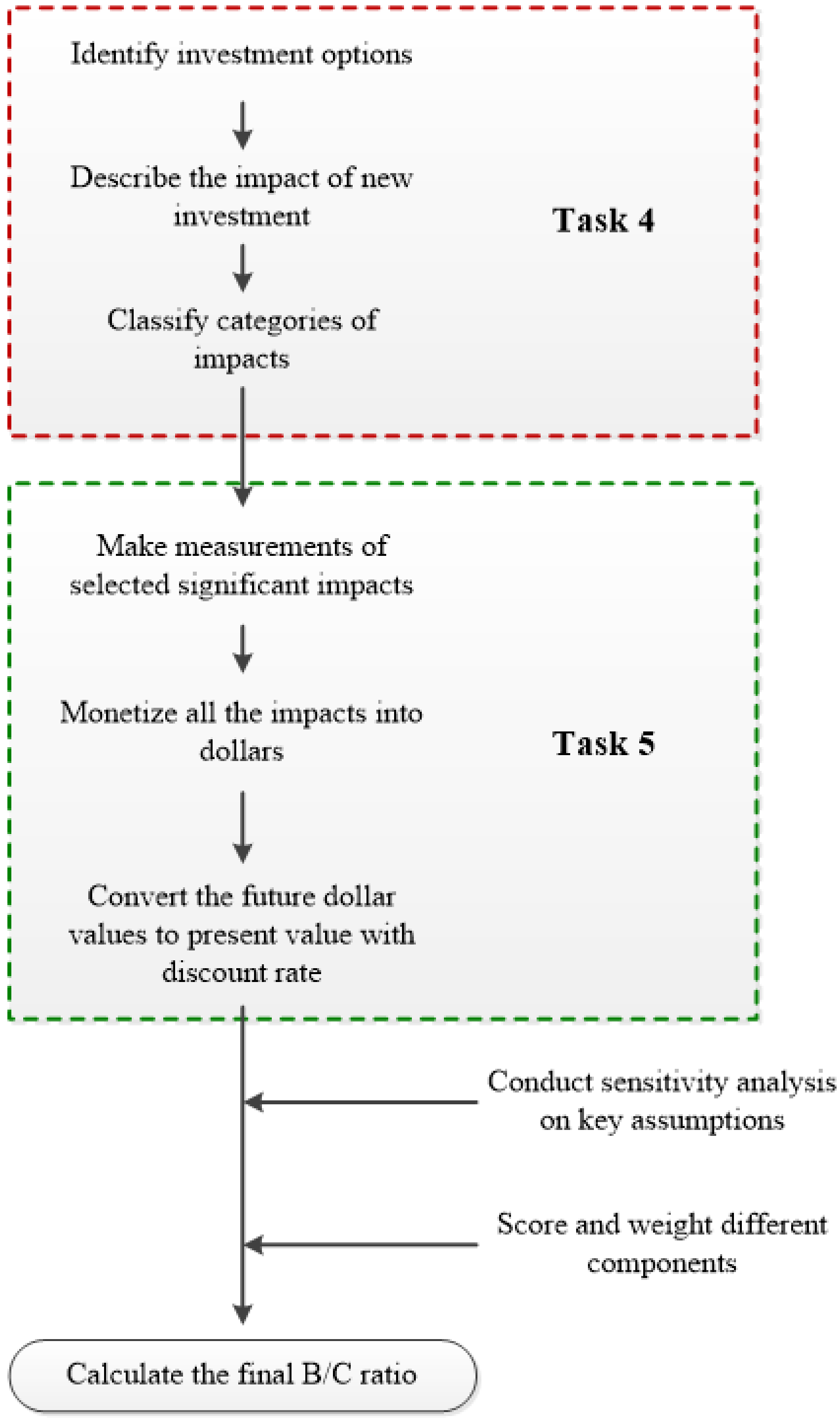

Figure 5: The Steps of a Full ROI/BCA Assessment

Table 14. Identified Traffic Impacts of MnPASS Projects

Component	Description
Traffic impacts	Main benefits reflected directly from traffic activities in the improved road network
Travel time savings (Auto and truck*)	Road network users' travel time savings due to reduced traffic congestion
Vehicle operating cost savings (Auto and truck)	Reduced vehicle operating cost resulting from reduced vehicle miles travelled
Crash cost savings/Safety benefit** (Auto and truck)	Relative safety of motor vehicles compared with the No-Build scenario
Travel time reliability (Auto and truck)	Improved travel time reliability for motor vehicles due to reduced travel delay
Transit benefit	Improved mobility for transit travelers due to the addition of MnPASS managed tolling lanes and reduced traffic congestion
Induced travel	Additional vehicle traffic loading in the improved road network as a result of changes in user travel cost

*The freight benefit is measured together with auto benefit

**By facility type and area type

Table 15. Identified Social and Environmental Impacts of MnPASS Projects

Component	Description
Social and environmental impacts	Other Benefits not directly related to traffic

Emergency response	Improved efficiency and higher-quality health outcomes for emergency vehicles and their patients due to the addition of MnPASS managed tolling lanes and reduced traffic congestion
Air pollution	Changes in vehicle tailpipe gas emissions
Noise	Changes in vehicle noise

Table 16. Identified Cost Components of MnPASS Projects

Component	Description
Costs	Costs of MnPASS lane construction and operation
Initial capital cost	Costs charged for project design and construction
Operating and maintenance costs	Long-term cost accruement for routing operation and preservation/rehabilitation
Remaining value	The expected value of project assets in continuing use

Travel demand forecasting analysis is introduced first because the outputs obtained in the base case and the improvement case serve as the basis for MnPASS ROI assessment and benefit-cost calculations. In the section describing approaches for benefit-cost analysis, some necessary assumptions closely related to the calculation of cost and benefit values are defined before the impact measurement. Impacts are measured in two categories: direct costs and expected benefits. This task provides guidance for estimating both the cost and benefit of MnPASS lane construction. The former focuses on measuring the dollar costs generated in the initial planning and construction, and routine facility operation and maintenance; the latter addresses all the typical benefits directly attributable to highway users. This process is conducted with the hope that by capturing typical impacts of the MnPASS project and presenting the measurement intelligently using credible sources, it can provide a refined and standard ROI assessment tool for policy makers to conduct better evaluations and make better decisions.

4.1 TRAVEL DEMAND FORECASTING

This section discusses how to measure changes in travel activity as a result of MnPASS lane construction. All the output data obtained in this step can be used for the establishment of the refined ROI assessment tool for the MnPASS system.

The MnPASS project changes the road network users' perception of travel cost (money or time) in the improved transportation network. Capturing the response of users of different travel modes (auto, truck, transit, etc.) to an improvement can be realized through travel demand forecasting analysis. This analysis can be very difficult and complex due to various data needs, such as the representation of the planned improvement, assumptions (analysis horizon, work day, and peak hour), link or corridor-based outputs of all travel modes, and so on. When the examined area is on a larger scale, the data analysis would require additional efforts. However, without a clear examination of the change in travel activity and the response of all travelers, there is almost no way to evaluate whether the proposed project is beneficial for the road network users, nor to measure the financial viability of such new investment.

For the MnPASS project, the analysis proceeds by comparing a No-Build scenario (Base case) and Build scenario (Improvement case), but some modifications to the traditional travel demand forecasting model for describing the tolling procedure of MnPASS lanes need to be made. This project will not provide model modification guidance to the travel demand forecasting procedures used for MnPASS project evaluation. Examples of modified versions of the Twin Cities Regional Travel Demand Model can be found in previous MnPASS project studies. Therefore, the discussion here will primarily focus on the analysis steps and outputs of the travel demand model that are used in the economic analysis.

With the necessary assumptions regarding planning horizon, day of the week, and peak hour settings, the travel demand forecasting analysis conducted for the MnPASS project evaluation can take the following steps to obtain the travel activity data of different travel modes in both cases, as shown in Figure 6. The purpose is to capture the changes of volume and travel cost data before and after the addition of MnPASS lanes.

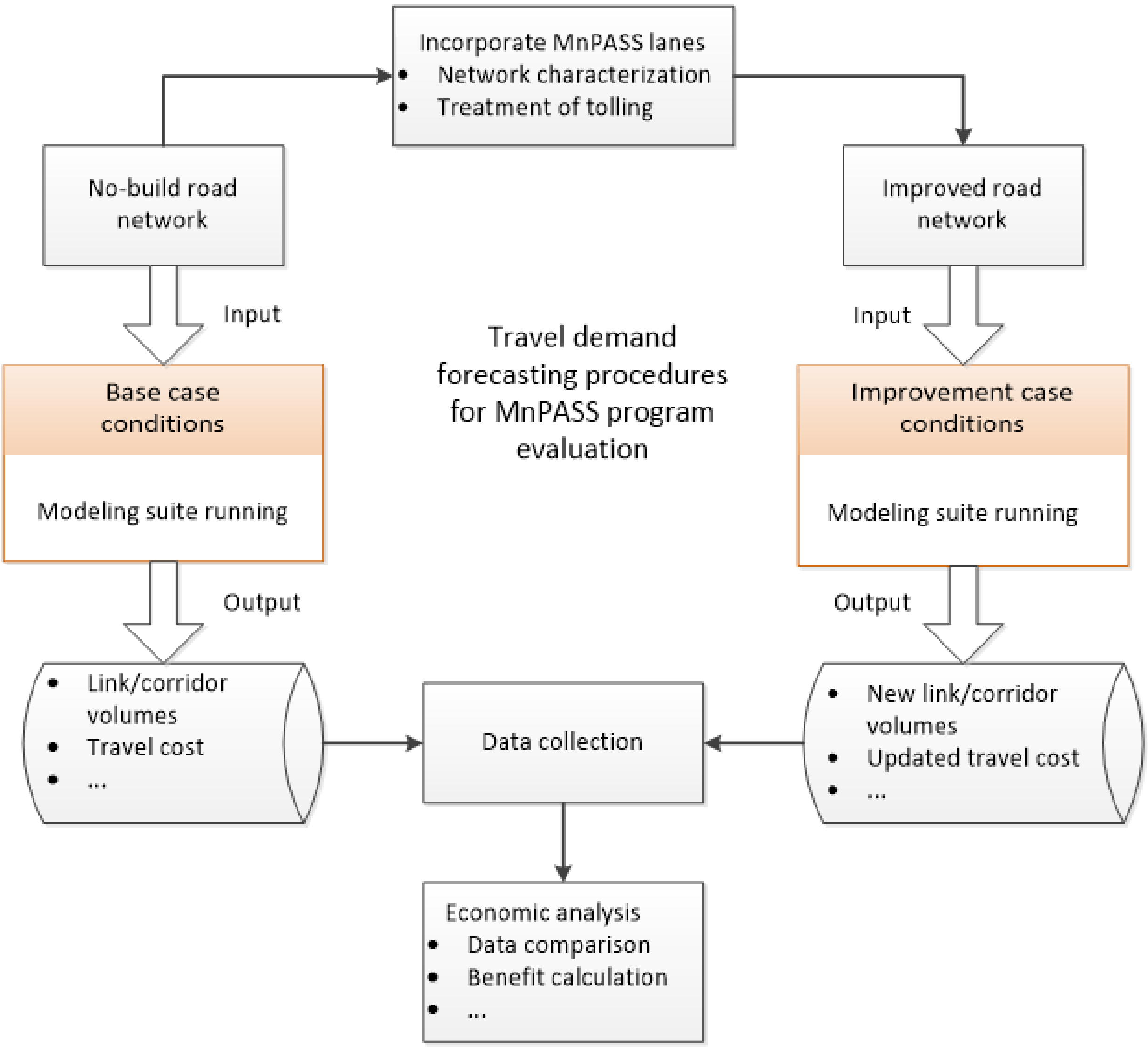

Figure 6: Travel Demand Forecasting Procedures for MnPASS Project Evaluation

The generated traffic data can be tracked and recorded by link or corridor for a given analysis period (tabulate the travel activity data of a corridor for the AM or PM peak hour). Considering the desired data needs for economic analysis in the later steps, it is important to include the following considerations in the travel demand forecasting analysis:

- Include all significantly affected links or corridors in the project analysis region to capture the potential effects of the MnPASS system
- Incorporate multiple travel modes, such as autos, trucks, and transit to facilitate the benefit measurement of different types of road network users

The results of travel demand forecasting efforts may include:

- Traffic volumes
- Vehicle miles traveled (VMT)
- Vehicle hours traveled (VHT)

This process generates outputs from the No-Build and Build scenario model runs. The outputs serve as the basis for MnPASS ROI assessment and benefit-cost calculations. Table 17 provides an illustration of what kinds of data might be potentially needed in the measurement of impacts from a transportation improvement project.

Table 17. Potential Data Needs for the Measurement of Impacts from a Transportation Improvement Project

Data needs	Travel time savings	Vehicle operation costs	Crash cost	Emissions	Noise	Transit	Travel time reliability	Induced travel	Freight	Emergency response
Vehicle miles traveled		√	√	√	√	√		√	√	
Vehicle hours traveled	√						√		√	√
Annual number or rate of crashes*			√							
Average speed		√		√	√		√		√	√
Throughput						√	√	√	√	
Annual average daily traffic					√			√		
Average bus headways	√					√	√			
Average bus occupancy	√					√	√			

*By facility type and area type

4.2 APPROACHES FOR BENEFIT-COST ANALYSIS

4.2.1 Assumptions

4.2.1.1 Analysis Period

The useful life of major MnPASS project components could be up to 100 years as shown in Figure 7. However, a few previous studies also indicated that 10 years after initial construction, the initial costs of some MnPASS components will be spent, e.g. electronics. MnDOT staff indicated that some of the MnPASS utilities, e.g., overhead signs, need to be replaced in 10 years. In consideration of the arguments about the likely self-driving car revolution ahead, for this analysis, benefits accrued within 20 years of project completion will be included, as recommended by MnDOT staff during the agency interview. In addition, for the purpose of this study, the economic analysis period can be assumed to begin with the initial relevant construction year when the capital costs occur and continue with another two to three years of construction for the full project completion.

	Useful Life	RCV Factor
ROW - LAND	100	0.91
MAJOR STRUCTURES	60	0.77
GRADING & DRAINAGE	50	0.7
SUB-BASE & BASE	40	0.59
SURFACE	25	0.24
OTHER	0	0

Figure 7: The Useful Life and RCV Factors of Major Components of MnPASS Projects

(Source: The Benefit-Cost Analysis of I-35W North Managed Lane Project)

The costs and benefits generated in each year can be counted in the accumulated total at the end of each year. The year immediately after the final project completion year is assumed to be the first full year to generate benefits. The total benefit is the discounted sum of all benefits realized in 10 years of actual operations.

4.2.1.2 Discount Rates

For project economic analysis, the dollar values of all the cost and benefit components occurring in future years should be expressed in terms of current year dollars. The discount/inflation rate could be considered within the range of one to seven percent. Figure 8 presents an example from the Length, Width, and Depth (LWD) Cost Estimate template (provided by MnDOT) on the selection of actual discount/inflation rates.

INFLATION ADJUSTMENTS										
PROJECT COSTS - 2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
FY 2012-15 STIP	0.02	0.04	0.05	0.05						
FY 2016-21					0.04	0.04	0.04	0.04	0.04	0.04
CUMULATIVE	1.02	1.0608	1.1138	1.1695	1.2163	1.265	1.3156	1.3682	1.4229	1.4798
	1.02	1.06	1.11	1.17	1.22	1.26	1.32	1.37	1.42	1.48
										10/21/2010

Figure 8: An Example of a Discount/inflation Rate Obtained from LWD Cost Estimate Template

4.2.1.3 Annualizing Factor

In the travel demand forecasting analysis of the MnPASS project, an urban commute-oriented setting is often adopted to perform the analyses for the weekday AM and PM peak periods. Results for other typical periods (weekday midday period, weekday off-peak hour, and weekend AM and PM peak periods) can also be collected to capture the travel behavior of road network users in different time samplings. However, outputs are produced on a daily basis and need to be converted into yearly values by using an annualizing factor. Generally, 260 weekdays per year (Monday-Friday) are used in the travel demand model, but different values could be considered based on the actual characteristics of projects. For example, only weekdays and peak periods are taken into account.

4.3 TOTAL COST ESTIMATION

To properly assess the ROI for the total costs of the MnPASS system, the following methodologies have been identified as the most comprehensive and up-to-date techniques to assess the initial and capital costs, operating and maintenance costs, and any remaining value of existing capital. Information presented below builds off past work assessing the MnPASS system, as well as more recent information and techniques captured in the literature review and interview process.

4.3.1 Initial and Capital Costs

Cost information is traditionally gathered in the following areas to assess the initial and capital costs for a project design:

- Planning
- Preliminary engineering and project design

- Environmental impact reports and ROI evaluations
- Project related staff training; final engineering
- Land acquisition
- Construction costs for MnPASS lane additions and improvements
- Construction equipment and vehicle rental/purchases
- ATM equipment required for MnPASS managed toll lane operation

The cost of each of these is then broken down and evaluated on a per mile basis using typical toll lane geometry.

MnDOT has developed a standard cost estimation method for new lane design in the project planning level analysis; it considers the length, width, and depth (LWD) information in the initial cost estimation. Due to the nature of this project, and a lack of additional information on the proposed layouts of new additions, we recommend using the LWD cost estimation method to calculate initial and capital costs of candidate MnPASS lanes. Without actual cost data, this is the best possible method to estimate costs for analysis of this cost component. Additionally, geometries and costs can vary significantly for structures like bridges and interchanges, and for this reason the initial and capital costs for each structure should be evaluated individually as a piece of the total initial and capital cost estimation.

A summary of implementation cost information for some toll lanes has been reported by the Federal Highway Administration and can be found at (FHWA, 2015): http://www.ops.fhwa.dot.gov/publications/fhwahop13007/app.htm. The implementation cost information is reported as:

- Capital construction costs
- Technology costs
- Total capital costs
- Project costs with financing
- Other complementary investments

Data is not provided for these categories for each reporting toll lane. Therefore a framework for estimating these costs is needed.

