Twin Cities Ramp Meter Evaluation

final report

prepared for

Minnesota Department of Transportation
Pursuant to Laws 2000: Chapter 479, HF2891

prepared by

Cambridge Systematics, Inc.

with

SRF Consulting Group, Inc.
N.K. Friedrichs Consulting, Inc.

February 1, 2001

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February 1, 2001

Minnesota Department of Transportation

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395 John Ireland Boulevard
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Pursuant to the Laws 2000, Chapter 479, HF2891, I am pleased to submit the final report of the Ramp Meter Shutdown Study.

This report details the results of a study on the traffic flow and safety impacts of ramp metering, and it meets the legally mandated deadline of February 1, 2001. It is the result of a study that was conducted in an independent and objective manner by a nationally recognized consultant team at a cost of $651,600. The study served two important public purposes:

1) It thoroughly documented the benefits resulting from ramp metering to traffic operations and related factors such as air quality in the Twin Cities metro region. Analysis of field data indicates that ramp metering is a cost-effective investment of public funds for the Twin Cities area,

2) It demonstrated the need for Mn/DOT to adjust its approach to ramp metering in a way that will optimize benefits while conforming to public expectations. Analysis of market research data shows that a clear majority of users of the Twin Cities metro region highways support continued operation of ramp meters as a congestion management tool in some modified form.

The combination of these two factors point 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 ramp meters."

Mn/DOT remains committed to continued evaluation and experimentation with the ramp metering system, in close consultation with concerned stakeholders and the public. We also remain committed to strategically addressing issues of growth, congestion, capacity expansion and transportation choice in the metro region. Ramp meters alone are neither the only problem nor the only solution to these major issues.

It has been my pleasure to work with the Legislature, Advisory and Technical Committees, the consulting team, and managers and staff throughout Mn/DOT on this important and timely study. I am satisfied that it meets the goal of the legislation, which was to evaluate and report any relevant facts, comparisons, or statistics concerning traffic flow and safety impacts associated with deactivating system ramp meters for a predetermined amount of time.

Sincerely,

Elwyn Tinklenberg
Commissioner

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Executive Summary

The Minnesota Department of Transportation (Mn/DOT) uses ramp meters to manage freeway access on approximately 210 miles of freeways in the Twin Cities metropolitan area. Mn/DOT first tested ramp meters in 1969 as a method to optimize freeway safety and efficiency in the metro area. Since then, approximately 430 ramp meters have been installed and used to help merge traffic onto freeways and to manage the flow of traffic through bottlenecks.

While ramp meters have a long history of use by Mn/DOT as a traffic management strategy, some members of the public have recently questioned the effectiveness of the strategy. A bill passed in the Year 2000 session by the Minnesota Legislature required Mn/DOT to study the effectiveness of ramp meters in the Twin Cities Region by conducting a shutdown study before the next legislative session [Laws 2000: Chapter 479, HF2891].

In response to the Legislative mandate, Mn/DOT formed two committees to represent the public and ensure the credibility and objectivity of the study, including the Advisory and Technical Committees. The two committees provided policy oversight and input into the consultant selection process, the proposed study work plan, measures of effectiveness, and evaluation measures. The committees also provided technical guidance, expertise, and quality control throughout the conduct of the study.

The study occurred in the fall of 2000, with the results presented to the Legislature and the public in early 2001. The goal of the study was to evaluate and report any relevant facts, comparisons, or statistics concerning traffic flow and safety impacts associated with deactivating system ramp meters for a predetermined amount of time. This study was completed at a cost of $651,600.

The study was conducted by a team of consultants led by Cambridge Systematics, Inc. (CS). Joining Cambridge Systematics on the evaluation team were SRF Consulting Group, N.K. Friedrichs Consulting, and a panel of nationally-recognized experts in the field of ramp metering and transportation evaluations. The panel members included Dolf May from the University of California, Tim Lomax from the Texas Transportation Institute, and Howard Preston from Howard R. Green Company.

This document presents the Executive Summary developed for the study by the CS team with significant input from the Technical and Advisory Committees. This summary presents the evaluation conclusions, supporting evaluation findings, and recommendations. Two separate documents (the Final Report and the Appendix to the Final Report) present additional detail on the evaluation objectives and performance measures, evaluation methodologies, field evaluation results, traveler perceptions, benefit/cost analysis, and secondary research.

■ Evaluation Methodology

The goals of the evaluation of ramp meter effectiveness in the Twin Cities included:

- The determination of whether the benefits of ramp metering outweigh the impacts and associated costs;
- The identification of other ramp metering impacts on surface streets and transit operations;
- The assessment of public attitudes toward ramp metering; and
- A comparison of the Twin Cities' system against ramp meter systems in other regions.

