9.0 Summary of Findings, Conclusions, and Recommendations

This section presents a summary of analysis findings, conclusions, and recommendations.

9.1 Evaluation Conclusions

During the study, extensive data were collected and analyzed to determine the impact of the ramp metering system related to a number of selected evaluation objectives. For each evaluation objective, one or more "measures of effectiveness" were identified to test the impact of ramp metering. Table 9.1 presents evaluation objectives and the related significant findings related to each performance measure.

The following sections provide summaries of the evaluation findings and conclusions for each performance measure, including traffic volumes and throughput, travel times, reliability of travel time, safety, emissions, fuel consumption, and public perception. In the benefit/cost analysis, these impacts were translated into annual monetary benefits for the Twin Cities metropolitan region, and then were compared to annual costs.

The analysis of field data indicates that ramp metering is a cost-effective investment of public funds for the Twin Cities area. This analysis is based on a conservative analysis of both costs and benefits in the following ways:

- The baseline cost analysis includes the costs of the entire regional congestion management system, even though many of these costs are unrelated to ramp metering.
- The calculation of benefits is based on the following assumptions:
  - The value of time lost in unexpected delay (i.e., reliability of travel time) is valued the same as routine travel time, even though the literature suggests it could be valued three times higher;
  - The impact of delays on long trips originating beyond the test corridors is not captured; and
  - The impact of more erratic acceleration/deceleration on freeways resulting from slower speeds, more congestion, and less predictable traffic conditions is not captured in the analysis of fuel consumption and emissions.

Table 9.1 Summary of Evaluation Findings

Evaluation Objective	Measures of Effectiveness
Quantify ramp metering safety impacts for selected corridors and the entire system.	• Crashes increased by 26 percent on metered freeways and ramps in the peak period when meters were turned off. • Crashes increased above expected normal seasonal variations on arterial roadways during peak periods when meters were turned off. • Rear-end crashes increased by 15 percent and side-swipe accidents increased by 200 percent on metered freeways and ramps when the meters were turned off. • The ramp metering system results in the avoidance of approximately 1,041 vehicle crashes per year on the metered corridors.
Quantify ramp metering traffic flow and travel time impacts for selected corridors.	• Freeway travel times increased by an average of 22 percent when meters were turned off. Arterial travel times were not observed to change significantly between the "with meters" and "without meters" scenarios. • Freeway travel speeds decreased by an average of 14 percent when meters were turned off. Arterial travel speeds were not observed to change significantly between the "with meters" and "without meters" scenarios. • Freeway traffic volumes decreased by an average of nine percent when meters were turned off. • The reliability of travel time decreased by 91 percent when the meters were turned off, making freeway travel time significantly less predictable. • Delay time in the ramp wait queues decreased by an average of 2.31 minutes per vehicle and the reliability of ramp travel time improved by 1.85 minutes when the ramp meters were turned off. • Considering both the change in freeway travel time and the change in ramp queue delay time, the operation of the ramp metering system results in a net travel time savings and a net increase the reliability of travel time.

Table 9.1 Summary of Evaluation Findings (continued)

Evaluation Objective	Measures of Effectiveness
Identify ramp metering impacts on local streets.	• Arterial traffic volumes generally remained unchanged on the specific corridors observed during the study. Some traffic volume increases were reported when the meters were turned off for various arterial locations not studied in this evaluation. • Ramp queues were minimized and ramp queue spillbacks into adjacent intersections were eliminated in all but a few ramps when the ramp meters were turned off.
Extrapolate ramp metering traffic flow and travel time impacts for the entire system.	• The ramp metering systems results in an annual saving of over 25,000 hours of travel time. • The ramp metering system increases system-wide travel time reliability resulting in a reduction of approximately 2.5 million hours of unexpected traveler delay.
Estimate ramp metering impacts on energy consumption and the environment.	• The ramp metering systems results in a net benefit in terms of decreased emissions. • The ramp metering system results in a net disbenefit in terms of increased fuel use.
Compare the system-wide ramp metering benefits with the associated impacts and costs.	• The ramp metering system results in an annual benefit of over $40 million. • The deployment and operation of the entire congestion management system results in an annual cost of $7.8 million. The annual cost of the ramp metering system alone is approximately $2.6 million. • The benefits of the ramp metering system exceeded the system's related costs by a ratio of over 15:1. • The benefits of the ramp metering system exceed the costs of the *entire* congestion management system by a ratio of over 5:1.
Identify ramp metering impacts on transit operations and park-and-ride usage.	• No statistically significant changes in transit travel times or patronage levels were observed during the duration of the "without meters" scenario. • No statistically significant impacts were observed in the usage of park-and-ride lots.