A summary of the information to be considered in the framework for the initial and capital costs is provided in Table 18.

Table 18. Summary of Initial and Capital Costs to be considered in the Framework

Cost Components		Fixed Fees/Rates	Cost Based on Lane Geometry
Initial and Capital Costs	Planning	√	
	Preliminary engineering and project design	√	
	Environmental impact reports and ROI evaluations	√	
	Project related staff training	√	
	Final engineering	√	
	Land acquisition		√
	Construction cost for MnPASS lane additions and improvements		√
	Construction equipment and vehicle rental/purchase	√	
	ATM equipment required for MnPASS lane operation	√	
	Bridge/interchanges		√

4.3.2 Operating and Maintenance Costs

An accurate estimation of the operation, preservation, and rehabilitation of toll systems requires the consideration of the following costs:

- Operations - traffic management, toll management, bus operations
- Preservation – routine service to maintain and preserve the condition of the toll lanes, routine maintenance, or isolated incidents such as dealing with crashes or weather events
- Rehabilitation – major repairs of facilities and lane resurfacing

Information gained from the literature search found that past studies identified very similar categories in the operations and maintenance cost estimates. These may serve as a good starting point for the estimation of new operations and maintenance costs associated with the expansion of existing toll ways. The annual operating cost will be estimated using MnDOT historical roadway operations and maintenance data as a per-mile value, and historical annual toll collection operating costs and roadway maintenance costs.

It can be assumed that additional operation and maintenance costs for expanded toll systems will be shared with the existing system, and that the increase in cost would be minimal for the following areas: administrative costs, back office functions, and general operations and management. Ultimately this will aid in reducing the overall cost of any expansion project, and will be considered in this evaluation. Additionally, to account for inflation and increases in staff, benefits, materials, and maintenance costs, an inflationary value should be applied when using older data to ensure all costs are expressed in constant-dollar terms. A framework for the cost data needs for this calculation is provided in Table 19.

Table 19. Summary Operations and Maintenance Costs to be considered in the Framework.

Operations	Traffic management
	Toll management
	Bus operations
Route preservation	Routine services to maintain condition of toll lanes
	Routine maintenance
	Maintenance associated with isolated incidents (crashes, weather events, etc.)
Rehabilitation	Major repairs to facilities
	Lane resurfacing
New Operations and Maintenance	Consider all costs above and apply an inflationary value and apply a multiplier to account for the relative percent increase in size of the toll lane system.

4.3.3 Remaining Capital Value

An integral part of the cost analysis includes representing the expected value of toll system assets and their continued use to their life expectancy. The method identified to capture the remaining capital value of toll systems can be expressed using the following equation:

$$RCV = A*(B-C)/B \qquad (1)$$

Where $A = (1+r)^n$

$B = ((1+r)^L - 1) / r(1+r)^L$

$C = ((1+r)^n - 1) / r(1+r)^n$

r = the discount rate

n = number of years in the analysis period

L = expected life span of the asset

4.4 POTENTIAL IMPACT MEASURES

Potential impacts from the new improvement can be measured once the output data from the regional travel demand model is processed and assumption data is assembled. From an ROI assessment point of view, these impacts are expected to be positive and desirable. For example, the economic analysis follows the reasonable assumption that the alternative transportation improvement projects (candidate MnPASS managed tolling corridors) should be beneficial to the existing travel system (mitigate the congestion levels) and should reduce user costs in travel time, accidents, and operation cost. These reductions are measured as user benefits from the construction of transportation improvement projects.

The following analysis compared each of the Build (Improvement case) to a No-Build (Base Case) scenario using the results of travel demand forecasting efforts, e.g., traffic volumes, vehicle miles traveled (VMT), vehicle hours traveled (VHT), and speeds. These results are calculated both with and without the proposed MnPASS lanes for each of the alternatives.

The following impact components identified in CHAPTER 3: will be measured to better capture the potential benefits of MnPASS, including:

- Travel time savings (reduction)
- Vehicle operation cost savings
- Crash cost savings
- Travel time reliability
- Freight user benefits
- Transit user benefits
- Induced traffic
- Emergency response
- Emission impact
- Noise impact

For each of the benefit components identified, an estimation methodology was developed, along with a unit cost value. There are several tool sets, specific to the Twin Cities region, which can be used to calculate the unit cost value for each component.

4.4.1 Travel Time Savings (Reduction)

MnPASS may provide additional capacity for vehicles and travelers, and faster travel times attract trips from general purpose lanes of other routes. Avoiding congestion is the key benefit to MnPASS users, and users in general purpose lanes or on parallel routes may also experience improved travel times with reduced traffic.

4.4.1.1 Tools Required

The Twin Cities Regional Travel Demand Model (TDM) is developed and maintained by the Metropolitan Council, and is made available to analysts evaluating corridor studies. The TDM consists of a network of links representing roadways in the region. All trips in the region are loaded to the roadway network, and the TDM reflects travel patterns, volumes, congestion, and travel times. The TDM is also used to compute several performance measures at a link, facility, or network level. One of the measures available from the TDM is VHT, which is calculated using the assigned model volumes and travel times.

4.4.1.2 Estimation Methodology

VHT can be calculated for every link in a study area for both the No-build and Build scenarios. The reduction in travel time is measured in VHT for both the general purpose and managed lanes along a corridor. Travel time cost unit value is measured in dollars per hour. Using the results from the travel demand model, change in VHT can be calculated for each scenario.

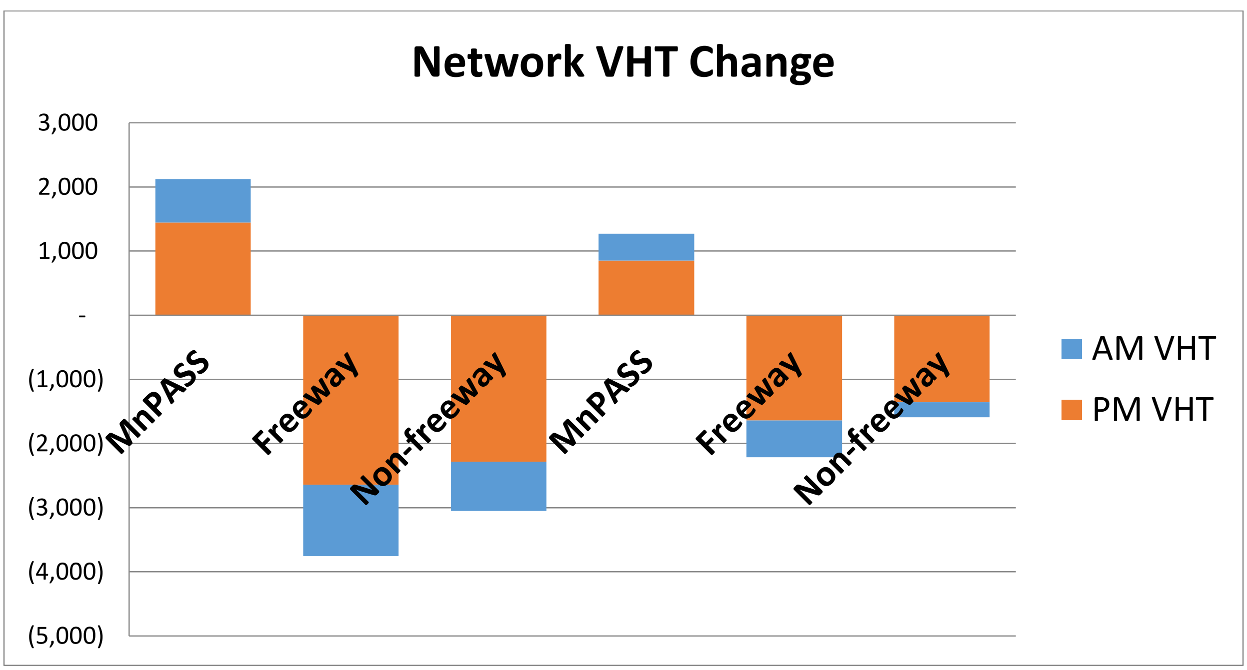

Figure 9: Travel Time Savings Graph (Build – No Build by Link Type)

The corridor travel times for each alternative are considered for different time periods, such as weekday peak and off-peak, as well as weekend peaks. The travel time savings may also be separated by general purpose and managed lane users. Travel time benefits accrue to travelers, whereas VHT measures travel times for vehicles. Therefore, there is a need to convert the travel time savings from the vehicles (VHT) to persons with a measure of person-hours traveled. This conversion is accomplished by multiplying VHT by vehicle occupancy measures. Regional vehicle occupancy averages may be available; however, additional treatment is needed for application to MnPASS. The expectation of a MnPASS facility is to serve vehicles with higher occupancy by attracting carpools; therefore, separate occupancy rates should be identified for general purpose and MnPASS traffic. These occupancy rates may be developed using the regional TDM, or other custom tools for this purpose.

4.4.1.3 Application of Component

The following equations demonstrate how the unit cost value is calculated for travel time savings, and how it can be used in the analysis.

$$VHT * Vehicle\ Occupancy = Person \cdot Hours\ Traveled\ (PHT)$$

$$Value\ of\ Time * Person\ Hours\ Traveled\ (No\ Build) = No\ Build\ Travel\ Time\ Cost\ (dollars\ per\ hour)$$

$$Value\ of\ Time * Person\ Hours\ Traveled\ (Build) = Build\ Travel\ Time\ Cost\ (dollars\ per\ hour)$$

$$Build\ Travel\ Time\ Cost - No\ Build\ Travel\ Time\ Cost = Travel\ Time\ Benefits$$

4.4.2 Vehicle Operating Cost Savings

Vehicle operating cost includes both fuel costs and vehicle wear and tear, and is applied using a per-mile cost. Operating cost is affected by changes in routes, and may result in increased or decreased mileage.

4.4.2.1 Tools Required

Similar to VHT, the VMT is an output from the Twin Cities regional travel demand forecasting model. VMT is calculated for every link using the link network distance and assigned model volume.

4.4.2.2 Estimation Methodology

Vehicle operating cost savings is measured by the reduction in VMT for both general purpose and managed lanes along a corridor. The unit cost value is measured by the travel distance cost (cost per mile).

4.4.2.3 Application of Component

The following equations demonstrate how the unit cost value is calculated for travel distance savings, and how it can be used in the analysis.

$$Value\ of\ Distance * Person\ Miles\ Traveled\ (No\ Build) = Travel\ Distance\ Cost\ (dollars\ per\ mile)$$

$$Value\ of\ Distance * Person\ Miles\ Traveled\ (Build) = Travel\ Distance\ Cost\ (dollars\ per\ mile)$$

$$Build\ Travel\ Distance\ Cost - \ No\ Build\ Travel\ Distance\ Cost = Benefits$$

4.4.3 Crash Cost Savings

4.4.3.1 Tools Required

The Twin Cities regional travel demand forecasting model is used to calculate the VMT (by segment) for each alternative. The FHWA Highway Economic Requirements System is used to identify segment crash rates by functional classification and traffic volume. For MnPASS studies, MnDOT crash data may be used, which is available from the MnDOT “Green Sheets” or Toolkit spreadsheet. The Green sheets provide average crash rates based on VMT for various functional class roadway. The Toolkit provides raw crash data by roadway.

4.4.3.2 Estimation Methodology

The assigned crash rate is multiplied by the VMT of each segment to calculate the number of crashes resulting in fatalities, injuries, and property damage. The unit cost value for this component is measured by the crash values, per crash.

4.4.4 Travel Time Reliability

Travel time reliability analysis evaluates the variability of travel times along a corridor. It is an optional, enhanced approach that supplements VHT (or PHT) from the TDM. Travel time reliability analysis would capture travel time performance in MnPASS and general purpose lanes under varying traffic demand and during non-recurring events like crashes and severe weather.

4.4.4.1 Tools Required

Travel time reliability can be predicted using a variety of tools developed in the Strategic Highway Research Program 2 (SHRP 2); the tool developed through SHRP 2 project L08 called FREEVAL-RL may provide suitable outputs to monetize the impacts of travel time reliability for no build and build conditions. Customized models based on existing data (loop detector, speed data, weather data, etc.) can also be used. Travel time reliability analysis requires much more detailed data collection, analysis, and model calibration. This represents an additional level of analysis detail beyond forecasting using the

TDM. This may be appropriate for a detailed corridor study involving traffic operations analysis, but may be of limited use for a system-wide study.

4.4.4.2 Estimation Methodology

A variety of outputs can be generated to illustrate the variability of travel times and throughput under different alternatives. For studies electing to perform enhanced analysis of travel time reliability, several types of graphical outputs can be produced to illustrate the performance of the facility. These include the samples shown in Figure 10 through Figure 12 (I-35W North Traffic Technical Memorandum), such as:

- Surface Plots – offer a visual representation of travel times relative to free flow times.
- Travel Time Thermometers – illustrate the typical variability in travel times by a user along the corridor, and can be limited to the peak period, representing a month of typical commuting times for the corridor.
- Stacked Bar Charts – incorporate travel time and throughput data into a single visual figure, showing not only the total person throughput in each alternative, but the throughput at different travel time index levels.

Figure 10: Sample Travel Time Surface Plot

Mon-Fri 06:00 to 09:00

Rank	Travel Time
1	14.7
2	15.4
3	16.0
4	16.6
5	17.4
6	18.6
7	20.3
8	22.4
9	24.2
10	25.2
11	26.9
12	29.3
13	32.3
14	34.4
15	35.3
16	35.5
17	35.7
18	35.9
19	36.4
20	40.5

2040 GP

Mon-Fri 06:00 to 09:00

Rank	Travel Time
1	14.7
2	15.9
3	16.7
4	17.8
5	19.3
6	21.3
7	23.5
8	25.6
9	27.5
10	29.6
11	32.2
12	34.6
13	36.6
14	38.2
15	39.7
16	41.4
17	43.0
18	43.9
19	45.0
20	48.3

2040 MnPASS (GP Lanes)

Mon-Fri 06:00 to 09:00

Rank	Travel Time
1	14.5
2	15.0
3	15.3
4	15.5
5	15.6
6	15.7
7	15.7
8	15.8
9	15.9
10	15.9
11	16.0
12	16.1
13	16.2
14	16.2
15	16.2
16	16.3
17	16.3
18	16.4
19	16.7
20	17.6

2040 MnPASS (MnPASS Lane)

Mon-Fri 06:00 to 09:00

Rank	Travel Time
1	14.7
2	16.5
3	18.5
4	21.0
5	23.9
6	27.3
7	32.2
8	36.6
9	40.7
10	43.0
11	43.5
12	44.4
13	46.2
14	48.3
15	50.8
16	54.1
17	56.7
18	58.6
19	58.8
20	58.8

2040 HOV (GP Lanes)

Mon-Fri 06:00 to 09:00

Rank	Travel Time
1	14.5
2	15.0
3	15.3
4	15.4
5	15.4
6	15.4
7	15.5
8	15.5
9	15.5
10	15.5
11	15.6
12	15.6
13	15.7
14	15.7
15	15.7
16	15.7
17	15.7
18	15.7
19	16.1
20	16.9

2040 HOV (HOV Lane)

Figure 11: Sample Travel Time Thermometer

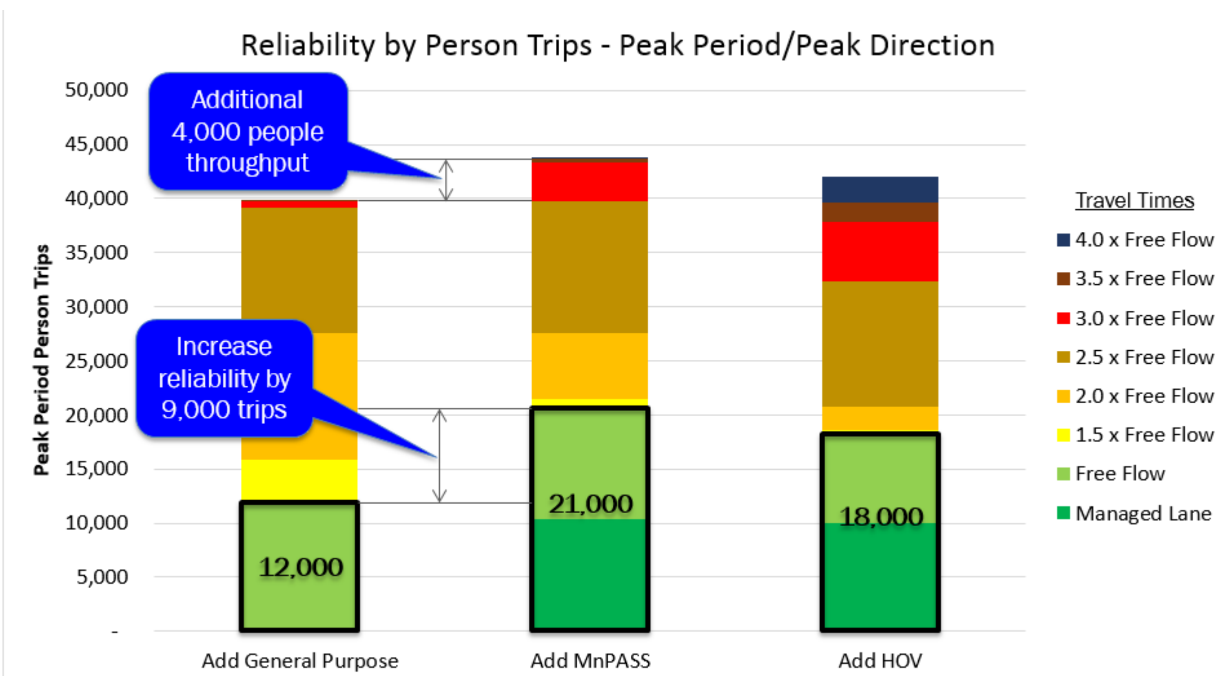

Figure 12: Sample Person Throughput Reliability Chart

4.4.4.3 Application of Component

The calculated VHT or person hours traveled can be used in place of travel time savings or vehicle operating costs by considering the reliability benefits specifically. One approach is to use reliability results as an input for VHT/PHT, which enhances the analysis by including variable levels of congestion and travel times. However, the research to quantify the value of travel time reliability above and beyond the value of travel time is ongoing. Future research may reveal additional benefits that would allow reliability to be monetized.