For each of the broad evaluation goals, several detailed objectives and performance measures were identified for the evaluation, including:

- Travel time;
- Reliability of travel time;
- Traffic volume and throughput;
- Crashes; and
- Transit operations.

Appropriate data were collected relating to each of these measures to provide the opportunity for assessment against the evaluation objectives and goals. The measures of effectiveness were focused on the incremental change observed between the two evaluation scenarios – "with" (meters on) and "without" (meters off). The evaluation measures were also designed to be "neutral" and not pre-suppose any outcome of the ramp meter test.

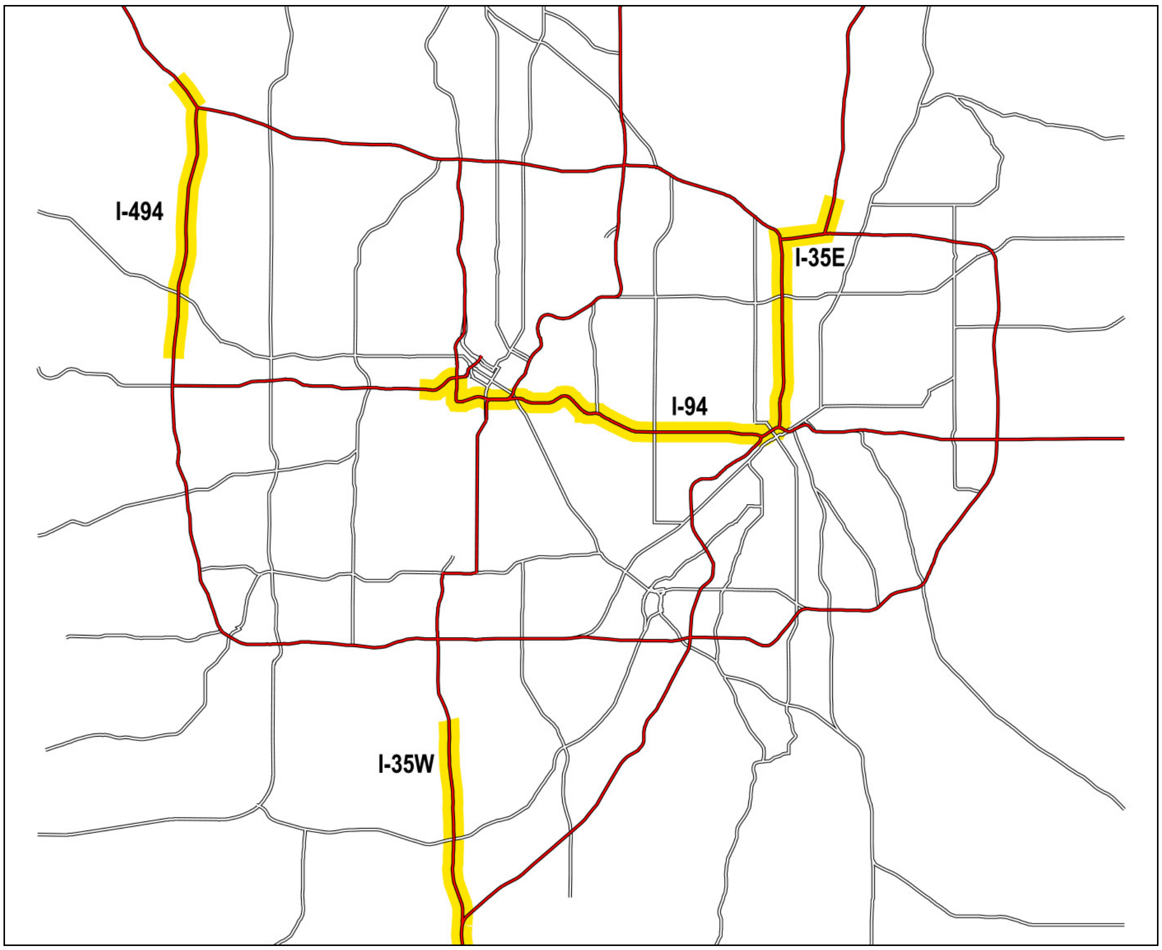
Data related to the measures of effectiveness were collected during two periods in the fall of year 2000. Data collected during the first period were used to assess the baseline or "with ramp meters" scenario. In this scenario, the ramp meters were operated according to established Mn/DOT practices. These data were used to establish a baseline for the purpose of identifying the incremental change occurring in the "without ramp meters" scenario.

Data collected during a second period were used to evaluate the "without ramp meters" scenario. In this scenario, all ramp meters were deactivated system-wide. The deactivated ramp meters were set to "flashing yellow" mode – consistent with their normal operation during off-peak periods. It is important to note that although the ramp metering system was effectively shut down, all other congestion management system capabilities were fully operational during the "without meters" period, including traffic surveillance and detection, incident management, and traveler information (variable message signs).