Table 9.1 Summary of Evaluation Findings (continued)

Evaluation Objective	Measures of Effectiveness
Document additional ramp metering benefits/impacts observed during the study.	• Significant peak period congestion was reported during the "without meters" period on non-metered freeways just outside of the I-494/I-694 beltway. This additional congestion was not included in the estimation of ramp metering benefits.
Assess the public's attitude toward ramp metering.	• A majority of travelers perceived that freeway travel is much safer when ramp meters are in operation. • More respondents in the "without meters" survey tended to believe that traffic conditions overall had become worse with the meters off. • Respondents in the "without meters" survey had an increased appreciation of the role of ramp meters, but also were more inclined to believe that there was too much metering in free flow conditions; that ramp meter wait times were too long; and that there were too many meters in general. • Overall, approximately 80 percent of respondents favored ramp metering in some capacity, although the number favoring modification of the system increased after the without meters period. There was no significant change in the number of travelers wanting the ramp meters permanently deactivated observed between the "with meters" and "without meters" study periods.
Identify benefits/impacts of ramp metering systems documented in other national and international studies.	• The benefits of ramp metering estimated in the evaluation of the Twin Cities' system are generally consistent with observed benefits from studies in other areas. • The overall benefit/cost ratio calculated in this study is within the range of benefit/cost ratios from ramp metering studies conducted in other regions.

A summary of the annual benefits of ramp metering is provided as follows:

- **Traffic Volumes and Throughput:** After the meters were turned off, there was an average nine percent traffic volume reduction on freeways and no significant traffic volume change on parallel arterials included in the study. Also, during peak traffic conditions, freeway mainline throughput declined by an average of 14 percent in the "without meters" condition.

- **Travel Time:** Without meters, the decline in travel speeds on freeway facilities more than offsets the elimination of ramp delays. This results in annual systemwide savings of 25,121 hours of travel time with meters.

- **Travel Time Reliability:** Without ramp metering, freeway travel time is almost twice as unpredictable as with ramp metering. The ramp metering system produces an annual reduction of 2.6 million hours of unexpected delay.

- **Safety:** In the absence of metering and after accounting for seasonal variations, peak-period crashes on previously metered freeways and ramps increased by 26 percent. Ramp metering results in annual savings of 1,041 crashes or approximately four crashes per day.

- **Emissions:** Ramp metering results in a net annual savings of 1,160 tons of emissions.

- **Fuel Consumption:** Ramp metering results in an annual increase of 5.5 million gallons of fuel consumed. This was the only criteria category which was worsened by ramp metering.

- **Benefit/Cost Analysis:** Ramp metering results in annual savings of approximately $40 million to the Twin Cities traveling public. The benefits of ramp metering outweigh the costs by a significant margin and result in a net benefit of $32 to $37 million per year. The benefit/cost ratio indicates that benefits are approximately five times greater than the cost of entire congestion management system and over 15 times greater than the cost of the ramp metering system alone.

9.1.1 Traffic Volumes and Throughput

After the meters were turned off, the evaluation team observed an average nine percent traffic volume reduction on freeways. No significant traffic volume change was observed on the parallel arterials which were studied by the evaluation team. There was some diversion to other time periods and no significant diversion to transit. The reduced freeway traffic volume most likely was diverted to earlier or later time periods and to local streets not under observation by the evaluation team. Figure 9.1 shows an example of freeway traffic volume reduction along with evidence of travel starting earlier in the peak period after the meters were turned off. Figure 9.2 shows another example of freeway traffic volume reduction along with small changes in parallel arterial traffic volumes.

During peak traffic conditions, freeway mainline throughput (measured by vehicle miles traveled) declined by an average of 14 percent in the meters-off condition. This decline was partially due to degradation in the freeway mainline speed in the absence of ramp metering (i.e., with higher speeds, more vehicles are able to travel in the same freeway segment during a given amount of time). The throughput decline is also due to the absence of ramp metering, which makes for smoother traffic flow on the freeway mainline with less speed variability and better merging of ramp traffic – thus improving the practical capacity of the mainline.

Figure 9.1 I-94 Eastbound Afternoon – Example of Freeway Traffic Volume Reduction and Earlier Departures