4.4.5 Freight Benefit

The values of time parameters are significantly higher for freight than private autos. Standard values can be used with known heavy vehicle percentages along a corridor. Current MnDOT/MnPASS policies do not accommodate trucks, because heavy vehicles are not eligible to use MnPASS lanes. Any freight benefits would be limited to travel time savings in general purpose lanes.

4.4.6 Transit Benefit

Transit benefits can be calculated by identifying travel time savings and applying the savings to ridership on existing transit routes. Examples of transit benefits are shown in Figure 13 and Figure 14 (I-35W North Traffic Technical Memorandum).

Travel Time Three-hour peak period (minutes)	AM		PM		Round Trip		
	Southbound		Northbound		Average		Total Savings (2-way)
	Bus	GP	Bus	GP	Bus	GP	
2040 No Build	26	33	33	42	**29.5**	**37.5**	**16**
2040 Add General Purpose	22	23	31	41	**26.5**	**32.0**	**11**
2040 Add MnPASS/HOV	20	28	24	39	**22.0**	**33.5**	**23**

Greater savings vs. General Purpose

I-35W North Corridor Managed Lane EA and Pre-Design

Figure 13: Sample Bus Travel Time Table

Alternative	Route 250	Route 252	Route 288	*Total*
2014 Existing	2,025	175	625	***2,825***
2040 No Build	3,400	200	700	***4,300***
2040 General Purpose	3,300	200	700	***4,200***
2040 MnPASS/HOV	3,700	200	700	***4,600***

Figure 14: Sample Ridership Forecast Table

4.4.7 Induced Traffic

The MnPASS project could potentially increase vehicle travel speeds and reduce travel cost in both general purpose and managed tolling lanes, and as a result, it could induce and attract additional vehicles. The induced traffic may include:

- New users (e.g. SOVs) that make trips they previously would not have made due to the lower travel cost in both general purpose and HOT lanes;
- More trips on transit or in HOVs in the HOT lanes.

In a benefit-cost analysis, economists usually use the elasticity of demand curve for travel on the facility and the concept of "consumer surplus" to calculate the benefits of both existing and induced users (Abelson and Hensher, 2001). The basic relationship between the demand curve and the change of consumer surplus due to new facility investment is shown in Figure 15. It portrays the user benefits through the changes of link volumes and the perceived travel cost of roadway users.

In the case described in Figure 15, at a certain link, before the construction of MnPASS lanes, the established travel equilibrium presents the original traffic volume v_1 and the travel cost p_1, which are described by the crossing point of travel cost curve S_1 before the improvement and travel demand curve D. After the improvement project, the travel cost of a given link is expected to reduce and the tendency can be captured by curve S_2.

If the analysis doesn't consider the effect of elastic demand, the expected travel cost would be p_e, and the consumer surplus (the benefit) of existing roadway users would be the area of rectangle ABHG. However, with the additional traffic of induced users attracted by the lower travel cost, new traffic equilibrium generated an increased volume v_2 (compared with v_1) and a higher travel cost p_2 (than

p_e) to account for the requirement of elastic demand change. Then the benefit of existing users is updated to be the area of rectangle ABEC, i.e., $v_1 \times (p_1 - p_2)$, which is another way of showing the travel time savings of existing roadway users.

Under the same traffic volume v_2 and travel cost p_2, the consumer surplus change of induced users ($v_2 - v_1$) can be measured by the area of triangle BEF with the assumption that the *D* curve can be treated as linear when the change of travel cost ($p_1 - p_2$) is relatively small. That is, the benefit of induced traffic at a given link can be calculated as:

$$0.5\ (v_2 - v_1) * (p_1 - p_2).$$

This equation highlights the following data needs in the induced traffic benefit accounting for a given link:

- Traffic volumes of multiple travel modes before and after the MnPASS lane construction;
- Travel time of multiple travel modes before and after the MnPASS lane construction;
- Unit cost of travel time, by mode.

This calculation provides a general methodology for computing the benefit of induced traffic at an individual link after a transportation improvement. For the operation of the MnPASS system (including both general purpose lanes and HOT lanes), there are multiple travel modes (e.g. auto, truck, and transit) and numerous affected links. The final calculation needs to compile all the repeated results for each mode and link.

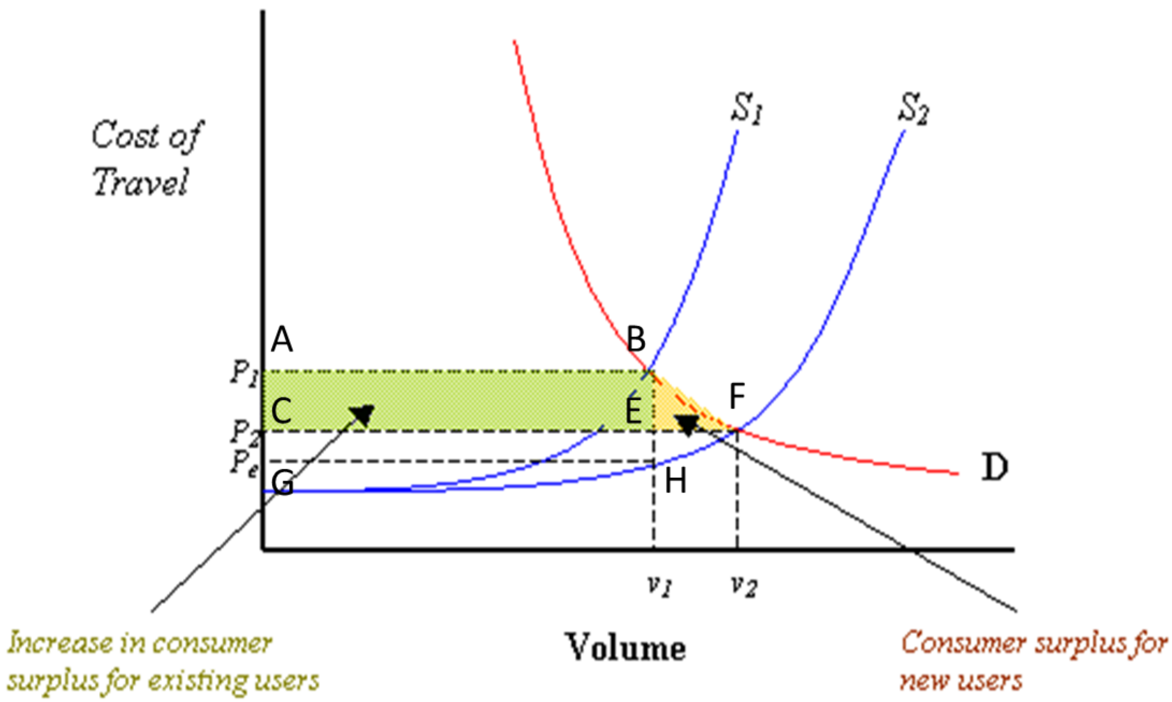

Figure 15: Existing and Induced User Benefits from New Transportation Improvement

(Source: https://sites.google.com/site/benefitcostanalysis/benefits/induced-travel/estimating)

4.4.8 Emergency Response

The Agency interviews identified emergency responders as an under-represented group of beneficiaries of MnPASS facilities. To further explore the potential benefits for emergency services using MnPASS facilities, including but not limited to police, ambulance, fire, and other Emergency Medical Services (EMS), a framework is developed for costs and benefits data needs in Table 20. The required data include identifying hospitals and fire stations nearby (within one mile of corridor), and engaging EMS users to determine frequency and importance of use. Values should be obtained through specific discussions with EMS users. Currently, no standard values exist for EMS use of toll facilities, as they do for passenger vehicles and trucks.

Because EMS use of toll ways is exempt, meaning they do not need to pay to use the tollways (FHWA, 2015), the cost of using the MnPASS does not need to be considered. One method to quantify the benefits of EMS using MnPASS facilities could be calculated by considering:

- The number of EMS trips that use MnPASS on average (AADT (EMS only)), versus the number of these trips that would otherwise have to use other routes,
- The length of the route using MnPASS (miles), versus the length of the alternate non-MnPASS route,

- The travel time (minutes) of the route using MnPASS, versus the travel time of the alternate general purpose lanes (peak hour and off-peak hour).

Table 20. Example of the Data Needs and Data Sources for the Determination of the Benefits from EMS Use of the MnPASS

Data needs	Data source
Toll lane use	Free/Waived
Proximity of toll lane to hospitals and fire stations	Count for each toll lane
Frequency of use	Number of trips as AADT for EMS only
Importance of use (e.g., transport only or medical emergency	Rank importance (1-10)
Length of route using MnPASS versus non-MnPASS route	Quantify for each trip
Total travel time using MnPASS versus non-MnPASS route	Quantify for each trip

With these data, the benefits of EMS use of the MnPASS could be calculated using the following formula:

> EMS benefits of using MnPASS (per mile/minute) = (Travel costs (dollars per mile) / travel time savings (minutes)) * (percent of EMS using the MnPASS facilities)

It is interesting to note that when total travel time and travel cost savings for EMS using the tollway are folded into the totals benefits for the tollway system, they likely represent only a small portion of the total benefits. However, this small portion of the financial benefits may be valued differently when it considers the cost of saving a life, preventing the loss of a structure from fire, or reduced medical care needs due to timely response and travel time by EMS.

4.4.9 Emissions Impact

The goal of the MnPASS project is to improve the congestion levels of the Twin Cities metropolitan area by changing travel patterns. As a result, it is also expected to reduce air pollutant emissions. According to the Environmental Protection Agency (EPA), the common air pollutants emitted either directly or indirectly from autos, trucks, and motorcycle vehicles include: Volatile organic compounds (VOC), Hydrocarbons (HC), Carbon monoxide (CO), Oxides of nitrogen (NOx), Particulate matter (PM_{10}), and Particulate matter ($PM_{2.5}$). The relative portion of each of these pollutants contributed by various travel modes is displayed in Figure 16.

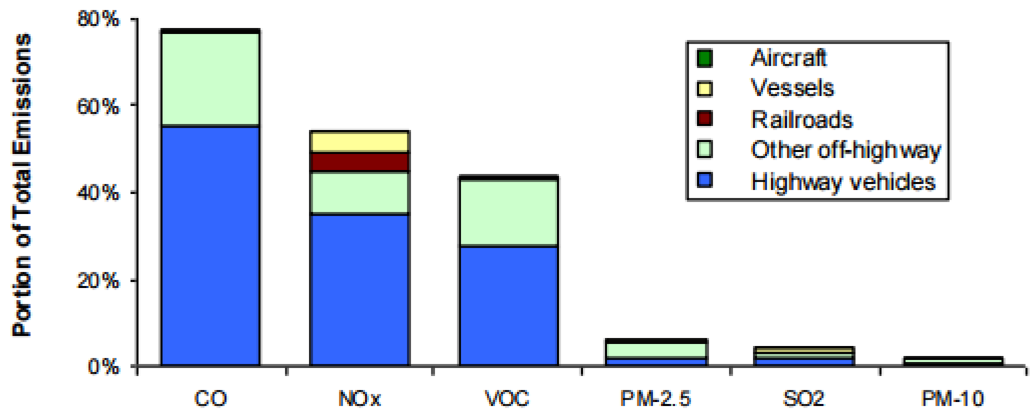

Figure 16: Contribution of Highway Vehicles (ORNL, 2005)

4.4.9.1 Estimation Methodology

In general, the amount of emissions generated by vehicles is highly related with the total vehicle miles traveled (VMT). Additionally, the MnPASS system is expected to increase the speed of the vehicle. At slower speeds vehicles emit pollutants at a greater rate compared to vehicles at higher speeds.

To evaluate the emissions benefits of the MnPASS project, it involves the following steps:

- Estimate the reduction in VMT for different motorized vehicles as a result of the addition of MnPASS managed tolling lanes.
- Estimate average emissions per vehicle per mile traveled.
- Calculate the emission benefit with an appropriate unit cost of emissions.

To facilitate the measurement process, the following necessary assumptions should be incorporated:

- All motorized vehicles (automobile, commercial truck, and bus) will be categorized into gasoline, diesel, ethanol and compressed natural gas (CNG) vehicle combinations.
- Average emissions will be calculated for each type of vehicle.

- Vehicle age, driving conditions and driving style are constant.

The following framework provides an illustration of how the data might be assembled for the measurement of emissions benefits.

Collect VMT data from travel demand forecasting analysis

By running the travel demand forecasting modeling suite for the No-Build and Build scenarios, VMT data for different types of motorized vehicles travelling before and after the MnPASS project can be captured and collected.

Before the MnPASS improvement project (No-Build case), the total number of miles per vehicle category in a roadway segment is shown as:

$$\boldsymbol{VMT(NoBuild)(miles)} \\ = [\boldsymbol{Number\ of\ miles} \\ * \boldsymbol{number\ of\ vehicles\ per\ day}]\boldsymbol{for\ each\ vehicle\ category}$$

For the improvement case, the total number of miles per vehicle category in a segment can be expressed as:

$$\boldsymbol{VMT(Build)(miles)} \\ = [\boldsymbol{Number\ of\ miles} * \boldsymbol{number\ of\ vehicles\ per\ day}]\boldsymbol{for\ each\ vehicle\ category}$$

The change of VMT then is represented as the difference of the total number of miles per vehicle category in a segment in both No-Build and improvement cases.

$$\boldsymbol{VMT\ reduction\ (miles) for\ each\ vehicle\ category} = \boldsymbol{VMT(NoBuild)} - \boldsymbol{VMT(Build)}$$

Estimate the emission factors (in grams per mile [g/mi]) for the average vehicle in each category

In general, the emission factor is used to calculate the total emissions from a source such as motorized vehicles or burning coal. An emissions factor is a representative value that relates the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant. For the MnPASS project, the emission factor is the quantity of airborne pollutants released to the atmosphere for each motorized vehicle category. Emission factors for motorized vehicles are usually expressed as the weight of a pollutant divided by a distance (e.g., grams per mile). In addition, the emission factor can be calculated for each pollutant type such as VOC, HC, CO, NOx, CO_2, PM_{10} and $PM_{2.5}$. Various factors such as geographic location, type of fuel and emissions controls can significantly impact the emission factors. Therefore, the EPA recommends using emission factors based on the individual location.

More recently, EPA's Motor Vehicle Emission Simulator (MOVES) is widely used to estimate emission factors for motorized vehicles. MOVES2014a is a software package developed by the EPA to provide an accurate estimate of emission factors from cars and trucks for a wide range of user defined conditions.

The inputs for the MOVES2014a for such estimation include vehicle types, time periods, fuel type, geographical areas, pollutants, vehicle operating characteristics, and road types. Figure 17 shows an interface of MOVES2014a for selecting geographic bounds for estimating the emission factor of various pollutants. More information on the EPA's MOVES is available in (http://www3.epa.gov/otaq/models/moves/index.htm#generalinfo-2014a). Emission factors calculated by MOVES2014a will be in grams per mile.

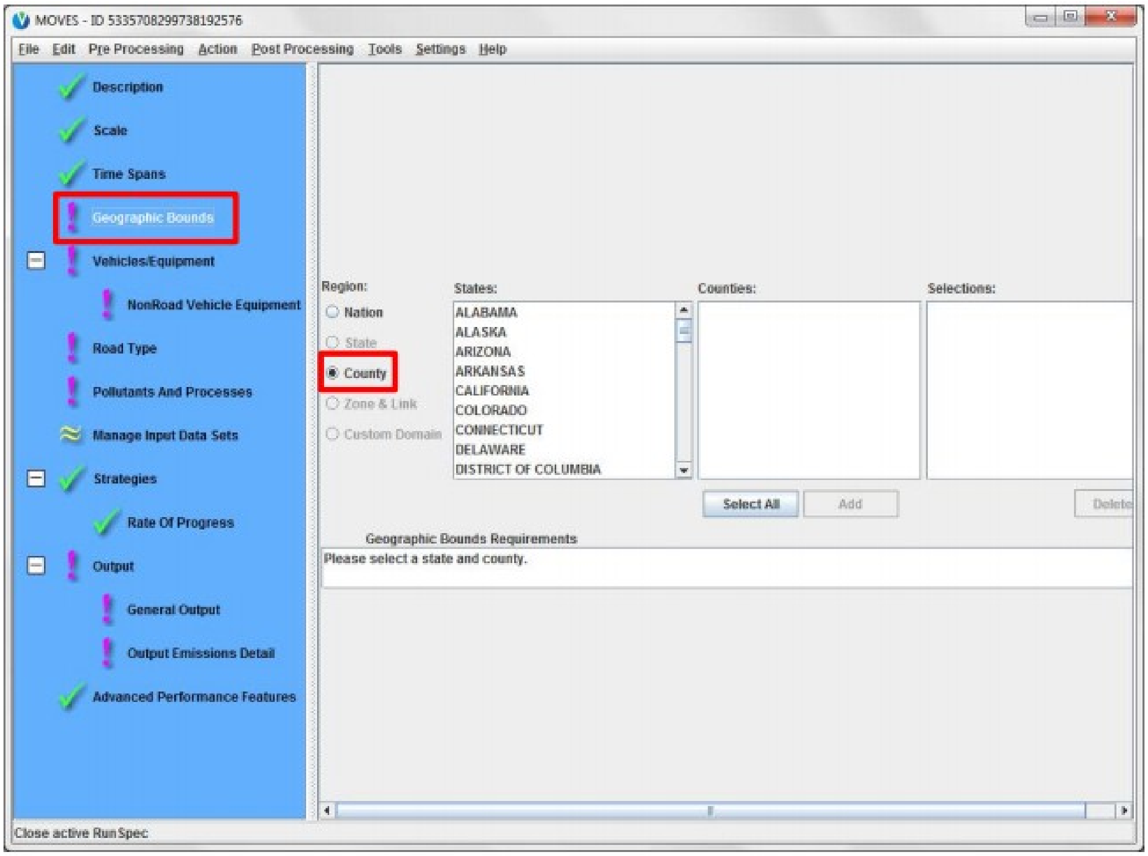

Figure 17: Selection of Geographic Bounds for Calculating Emission Factors (US Environmental Protection Agency - MOVES User Guide 2014a)

For the MnPASS project, the emission factor of common pollutants for different vehicle categories can be calculated based on a variety of inputs that closely mimic that MnPASS location.