Although all ramp meters throughout the system were deactivated during the test, the data collection effort was focused on four selected corridors, which included sections of

I-494, I-94, I-35W, and I-35E. These corridors were selected as representative of other corridors throughout the metropolitan region. In addition to the freeway corridors themselves, several parallel arterials were also identified to provide data on surface street conditions during the "with" and "without" scenarios. The four corridors selected for the study are shown in Figure ES.1. Other system-wide data were collected during this period to allow for the normalization of data collected in the selected corridors.

Figure ES.1 Twin Cities Corridors Selected for Detailed Evaluation



In parallel with the field traffic data collection, a series of market research studies were conducted. This effort included both focus groups and surveys conducted during both the "with" and "without" scenarios.

Data collection occurred over a five-week period during both the "with" and "without" scenarios. "With ramp meter" data collection occurred between September 11th (following the Labor Day holiday and the return of normal fall business and school activity) and October 15th, 2000. The ramp meters were deactivated from October 16th through December 8th, thereby enabling data collection to conclude prior to the onset of the

Holiday shopping season. Traffic data were not collected during the first week following deactivation to allow traffic patterns to adjust to the change.

Following the conclusion of the "without" scenario test, data analysis was conducted to isolate the incremental impact observed between the two scenarios. These incremental impacts were then extrapolated and combined with other data to support the region-wide analysis of ramp meter effectiveness.

To support the evaluation, several data collection and analysis efforts were conducted. Each effort focused on a specific aspect of the study. Yet, all the data collection and analysis efforts were carefully coordinated. The data collection and analysis activities included:

- **Corridor Selection –** The evaluation team defined corridor selection criteria and selected corridors for data collection;
- **Field Data Collection for Selected Corridors –** The evaluation team collected field data at selected corridors;
- **Market Research –** The evaluation team conducted focus groups and survey data collection;
- **Benefit/Cost Analysis –** The evaluation team extrapolated impacts observed on the selected corridors to develop estimates of region-wide impacts; and
- **Secondary Research –** The evaluation team conducted research to compare and contrast the ramp metering system in the Twin Cities with systems in other locations.

Evaluation Conclusions

This section provides a summary 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 benefit calculation 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.

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.

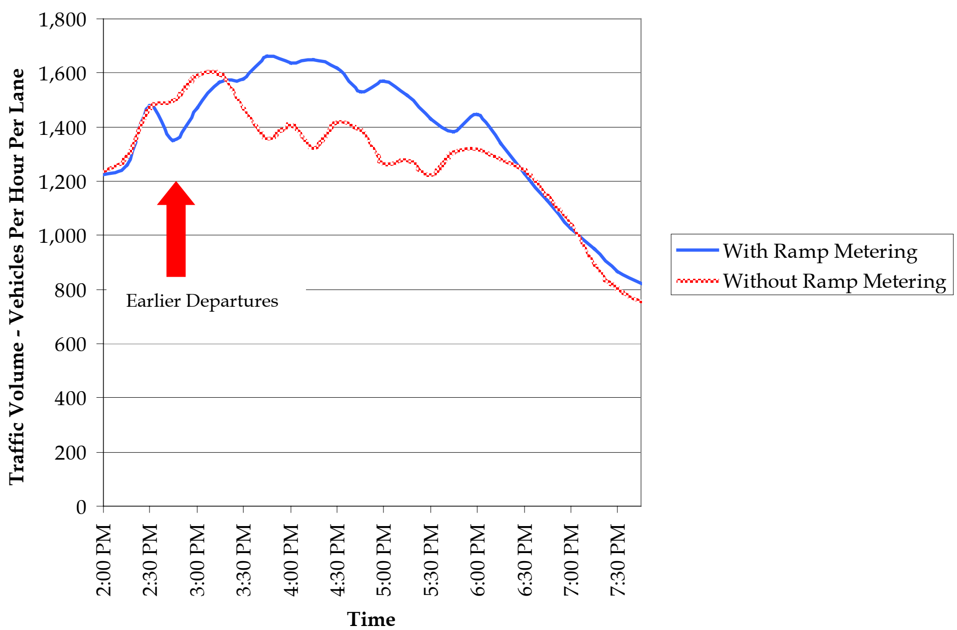
- **Benefit/Cost Analysis:** Ramp metering results in annual savings of approximately $40 million to the Twin Cities traveling public. The benefits of ramp metering outweigh the costs by a significant margin and result in a net benefit of $32 to $37 million per year. The benefit/cost ratio indicates 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.

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 ES.2 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 ES.3 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.