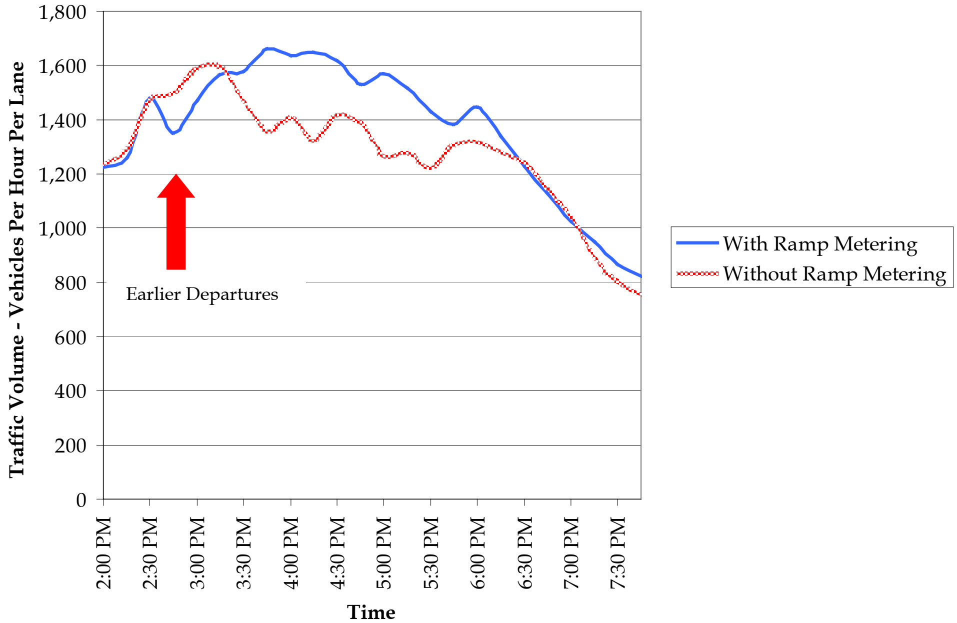
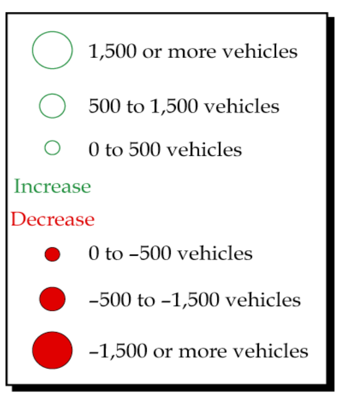
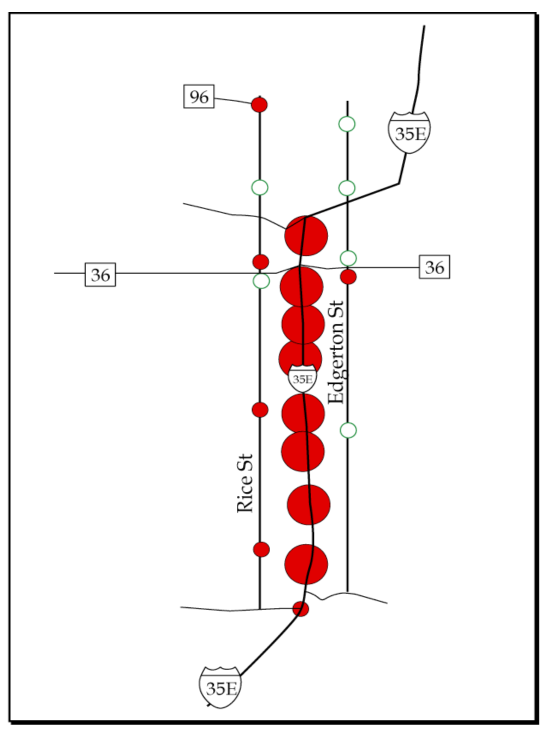


Figure 9.2 I-35E Southbound Morning – Example of Traffic Volume Reduction



Average Volumes	I-35E	Rice	Edgerton
With Ramp Metering	14,552	1,652	1,395
Without Ramp Metering	12,140	1,538	1,742



9.1.2 Travel Time

With meters on, the evaluation team observed a 2.3 minute average per vehicle wait at metered on-ramps during the peak period. On average, in the absence of metering, freeway speeds decreased by approximately seven miles per hour in the peak period and by 18 miles per hour during the peak hour. This corresponds to an increase of freeway travel time of 22 percent (2.5 minutes per vehicle) during the peak period on the tested corridor segments (which averaged about nine miles in length and about 12 minutes of travel time). In the without meters condition, the wait at on-ramps was essentially eliminated. However, the decline in freeway speed more than outweighed the gain in travel time realized by the elimination of ramp queues. It should also be noted that the increase in overall regional travel time was actually longer than indicated by this analysis, because:

- Not all travelers encountered meters and hence experienced a reduction in travel time due to their absence. Based on the market research data, only 54 percent of peak period travelers in the test corridors routinely encounter an operational (red/green) ramp meter during their commute. The other 46 percent experience flashing yellow meters, no meters (because their trips originate outside of the meter system), or use the HOV bypass lanes.

- Many travelers have trips longer than the nine-mile corridor test segments and would thus have experienced a longer absolute increase in travel time than the 2.5 minutes indicated by the test travel time runs. Again based on the market research data, the average freeway trip length in the test corridors ranged from 20 to 24 minutes, or more than twice as long as the test corridor trips. Therefore, the average commuter would experience an increase in travel time of at least five minutes.

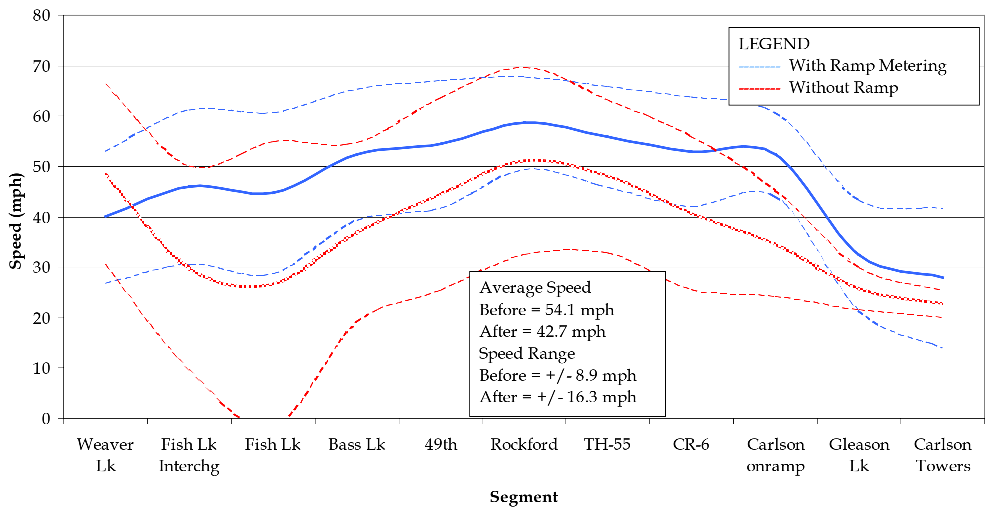
In addition to the increase in travel times observed on the test corridors during the "without meters" period, significant increases in congestion were reported on some non-metered freeways outside of the corridors observed by the evaluation team. This finding is consistent with the travel survey data in which travelers reported that traffic conditions worsened furthest from the urban core. Also, isolated reports were received regarding changes in arterial travel times and speeds (both positive and negative); however, no statistically significant impacts were observed for the arterials included in the data collection effort. These reported impacts on non-metered freeways and arterials were not included in the accounting of benefits presented in this report.