The emissions reductions for each air pollutant due to the MnPASS project are calculated by multiplying VMT reductions by emission factors for each type of vehicle.

$$\textit{Emission reduction per vehicle type}\ (lb) =$$

$$\left[\textit{emisson factor}\ \left(\frac{g}{mile}\right) * \ \textit{VMT reduction}\ (miles) * \frac{1lb}{454\ g}\right] \ \ \textit{for each pollutant}$$

Monetize emission factor

In order to monetize the emissions, two approaches are used, such as estimating damage costs (due to air pollution) and control costs (avoid or mitigate air pollution). In addition, health decline cost was included to monetize the emissions. Cost of emissions are usually measured in dollars per ton (or metric ton) or cents per kilogram. Numerous studies were conducted to estimate emissions costs. (Litman, 2010) summarized various studies that estimated emissions costs (Table 21).

Table 21: Emissions Cost based on Type of Vehicle and Pollutant

Publication	Costs	Cost Value	2007 USD
			Per Vehicle Mile
CE Delft (2008)	Urban Car	0.0017 - 0.0024 €/km (2000)	\$0.003 - 0.004
	Urban Truck	0.106 - 0.234 €/km	0.189 - 0.417
Delucchi et al (1996)	Light Gasoline Vehicle	\$1990/VMT 0.008 - 0.129	0.013 - 0.205
	Heavy Diesel Truck	0.054 – 1.233	0.086 - 1.960
Eyre et al. (1997)	Gasoline Urban	\$/VMT 1996 0.030	0.040
	Diesel Urban	0.074	0.098
FHWA (1997)	Automobiles	\$/VMT 0.011	0.015
	Pickups/Vans	0.026	0.034
	Diesel trucks	0.039	0.051
			Per Tonne/Ton
AEA Technology (2005)	NH3 / tonne Europe	2005** €19,750	\$26,061
	NOx	€7,800	\$10,293
	PM2.5	€48,000	\$63,339
	SO2	€10,325	\$13,624
	VOCs	€1,813	\$2,392
RWDI (2006)	PM2.5 / tonne	2005 Canadian \$317,000	\$277,359
	O3 Total	\$1,739	\$1,522
Wang, Santini & Warinner (1994), US cities	NOx	1989 \$/ ton \$4,826	\$8,059
	ROG	\$2419	\$4,040
	PM 10	\$6508	\$10,868
	SOx	\$2906	\$4,853

In addition to estimating emissions cost based on common air pollutant, studies also estimated the emissions cost per vehicle mile for different motorized vehicles such as urban car, urban truck, diesel trucks, etc., without differentiating for individual pollutants.

For the MnPASS project, cost per pound of emissions reduction can be calculated by multiplying reduction in emissions (lb) by the unit cost per pound for a specific air pollutant.

$$\textit{Cost per pound of emission reduction}\ (\$) = \textit{emission reduction}\ (lb) * \textit{cost per pound}\left(\frac{\$}{lb}\right) \textit{for a specific air pollutant} \qquad (1)$$

The total estimated benefit due to emissions reduction will be calculated based on the cost savings for each pollutant type with respect to different vehicle category. For this, total emissions reduction for each pollutant will be calculated by adding all of the emissions reduction for different vehicle categories. Finally, total benefit of the MnPASS project related to emissions reduction can be calculated by adding cost savings for each pollutant type.

4.4.10 Noise Impact

The MnPASS project is expected to change traffic volumes (increase) and travel patterns, which could result in a change of noise levels for nearby residents and businesses. The noise generated by all motorized vehicles (e.g., automobile, commercial truck, and bus) can impair people's hearing, increase stress, disturb sleep, and contribute to ill health. The MnPASS system is also expected to increase the speed of the vehicle. At higher speeds vehicles may generate more noise. Similarly, an increase in traffic volume plays a significant role in increasing the traffic noise. The MnPASS project may increase vehicle speed which may increase noise. Conversely, MnPASS project may reduce the congestion levels and reduce noise pollution.

4.4.10.1 Methodology

Noise is generally measured using weighted decibels (dBA), which are adjusted to include only frequencies that humans can hear. Common noise levels range from 30 to 90 dB (A). In most cases, the noise we hear is not steady and it tends to change with time. L_n is the most commonly used term to represent the changes in noise levels over a period of time. L_n, is the noise level exceeded for n percent of the time. In other words, for n percent of the time, the fluctuating noise levels are higher than the L_n level. L_n value can be obtained by determining statistical means of a given noise. For example,

- L_{10} is the level exceeded for 10% of the time. For 10% of the time, the sound or noise level is above L_{10}
- L_{90} is the level exceeded for 90% of the time. For 90% of the time, the sound or noise level is above L_{90}
- L_{50} is the level exceeded for 50% of the time. For 50% of the time, the sound or noise level is above L_{50}

For varying sound, L_{10} is greater than L_{50} and L_{50} is greater than L_{90}. In addition, L_{eq} represents the equivalent continuous sound level in dB(A) for a specific time period. In other words, L_{eq} is calculated by averaging the sound over a given period of time. The Federal Highway Administration (FHWA) and many state highway agencies use L_{10} and L_{eq} as a standard for measuring noise.

4.4.10.2 Estimate the changes in noise

Various factors such as traffic volumes, speed, class of vehicle, and pavement types play a role in assessing noise. The FHWA has developed models to estimate noise based on various factors. Various state agencies have developed their own models by adopting the FHWA model and altering limited factors.

Currently, MnDOT uses a noise evaluation model named "MINNOISEV31," a version of the FHWA "STAMINA." MINNOISEV31 has input limits for roadways, barriers and receivers. When estimating noise levels, the inputs of this model include vehicle type, vehicle per hour, speed of the vehicle, shielding factors, time factors, road types, fuel type, and geographical areas. Based on the required inputs, MINNOISEV31 provides a list of outputs such as L_{eq}, L_{10}, L_{50} and L_{90} (Figure 18).

```
NORTH FREEWAY
PROGRAM INITIALIZATION PARAMETERS

     HEIGHT      CODE            DESCRIPTION
      0.0          1     RECEIVER HEIGHT ADJUSTMENT
      1.00         2     A-WEIGHTED SOUND LEVEL ONLY
      0.0          3     HEIGHT ADJUSTMENT FOR PASSENGER CARS (CARS)
      8.00         4     HEIGHT ADJUSTMENT FOR HEAVY TRUCKS   (HT)
      2.30         5     HEIGHT ADJUSTMENT FOR MEDIUM TRUCKS  (MT)

ROADWAY    1      EASTBOUND LANES

                      VEHICLE TYPE    VEHICLES/HOUR      SPEED
                         CARS                800.          55.
                         HT                  200.          55.
                         MT                   50.          55.
                     ------------COORDINATES-------------
                            X              Y              Z      GRADE
E1                       -2000.          162.             0.       0
E2                        2000.          162.             0.       0

ROADWAY    2      WESTBOUND LANES

                      VEHICLE TYPE    VEHICLES/HOUR      SPEED
                         CARS                800.          55.
                         HT                  250.          55.
                         MT                   70.          55.
                     ------------COORDINATES-------------
                            X              Y              Z      GRADE
W1                       -2000.          216.             0.       0
W2                        2000.          216.             0.       0
DEERFIELD ESTATES
                     ------------COORDINATES-------------
                            X              Y              Z
R1                          0.             0.             5.
  ALPHA FACTORS - ROADWAY ACROSS,RECEIVER DOWN

 1 * 0.5 0.5
  SHIELDING FACTORS - ROADWAY ACROSS,RECEIVER DOWN

 1 * 0.0 0.0
NORTH FREEWAY
RECEIVER      LEQ(H)    SIG    L10    L50    L90

R1             71.1     3.6    74.3   69.7   65.1
```

Figure 18: Example of Output from "STAMINA" Noise Model

The FHWA and many state highway agencies use L_{10} and L_{eq} as a standard for measuring noise. For the MnPASS project, noise levels for different vehicle categories can be calculated based on the variety of inputs that closely mimics that MnPASS location.

The change of noise level then is represented as the difference in L_{10} per vehicle category in a segment in both No-Build and improvement cases, which can be expressed as:

$$Changes\ in\ noise\ level\ (dBA) per\ vehicle\ category = [L_{10}(Build) - L_{10}(NoBuild)]$$

4.4.10.3 Noise abatement

Transportation agencies implement noise abatement measures such as noise barriers, traffic management, buffer zones and open space to reduce the noise levels due to a new project. In general, noise abatement is essential if the noise level is above a certain threshold limit after implementation of a new project. For example, North Carolina DOT considers noise abatement measures if there is an increase of 10 dBA to 15 dBA after the construction of a new transportation project (NCDOT, 2016). Also, agencies implement noise abatement measures if the predicted noise levels approach or exceed those criteria as shown in Table 22.

Table 22. Noise Abatement Criteria (NCDOT, 2016).

Activity	Hourly A - Weighted Noise Level, dBA L_{eq} (h)	Description of Activity Category
A	57 (Exterior)	Lands on which serenity and quiet are of extraordinary significance and serve an important public need, and where the preservation of those qualities is essential if the area is to continue to serve its intended purpose
B	67 (Exterior)	Residences, churches, school, libraries, hospitals, motels, hotels, parks, picnic and recreation areas, active sports areas and playgrounds
C	72 (Exterior)	Developed lands, properties or activities not included in Categories A or B
D	Not Applicable	Undeveloped lands
E	52 (Interior)	Residences, motels, hotels, public meeting rooms, schools, churches, libraries, hospitals and auditoriums

For the MnPASS project, the requirement for noise abatement measures can be determined based on the changes in noise level (dBA) per vehicle category measured from the noise models, such as MINNOISEV31. If noise abatement is required, then the cost of constructing an abatement facility can be estimated and included in the overall costs.

4.4.10.4 Monetize noise levels

In order to monetize the noise level for the MnPASS project, it is important to determine the change in VMT due to MnPASS managed tolling lane construction and assign noise cost for each mile per vehicle category. Numerous studies have attempted to estimate the dollar value for noise levels. In general, studies assigned a relatively low cost per mile for traffic noise. However, recent studies tended to assign higher dollar values for urban driving, especially for noisy vehicles and for night conditions. Litman (2010) summarized various studies that estimated noise costs (Table 23).

For the MnPASS project, noise benefit (or cost) can be calculated by multiplying VMT reduction (miles) for each vehicle category (due to the MnPASS project) and noise cost per mile for a specific vehicle category. Any additional noise abatement cost can be added to determine the overall benefit or cost of MnPASS with respect to noise evaluation per vehicle category.

$$\begin{aligned} &Noise\ benefit\ or\ cost\ per\ vehicle\ category\ (\$) \\ &\quad = [VMT\ reduction\ (miles) for\ each\ vehicle\ category \\ &\quad * noise\ cost\ per\ mile\ for\ a\ specific\ vehicle\ category] \\ &\quad + \text{noise abatement cost } (\$)(\text{if any}) \end{aligned}$$

Finally, the total benefit (or cost) of the MnPASS project relevant to noise reduction can be calculated by adding benefit or cost estimation for each vehicle type.

Table 23: Noise Cost based on Vehicle Type (Litman, 2010)

Publication	Costs		Cost Value	2007 US $ / VMT
FHWA (1997)	Automobile		median values 0.11	0.001
Scope: Urban highways	Pickup & Van		0.10	0.001
	Buses		1.72	0.022
Units: 1997 cents per Vehicle- mile	Combination Trucks		3.73	0.048
	All Vehicles		0.24	0.003
Delucchi and Hsu (1998)	Cars (Urban Arterial)		1.18	0.002
	Medium trucks		7.02	0.011
	Heavy trucks		20.07	0.031
Units: 1991 USD/1000 VMT	Buses		7.18	0.011
	Motorcycle		8.71	0.013
CE Delft (2008)	Car	Day	0.76	0.014
Scope: Urban roads		Night	1.39	0.025
	Motorcycle	Day	1.53	0.027
Units: 2000 Euro cents per vehicle-km		Night	2.78	0.050
	Bus	Day	3.81	0.068
		Night	6.95	0.124
	Heavy truck	Day	7.01	0.125
		Night	12.78	0.228

4.5 SUMMARY

This task focused on the measurements of the direct costs and primary impacts/benefits of MnPASS projects. Tractable methodologies, data needs, adaptable tools, and estimation steps are provided for the measurement of each component. A summary of these estimation methods is shown in Table 24 and Table 25. In combination with this general MnPASS ROI assessment framework, location-specific data can be used in the analysis to develop case study and scenario comparisons.

Table 24. A Summary of Cost Estimation Methods for MnPASS Projects

Cost component	Estimation methodology and data needs	Cost calculation
Initial/capital cost	LWD cost estimation method from MnDOT	Cost (+)
Operating and maintenance costs	•MnDOT historical roadway operations and maintenance data •Historical annual toll collection operating cost	Cost (+)
Remaining capital value	Equation (1): RCV=A*(B-C)/B	Cost (-)

Table 25. A Summary of Benefit Estimation Methods for MnPASS Projects

Benefit component	Estimation methodology and data needs	Monetization	Benefit calculation
Travel time savings	Travel demand forecasting model •VHT reduction	Travel time unit cost value	Benefit (+)
Vehicle operation cost savings	Travel demand forecasting model •VMT reduction	Travel distance unit cost value	Benefit (+/-)
Crash cost savings/Safety benefit	•Travel demand forecasting model, VMT change •FHWA Economic Requirements System, segment crash rates	Crash unit cost value	Benefit (+/-)

Travel time reliability	•Travel demand forecasting model •FREEVAL-RL developed by SHRP 2 project L08	Monetary value of reliability	Benefit (+)
Freight benefit	Travel demand forecasting model •VHT reduction by trucks	Travel time unit cost value by truck	Benefit (+)
Transit benefit	Travel demand forecasting model •VHT reduction by transit	Travel time unit cost value by transit	Benefit (+)
Induced travel	Travel demand forecasting model •Traffic volume •Travel time	Travel time unit cost value, by mode	Benefit (+)
Emergency response	Travel demand forecasting model •Travel time (Emergency vehicle) •Length of route •Number of EMS trips	Travel time unit cost value of emergency vehicle	Benefit (+)
Emission impact	•Travel demand forecasting model, VMT reduction •EPA's Motor Vehicle Emission Simulator (MOVES)	Emission unit cost value	Benefit (+/-)
Noise impact	•Travel demand forecasting model, VMT reduction •Noise model "MINNOISEV31", a version of the FHWA "STAMINA"	Noise unit cost value	Benefit (+/-)

CHAPTER 5: DEMONSTRATION

The objective of this task was to develop a refined Return on Investment (ROI) assessment framework based on past efforts and recently completed work on MnPASS facilities. Ultimately, the goal was to develop a comprehensive and consistent ROI assessment tool for MnDOT to apply in the economic analysis of future MnPASS systems. The refined tool integrates additional information sources; enhanced information and data accuracy; allows for consideration and comparison of alternative options; can be easily modified to incorporate changes in future practices, use, or design; and provides information to serve as recommendations for effective investments.

The previous section reviewed the developed MnPASS ROI assessment framework, which provides tractable data analysis methodologies, data needs, adaptable tools, and estimation steps for the measurement of the direct costs and primary impacts/benefits of MnPASS projects. The goal was to use location-specific data to demonstrate the performance of this refined tool in practical MnPASS project evaluations.

This chapter:

- Describes the base case data and the selected demonstration area;
- Calculates cost and benefit values of new construction in the Build scenarios and analyzes results from the ROI/BCA calculation by using the refined methodology;
- Compares ROI/BCA results from the original methods used in the previous work with the results for the refined tool developed in this study;
- Summarizes the demonstration results.

5.1 BACKGROUND INFORMATION ON CASE STUDY

The research team selected a previous benefit-cost analysis (BCA) on the I-35W North Managed Lanes project as the foundation for data sharing to demonstrate the application of the refined ROI framework developed in this project versus the original framework.

This BCA compared two alternative options - a No-Build versus a preferred Build. The No-Build alternative assumes there are no roadway improvements along I-35W in the project area, i.e., no new lane-miles or MnPASS lanes are considered. The preferred Build alternative includes the construction, operation, and maintenance of new MnPASS lanes; the addition of spot improvements; and the replacement of bridges over I-35W. Based on the traffic data for base year 2010, the forecasted data for future year 2040 were obtained. Since the construction was assumed to start in 2019 and end in 2021, the benefits were assumed to accrue from year 2022, and the BCA analyzed a 20-year period from 2022 to 2041.

Based on the results of the travel demand model, the BCA was conducted to capture the forecasted changes in vehicles miles traveled (VMT), vehicle hours traveled (VHT), and safety of both base year

2010 and forecasting year 2040. To quantify the benefits and costs of the roadway improvements, the forecasted consequences were then monetized based on the cost of VMT, the value of time for travelers, the value of crash reductions, and the cost of operating and maintaining the roadway.