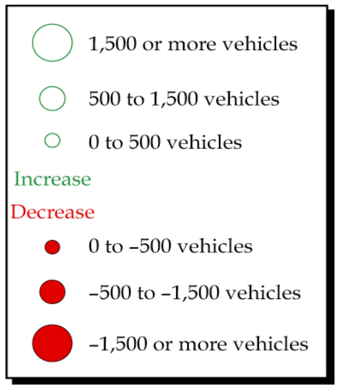
Figure ES.2 I-94 Eastbound Afternoon – Example of Freeway Traffic Volume Reduction and Earlier Departures



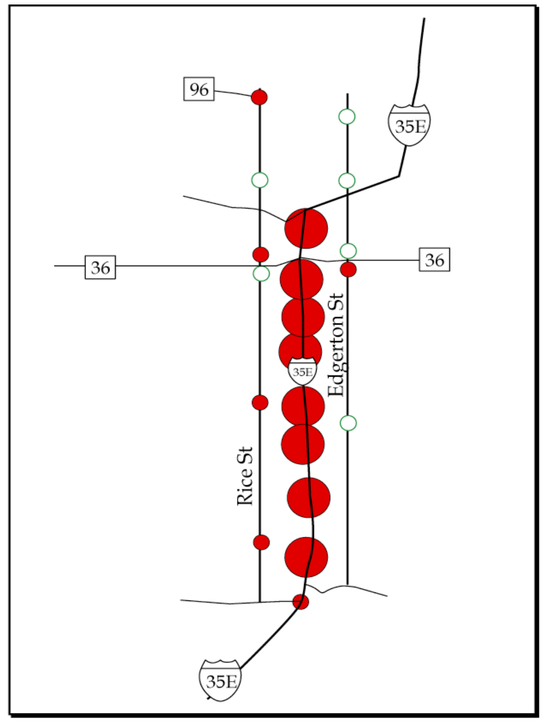
Travel Time

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

Figure ES.3 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



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:

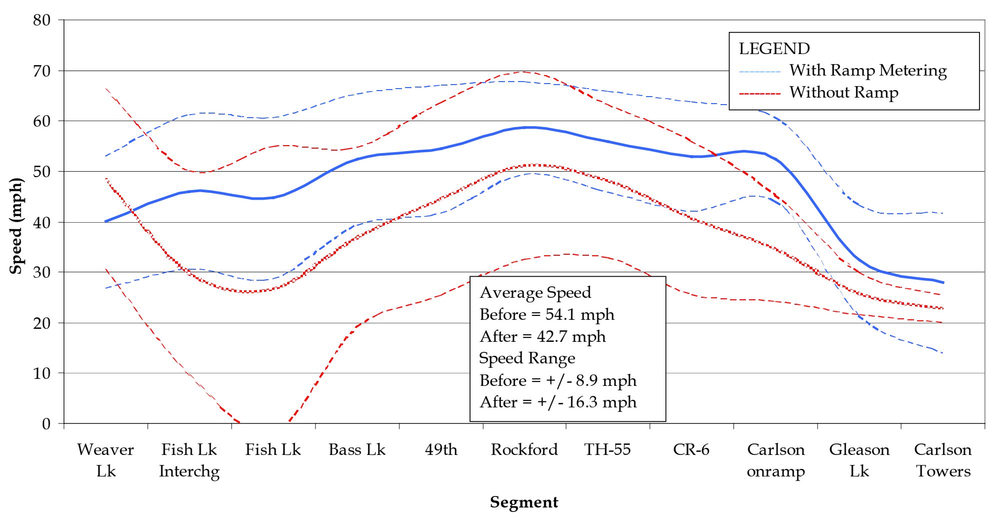
- Not all travelers encountered meters and hence experienced a reduction in travel time due to their absence. Based on the market research data, only 54 percent of peak period travelers in the test corridors routinely encounter an operational (red/green) ramp meter during their commute. The other 46 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 ES.4 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.

Figure ES.4 I-494 Southbound Morning Speed – Example of Reduced Freeway Speed and Increased Speed Variability