Figure 9.3 shows an example of reduced freeway travel speeds and increased speed variability in the absence of metering. The solid lines represent the average travel speed; the dashed lines represent the typical range of observed travel speeds.

9.1.3 Travel Time Reliability

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

Figure 9.3 I-494 Southbound Morning Speed – Example of Reduced Freeway Speed and Increased Speed Variability

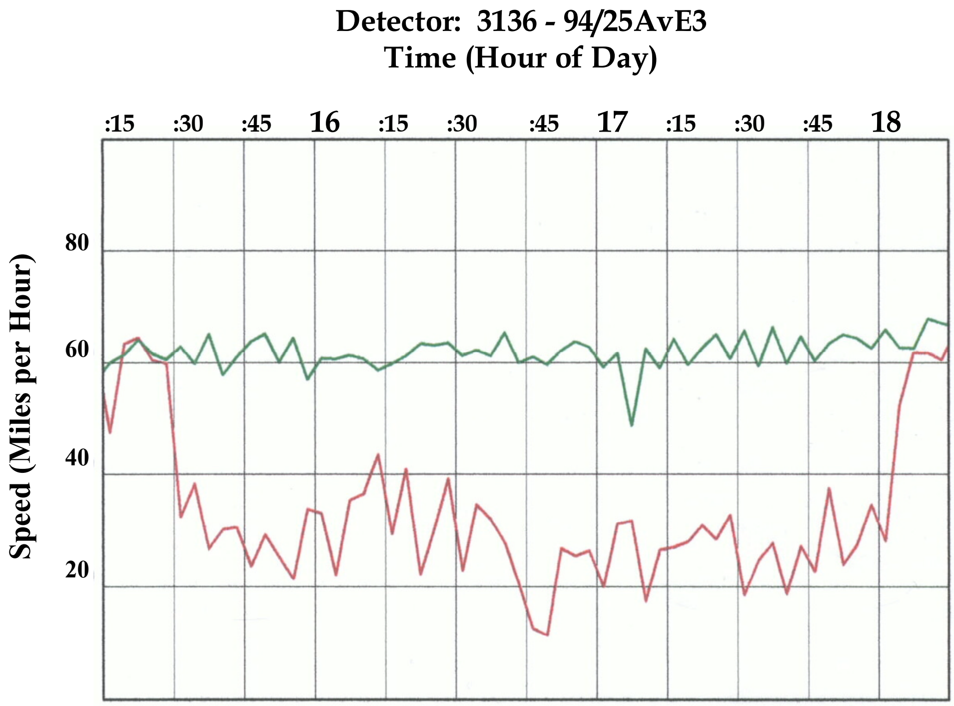


significant benefit to travelers as individuals are better able to predict their travel times and, therefore, budget less time for the trip. While the travel time performance measure presented above quantifies changes in travel time on average or "normal" travel days, travel time reliability is a more 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.

On average, the reliability of freeway travel time was found to be degraded by 91 percent (1.9 minutes for a nine-mile freeway segment) without ramp metering. The largest declines in freeway travel time reliability were observed on I-494 southbound a.m. (180 percent), on I-94 westbound p.m. (154 percent), and on I-94 eastbound p.m. (153 percent). This finding is supported by the increased number of crashes, the reported increase in the duration of incidents, and by state trooper reports that it took longer to get to the accident scene. Figure 9.4 demonstrates the overall decreased average speed and the increased variability of freeway travel speed in the absence of ramp meters.

On the other hand, meters off resulted in an average improvement in on-ramp travel time reliability of approximately 1.85 minutes per vehicle. On balance, the degradation in freeway travel time reliability in the absence of ramp metering outweighed the gains in travel time reliability at on-ramps. Again, it is important to note that not all travelers encounter ramp meters and hence experienced the improvement in reliability at the ramps, and that the decline in reliability (as measured by minutes of unexpected delay) was greater for longer trips.