The following data were used for the BCA of the I-35W North Managed Lanes project:

- Vehicle miles traveled (VMT)
- Vehicle hours traveled (VHT)
- Value of time
- Crash rates by severity and facility type
- Construction costs
- Unit operations and maintenance costs
- Remaining capital value factor
- Useful life of project components

As a result, the benefits were defined by the vehicle operating cost, vehicle travel time savings, and the reduction of crashes. The costs were defined by project construction, MnPASS lane operations and maintenance, and remaining capital value. The BCA of I-35W North Managed Lane Project estimated all the future project benefits and costs that would occur within the analysis period (2022-2041) and discounted them back to the current year US dollars (2015). The preferred Build alternative was found to have a benefit-cost ratio of 2.11 from this analysis. (Source: *I-35W North Corridor Preliminary Design Project Environmental Assessment*, August 2016, available at http://www.dot.state.mn.us/metro/projects/i35wroseville/pdf/I-35W-North-Corridor-EA-no-appendices.pdf)

5.1.1 Demonstration Project

In the demonstration conducted in this task, a subarea of this BCA study was selected, which covers fewer unchanged road segments but captured all the MnPASS improvements (before-and-after), as shown in Figure 19.

Where possible, assumptions are held constant in the demonstration of the refined ROI assessment framework (Table 26), so as to facilitate the comparison of results under the same conditions, e.g., even though the current year was 2016 when the BCA was conducted, a consistent present value of 2015 is calculated.

Table 26. Assumptions Used in the Demonstration

Current Year	2015
Discount Rate	1.7%
Annual Pavement Maintenance Cost per Lane Mile	$12,000
Additional Lane Miles	22.10

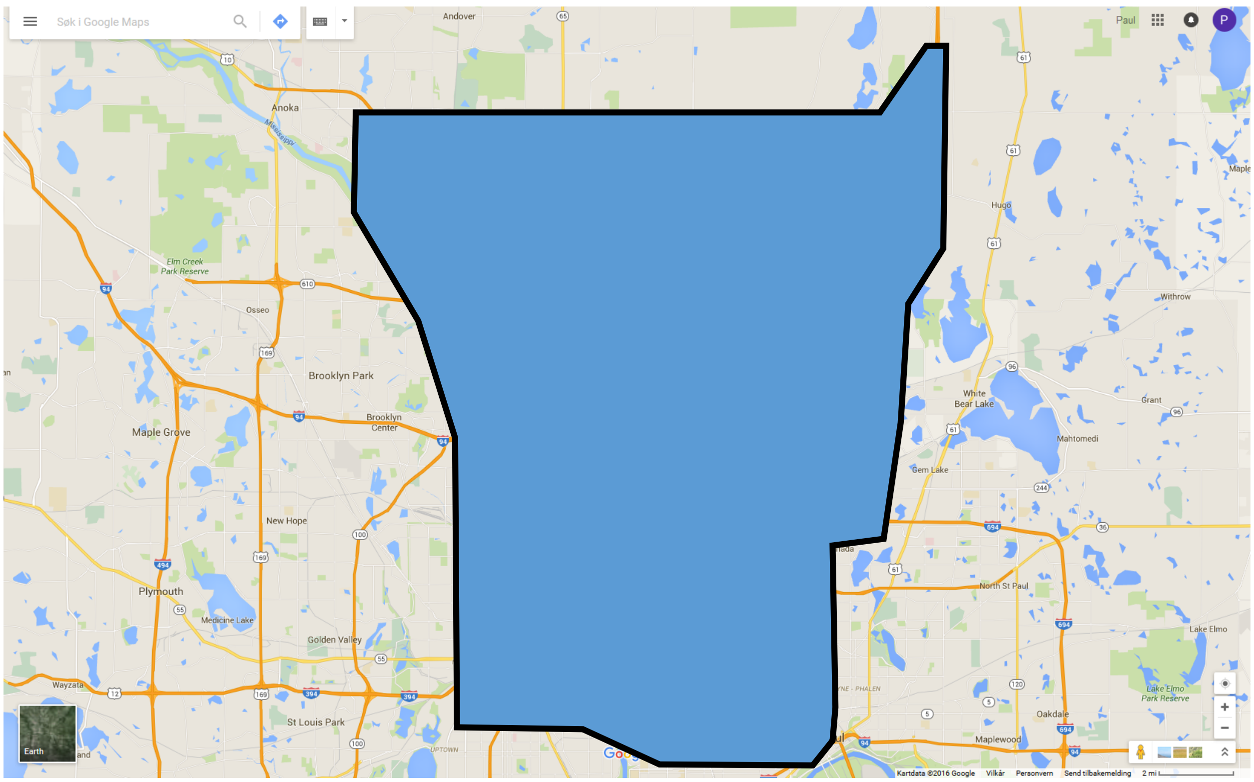

Figure 19. Sub-area Selected from the I-35W North Managed Lanes Project for Use in This Project Testing the Refined MnDOT MnPASS ROI.

5.2 COST AND BENEFIT ESTIMATION BY USING THE REFINED METHODOLOGY

5.2.1 Total Cost Estimation

The subarea selected for this demonstration covers all the planned MnPASS improvements, so the total cost estimation pertaining to the construction, operation and maintaining of these new MnPASS lanes will follow the same estimations obtained in the BCA of the I-35W North Managed Lanes project.

5.2.1.1 Initial Capital Costs

Initial investment costs of the I-35W North Managed Lane project mainly include engineering construction (roadway pavement and earthwork, bridge cost, median barrier), service utility (drainage, noise wall, roadway lighting, signing/traffic management system, etc.), design-build costs, and risk factors. These costs were estimated by using the LWD (Length, Width, and Depth) method and include costs expended in 2019-2021. With a discount rate of 1.7% suggested by MnDOT, the present value of initial capital costs translated to approximately $169.5 million (2015$).

5.2.1.2 Operations and Maintenance Costs

The facility is assumed to be operational starting in 2022, thus the annual costs of operating and maintaining the additional 22.1 lane-miles for the Build alternative (beginning in 2022 and ending in 2041) are included in the total cost estimation. In this analysis, the undiscounted annualized operations and maintenance costs are $62,000 per lane-mile. Additionally, MnDOT has previously suggested an annual cost of $400,000 for MnPASS system operation, which would include operating the additional electronics and communications, managing the freeway system and toll rates, and providing customer support by selling transponders and managing toll accounts. After summing up the constant annual operations and maintenance costs of each year between 2022 and 2041 and discounting the total value back to 2015 US dollars with a 1.7% discount rate, this cost component contributes just over $26.8 million to the total cost value (Appendix A). For purposes of comparison to the traditional benefit-cost analysis completed for this project, the additional $400,000 in annual MnPASS operations costs increased the discounted total operations and maintenance costs by approximately $6 million, from $20.8 million.

5.2.1.3 Remaining Capital Value (RCV)

The analysis period of this BCA is 20 years (ends in 2041); thus, at the end of this period, the residual value of infrastructure (e.g., major structures, surface, etc.) should be considered. The useful life and RCV factors of major components of the projects were provided by MnDOT and are shown in Table 27. After discounting to present value, a total of $35,522,760 is subtracted from the capital costs and operations and maintenance costs.

Table 27. The Useful Life and RCV Factors of Major Components of MnPASS Projects

	Useful Life	RCV Factor
ROW - LAND	100	0.91
MAJOR STRUCTURES	60	0.77
GRADING & DRAINAGE	50	0.7
SUB-BASE & BASE	40	0.59
SURFACE	25	0.24
OTHER	0	0

As a result, an overall cost of $160,782,596 was obtained (Table 28).

Table 28. Total Cost Estimation Results

Costs	
Total Capital Costs	$169,466,823
Total O&M Differential	$26,838,533
Present Value of Remaining Capital Value	-$35,522,760
Total Cost	$160,782,596

5.2.2 Total Benefit Estimation

This section discusses the input valuations used for each benefit component and presents a summary of results. It is important to note that the estimation of freight benefit is merged into that of auto benefit when measuring travel time reduction, vehicle operating cost savings, crash cost savings, and travel time reliability. More details of the calculation processes are available in Appendices B - E.

5.2.2.1 Travel Time Savings (Both Auto and Truck)

In-vehicle travel time benefits for both auto and truck drivers and passengers are captured in the travel time savings. In this analysis, this benefit is measured with a change in VHT based on the subarea traffic demand forecasting results of both 2010 and 2040 Build and No-Build scenarios. Consistent with the format of the I-35W North Managed Lanes project BCA, a summary of the VHT changes is also given based on facility type (Table 29): Freeway (freeways, freeway ramps, MnPASS, CD roads) and Non-Freeway (divided arterials, undivided arterials, and collectors).

Table 29. VHT Travel Demand Results

Model Results (Vehicle-Hours/Day)	Values (No-Build)	Values (Build)	Build Benefit/(Disbenefit)
2010 Freeway	245,783	245,707	76
2010 Non-Freeway	247,552	245,950	1,602
2040 Freeway	341,246	340,196	1,050
2040 Non-Freeway	362,966	357,959	5,007

Under the same assumptions about the value of time per person-hours for autos ($17.00/per-hr), the value of time per person-hours for trucks ($27.90/per-hr), the average auto occupancy (1.30 per/veh), the average truck occupancy (1.02 per/veh), and the percentage of trucks in the corridor (6% on average), a composite value of time per vehicle–hour ($22.48/per-hr) is obtained and used to calculate the total travel time savings of both autos and trucks. The reduction in VHT after the construction of new facilities is assumed to accrue starting in 2022. After it is discounted to present value, the annual travel time savings for the subarea MnPASS construction is around $398 million compared to the No-Build scenario over the 20-year analysis period (Appendix B).

5.2.2.2 Vehicle Operating Cost Savings

Vehicle operating cost savings of both autos and trucks are associated with the change in VMT based on the subarea traffic demand forecasting results for both 2010 and 2040 Build and No-Build scenarios. The resulting VMT values (grouped as Freeway and Non-Freeway) are shown in Table 30.

Table 30. VMT Travel Demand Results

Model Results (Vehicle-Miles/Day)	Values (No-Build)	Values (Build)	Build Benefit/ (Disbenefit)
2010 Freeway	10,209,815	12,518,887	-2,309,072
2010 Non-Freeway	6,048,022	7,643,509	-1,595,487
2040 Freeway	10,264,111	12,613,000	-2,348,889
2040 Non-Freeway	6,022,739	7,585,619	-1,562,880

In the I-35W North Managed Lanes BCA study, auto and truck per-mile operating and emissions costs were used, i.e., \$0.28/veh-mi and \$1.09/veh-mi, respectively. Used here to measure the separate impacts of vehicle operating and emissions, these costs were adjusted down based on the available 2017 dollar values of these parameters (Source: http://www.dot.state.mn.us/planning/program/appendix_a.html). In addition, a composite cost per vehicle–mile (\$0.271/veh-mi) is obtained based on the adjusted auto operating costs (\$0.233/veh-mi), the adjusted truck operating costs (\$0.858/veh-mi), and the percentage of trucks in the corridor (6% on average), shown in Table 31. For the analysis period (2022-2041), the total annual benefit from vehicle operating cost savings is calculated and discounted to present value, and an increase in VMT after the construction of new facilities contributes to a negative benefit, around -\$36 million (Appendix C).

Table 31. Auto and Truck Vehicle Operating Costs (Dollars per Vehicle-Mile Traveled)

	2017$	2015$
Auto total operating & emissions costs	0.30	0.28
Truck total operating & emissions costs	1.08	1.09
Auto per-mile operating costs	0.25	0.233
Truck per-mile operating costs	0.85	0.858
Composite value of cost (Percentage of Truck, 6%)		0.271

5.2.2.3 Crash Cost Savings

The changes in the number of accidents after the new construction on the roadway network are related with the changes in VMT. By using the same crash rates by severity (Fatal, Type A, Type B, Type C, and Property Damage Only) and facility type (Freeway and Non-Freeway) and the crash values by severity (Table 32), the crash cost savings (safety benefit) as a result of the new constructions are calculated based on the subarea traffic demand forecasting results of both 2010 and 2040 Build and No-Build scenarios. Due to the increase of freeways in the new roadway network and lower crash rates on freeways, the discounted present value turns out to have a positive effect on the total annual benefit, approximately $7.6 million (Appendix D).

Table 32. The Crash Rates of Freeway and Non-Freeway by Severity

	Freeway	Non-Freeway
Crashes per 100 million vehicle miles (Fatal)	0.15	0.68
Crashes per 100 million vehicle miles (Type A)	0.5	1.47
Crashes per 100 million vehicle miles (Type B)	6.73	10.18
Crashes per 100 million vehicle miles (Type C)	19.41	31.39
Crashes per 100 million vehicle miles (PDO)	77.04	98.24

5.2.2.4 Travel Time Reliability

Improving the reliability of travel times for users is a primary objective of investments in MnPASS lanes. By managing new capacity to ensure free flow conditions and encouraging higher vehicle occupancies, MnPASS lanes attempt to maximize the number of users that can count on reliable travel. Several recent efforts in Minnesota and around the country have sought to enhance the ability to predict and quantify the economic benefits of improved travel time reliability, including the second Strategic Highway Research Program (SHRP2) and the I-35W North Preliminary Design Project. Current literature reviewed on this topic describes several potential methodologies and parameter values for reliability. The research team has attempted to demonstrate a calculation method that represents the state of the practice at the time of this work. As reliability calculations are performed for potential future MnPASS investments, analysts should continue to consult up-to-date literature for further advancement or convergence towards standardized and widely adopted methodologies.

A variety of theories and methods for economic valuation of reliability have been identified from projects around the country. A prevalent school of thought considers the cost of reliability – variability or unreliability of travel times – to be a "planning time" cost. In this context, the time a commuter must budget for a trip includes not only the in-vehicle time, but potentially additional time to account for non-recurring delays. As a result, methods applied for this theory often capture planning time costs that are not realized as true travel times. Approaches that have been proposed for this include using a statistical measure of the range of travel times, such as the planning time index (PTI), buffer index (BI), or standard deviation. Monetizing these time values requires using an accepted value of time parameter and a multiplier known as a reliability ratio (RR), frequently valued in the 0.7 to 0.8 range of the value of time.

The other common approach to valuing travel time reliability is to account for only the realized travel time costs experienced by travelers. The range of travel times observed over time tend to vary widely compared to those predicted by traditional planning tools as a result of non-recurring conditions such as severe weather, crashes, and fluctuations in traffic demand. The resulting travel times can be tabulated to capture the variability of in-vehicle times. These can be summed to account for the total travel time experienced by travelers not considered in traditional tools. Due to the current lack of scientific consensus for specific parameter values the first approach describes planning time costs, while the second approach conservatively counts only realized costs applied to this demonstration.

The travel time reliability category measures the total VHT when travel times deviate from the base travel time predicted by the regional travel demand model (RTDM). Figure 20 provides three typical examples illustrating the travel time reliability measurement method. The base travel time is obtained from the Twin Cities RTDM, and the variable travel time is obtained from the reliability estimation process, which incorporates the effects of crashes, snow, and variable traffic demand.

The areas between the curves represent the difference in travel times between the base travel time and the reliability travel time estimates. When the reliability travel time is higher than base travel time, this is counted as "increased reliability cost." When the reliability travel time is lower than base travel time, this is counted as "decreased reliability cost". Typically, reliability under the snow, crash, or unusually high traffic demand conditions results in increased reliability costs. The net total of reliability VHT is calculated by multiplying the total areas between the two curves during weekday peak periods (*AM Peak Period: 6 a.m. to 9 a.m., and PM Peak Period: 3 p.m. to 6 p.m.)* by the number of users. The result includes all of the increased and decreased reliability costs for one year to capture the travel time reliability of the no build and MnPASS project alternatives.

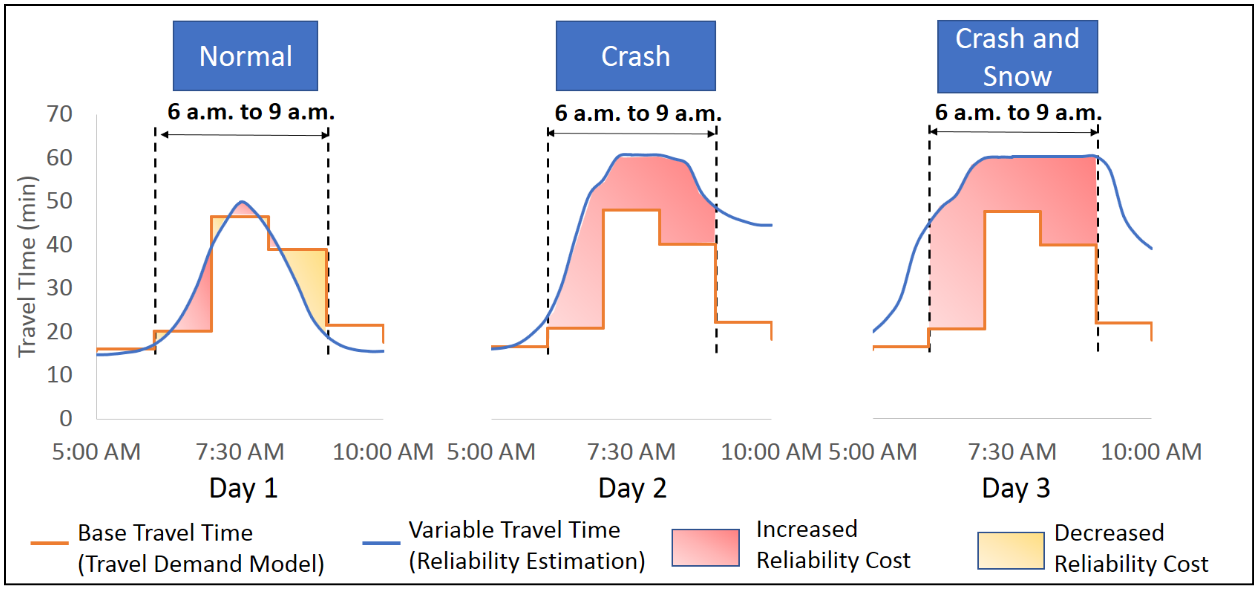

Figure 20. Travel Time Reliability Measurement (I-35W Southbound AM Peak Period Examples)

The resulting reliability VHT totals are subsequently multiplied by the value of time parameter established for the VHT benefit category.