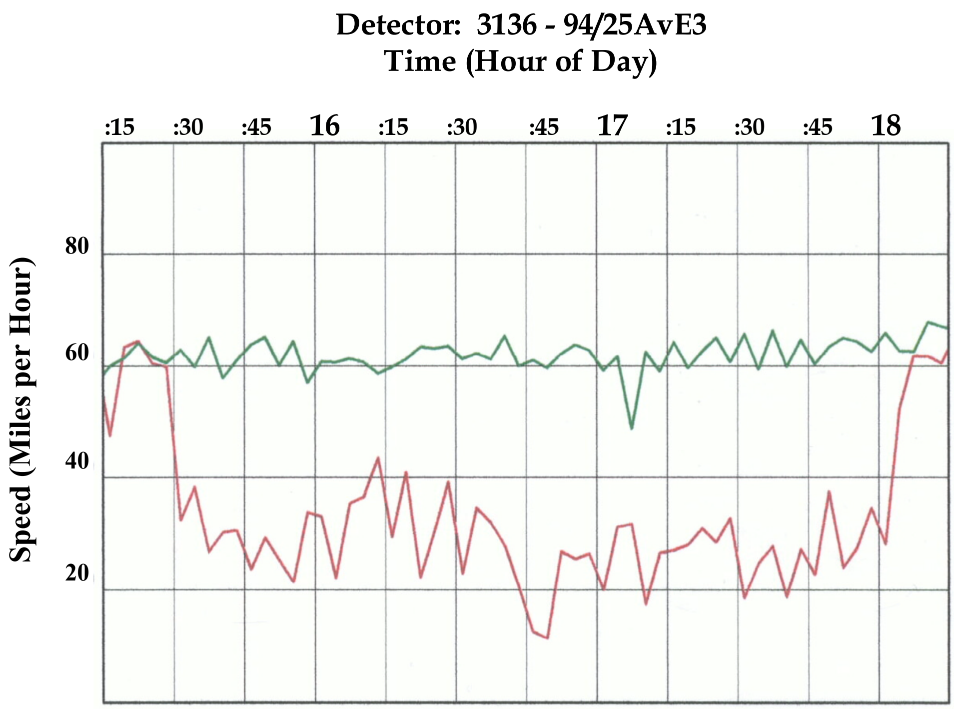


Travel Time Reliability

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 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 ES.5 demonstrates the overall decreased average speed and the increased variability of freeway travel speed in the absence of ramp meters.

Figure ES.5 Example of Increased Speed Variability (I-94 Corridor Location)



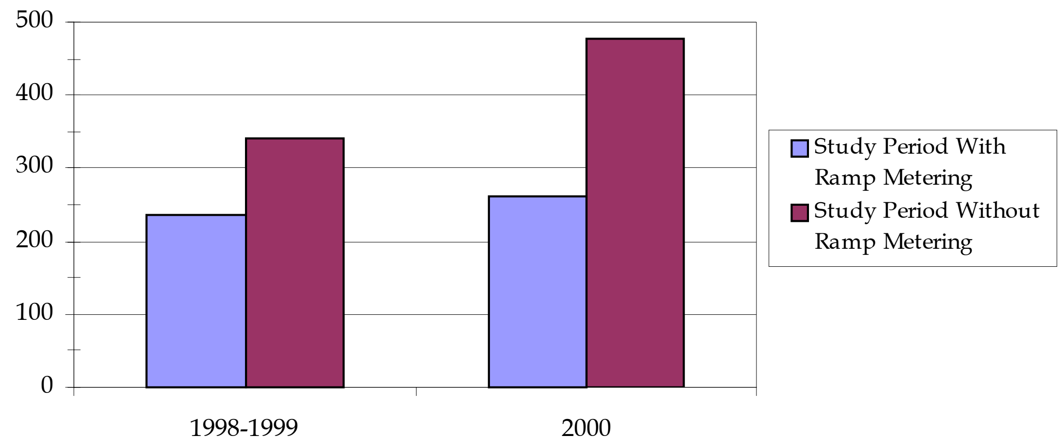
Condition	Date	Field	Sample	Volume
Meters off	Mon, Oct 16, 2000	25′	100%	25,181
Meters on	Mon, Oct 9, 2000	25′	100%	25,294

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.

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 ES.6 depicts the increase in crashes in the absence of metering.

Figure ES.6 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.

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 ES.1.

Table ES.1 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.

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 ES.2 provides detail on the system costs.

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.

Table ES.2 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.

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 ES.3. ***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 ES.3 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.

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.

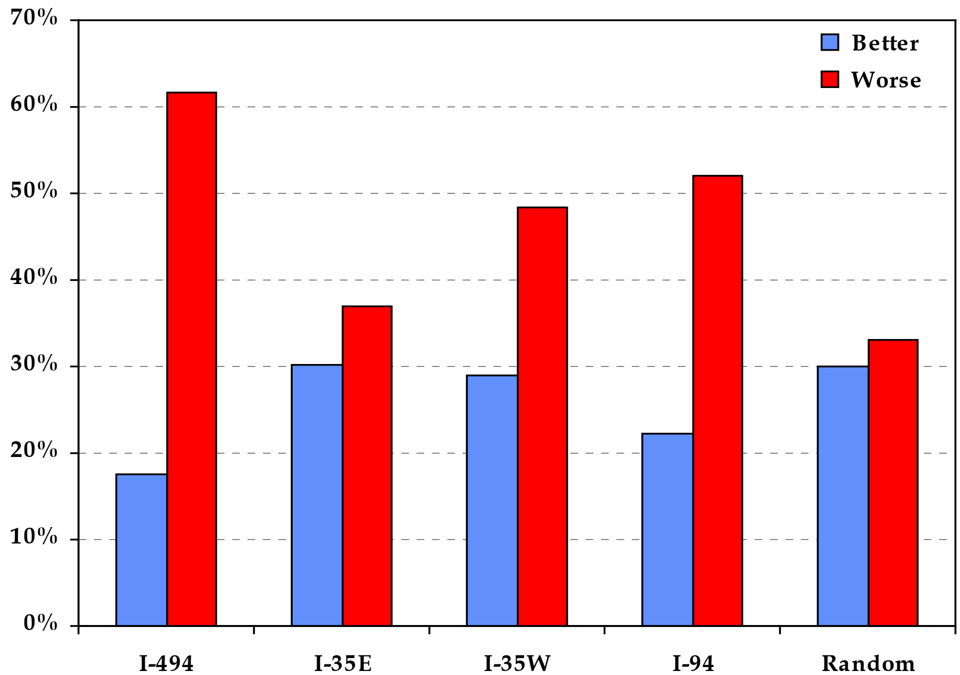
The surveys included both a random sample of area travelers, as well as four corridor-specific samples that focused on the area's freeway corridors for which traffic and travel time data were also collected. These surveys were fielded twice, both before and during the ramp meter shutdown. A total of 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 ES.7 summarizes traveler perceptions of changes in traffic conditions after the ramp meter shutdown.