Figure 9.4 Example of Increased Speed Variability (I-94 Corridor Location)

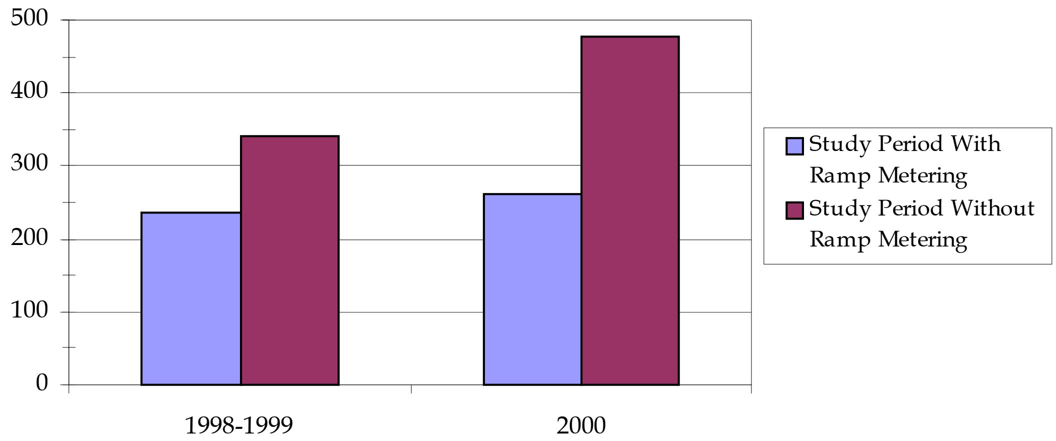


Condition	Date	Field	Sample	Volume
Meters off	Mon, Oct 16, 2000	25′	100%	25,181
Meters on	Mon, Oct 9, 2000	25′	100%	25,294

9.1.4 Safety

In the absence of metering and after accounting for seasonal variations, peak-period crashes on metered freeways and ramps increased by 26 percent. With meters on, there were 261 crashes on metered freeways; with meters off, there were 476 crashes on the same freeways and during the same amount of time (an increase of 82 percent). Based on historical seasonal variations (there were more crashes in the October/November meters-off period than in the September/October meters-on period due to the shortening daylight and onset of bad weather), the crashes in the "without" period would be expected to increase by only 116 crashes to 377 total crashes. The analysis shows that, in the absence of ramp metering, the number of crashes increased by 26.2 percent above the increase normally expected due to seasonal variation. Figure 9.5 depicts the increase in crashes in the absence of metering.

Figure 9.5 Crash Occurrence in the "With Meters" and "Without Meters" Study Periods (for Metered Freeways in the Morning and Afternoon Peak Periods)



The expected annual increase in crashes caused by the absence of metering amounts to a total of 1,041 additional crashes per year, or approximately four additional crashes per day. The analysis of crashes by type revealed that "rear-end" crashes increased by 15 percent, "side-swipes" increased by 200 percent, and "ran-off road" crashes increased by 60 percent. These types of accidents could be related to the change in merge conditions resulting from the absence of metering, which functions to break up platoons of vehicles entering a freeway.

9.1.5 Annual Benefits of Ramp Metering

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 geometric characteristics shared with the selected corridors. This process allowed for extrapolation of field evaluation results to the entire Twin Cities metered transportation system.

The observed changes in facility speed, vehicle travel time, travel time variability, and number of accidents were then summed across all metered corridors, along all directions, and all periods of operation (a.m. and p.m. peak period). Additionally, changes in emissions and fuel use were calculated based on the overall observed changes in facility speeds. Established per unit dollar values based on national and Twin Cities data were then applied to the sum of the changes. The dollar values for each impact category were then summed to estimate the average annual impact value for the entire ramp metering system. This annual benefit figure forms the basis for comparison with the ramp metering system costs.

The benefit analysis found that ***ramp metering results in annual savings of approximately $40 million to the Twin Cities traveling public.*** The annual benefits of ramp metering are summarized in Table 9.2.

Table 9.2 Annual Benefits of the Ramp Metering System (Year 2000 Dollars)

Performance Measure	Annual Benefit	Annual $ Savings
Travel time	25,121 hours of travel time saved	$247,000
Travel time reliability	2,583,620 hours of unexpected delay avoided	$25,449,000
Crashes	1,041 crashes avoided	$18,198,000
Emissions	1,161 tons of pollutants saved	$4,101,000
Fuel consumption	5.5 million gallons of fuel depleted	($7,967,000)
Total annual benefit		**$40,028,000**

The annual benefits of ramp metering are broken down by performance measure as follows:

- ***Travel Time: With meters off, degraded travel speeds on freeway facilities more than offset the lack of ramp delays. This results in annual system-wide savings of 25,121 hours of travel time or $0.25 million.***
- ***Travel Time Reliability: Without ramp metering, freeway travel time is almost twice as unpredictable as with ramp metering.*** This produces annual savings of 2.6 million hours of unexpected delay or $25 million. This is a conservative estimate because unexpected delays were valued at the same level as recurrent delays; typically, unexpected delays are valued at a rate three times higher than recurrent congestion. This finding is collaborated by the amount of incident delay caused by the increased number of freeway crashes.
- ***Safety: Ramp metering results in annual savings of 1,041 crashes (four crashes per day) or $18 million.***
- ***Emissions: Ramp metering results in annual savings of 1,160 tons of emissions or $4 million.*** This is a conservative estimate because the analysis did not take into account potential additional savings resulting from reduced vehicle acceleration and deceleration during stop-and-go traffic in the "with meters" condition compared to the "without meters" condition.
- ***Fuel Consumption: Ramp metering results in an annual increase of 5.5 million gallons of fuel consumed or an annual loss of $8 million.*** This also is a conservative estimate because the analysis did not take into account the smoothing of travel speed variability

observed during meter operation. Increased acceleration and deceleration observed in the without meters scenario would be expected to result in increased fuel consumption and a reduced disbenefit. The analysis as is shows a disbenefit for metering, because the reduction in freeway speed in the meters-off condition actually results in a fuel savings.