Table 33 summarizes the value of reliability VHT calculations performed for the selected area for the No-Build and Build alternatives. The difference in user costs for these alternatives represents the net benefits for the MnPASS alternative.

Table 33. Travel Time Reliability Calculation Results

	2040 No-Build		2040 MnPASS Build			
			General Purpose Lane		MnPASS	
	Northbound	Southbound	Northbound	Southbound	Northbound	Southbound
Reliability (Veh-Hr)	1,529,636	1,349,944	1,549,131	811,477	2,884	3,473
Time Value ($/Hr/Veh)	$22.48	$22.48	$22.48	$22.48	$22.48	$22.48
Value of Reliability VHT ($)	$34,386,225	$30,346,732	$34,824,470	$18,242,003	$64,841	$78,073
Subtotal User Cost ($)	$64,732,958		$53,209,387			
Annual Benefit			$11,523,570			

These results show that an annual benefit of the MnPASS project is approximately $11.5 million for year 2040 conditions, and the total travel time reliability benefit of the MnPASS project is approximately $130 million compared to the No-Build alternative over the 20-year analysis period, as detailed in Appendix E.

The estimated travel time reliability user savings of $130 million is approximately 33 percent of the estimated travel time savings of $398 estimated for this project. This high proportion suggests that non-recurring factors contributing to variable travel times, such as crashes, snow, and traffic demand are important considerations in evaluating the user costs for MnPASS.

The results presented in this demonstration are based on outcomes of a customized travel reliability evaluation completed for the I-35W North Managed Lane project. Several other models and tools are either currently available or under development to perform reliability analysis, including traffic models at the macroscopic, mesoscopic, and microscopic levels. Future evaluation of potential MnPASS investments should consider use of multiple such tools to generate an estimate for impact to reliability user benefits.

5.2.2.5 Transit Benefit

MnPASS lanes also provide travel time benefits to transit users by serving bus trips with the same managed conditions available to HOV and toll-paying SOV users. As a result, travel times are typically shorter than non-MnPASS highways, even if other transit advantages such as bus-only shoulders are present. This section describes how transit travel times and ridership estimates prepared for the I-35W North Preliminary Design project were used to calculate transit benefits for this demonstration.

The transit benefit was calculated based on the bus travel time and the ridership under the 2040 No-Build and 2040 MnPASS Build alternatives. Under No-Build conditions buses are allowed to use the shoulders when the traffic speed drops under 35 mph. Under MnPASS Build conditions, it is assumed buses would travel at free flow speeds in the MnPASS lanes wherever they are available. Travel times for buses and automobiles were generated with CORSIM models, and the results are summarized below (Table 34).

Table 34. Transit Benefit Results

Travel Time 3-hour peak period (minutes)	AM		PM		Round Trip		
	Southbound		Northbound		Total Travel Time		Total Savings
	Bus	GP	Bus	GP	Bus	GP	(2-way)
2040 No-Build	26	33	33	42	59	75	16
2040 MnPASS Build	20	28	24	39	44	67	23

*GP = General Purpose Lanes

The ridership forecasts for routes along the I-35W north corridors are shown in Table 35.

.

Table 35. Ridership Forecasting Results for Routes along the I-35W North Corridors

Scenario	Route 250	Route 252	Route 288	Total
2040 No-Build	3,400	200	700	4,300
2040 Build	3,700	200	700	4,600

The transit benefit is calculated as the saved travel time multiplied by the value of time. The round-trip transit travel time for the 2040 No-Build alternative is 0.98 hour and for the 2040 MnPASS Build alternative is 0.73 hour. The ridership for the MnPASS alternative is 300 people higher. It is assumed that the 300 trips are auto trips using general purpose lanes under the No-Build alternative. Considering the travel time savings and the ridership for weekday peak periods, the annual transit benefit for the 2040 MnPASS Build alternative is nearly $5.1 million compared to the No-Build alternative (Table 36).

Table 36. Annual Transit Benefit Estimation of Year 2040

Measures	2040 No-Build	2040 Build
Round Trip Transit Travel Time (hr)	0.98	0.73
Round Trip Auto Travel Time (hr)	1.25	1.12
Ridership (persons)	4,300	4,600
Subtotal – Transit Passenger Travel Time (hr)	4,227	3,373
Auto Trips (if no MnPASS) (persons)	300	-
Subtotal – Auto Driver Travel Time (hr)	376	-
Total Travel Time (hr)	4,603	3,373
Value of Time ($)	$15.88	$15.88

Total Cost ($)	$73,114	$53,578
Benefit ($)	-	$19,536
Annual Benefit ($)	-	$5,079,360

Following the same calculation steps, the total transit benefit accrued over the 20-year analysis period is estimated, and a total value of approximately $57 million contributes to the total benefit accountings (Appendix F).

5.2.2.6 Emergency Response

MnPASS lanes can potentially provide benefits for emergency responders as well as for commuters. Higher speeds, little congestion, and lower volumes make it easier for emergency vehicles to travel quickly along the highway even as general purpose lanes are congested. While these trips may be relatively few in number compared to overall vehicle traffic, their dramatically higher value of time – consider an ambulance transporting a heart-attack victim – have the potential to produce meaningful benefits.

This section describes a hypothetical set of scenarios for emergency response benefits for the I-35W North Managed Lane project, envisioning ambulance trips between North metro communities to Hennepin County Medical Center in downtown Minneapolis.

The annual emergency response cost is calculated for both the 2040 No-Build and 2040 MnPASS Build scenarios. The following assumptions were used to calculate the annual cost, in addition to the annual emergency response travel time savings:

- Under the No-Build scenario, when the mainline speed was less than 40 miles per hour (mph), it is assumed that ambulances would be able to travel 45 mph. Otherwise, under free flow conditions, it was assumed that ambulances could travel at 75 mph.
- In the 2040 MnPASS Build scenario, it is assumed that ambulances could travel at 75 mph under both free flow and congested conditions.

The average ambulance travel time in the southbound direction is calculated for the corridor. For the No-Build scenario, the travel time is determined to be 19.6 minutes. Under the MnPASS scenario, the travel time is calculated to be 15.5 minutes. The annual emergency response cost is calculated assuming two, six, and ten ambulance trips per day along the corridor, and with a value of time of 100, 500, and

1,000 dollars per hour. The results of the emergency response cost calculations are shown in Table 37 and Table 38.

Table 37. Year 2040 No-Build Annual Emergency Response Cost

Daily Ambulance Trips	Value of Time		
	$100/hour	$500/hour	$1,000/hour
2	$16,988	$84,939	$169,878
6	$50,963	$254,816	$509,633
10	$84,939	$424,694	$849,388

Table 38. Year 2040 Build Annual Emergency Response Cost

Daily Ambulance Trips	Value of Time		
	$100/hour	$500/hour	$1,000/hour
2	$13,440	$67,201	$134,403
6	$40,321	$201,604	$403,209
10	$67,201	$336,007	$672,015

The annual emergency response savings between the MnPASS and No Build scenario is shown in Table 39.

Table 39. Year 2040 Annual Savings

Daily Ambulance Trips	Value of Time		
	$100/hour	$500/hour	$1,000/hour
2	$3,547	$17,737	$35,475

6	$10,642	$53,212	$106,424
10	$17,737	$88,687	$177,373

Under a future MnPASS evaluation, it is recommended that MnDOT hold discussions with emergency response personnel to confirm reasonable assumptions for the specific project. For the purpose of this demonstration, an annual benefit of approximately $100,000 may be considered applicable. As a result, the total emergency response benefit of the MnPASS project over the 20-year analysis period is approximately $1.5 million (see Appendix G).

5.2.2.7 Induced Traffic

Experience has shown that when capacity is added to the highway system, particularly on congested facilities, additional travel occurs in response. This illustrates that the improved travel times resulting from the project increase travelers' willingness to make longer trips or new trips. In economic terms this is a fundamental principle of supply and demand: when the cost of a good decreases (e.g. travel time decreases by adding capacity), the quantity consumed increases (VMT goes up). This additional travel has economic value to society, for example by allowing workers to access more and better jobs, and increasing opportunities for commercial and social activities.

The value of these benefits can be captured for transportation projects using the economic term known as consumer surplus. These are additional benefits experienced by those users making new or longer trips, beyond the existing user costs captured in the travel time savings (VHT benefits) and vehicle operating cost savings (VMT benefits) categories. Figure 21 below shows an illustration of these parameters for a highway capacity project. The blue lines represent the supply curves for the no build (S_1) and build (S_2) conditions. Both have an increasing cost of travel (travel time) as volume increases, however S_2 increases more slowly since the added capacity can accommodate higher volumes.

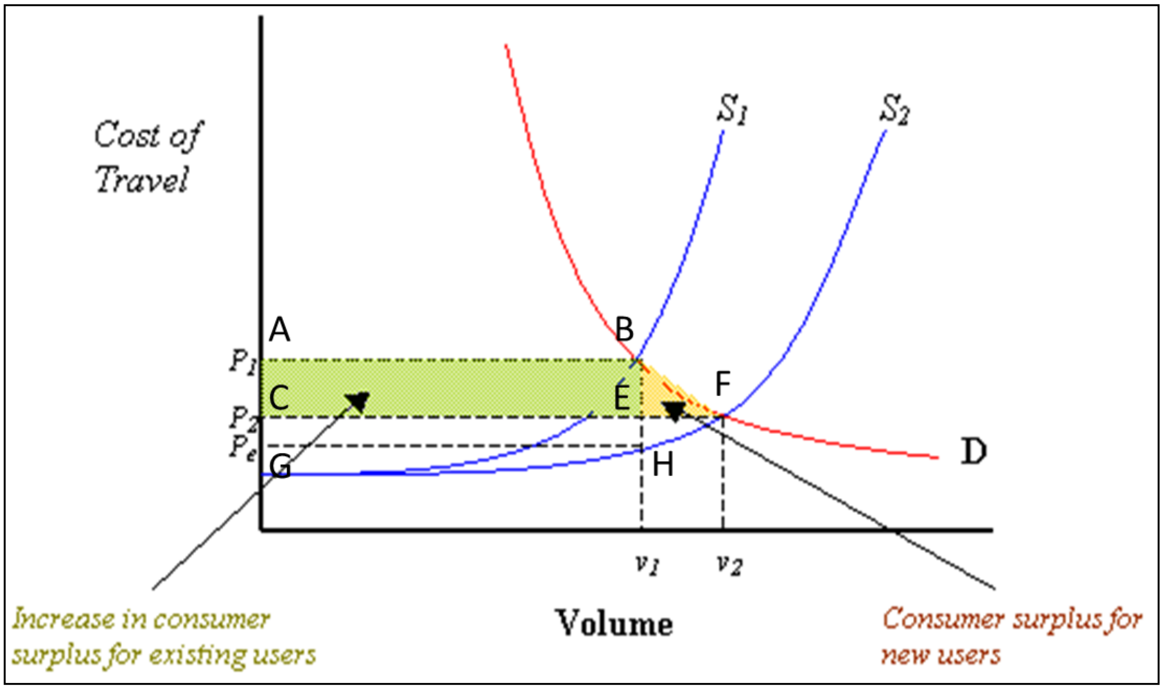

Figure 21. Existing and Induced User Benefits from New Transportation Improvement (Source: Estimating Induced Travel, TRB Transportation Economics Committee https://sites.google.com/site/benefitcostanalysis/benefits/induced-travel/estimating)

The equilibrium points for these curves shift between the locations where the supply curves intersect the fixed red demand curve (D). The realized user costs for no build (VHT total) is represented by the rectangle formed by lines p_1 and v_1, and for build by p_2 and v_2; these real costs are counted in the travel time savings (VHT benefits) category. Therefore, the area between these rectangles and the demand curve represents the difference in consumer surplus, or value of induced traffic, between the alternatives. For simplicity, this area is estimated using the formula for a right triangle.

Value of Induced Demand = $\frac{1}{2}(v_2 - v_1)(p_1 - p_2)$

Traffic modeling results for the I-35W North project were reviewed to perform a demonstration analysis of induced demand benefits. This review concluded that the modeling approach used for that project did not utilize different trip tables for the no build and build conditions highway assignment procedures, which is common practice for highway capacity project evaluations. As a result, these modeling results did not provide estimates of new or longer trips predicted in response to the MnPASS improvement, rendering the induced demand benefit category inconsequential.

In lieu of a quantitative evaluation, the research team has identified a series of considerations for future researchers and practitioners with respect to induced demand benefit calculations. First, in contrast to the findings of the literature review, which recommends performing these calculations on a link-by-link basis, it is suggested that calculations should be performed at the level of origin-destination (O-D) pairs. Parsing those O-D pairs with increases or decreases of trips will provide analysts with more detailed information about trip patterns increasing or decreasing in response to the capacity improvement.

If the overall number of trips predicted by the model increases, this would suggest the generation of new trips taken in response to the capacity increase. It is also likely that while some O-D pairs would show an increase in trips, others may show a decrease, as a result of some travelers choosing to make longer trips. In this case, it would be necessary to incorporate the lengths of each trip, to assess whether the shifts in trips are, in fact, longer than those taken under the no build alternative. Taken together, these findings would support the hypothesis that the new capacity induces additional travel, thereby increasing mobility for affected O-D pairs. Further research may also investigate the purpose of affected trips and whether trip length elasticity in the model is meaningfully different based on trip type (e.g. work versus shopping, etc.).

An additional consideration regards the deployment of a new regional travel demand model. While the I-35W North project was completed using the Metropolitan Council's traditional four-step model, it is expected that future traffic forecasting work performed for MnPASS facilities will utilize the recently developed activity-base model (ABM) developed for the Twin Cities Metropolitan Area. Additional investigation of induced demand benefits should focus on the capabilities of this model to generate applicable and reasonable travel estimates to support calculations for this benefit category.

5.2.2.8 Emissions Impact

The MnPASS project will produce emission impacts due to the change of automobile and truck VMT. Consistent with the format of the I-35W North Managed Lanes project BCA, the total emission impacts can be measured and monetized by using the auto and truck per-mile emissions costs, provided by MnDOT. The 2015 dollar values of both auto and truck climate and health related emissions costs were not shown in the I-35W North Managed Lanes study, but can be derived based on the available 2017 dollar values of these parameters (Source: http://www.dot.state.mn.us/planning/program/appendix_a.html) and the known auto and truck total operating & emissions costs listed in the I-35W North Managed Lanes project BCA summary.

Table 40 shows the results obtained for Auto, Truck, and Composite emission costs in SFY 2015, measured in dollars per vehicle-mile.

Table 40. Auto and Truck Emissions Costs (Dollars per Vehicle-Mile Traveled)

	2017$	2015$[1]
Auto total operating & emissions costs	0.3	0.28
Truck total operating & emissions costs	1.08	1.09
Auto per-mile emissions costs	0.05	0.047
Truck per-mile emissions costs	0.23	0.232
Composite value of cost (Percentage of Truck, 6%)		0.058

[1]Values were scaled to represent 2015 estimates for consistency with published 2017 values. Actual values referenced by MnDOT in 2015 were $0.033 for Auto, $0.264 for truck, with a composite of $0.047.

Based on daily VMT changes (see Appendix I, Table 47), the annual VMT numbers could be obtained and serve as a component to calculate the total annual emission costs. Using the same discount rate of 1.7%, the results suggest that the increase in VMT incurred an emission cost (negative benefit) of approximately -$7.7 million compared to the No- Build alternatives (Appendix I).

5.2.2.9 Noise Impact

VMT change also creates environmental impacts associated with noise. Following the same estimation method based on a Federal Highway Administration cost allocation study report (Source: https://www.fhwa.dot.gov/policy/hcas/addendum.cfm, Table 41), the high, low and likely values for the cost of urban automobile and truck noise were calculated on a per-VMT basis.

In view of the characteristics of the selected subarea in the Twin City metropolitan area, an urban/rural split of 100 percent to 0 percent was used. All values were calculated with the study's 2000 values first. For the likely noise cost of trucks, an average of 2.24 cents per VMT was adopted to create a weighted average of all types of travelling trucks, i.e., 40,000 pound 4-axle Single Unit Truck (1.50 cents per mile), 60,000 pound 4-axle S.U. Truck (1.68 cents per mile), 60,000 pound 5-axle Combination (2.75 cents per mile), and 80,000 pound 5-axle Combination (3.04 cents per mile). A composite likely noise cost of 2.19 cents per VMT was then obtained with a relative low urban automobile noise cost of 0.09 cents per VMT, when using the same assumption for percentage of trucks (6%).

According to the PRISM™ sensitivity analysis, the high and low values for the unit costs of urban automobile and truck noise were calculated as +/- 10 percent of the likely case, as shown in Table 41. By using a CPI adjustment (Bureau of Labor Statistics, Consumer Price Index, All Urban Consumers, US City Average, All Items, Series CUUR0000SA0, Source: http://data.bls.gov/pdq/SurveyOutputServlet), all values of 2000$ were then adjusted to the present 2015$.

Table 41. Unit Noise costs, Auto and Truck, 100-0 Urban-Rural Split

	Noise Costs per VMT Low	Noise Costs per VMT Likely	Noise Costs per VMT High
Auto and Truck (2000 cents/mi)	1.97	2.19	2.41
Auto and Truck (2015 cents/mi)	2.71	3.01	3.32

The noise costs for the years from 2022-2041 are discounted to a 2015-dollar value with a 1.7% discount rate. The final calculation reveals that the increase of VMT after the construction of MnPASS managed tolling lanes will result in a negative impact to the total project benefit in the form of noise pollution, approximately -$4.02 million in the likely case (Appendix J).