Figure ES.7 Reported Changes in Traffic Conditions After the 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.

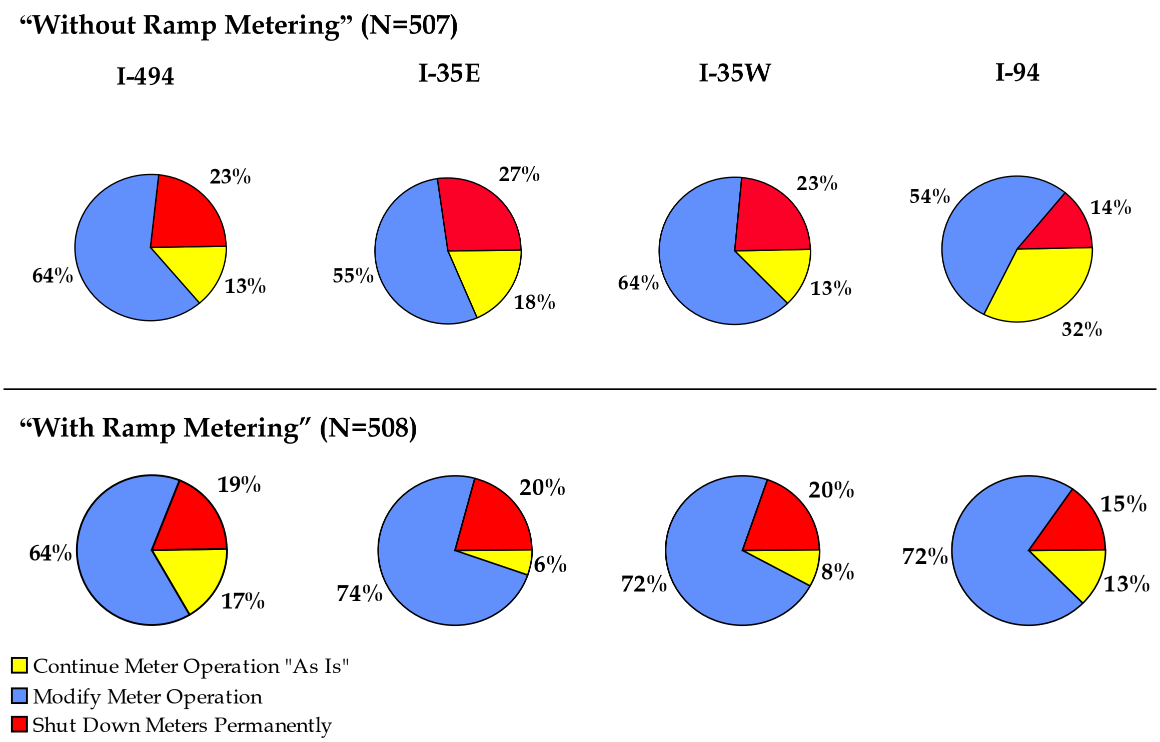
- Findings varied considerably with trip length, consistent with the traffic data. Respondents with origins furthest from the urban core, and with the longest trips, were most likely to believe that traffic conditions got worse during the shutdown. These travelers also had a greater appreciation for 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 ES.8 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 ES.8 Travelers' View of the Future of Ramp Metering



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 current 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.

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.

1.0 Project Background

The Minnesota Department of Transportation (Mn/DOT) uses ramp meters to manage freeway access on approximately 210 miles of freeways in the Twin Cities metropolitan area. Mn/DOT first tested ramp meters in 1969 as a method to optimize freeway safety and efficiency in the metro area. Since then, approximately 430 ramp meters have been installed and used to help merge traffic onto freeways and to help manage the flow of traffic through bottlenecks.