9.1.6 Annual Costs of Ramp Metering

The annual capital 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 equipment required for deployment and operation of ramp meters. Annual operating and maintenance (O&M) costs were then added to estimate the total annual expenditure necessary to provide and operate the system. Operational costs include personnel, electricity, and communications, while maintenance costs include field personnel, replacement equipment, etc. This method provides a snapshot of costs for the current year suitable for comparison with the estimation of benefits for the same year.

The cost analysis found that ***the total annual cost of the entire congestion management system is approximately $8 million.*** The cost of the ramp metering system alone is approximately $2.6 million annually. Table 9.3 provides detail on the system costs.

Table 9.3 Annual Congestion Management and Ramp Metering System Costs (Year 2000 Dollars)

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 activities related to ramp metering.

The estimation of the precise cost of the ramp metering system deployed in the Twin Cities is complex, because many of the system components were deployed as part of an integrated congestion management system. Congestion management capabilities, such as the loop detection system and the camera surveillance system, support a number of other functions such as incident detection and traveler information. Further complicating this issue is the fact that many of these systems share equipment with the ramp metering system. Although some of this shared equipment would need to be installed even in the absence of the ramp metering system, the evaluation team took a conservative approach by comparing the total cost of the congestion management system plus the costs for HOV bypass lanes with the benefits of only ramp metering.

9.1.7 Comparison of Ramp Metering Benefits and Costs

The benefit/cost analysis provides a "snapshot" of the current benefits and costs related to ramp metering. ***The benefits identified in this study are shown to greatly outweigh the costs of the ramp metering system.*** The analysis used the most conservative estimate of costs by taking into account the full cost of the Twin Cities congestion management system, even though many of these costs are not directly related to ramp metering.

The results from the comparison of ramp metering benefits and the costs of the congestion management system are presented in Table 9.4. ***The benefits of ramp metering outweigh the costs by a significant margin and result in a net benefit of approximately $32 to $37 million per year. The benefit/cost ratio indicates that benefits are approximately five times greater than the cost of the 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 five to one.

This result is validated favorably when compared to ramp meter benefits estimated at other metropolitan areas. Actually, the five-to-one benefit/cost ratio is low when compared to other ramp meter evaluation studies. This is because conservative assumptions were employed in the estimation of both benefits and costs in the Twin Cities. These assumptions notwithstanding, ***ramp metering in the Twin Cities is found to be a good investment of public funds.***

Table 9.4 Comparison of Annual Costs and Benefits

Measure	Value
Annual ramp metering benefits	$40,028,000
Annual costs for *entire* congestion management system	$7,877,000
Annual net benefit	$32,151,000
Benefit/cost ratio	**5:1**

When the benefits of the ramp metering system are compared with only those costs directly related to providing ramp metering capabilities, the benefit/cost ratio increases significantly to 15:1. This benefit/cost ratio is more consistent with those estimated for other ramp metering systems.

9.1.8 Results from the Traveler Surveys and Focus Groups

In parallel to the field data collection and analysis, the evaluation team conducted traveler surveys and focus groups to elicit travelers' overall perception of the operation of ramp meters in the Twin Cities' roadway system, and the impact of shutting down the ramp meters on travelers' general travel patterns.

Four focus group sessions were held among individuals who traveled on one or more of the four test corridors. In order to qualify for participation, individuals had to travel the test routes during the a.m. and p.m. peak periods, when ramp meters were in operation. Separate focus groups were conducted based on the frequency of travel, including "light" and "heavy" ramp and corridor users.

The surveys included both a random sample of area travelers, as well as four corridor-specific samples that focused on the area's freeway corridors for which traffic and travel time data were also collected. These surveys were fielded twice, both before and during the ramp meter shutdown. A total of 1,500 telephone surveys were conducted for purposes of this analysis. The total sample size was equally split between the two waves of "with meters" and "without meters" field data collection.