5.3 BENEFIT-COST ANALYSIS RESULTS

In summary, Table 42 outlines the changes for each impact category. All benefits and costs were estimated in current 2015 dollars over an economic analysis period from 2022 to 2041, after the MnPASS project completion in 2021. Over the entire analysis period, the MnPASS project leads to increases in VMT and decreases in VHT due to the improvement of traffic conditions and average travel speed. As a result, the vehicle operating cost of all road network users, and the emission and noise impacts of new infrastructure increase to some extent. However, the savings in vehicle travel time, crash cost, travel time reliability, transit, and even emergency response service contribute to a significant benefit.

Table 42. Project Impacts for I-35W North Managed Lanes Project Subarea Demonstration (2022-2041)

Benefit Component	Benefit Calculation	Contribution to the Total Benefit
Travel Time Savings (Auto and truck)	$398,386,602	Positive
Vehicle Operation Cost Savings (Auto and truck)	-$36,154,055	Negative
Crash Cost Savings/Safety Benefit (Auto and truck)	$7,624,153	Positive
Travel Time Reliability	$129,588,931	Positive
Transit Benefit	$57,120,143	Positive
Induced Travel	$0	-
Emergency Response	$1,521,542 with an assumption of $100,000 annual benefit	Positive
Emission Impact	-$7,715,881	Negative
Noise Impact	Ranging from -$3,620,029 (Low) to -$4,428,563 (High), with a likely case of -$4,024,296	Negative
Total Benefit	$546,347,139*	

*When a likely value of noise impact (-$4,024,296) was included.

As a result, benefits total $546,347,139 in net present value (discounted to 2015 dollars) over the 20-year economic analysis period, of which there are $594,241,371 in positive benefits and -$47,894,232 in negative benefits. Most of the positive benefits were generated by the travel time savings (67.0%) and travel time reliability (21.8%), followed by transit benefit (9.6%), safety (1.3%), and emergency response (0.3%), as shown in Figure 22. Negative benefits were generated by vehicle operating cost (75.5%), emission impact (16.1%), and noise impact (8.4%), respectively, as shown in Figure 23.

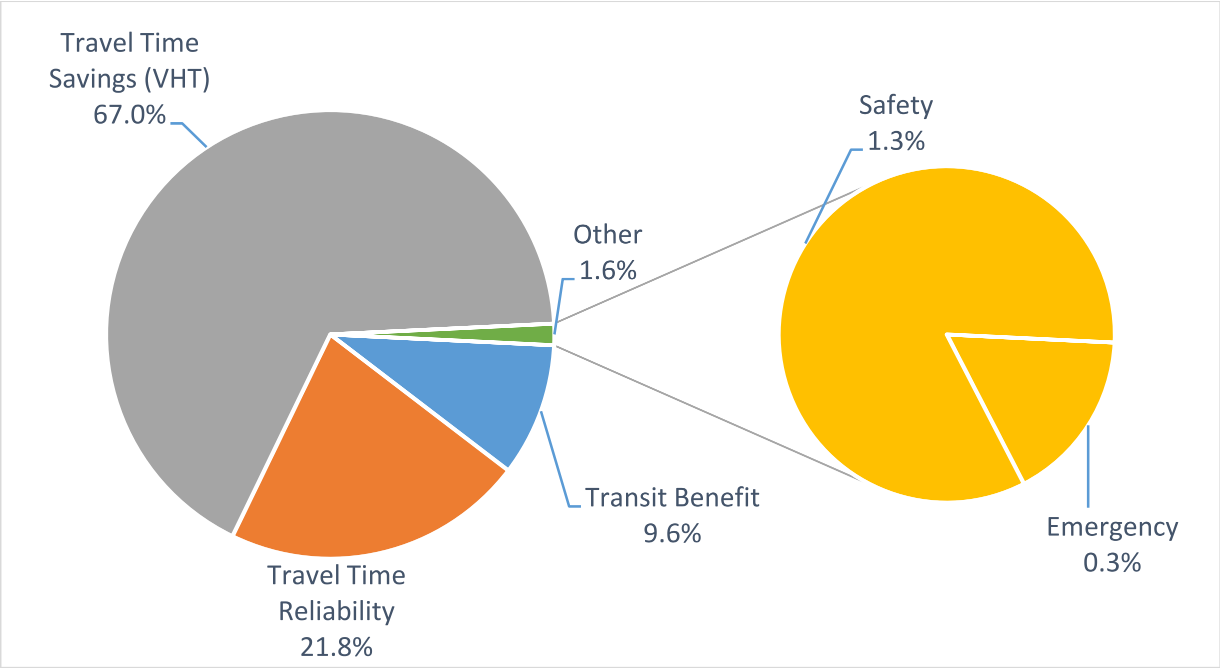

Figure 22. Positive Benefits by Category

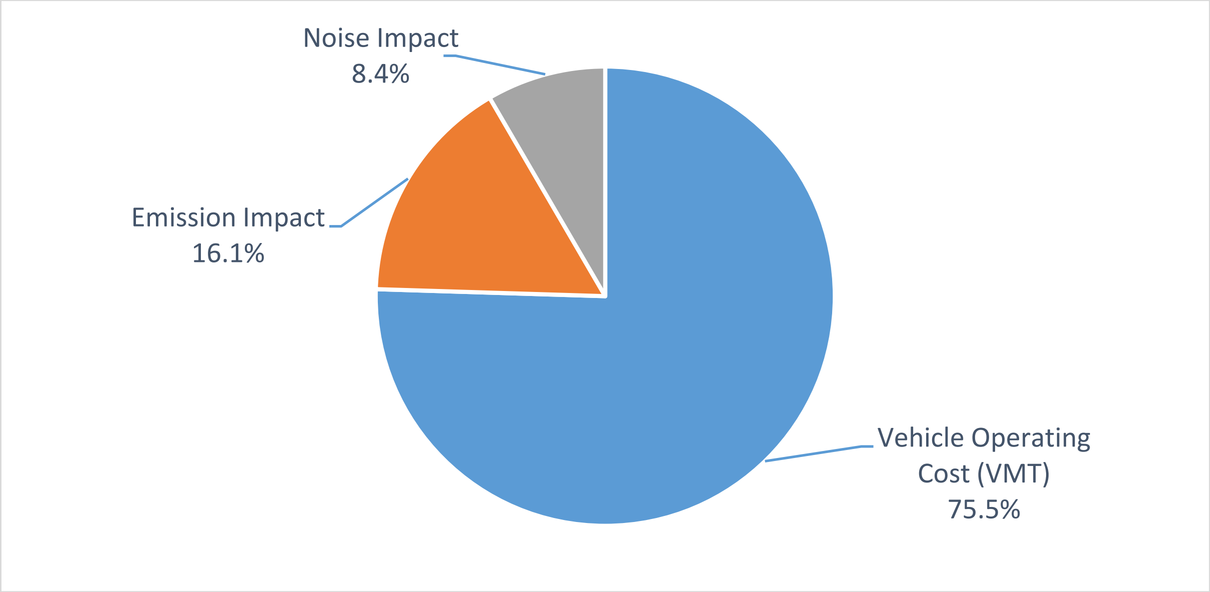

Figure 23. Negative Benefits by Category

A waterfall diagram is a useful means for quickly visualizing the impact of each benefit and cost category on the overall analysis outcome. This graphic uses bar heights to represent the individual contribution of each category, and accumulates the overall net present value from left to right across the graph as all categories are considered. Figure 24 uses this approach to illustrate the results of the previously completed traditional benefit-cost analysis for the I-35W North MnPASS project and for the refined ROI demonstration. The values shown in the diagram are the cumulative net present value after each category is added. The final net present value of the ROI demonstration of $385.6 million is shown on the far right for the refined ROI method, which is significantly higher than the $187.9 million value from the traditional BCA.

Figure 24. Waterfall Diagrams for Previous BCA and Refined ROI Demonstration

This diagram reveals that several categories have a dominant influence on the overall results of the evaluation. On the benefits side, travel time savings and reliability provide the majority of user benefits, while vehicle operation costs and transit savings are also significant. Capital cost is the major driver among the costs, while remaining capital value provides a small offset. These findings should be helpful when considering the benefit categories with the potential to meaningfully influence ROI results in future MnPASS analyses.

5.4 COMPARISON ANALYSIS AND CONCLUSION

The research team conducted a comparison analysis of the two ROI/BCA assessment frameworks, i.e., the original one used in the I-35W North Managed Lane Project and the refined one developed in this study. The results are presented in Table 43. After integrating a wider range of project impact categories, the project yields a much higher benefit-cost ratio of 3.40 over the same 20-year analysis period, which means that the MnPASS projects have more positive impacts on the society and economy than previously identified, and the new refined methodology is helpful in capturing these additional benefits of MnPASS compared to the original methods.

Table 43. Comparison Results of Original and Refined ROI Assessment Frameworks

	Category	Original Framework	Refined Framework
Cost Component	Capital Cost	$169,466,823	$169,466,823
	Operation and Maintenance Cost	$20,848,172	$26,838,533
	Remaining Capital Value	-$35,522,760	-$35,522,760
	Total Cost (2015$)	$154,792,236	$160,782,596
Benefit Component	Travel Time Savings (VHT)	$368,122,531	$398,386,602*
	Vehicle Operating Cost (VMT)	-$49,037,258	-$36,154,055*
	Crash Cost/Safety	$6,766,596	$7,624,153*

	Travel Time Reliability		$129,588,931
	Transit Benefit		$57,120,143
	Induced Travel		-
	Emergency Response		$1,521,542
	Emission Impact		-$7,715,881
	Noise Impact		-$4,024,296
	Total Benefit (2015$)	$325,851,870	$546,347,139
	Benefit-Cost Ratio	2.11	3.40

* The change in value for these benefit categories is a result of modification of the subarea of the regional travel demand model used to summarize these measures and is not attributable to any refined computational methods.

The performance of the refined ROI methodology demonstrates an improved tool for assessing MnPASS projects. Compared with the traditional ROI/BCA economic analysis methods used for MnPASS project assessment, this refined methodology incorporates a more comprehensive set of factors from the triple perspectives of economy, society, and environment, which closely pertain to the effects of MnPASS projects. As such, more significant benefits from the traffic efficiency improvements (e.g., travel time reliability and transit benefit) and other impacts (e.g., emergency response, and emission and noise impacts) can be captured and considered when making the selection of the most cost-effective project alternatives. The refined ROI assessment of future MnPASS projects will:

- Improve the accuracy of the current MnPASS ROI methodology;
- Improve the ability to demonstrate the financial desirability of MnPASS corridors and alternatives in addressing mobility and congestion issues of public travel;
- Make project/alternative comparisons more comprehensive and consistent;
- Provide better recommendations for practical and cost-effective investments.

CHAPTER 6: CONCLUSIONS AND SUMMARY

As stated in the Research Need Statement, the research objective of this project follows:

> "The Return on Investment (ROI)/Benefit Cost Analysis methodology/tool for MnPASS priced managed lane projects and the overall MnPASS system needs to be refined and made more consistent/standardized to better assess MnPASS project alternatives, compare potential MnPASS corridors, and communicate why MnPASS is a financially effective long-term strategy for addressing mobility and congestion issues. Additional factors should be evaluated for inclusion in the refined MnPASS ROI/BCA methodology, such as transit impacts and travel time reliability."

The research was tailored to meet the objectives of refining the ROI methodology and developing a tool for MnPASS by filling in current gaps and addressing challenges in the development of a revised framework. The research team completed the systematic and sequential series of tasks and approaches outlined below:

- Identified the limitations in the MnPASS ROI methodology through a review of related background studies and the development of a list of broader points to be considered for inclusion in the refinement process (Chapter 1)
- Conducted agency interviews with stakeholders to obtain MnPASS operating agencies objectives, experience, needs, related benefits and costs of the system, necessary data in support of the research, and the use of ROI analysis in the agency (Chapter 2)
- Defined typical ROI categories for MnPASS investments and established a relationship diagram of these categories and their associated benefits and costs (Chapter 3)
- Adopted appropriate measures that support sound economic evaluations to estimate benefit-cost ratios of invested projects, and developed a refined ROI framework for MnPASS with an emphasis on the above identified additional considerations (Chapter 4)
- Conducted a comparative demonstration of the revised methodology by using original and refined tools to develop recommendations (Chapter 5)

The effort in this project was focused on two related targets, from the identification of economic and external impacts (e.g., cost and benefit components) to the development of a refined ROI assessment framework (e.g., component measurement). The main purposes for constructing MnPASS Express Lanes in the Twin Cities metropolitan area have been to improve the performance of the regional highway system, to provide congestion-free travel options and to incentivize carpool and transit use. This study applied the rules of benefit component selection from the BCA study, which included:

- Use components that are commonly accepted as the direct impacts of a MnPASS project

- Represent multiple aspects of project impacts and ensure that the measurements are not overlapping
- Use measurable and computational methods that are technically sound

Using this approach, the evaluation framework established in this research for future MnPASS ROI assessment includes the range of benefits listed in Chapter 3: Identification of MnPASS ROI Investment Categories (Table 44).

Table 44: Benefits of ROI Assessment

Social/Health	Economic/ Transportation
• Safety/Crash costs • Noise • Emissions	• Travel time savings • Vehicle operation costs • Travel time reliability • Induced traffic • Transit • Freight • Emergency response

Like travel demand methods, the tractable methodologies, data needs, and estimation steps for measuring these economic, environmental, and social benefits are generally applicable to MnPASS BCA. All the direct costs of new investments in a MnPASS project can be calculated by estimating the initial capital costs, annual operating and maintenance cost, and remaining capital value.

Based on the available data resources from the benefit-cost analysis on the I-35W North Managed Lanes project, Chapter 5 of this report presents a comparative demonstration on the performance of the proposed methodology/tool. The comparison shows that beyond the traditional traffic efficiency indicators (e.g., travel time savings, vehicle operating cost), several additional categories also have a substantial influence on the overall results of the evaluation, e.g., over the same 20-year economic analysis period, most of the positive benefits are generated by the travel time savings (67%) and travel time reliability (22%), followed by transit benefit (10%), safety (1%), and emergency response (<1%). While the negative emissions (16%) and noise (8%) impacts are also meaningful, most of the disbenefits are attributable to the traditional vehicle operating cost (76%).

It should be noted that results for the induced demand benefit category were not incorporated into the demonstration evaluation for the I-35W project. This was due to two factors, specifically that travel demand modeling results were not available in a format that supported these benefit calculations and findings from the literature search may not have been applicable to the case study. Thus, the order of magnitude of user benefits from this category could not be compared to the other benefit categories. However, future attention should be given to this category as the region's new activity-based model and modified methods may facilitate estimation of these user benefits.

After integrating a wider range of project impact categories, the analysis yields a notably higher benefit-cost ratio of 3.40 compared to the original BCA study in the I-35W North Managed Lanes project, for which the benefit-cost ratio was 2.11. This result suggests that MnPASS projects indeed have more positive impacts on society and the economy than previously identified.

Based on the findings of this comparison, MnDOT may wish to revise its benefit-cost guidance for evaluation of MnPASS facilities. While all of the new user cost (benefit) categories help to capture additional impacts of MnPASS investments, MnDOT should also consider the level of effort required to produce these measures relative to their influence on the overall outcome of the evaluation. For example, the measures capturing reliability and transit impacts produce a meaningful change in the overall benefits. On the other hand, emergency response and noise impacts are found to be very small relative to overall project user costs. Emissions show some impact, but less than many other measures, while further investigation is needed to identify the impact of induced traffic/travel.

