7.0 Benefit/Cost Analysis

The objective of the benefit/cost analysis was to extrapolate the findings from the analysis of the select corridors to provide estimates of the systemwide benefits and costs of the ramp metering system. A number of performance measures were identified to estimate the positive and negative impacts of ramp metering, including system travel time, travel time reliability, safety, vehicle emissions, and fuel use. The ramp metering system's capital, operating, and maintenance costs were also quantified for comparison with the system's benefits.

7.1 Analysis Approach

Detailed field data collection was conducted on four selected corridors during the ramp meter evaluation period. The findings from this data collection and analysis provide valuable insight into the performance of these corridors both "with" and "without" ramp meters in operation. In order to compare the systemwide benefits and costs, the extrapolation of these impacts to all metered corridors in the region was required.

7.1.1 Estimation of Benefits

The four corridors selected for focused field data collection were used to provide estimates of performance impacts on varying types of metered corridors. Other metered corridors in the region were then categorized according to the similarities in performance and geometrics shared with the selected corridors. Other metered corridors resembling more than one selected corridor were assigned to the different categories using percentages. Section 4.5 provides additional detail on the criteria used and the resulting percentages applied to the metered corridors.

Two databases were then developed containing baseline (with meters) peak period performance characteristics for all segments of the metered corridors that were in operation during either the morning or afternoon peak periods. Segments included both mainline freeway and ramp locations. Arterial segments were not included in the benefit analysis as the arterial performance data from the selected corridors showed no statistically significant changes between the "with" and "without" periods. Performance measures and geometric information for each segment and each direction included:

- Average mainline speeds;
- Average mainline volumes;
- Average ramp delay per vehicle;

- Average ramp volumes;
- Average number of accidents by accident type (fatality, injury, property damage);
- Segment lengths; and
- Number of ramp meters on each segment by direction.

The appropriate traffic impact was then applied to each individual segment of the metered corridors based on their categorization and the impact observed on the relevant selected corridors.[1] The traffic impacts applied included the percentage change in freeway speeds and speed variability, the "per vehicle" change in ramp delay and ramp delay variability, and the change in accident rates. The spreadsheet models calculated estimates of speeds, travel time, and delay for each individual metered corridor based on these observed impacts applied to the baseline performance characteristics. Only corridor segments and travel directions having operating ramp meters in the "with" scenario were included in the analysis for each of the peak periods. No impacts were applied to non-metered corridors.

The resulting changes in facility speed, vehicle travel time, travel time variability, and number of accidents (by accident type) were then summed across all metered corridors, all directions, and all periods of operation (a.m. or p.m. peak period). Additionally, a simplified approach, based on changes in facility speeds, was used to estimate changes in fuel use and emissions, due to the demanding schedule requirements of this study.

Established per unit dollar values were then applied to the sum of the changes. For example, the estimated change in vehicle hours of travel was first multiplied with an average vehicle occupancy rate to estimate the change in person hours of travel. A value of travel time ($9.85 per hour) was then applied to the change in person hours of travel to determine the incremental dollar value of the impact. Identical values were applied regardless of the positive or negative nature of the impact. Table 7.1 presents the unit values that were applied to estimate the dollar value of the various impact categories.

The dollar values for each impact category were then summed to estimate the average daily impact value for the entire ramp metering system. This figure was multiplied by 247, the number of days per year the ramp metering system is operated, to provide the annual benefit/impact estimate. This annual benefit figure forms the basis for comparison with the ramp metering system costs.

7.1.2 Estimation of Costs

In order to provide a meaningful comparison of ramp metering costs and benefits, an annual estimate of system-related costs was required. This snapshot estimate of current system costs was calculated by analyzing deployment cost information for Mn/DOT's

[1] The baseline performance measures and impacts for the selected corridors were derived from directly observed measures from the field data collection.