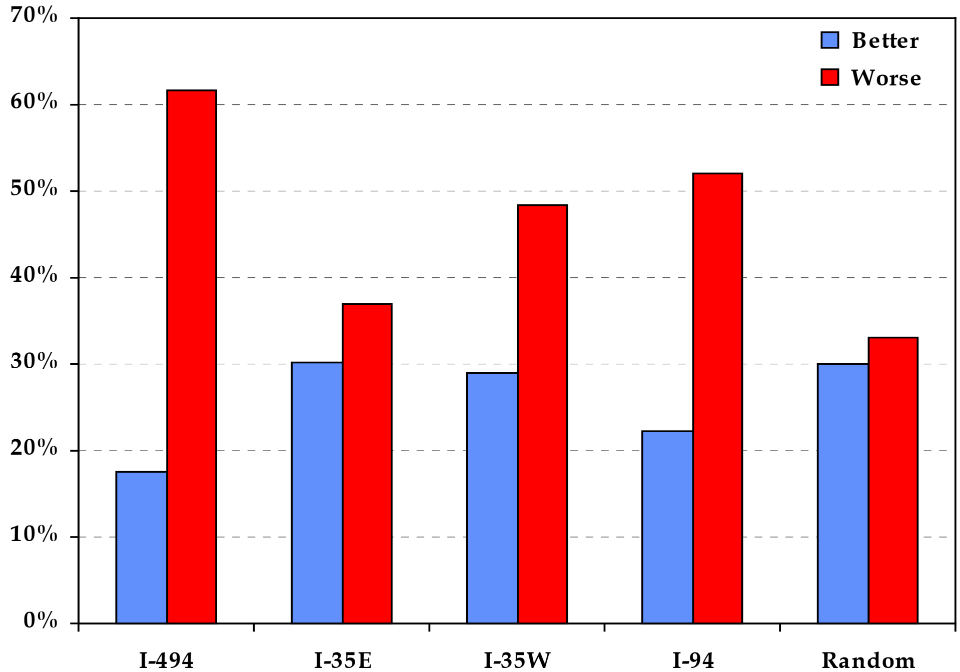
The results from the analysis of the traveler surveys and focus groups are summarized as follows:

- Respondents reported experiencing average wait times at ramps in the "with meters" survey of four to nine minutes depending on the corridor, but mainly between five to six minutes. This is consistent with the observed field data for the peak hour only, and is about twice as long as for the peak period. It is typical of travelers to perceive wait times as being about double what they are in reality.

- Respondents in the "without meters" survey tended to believe that traffic conditions overall had become worse with the meters off. Travelers in the I-494 corridor believed that their trips had become longer while travelers in the I-35W corridor believed that their trips had become shorter. These findings are generally consistent with the traffic data, which indicate that travel conditions had on the whole deteriorated, but that some trips in some corridors did become shorter. Figure 9.6 summarizes traveler perceptions of changes in traffic conditions after the ramp meter shutdown.

- Respondents in the "without meters" survey had an increased appreciation of the role of ramp meters, but also were more inclined to believe that there was too much metering in free flow conditions; that ramp meter wait times were too long; and that there were too many meters in general.

Figure 9.6 Reported Changes in Traffic Conditions After the Shutdown

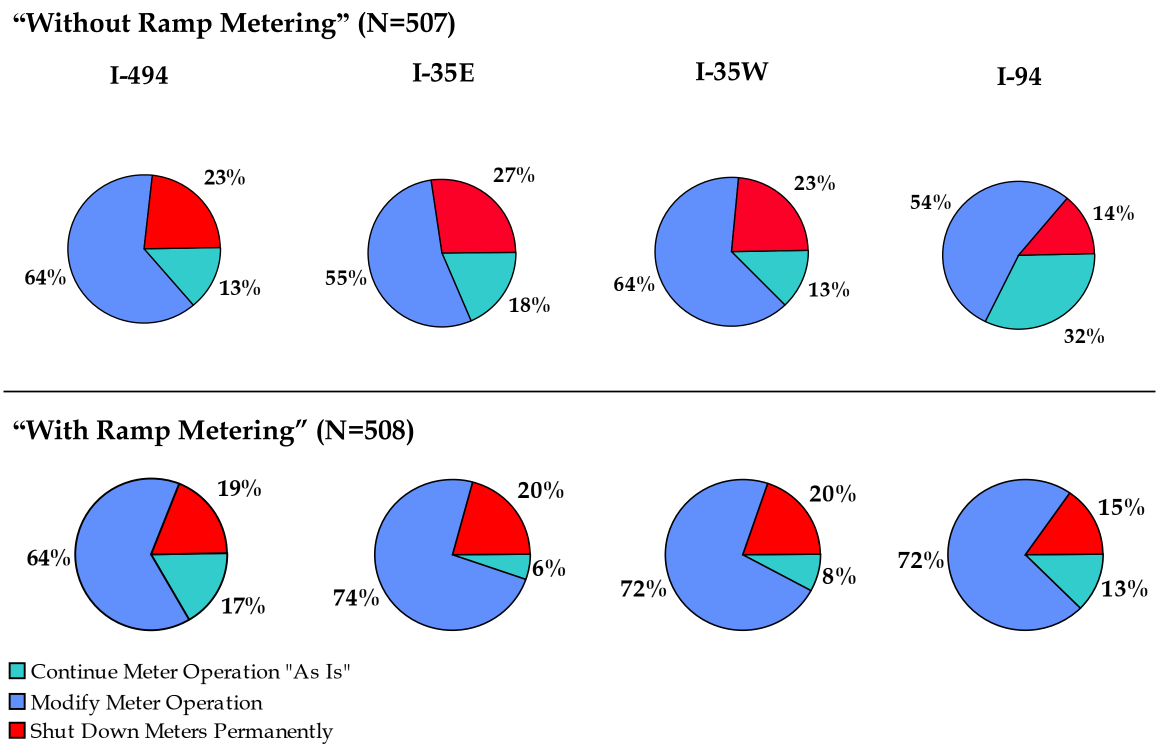


- Findings varied considerably with trip length, consistent with the traffic data. Respondents with origins furthest from the urban core, and with the longest trips, were most likely to believe that traffic conditions got worse during the shutdown. These travelers also had a greater appreciation for the role of metering and were least supportive of a continued shutdown. This was particularly true in the I-494 corridor which saw the most significant shift in support of ramp metering.