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APPENDIX A:

OPERATIONS AND MAINTENANCE COSTS

OPERATIONS AND MAINTENANCE COSTS

Year of Completion	2021
Discount Rate	1.70%
Current Year	2015
Annual Pavement Maintenance Cost per Lane Mile	$62,000
Additional Lane Miles	22.1
Annual MnPASS System Operation Cost	$400,000

Table 45. Annual Operations and Maintenance Cost Estimation

Year	Additional Lane Costs in Constant Dollars	Annual MnPASS System Operation Cost in Constant Dollars	Present Value in Total $
2022	$1,370,200	$400,000	$1,570,709
2023	$1,370,200	$400,000	$1,544,108
2024	$1,370,200	$400,000	$1,517,957
2025	$1,370,200	$400,000	$1,492,250
2026	$1,370,200	$400,000	$1,466,977
2027	$1,370,200	$400,000	$1,442,133
2028	$1,370,200	$400,000	$1,417,710
2029	$1,370,200	$400,000	$1,393,700
2030	$1,370,200	$400,000	$1,370,097
2031	$1,370,200	$400,000	$1,346,894
2032	$1,370,200	$400,000	$1,324,083
2033	$1,370,200	$400,000	$1,301,659
2034	$1,370,200	$400,000	$1,279,615
2035	$1,370,200	$400,000	$1,257,944
2036	$1,370,200	$400,000	$1,236,640
2037	$1,370,200	$400,000	$1,215,697

2038	$1,370,200	$400,000	$1,195,108
2039	$1,370,200	$400,000	$1,174,869
2040	$1,370,200	$400,000	$1,154,972
2041	$1,370,200	$400,000	$1,135,412
			$26,838,533

APPENDIX B:

TRAVEL TIMES SAVINGS (VHT)

TRAVEL TIMES SAVINGS

Year of Completion	2021
Days in a Year	260
Discount Rate	1.7%
Current Year	2015
Annual VHT Change (Base)	1.193%
Annual VHT Change (Alternative)	1.176%
Composite Costs per Vehicle-Mile	$22.48

Table 46. Annual Travel Time Savings Estimation

Year	Base VHT	Alternative VHT	Difference	Annual Savings in Constant Dollars	Present Value of Savings
2022	568,809	565,689	3,120	$18,235,254	$16,172,846
2023	575,597	572,340	3,257	$19,036,178	$16,596,171
2024	582,466	579,069	3,397	$19,853,518	$17,014,498
2025	589,417	585,877	3,539	$20,687,551	$17,427,868
2026	596,451	592,766	3,685	$21,538,557	$17,836,322
2027	603,569	599,735	3,834	$22,406,822	$18,239,901
2028	610,771	606,786	3,985	$23,292,635	$18,638,646
2029	618,060	613,920	4,140	$24,196,289	$19,032,596
2030	625,436	621,138	4,298	$25,118,085	$19,421,791
2031	632,900	628,441	4,458	$26,058,323	$19,806,272
2032	640,452	635,830	4,622	$27,017,312	$20,186,078
2033	648,095	643,306	4,790	$27,995,365	$20,561,247
2034	655,830	650,869	4,960	$28,992,798	$20,931,819
2035	663,656	658,522	5,134	$30,009,933	$21,297,831
2036	671,576	666,264	5,312	$31,047,097	$21,659,323
2037	679,590	674,098	5,493	$32,104,622	$22,016,331

Year	Base VHT	Alternative VHT	Difference	Annual Savings in Constant Dollars	Present Value of Savings
2038	687,700	682,023	5,677	$33,182,844	$22,368,894
2039	695,907	690,042	5,865	$34,282,106	$22,717,050
2040	704,212	698,155	6,057	$35,402,755	$23,060,834
2041	712,616	706,363	6,253	$36,545,144	$23,400,284
					$398,386,602

APPENDIX C:
VEHICLE OPERATING COST (VMT)

VEHICLE OPERATING COSTS

Year of Completion	2021
Days in a Year	260
Discount Rate	1.7%
Current Year	2015
Annual VMT Change (Base)	0.72%
Annual VMT Change (Alternative)	0.72%
Composite Costs per Vehicle-Mile	$0.271

Table 47. Annual Vehicle Operating Cost Estimation

Year	Base VMT	Alternative VMT	Difference	Annual Savings in Constant Dollars	Present Value of Savings
2022	17,719,624	17,751,331	-31,707	-$2,232,452	-$1,979,962
2023	17,847,216	17,879,159	-31,942	-$2,249,032	-$1,960,757
2024	17,975,727	18,007,907	-32,179	-$2,265,734	-$1,941,738
2025	18,105,163	18,137,582	-32,418	-$2,282,561	-$1,922,903
2026	18,235,532	18,268,191	-32,659	-$2,299,512	-$1,904,252
2027	18,366,839	18,399,740	-32,902	-$2,316,589	-$1,885,781
2028	18,499,091	18,532,237	-33,146	-$2,333,792	-$1,867,489
2029	18,632,296	18,665,688	-33,392	-$2,351,124	-$1,849,374
2030	18,766,460	18,800,100	-33,640	-$2,368,584	-$1,831,435
2031	18,901,589	18,935,479	-33,890	-$2,386,173	-$1,813,670
2032	19,037,692	19,071,834	-34,142	-$2,403,893	-$1,796,077
2033	19,174,775	19,209,171	-34,395	-$2,421,744	-$1,778,655
2034	19,312,845	19,347,496	-34,651	-$2,439,728	-$1,761,401
2035	19,451,910	19,486,818	-34,908	-$2,457,846	-$1,744,315
2036	19,591,975	19,627,142	-35,167	-$2,476,097	-$1,727,395
2037	19,733,049	19,768,478	-35,428	-$2,494,484	-$1,710,638

Year	Base VMT	Alternative VMT	Difference	Annual Savings in Constant Dollars	Present Value of Savings
2038	19,875,139	19,910,831	-35,691	-$2,513,008	-$1,694,044
2039	20,018,252	20,054,209	-35,956	-$2,531,669	-$1,677,611
2040	20,162,396	20,198,619	-36,223	-$2,550,468	-$1,661,337
2041	20,307,578	20,344,070	-36,492	-$2,569,407	-$1,645,222
					-$36,154,055

APPENDIX D:

CRASH COST SAVINGS/SAFETY

CRASH COSTS SAVINGS/SAFETY

Year of completion	2021
Days in a Year	260
Discount Rate	1.7%
Current Year	2015
Annual VMT Change (Base-Freeway)	0.682%
Annual VMT Change (Base-Non-Freeway)	0.783%
Annual VMT Change (Alternative-Freeway)	0.689%
Annual VMT Change (Alternative-Non-Freeway)	0.772%
MnDOT Crash Value (Fatal)	$10,600,000
MnDOT Crash Value (Type A)	$570,000
MnDOT Crash Value (Type B)	$170,000
MnDOT Crash Value (Type C)	$83,000
MnDOT Crash Value (PDO)	$7,600

Table 48. Annual Crash Cost Saving Estimation

	Base			Alternative				
Year	Freeway VMT	Non-Freeway VMT	Annual Crash Costs	Freeway VMT	Non-Freeway VMT	Annual Crash Costs	Annual Savings in Constant Dollars	Present Value of Savings
2022	11,077,379	6,641,790	$376,927,857	11,146,029	6,605,000	$376,603,008	$324,849	$288,108
2023	11,152,920	6,693,827	$379,728,470	11,222,856	6,655,991	$379,385,367	$343,103	$299,125
2024	11,228,977	6,746,271	$382,549,984	11,300,213	6,707,376	$382,188,343	$361,641	$309,927
2025	11,305,552	6,799,126	$385,392,557	11,378,103	6,759,157	$385,012,090	$380,467	$320,518
2026	11,382,650	6,852,395	$388,256,347	11,456,530	6,811,338	$387,856,764	$399,583	$330,899
2027	11,460,273	6,906,082	$391,141,512	11,535,498	6,863,922	$390,722,518	$418,994	$341,075
2028	11,538,426	6,960,189	$394,048,212	11,615,010	6,916,912	$393,609,510	$438,702	$351,047
2029	11,617,112	7,014,720	$396,976,610	11,695,070	6,970,311	$396,517,898	$458,712	$360,819

	Base			Alternative				
Year	Freeway VMT	Non-Freeway VMT	Annual Crash Costs	Freeway VMT	Non-Freeway VMT	Annual Crash Costs	Annual Savings in Constant Dollars	Present Value of Savings
2030	11,696,334	7,069,678	$399,926,868	11,775,681	7,024,122	$399,447,841	$479,027	$370,393
2031	11,776,097	7,125,067	$402,899,150	11,856,849	7,078,348	$402,399,499	$499,650	$379,772
2032	11,856,403	7,180,890	$405,893,620	11,938,576	7,132,994	$405,373,034	$520,586	$388,958
2033	11,937,257	7,237,150	$408,910,446	12,020,866	7,188,061	$408,368,607	$541,838	$397,954
2034	12,018,663	7,293,851	$411,949,794	12,103,723	7,243,553	$411,386,383	$563,411	$406,763
2035	12,100,623	7,350,997	$415,011,834	12,187,152	7,299,474	$414,426,527	$585,306	$415,388
2036	12,183,143	7,408,590	$418,096,736	12,271,155	7,355,826	$417,489,206	$607,530	$423,830
2037	12,266,225	7,466,634	$421,204,671	12,355,738	7,412,613	$420,574,586	$630,085	$432,092
2038	12,349,874	7,525,133	$424,335,812	12,440,904	7,469,839	$423,682,836	$652,976	$440,178

	Base			Alternative				
Year	Freeway VMT	Non-Freeway VMT	Annual Crash Costs	Freeway VMT	Non-Freeway VMT	Annual Crash Costs	Annual Savings in Constant Dollars	Present Value of Savings
2039	12,434,093	7,584,090	$427,490,332	12,526,656	7,527,507	$426,814,127	$676,206	$448,088
2040	12,518,887	7,643,509	$430,668,409	12,613,000	7,585,619	$429,968,629	$699,779	$455,826
2041	12,604,259	7,703,394	$433,870,217	12,699,939	7,644,181	$433,146,516	$723,700	$463,394
								$7,624,153

APPENDIX E:

TRAVEL TIME RELIABILITY

TRAVEL TIME RELIABILITY

Year of Completion	2021
Discount Rate	1.7%
Current Year	2015
Composite Costs per Vehicle-Hour	$22.48

Table 49. Annual Travel Time Reliability Benefit Estimation

Year	Value of Reliability		Annual Savings in Constant Dollars	Present Value of Savings
	No-Build	Build		
2022	$31,175,393	$25,625,634	$5,549,759	$4,932,049
2023	$33,039,702	$27,158,064	$5,881,638	$5,139,616
2024	$34,904,011	$28,690,494	$6,213,517	$5,338,865
2025	$36,768,320	$30,222,924	$6,545,396	$5,530,016
2026	$38,632,630	$31,755,354	$6,877,276	$5,713,286
2027	$40,496,939	$33,287,784	$7,209,155	$5,888,883
2028	$42,361,248	$34,820,214	$7,541,034	$6,057,013
2029	$44,225,557	$36,352,644	$7,872,913	$6,217,877
2030	$46,089,866	$37,885,074	$8,204,793	$6,371,671
2031	$47,954,176	$39,417,504	$8,536,672	$6,518,585
2032	$49,818,485	$40,949,934	$8,868,551	$6,658,808
2033	$51,682,794	$42,482,364	$9,200,430	$6,792,521
2034	$53,547,103	$44,014,794	$9,532,310	$6,919,903
2035	$55,411,412	$45,547,223	$9,864,189	$7,041,129
2036	$57,275,722	$47,079,653	$10,196,068	$7,156,369

2037	$59,140,031	$48,612,083	$10,527,947	$7,265,788
2038	$61,004,340	$50,144,513	$10,859,827	$7,369,550
2039	$62,868,649	$51,676,943	$11,191,706	$7,467,813
2040	$64,732,958	$53,209,373	$11,523,585	$7,560,731
2041	$66,597,268	$54,741,803	$11,855,464	$7,648,456
				$129,588,931

APPENDIX F:
TRANSIT BENEFITS

TRANSIT BENEFITS

Year of Completion	2021
Discount Rate	1.7%
Current Year	2015
Composite Costs per Person-Hour	$15.88

Table 50. Annual Transit Benefit Estimation

Year	Value of Reliability		Annual Savings in Constant Dollars	Present Value of Savings
	No-Build	Build		
2022	$9,155,094	$6,708,874	$2,446,220	$2,173,946
2023	$9,702,574	$7,110,069	$2,592,505	$2,265,437
2024	$10,250,055	$7,511,264	$2,738,791	$2,353,262
2025	$10,797,536	$7,912,459	$2,885,076	$2,437,518
2026	$11,345,016	$8,313,654	$3,031,362	$2,518,299
2027	$11,892,497	$8,714,849	$3,177,648	$2,595,699
2028	$12,439,978	$9,116,044	$3,323,933	$2,669,807
2029	$12,987,458	$9,517,240	$3,470,219	$2,740,713
2030	$13,534,939	$9,918,435	$3,616,504	$2,808,502
2031	$14,082,420	$10,319,630	$3,762,790	$2,873,259
2032	$14,629,900	$10,720,825	$3,909,075	$2,935,066
2033	$15,177,381	$11,122,020	$4,055,361	$2,994,004
2034	$15,724,862	$11,523,215	$4,201,647	$3,050,152
2035	$16,272,342	$11,924,410	$4,347,932	$3,103,585
2036	$16,819,823	$12,325,605	$4,494,218	$3,154,381

2037	$17,367,304	$12,726,800	$4,640,503	$3,202,610
2038	$17,914,784	$13,127,995	$4,786,789	$3,248,347
2039	$18,462,265	$13,529,191	$4,933,074	$3,291,659
2040	$19,009,746	$13,930,386	$5,079,360	$3,332,615
2041	$19,557,226	$14,331,581	$5,225,646	$3,371,283
				$57,120,143

APPENDIX G:

EMERGENCY RESPONSE

EMERGENCY RESPONSE

Year of Completion	2021
Discount Rate	1.7%
Current Year	2015

Table 51. Annual Emergency Response Benefit Estimation

Year	Annual Savings in Constant Dollars	Present Value of Savings
2022	$100,000	$88,870
2023	$100,000	$87,384
2024	$100,000	$85,923
2025	$100,000	$84,487
2026	$100,000	$83,075
2027	$100,000	$81,686
2028	$100,000	$80,321
2029	$100,000	$78,978
2030	$100,000	$77,658
2031	$100,000	$76,360
2032	$100,000	$75,083
2033	$100,000	$73,828
2034	$100,000	$72,594
2035	$100,000	$71,381
2036	$100,000	$70,188

2037	$100,000	$69,014
2038	$100,000	$67,861
2039	$100,000	$66,726
2040	$100,000	$65,611
2041	$100,000	$64,514
		$1,521,542

APPENDIX H:
INDUCED TRAFFIC

INDUCED TRAFFIC

Year of Completion	2021
Discount Rate	1.7%
Current Year	2015
Composite Costs per Vehicle-Hour	$22.48

Table 52. Annual Induced Traffic Benefit Estimation

Year	Annual Induced Demand Benefits	Present Value of Savings
2022	$0	$0
2023	$0	$0
2024	$0	$0
2025	$0	$0
2026	$0	$0
2027	$0	$0
2028	$0	$0
2029	$0	$0
2030	$0	$0
2031	$0	$0
2032	$0	$0
2033	$0	$0
2034	$0	$0
2035	$0	$0
2036	$0	$0

2037	$0	$0
2038	$0	$0
2039	$0	$0
2040	$0	$0
2041	$0	$0
		$0

APPENDIX I:

EMISSIONS IMPACT

EMISSIONS IMPACTS

Year of Completion	2021
Current Year	2015
Discount Rate	1.7%
Percentage of Trucks	6%
Auto Emission Costs per Mile	$0.047
Truck Emission Costs per Mile	$0.232
Composite Emission Costs per Mile	$0.058

Table 53. Annual Emissions Cost Estimation

Year	Annual VMT Change	Annual Benefit in Constant Dollars	Present Value
2022	-8,243,747	-$476,443	-$422,557
2023	-8,304,969	-$479,981	-$418,458
2024	-8,366,646	-$483,546	-$414,399
2025	-8,428,780	-$487,137	-$410,380
2026	-8,491,376	-$490,754	-$406,399
2027	-8,554,436	-$494,399	-$402,457
2028	-8,617,964	-$498,070	-$398,553
2029	-8,681,963	-$501,769	-$394,687
2030	-8,746,437	-$505,495	-$390,859
2031	-8,811,389	-$509,249	-$387,068
2032	-8,876,823	-$513,031	-$383,313
2033	-8,942,743	-$516,841	-$379,595
2034	-9,009,151	-$520,679	-$375,913
2035	-9,076,053	-$524,545	-$372,266
2036	-9,143,451	-$528,441	-$368,655
2037	-9,211,349	-$532,365	-$365,079

2038	-9,279,750	-$536,318	-$361,537
2039	-9,348,659	-$540,301	-$358,030
2040	-9,418,079	-$544,313	-$354,557
2041	-9,488,015	-$548,355	-$351,118
			-$7,715,881

APPENDIX J:
NOISE IMPACTS

Table 54. Annual Noise Cost Estimation

Year	Annual VMT Change	Unit Noise Cost (Likely)	Total Annual Noise Cost (Likely)	Present Value (Low)	Present Value (Likely)	Present Value (High)
2010	-7,543,315	$ 0.0277				
2011	-7,599,340	$ 0.0286				
2012	-7,655,781	$ 0.0292				
2013	-7,712,641	$ 0.0296				
2014	-7,769,923	$ 0.0301				
2015	-7,827,630	$ 0.0301				
2016	-7,885,765	$ 0.0301				
2017	-7,944,331	$ 0.0301				
2018	-8,003,332	$ 0.0301				
2019	-8,062,771	$ 0.0301				
2020	-8,122,651	$ 0.0301				
2021	-8,182,975	$ 0.0301				
2022	-8,243,747	$ 0.0301	-$248,494	-$198,249	-$220,389	-$242,528
2023	-8,304,969	$ 0.0301	-$250,339	-$196,326	-$218,251	-$240,176

Year	Annual VMT Change	Unit Noise Cost (Likely)	Total Annual Noise Cost (Likely)	Present Value (Low)	Present Value (Likely)	Present Value (High)
2024	-8,366,646	$ 0.0301	-$252,198	-$194,422	-$216,134	-$237,846
2025	-8,428,780	$ 0.0301	-$254,071	-$192,536	-$214,038	-$235,539
2026	-8,491,376	$ 0.0301	-$255,958	-$190,669	-$211,962	-$233,255
2027	-8,554,436	$ 0.0301	-$257,859	-$188,819	-$209,906	-$230,992
2028	-8,617,964	$ 0.0301	-$259,774	-$186,988	-$207,870	-$228,751
2029	-8,681,963	$ 0.0301	-$261,703	-$185,174	-$205,853	-$226,533
2030	-8,746,437	$ 0.0301	-$263,646	-$183,378	-$203,856	-$224,335
2031	-8,811,389	$ 0.0301	-$265,604	-$181,599	-$201,879	-$222,159
2032	-8,876,823	$ 0.0301	-$267,577	-$179,837	-$199,921	-$220,004
2033	-8,942,743	$ 0.0301	-$269,564	-$178,093	-$197,981	-$217,870
2034	-9,009,151	$ 0.0301	-$271,565	-$176,365	-$196,061	-$215,757
2035	-9,076,053	$ 0.0301	-$273,582	-$174,655	-$194,159	-$213,664
2036	-9,143,451	$ 0.0301	-$275,614	-$172,960	-$192,276	-$211,591
2037	-9,211,349	$ 0.0301	-$277,660	-$171,283	-$190,411	-$209,539
2038	-9,279,750	$ 0.0301	-$279,722	-$169,621	-$188,564	-$207,506

Year	Annual VMT Change	Unit Noise Cost (Likely)	Total Annual Noise Cost (Likely)	Present Value (Low)	Present Value (Likely)	Present Value (High)
2039	-9,348,659	$ 0.0301	-$281,799	-$167,976	-$186,734	-$205,493
2040	-9,418,079	$ 0.0301	-$283,892	-$166,346	-$184,923	-$203,500
2041	-9,488,015	$ 0.0301	-$286,000	-$164,733	-$183,129	-$201,526
				-$3,620,029	-$4,024,296	-$4,428,563