Table 7.1 Impact Value Assumptions

Impact Performance Measure	Unit	Value
Travel time	Person hour	$9.85
Travel time variability	Person hour	$9.85
Fatality accidents	Per accident	$1,176,584
Injury accidents		
Severe	Per accident	$57,287
Moderate	Per accident	$21,711
Minor	Per accident	$13,471
Property damage only accidents	Per accident	$6,789
Hydrocarbons	Per ton	$1,774
Carbon monoxide	Per ton	$3,731
Nitrous oxide	Per ton	$3,889
Fuel use	Per gallon	$1.45

various subsystems related to congestion management. Historical expenditures, as well as recent "per unit" contract bid costs, were used to construct the capital equipment cost of the system. The annual capital costs were estimated by dividing the total equipment deployment costs by the useful life of the equipment. These capital costs were then compared with costs experienced in other regions and were found to be consistent.

In addition to the capital cost of deploying the ramp metering system, Mn/DOT incurs ongoing expenses related to the day-to-day operation and maintenance of the system components. Labor and overhead cost estimates for operations, maintenance, administrative, and managerial personnel were based on recent records from the *Minnesota State Activity Based Accounting System*, which tracks labor hours by activity. Additional costs, including facility costs, utility expenses, replacement equipment, and the value of research contracts, were also included in the cost estimate. These ongoing operation and maintenance costs were added with the annual capital costs to estimate the denominator for the benefit/cost comparison.

The estimation of a precise cost estimate of the ramp metering system deployed in the Twin Cities is not straightforward, because many of the system components were deployed as part of an integrated congestion management system. A number of the subsystems related to congestion management contribute to the operation of the ramp metering system, although this is not the primary function of these other supporting subsystems. Congestion management capabilities, such as the loop detection system and the camera surveillance system, support a number of other functions, in addition to ramp metering. It is important to note that, during the study, only the ramp metering components were deactivated. Other congestion management capabilities, such as traffic surveillance and incident detection, were fully operational during both the with and without periods.

Further complicating this issue is the fact that many of these systems share equipment with the ramp metering system. Therefore, some of this shared equipment would need to be installed even in the absence of the ramp metering system. An overview comparison of congestion management system costs in other metropolitan areas without ramp metering confirms that significant congestion management costs for traffic surveillance, detection, and management can be incurred without the deployment of a ramp metering system.

To address this issue, the evaluation team identified a number of supporting subsystems that are related to ramp metering, including the traffic detection subsystem, the camera surveillance subsystem, and the traffic management center. The capital cost of deploying each of these systems was estimated individually, and then summed to estimate the total cost of all congestion management systems. Proportions were then developed which represent the extent to which each subsystem supports the ramp metering system (i.e., the proportion of that subsystem's capabilities that are devoted to supporting the ramp metering system). These proportions are presented in Table 7.2.

Table 7.2 Congestion Management Subsystems Proportional Support of Ramp Metering

Congestion Management Subsystem	Percent of Functions that Support Ramp Metering
Ramp metering field components	100%
HOV ramp bypass*	100%
Traffic detection system	15%
Traffic management center	10%
Camera surveillance**	0%

* HOV ramp bypasses are generally considered a transit initiative, not a subsystem of the congestion management system. In order to consider the full cost of the ramp metering system, these costs have been included in the analysis.

** Although the camera surveillance subsystem is occasionally used to spot check ramp locations, virtually none of the functionality of the surveillance system is directly tied to the ramp metering system. An elimination of the ramp metering system would not be expected to result in any appreciable reduction in camera surveillance costs.

The proportions presented above were used to estimate the costs of the various supporting systems attributable to ramp metering system. The benefit/cost analysis was conducted using this proportional cost. To provide additional sensitivity analysis, the benefit/cost comparison was also performed using the total cost of all congestion management subsystems, regardless of their relationship with the ramp metering system. The results of these analyses are presented in the following sections.

7.2 Analysis Findings

7.2.1 Benefits of Ramp Metering

In general, the operation of the ramp meters produced significant amounts of traveler delay in the ramp wait queues. This delay was balanced against improved travel conditions on the freeway facilities themselves. Isolated instances of changes in parallel arterial performance characteristics were reported during the after data collection period; however, the data analysis showed these impacts to be statistically insignificant and lacking in clear direction (positive or negative) to allow the estimation of any meaningful arterial impacts.