- Support for modification of the Twin Cities metering system increased among corridor users from the "with meters" to the "without meters" sample, from about 60 percent to 70 percent. Support for continued shutdown remained the same at about 20 percent. Support for returning to the pre-shutdown condition declined from about 20 percent to 10 percent. Figure 9.7 summarizes the travelers' view of the future of ramp metering in the Twin Cities.

- The most commonly supported modifications were to shorten the wait times; to increase green time when freeway flow at the ramp was light; to shorten hours of meter operation; and, to reduce the number of meters and limit them to areas of high traffic congestion.

Figure 9.7 Travelers' View of the Future of Ramp Metering



9.2 Secondary Research

The benefits and disadvantages of ramp metering described in this report are similar to those experienced elsewhere in the country.

- This study's finding of 22 percent savings in freeway travel time is well within the seven percent to 91 percent range observed in other areas (average of 25 percent travel time savings for 13 observations). The 22 percent travel time savings is also within the range of prior studies conducted on ramp metering within the Twin Cities (14 to 26 percent).

- Systemwide crashes for the Twin Cities increased by 26 percent without ramp metering. The average across eight other ramp meter evaluation studies reviewed by the evaluation team is 32 percent reduction in crashes. The range of values for reductions in crashes due to ramp metering is from five percent to 50 percent. In areas with more than 50 meters, the average crash reduction is 29 percent.

- This evaluation shows that there is a 14 percent increase in freeway throughput due to ramp metering. The average for the 12 other studies reviewed by the evaluation team is 18 percent, with a range from zero percent to 86 percent. Long Island, Phoenix, Portland, and Seattle (cities with more than 50 meters) show an average of 38 percent increase in freeway throughput.

- Other evaluation studies have limited impact information related to emissions impacts of ramp metering. Three other metropolitan areas (Denver, Detroit, Long Island), which evaluated emissions as part of their ramp meter study, showed some improvement in overall emissions due to ramp metering. Long Island showed a 6.7 percent increase in NOx, and the improvements in CO and HC of 17.4 and 13.1 percent, respectively.

- Four areas which evaluated fuel consumption impacts of ramp metering showed savings due to ramp metering ranging from about six percent to 13 percent. However, as mentioned in Section 7.0 of this report, the fuel consumption analysis used in this evaluation used a simple straight-line estimation technique which does not address the tempering of flow typically due to ramp metering, by smoothing the travel speed variability (less acceleration and deceleration).

- There is limited information on benefit/cost ratios of ramp metering evaluations. This study's benefit/cost ratio of 5:1 for the entire congestion management system and 15:1 for the ramp metering costs only are within the ranges seen for other areas. For five areas (Abilene, Atlanta, Phoenix, Seattle, and previous Minneapolis/St. Paul evaluation efforts), the range of benefit/cost ratios is from 4:1 to 62:1, with an average of 20:1.

■ 9.3 Recommendations

The analysis of field data indicates that ramp metering is a cost-effective investment of public funds for the Twin Cities area. This finding notwithstanding, the Twin Cities users of the highway system support the need for modifications toward an efficient but more publicly acceptable operation of ramp meters. The combination of these two factors points towards the adoption of an overriding principle regarding the operation of ramp meters in the Twin Cities: This principle would seek to ***"balance the efficiency of moving as much traffic during the rush hours as possible, consistent with safety concerns and public consensus regarding queue length at meters."***

In light of this "new balance" and pending the development of a general policy for optimizing ramp meter operation, several steps were taken soon after the evaluation data collection was completed, including reducing the operating timeframe of ramp meters, allowing meters to change more quickly from red to green, and keeping several meters at flashing yellow. Until a policy for optimizing ramp meter operation is developed, it is recommended that Mn/DOT continues to monitor ramp wait times, freeway travel time and its reliability, crashes, and conduct market research to identify changing traveler perceptions.

A critical recommendation for the medium-term is to ***develop a policy for optimizing ramp meter operation that is based on the lessons learned from the evaluation.*** It is recommended that in coordination with key stakeholders, Mn/DOT define a new set of objectives, constraints and criteria for ramp meter application and operation. This policy would be based on a thorough investigation of efficiency, safety, equity, and other criteria for the evaluation of ramp metering strategies. Criteria may involve variables such as safety, ramp wait times and ramp storage capacities, target freeway peak-period speeds, maximum metering rates, and commute differences between different origins and destinations in the Twin Cities metropolitan area.

An additional recommendation points toward the ***establishment of a systematic process for developing long-range recommendations for ramp meter operation and modifications.*** This process will emerge by identifying, evaluating and recommending methods for developing and testing long-range ramp metering strategies. This process would also include the creation of a forum for public input into the continued evolution of the ramp metering system, and the development of a plan for continued evaluation of ramp metering strategies after their implementation. ***It is also recommended that Mn/DOT responds to the public's need for information on traffic management strategies.***

Finally, it should be recognized that ramp metering is but a single traffic management strategy which cannot by itself solve the problems of growing congestion in the region brought about by rapid economic growth in the 1990s and the lack of major investments in new transportation system capacity. The future of ramp metering strategies in the region should be discussed in this larger context.