While ramp meters have a long history of use by Mn/DOT as a traffic management strategy, some members of the public have recently questioned the effectiveness of the strategy. A bill passed in the Year 2000 session by the Minnesota Legislature requires Mn/DOT to study the effectiveness of ramp meters in the Twin Cities Region by conducting a shutdown study before the next legislative session [Laws 2000: Chapter 479, HF2891].

The study occurred in the fall of 2000, with the results presented to the Legislature and the public in early 2001. The goal of the study is to evaluate and report any relevant facts, comparisons, or statistics concerning traffic flow and safety impacts associated with deactivating system ramp meters for a predetermined amount of time. This study was conducted as a cost of $651,600.

In response to the Legislative mandate, Mn/DOT formed two committees to represent the public and ensure the credibility/objectivity of the study, including:

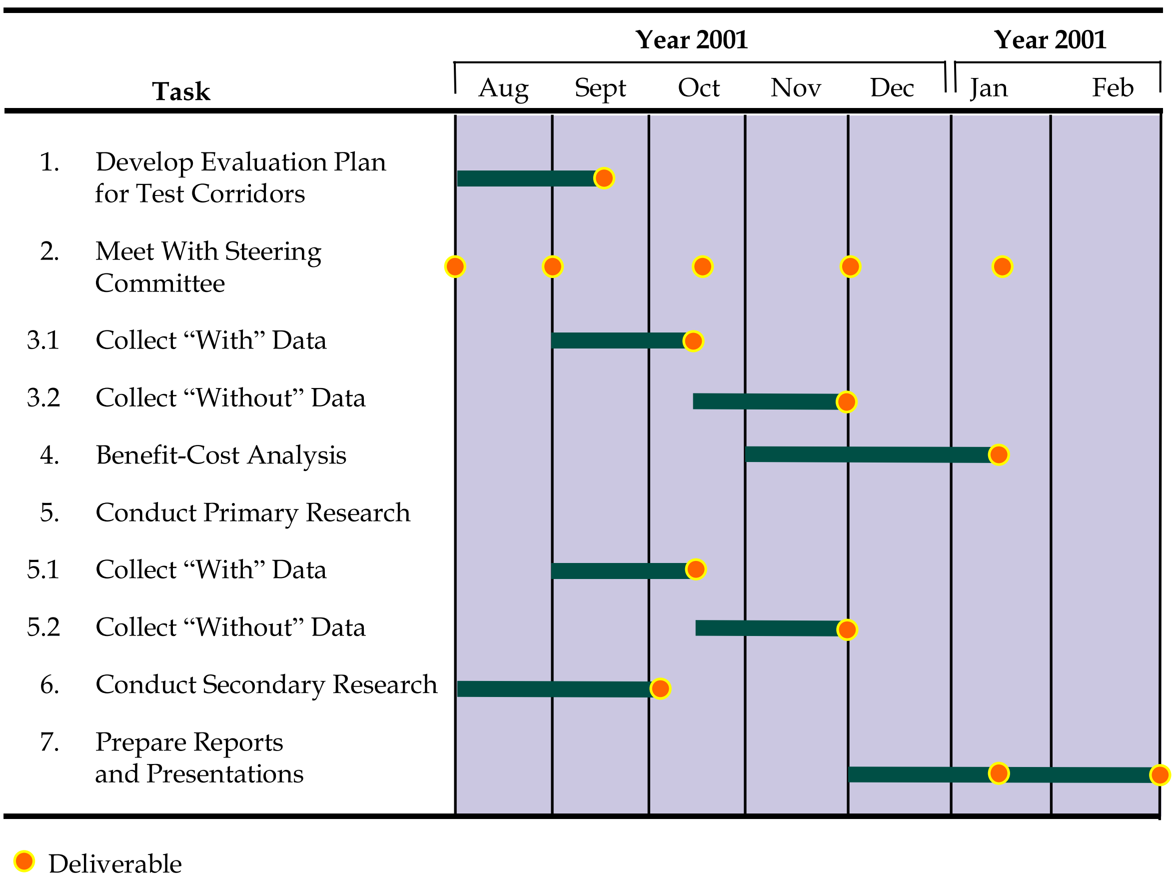
- **Advisory Committee –** Provided policy oversight and input into the consultant selection process, the proposed study work plan, measures of effectiveness, and evaluation measures.

- **Technical Committee –** Provided technical guidance, expertise, and quality control. Also provided technical input to the consultant selection process, proposed study work plan, measures of effectiveness, and evaluation measures.