From changes in systemwide performance characteristics, impacts were estimated for various performance measures, including travel time, travel time reliability, safety, emissions, and fuel use. The analysis of the ramp metering system resulted in positive benefits estimated for most categories. Overall, when all the impact categories are summed, the impacts of ramp metering are positive and reflect approximately $40 million in benefits per year. Each of the impact categories is discussed in further detail below.

Travel Time Impacts

Twin Cities travelers experienced a daily average of approximately 70.5 person hours of delay per metered ramp location. Improved travel speeds on the freeway facilities, however, resulted in lower freeway travel times that more than offset the ramp delays – resulting in a systemwide reduction of 25,100 person hours of travel time per year. The greater speeds and volume of the freeway facilities produced lower overall travel times for the metered corridors that more than offset the ramp delays. This travel time represents savings of over $247,000 annually.

Travel Time Reliability Impacts

Travel time reliability is a measure of the expected range in travel time and provides a quantitative measure of the predictability of travel time. Reliability of travel time is a significant benefit to travelers as individuals are better able to predict their travel times and, therefore, budget less time for the trip. While the travel time performance measure presented above quantifies changes in travel time on average or "normal" travel days, travel time reliability is a more appropriate quantification of the unexpected non-recurring delays that occur due to incidents, special events, bad weather, or excessive congestion. Being on time for day care, a meeting, a flight, or a delivery are typical examples of commuter expectations for reliable travel time.

The benefit of improved travel time reliability observed during ramp meter operation was significantly higher than when the meters were turned off. Travel time reliability is a measure of the standard deviation of expected travel time and provides a value to the predictability of travel time. A higher value is typically assigned to travel time reliability than to the measure of average travel time due to the great usefulness of predictable travel times. However, to maintain a conservative approach to the benefit/cost analysis, normal value of travel time was applied. The improved travel time reliability results in an annual benefit of over $25 million.

Safety Impacts

The safety analysis estimated a 26 percent reduction in the accident rate on metered corridors attributable to the ramp metering system. This reduction in the accident rate results in a decrease of approximately 1,040 vehicle accidents per year (approximately four accidents per day). While the majority of these accidents (700+) are anticipated to be minor accidents without personal injury, small decreases in injury and fatality accidents were also attributed to ramp meter operation. On an annual basis, the decrease in accidents results in a benefit of $18 million.

Emissions Impacts

The analysis of the emissions impacts of the ramp metering system produced both positive and negative benefits. Emissions of hydrocarbons and carbon monoxide were anticipated to decrease, while nitrous oxides emissions increased. The emission values were calculated based on a simplified approach based on average changes in speeds. The rates for nitrous oxides emissions increase in a direct relationship with speed (for the speed ranges observed during this study), thus, producing higher estimates for this emission. Overall, the sum of emissions benefits is positive, however, at approximately $4 million per year.

Fuel Use

The application of the speed increase on the freeway facilities resulted in a greater fuel usage being estimated for the "with meters" scenario. This fuel use increase equates to an annual disbenefit of nearly $8 million. Increased freeway speeds resulted in higher fuel use estimates during periods when the meters are in operation. Although not captured in the analysis, the fuel use increase may be tempered by the smoothing of travel speed variability observed during meter operation. The analysis rates used in this study assumed constant operating speeds. Increased acceleration and deceleration caused by increased freeway congestion levels observed in the "without meters" scenario would be expected to result in increased fuel consumption and a reduced disbenefit.

All Impact Categories

Table 7.3 presents the individual annual estimates of impacts for each of the performance measures accruing as a result of the ramp metering system. A summary of daily and annual benefits is presented as Appendix J.

Table 7.3 Annual Ramp Metering Benefits

Performance Measure	Change	Value
Travel time	25,121 hours saved	$247,443
Travel time reliability	2,583,694 hours saved	$25,449,390
Fatality accidents	5.6 accidents avoided	$6,628,063
Injury accidents		
Severe	29.9 accidents avoided	$1,711,617
Moderate	120.7 accidents avoided	$2,621,074
Minor	183.3 accidents avoided	$2,469,895
Property damage only accidents	702 accidents avoided	$4,766,992
Hydrocarbons	104 tons saved	$186,247
Carbon monoxide	1,213 tons saved	$4,527,229
Nitrous oxide	157 tons added	($612,442)
Fuel use	5,494,829 gallons depleted	($7,967,502)
Total annual benefit		**$40,028,008**

7.2.2 Ramp Metering Costs

The annual costs associated with the ramp metering system were estimated by dividing the capital equipment costs associated with ramp metering by the useful life of the components. Figures representing the annual operating and maintenance costs were then added to estimate the total annual expenditure necessary to provide and operate the system.

One of the challenges in estimating the ramp metering costs relates to identifying those costs of the broader congestion management system that were related to the ramp metering subsystem. The current year equivalent of approximately $63 million has been spent over the past years to develop and deploy the entire congestion management system. When the capital costs are converted into equipment lifecycle costs, $5.8 million annually is spent to develop and deploy the congestion management system. An additional $2.1 million is required to operate and maintain the various systems on an annual basis.

The ramp metering system represents a portion of the larger congestion management system. The annual capital and O&M expenditures for the components of the congestion management system related to ramp metering are estimated to be $0.75 million and $1.1 million, respectively. This indicates that approximately one-third of the congestion management system costs are related to the ramp metering capabilities. In addition, a cost of approximately $730,000 is incurred each year to build and maintain the HOV bypass ramps. Table 7.4 details these cost figures.

Table 7.4 Annual Congestion Management and Ramp Metering System Costs

Cost Item	All Congestion Management Capabilities	Amount Related to Ramp Metering
Annual capital costs		
Congestion management/ramp metering	$5,035,950	$745,667
HOV ramp bypass	$730,000	$730,000
Subtotal	*$5,765,950*	*$1,475,677*
Annual operating and maintenance costs		
Operations costs	$893,836	$431,879
Maintenance costs	$967,489	$464,395
Research costs	$250,000*	$250,000
Subtotal	*$2,111,325*	*$1,146,274*
Total annual cost	**$7,877,275**	**$2,621,950**

*Represents only those research contracts related to ramp metering.

7.2.3 Comparison of Ramp Metering Benefits and Costs

The benefit/cost analysis provides a snapshot analysis of the current benefits and costs related to ramp metering. Benefits and costs for past years were not calculated and no attempt was made to forecast benefits for future years. This approach provides a valid view of the current operational performance and effectiveness of the ramp metering system.

The results from the comparison of ramp metering benefits and the costs of the entire congestion management system are presented in Table 7.5. The benefits of ramp metering outweigh the costs by a significant margin and result in a net benefit of approximately $32 million per year. The benefit/cost ratio indicates that benefits are approximately five times greater than the cost of the system.

The ramp metering benefits identified in Table 7.5 are shown to greatly outweigh the costs of the congestion management system. The analysis used the most conservative estimate of costs by taking into account the full cost of the Twin Cities congestion management system. Although the congestion management system contains many cost items that are not directly related to the ramp metering system, the estimated benefits still outweighed costs by a ratio of 5.1 to 1.

When the costs for congestion management components not related to ramp metering are removed from the analysis, the annual costs of ramp metering are reduced to $2.6 million. Thus, a comparison of ramp meter benefits with those costs directly attributable to the ramp metering system results in an increased benefit/cost ratio of over 15:1. This ratio is comparable with benefit/cost comparisons performed on ramp metering systems in other regions. Appendix J presents greater detail of the benefits and costs estimated in this analysis.

Table 7.5 Comparison of Annual Costs and Benefits

Measure	Value
Annual ramp metering benefits	$40,028,008
Annual ramp metering costs	$7,877,275
Annual net benefit (benefits–costs)	$32,150,734
Benefit/cost ratio	5.1:1