On June 19, 2000, Mn/DOT issued a Request for Proposals (RFP) to study and report on the traffic flow and safety results of deactivating ramp meters in the Twin Cities Region. Members of both the Advisory Committee and the Technical Committee served on a selection committee to design and approve consultant selection criteria, and evaluate proposals from consultants received in response to the RFP. A consultant team led by Cambridge Systematics, Inc. (CS) was selected to conduct the ramp meter evaluation. Joining Cambridge Systematics on the evaluation team were SRF Consulting Group, N.K. Friedrichs Consulting, and a panel of nationally-recognized experts in the field of ramp metering and transportation evaluations.

The project schedule and key task deliverables are shown in Figure 1.1. The evaluation team developed the Evaluation Plan (Task 1) during the months of August and September 2000. The secondary research (Task 6) also began immediately. During September and the first half of October 2000 the evaluation team prepared for and conducted the "with ramp metering" data collection, including both traffic field data (Task 3) and survey data (Task 5). After the meter shutdown, data collection was prepared for and conducted in the second half of October and November 2000 (Tasks 3 and 5). Preparations for the cost/benefit analysis (Task 4) began in November 2000 and were completed by January 2001. The draft report and legislative presentation (Task 7) were completed by mid-January 2001, in time for Mn/DOT and committee review and comment, such that the documents were ready for delivery to the legislature by February 1, 2001.

Figure 1.1 Project Schedule



The CS team met with the committees at eight critical milestones in the project, as follows. The objective of these meetings was to ensure that a broad cross-section of stakeholders with both technical and non-technical levels of expertise participated in and guided the study to ensure that the results have credibility throughout the community.

- Kickoff meeting;
- Evaluation strategy: Recommendation for the study period, corridor selection, corridor criteria, and metering shut down;
- Completion of evaluation plan;
- Completion of "with ramp metering" data collection;
- Completion of "without ramp metering" data collection;
- Completion of "top-down" overview of draft study report;
- Completion of cost/benefit analysis and draft report; and
- Completion of the secondary research.

The CS team also participated in media briefings and supplied the following materials for the meetings and presentations. Electronic and hardcopy versions of all materials were provided to the Mn/DOT project manager.

- Presentation materials;
- Hard copy handouts to all attendees; and
- Drafts of technical memoranda in advance of the meetings.

This document represents the Final Report developed for the study by the CS team with significant input from the Technical and Advisory Committees. The organization of this Final Report is as follows:

- **Evaluation team** and organizational hierarchy (Section 2.0).
- **Evaluation objectives and performance measures** (Section 3.0).
- **Evaluation methodologies** (Section 4.0) presents a summary of methodologies and technical approaches for corridor selection, field data collection, focus groups and traveler surveys, benefit-cost analysis (including the corridor extrapolation process), and secondary research.
- **Field evaluation results** (Section 5.0) presents a summary of findings in terms of travel time, reliability of travel time, traffic volume and throughput, crashes, and transit operations.
- **Primary market research** (Section 6.0) presents a summary of findings from focus groups and surveys conducted as part of the evaluation.
- **Benefit-cost analysis** (Section 7.0).
- **Secondary research** (Section 8.0).

- **Conclusions and recommendations** (Section 9.0).
- The **Executive Summary** is a separate document that presents a summary of the evaluation conclusions, supporting evaluation findings, and recommendations. The **Appendix to the Final Report** is a separate volume which includes more detailed summaries of evaluation data and data analysis methodologies.

2.0 Evaluation Team

The evaluation team assembled for this study is knowledgeable and experienced in the evaluation of traffic management strategies, such as ramp metering. The evaluation team was carefully selected and structured to provide an independent, credible, and objective study.

Two committees were formed to represent the public in the implementation of the study. The **Advisory Committee** was comprised of legislators, legislative staff, local government representatives, researchers, industry representatives, and stakeholder representatives. The Advisory Committee provided policy oversight, input, and guidance to the study. The Advisory Committee was chaired by David Jennings, President of the Greater Minneapolis Chamber of Commerce. Other organizations represented on the Advisory Committee include:

- Association of Minnesota Counties;
- Department of Public Safety – Minnesota State Patrol;
- Hennepin County Community Health Department;
- Southwest Metro Transit Commission;
- State Legislators (4);
- Federal Highway Administration;
- Murphy Warehouse Company;
- American Automobile Association (AAA);
- Metropolitan Council;
- Minnesota Department of Transportation (Mn/DOT);
- Citizens League;
- Metro Transit; and
- City of Eagan.

The Advisory Committee was assisted in the day-to-day technical oversight and project quality control by a qualified **Technical Committee**. The Technical Committee was chaired by James Grube, Director of the Hennepin County Transportation Department. Other organizations represented on the Technical Committee include:

- Pollution Control Agency;
- Dakota County Highway Department;
- City of Ramsey;

- City of St. Paul;
- Mn/DOT – Metro Division;
- Mn/DOT – Office of Investment Management;
- Metropolitan Council;
- City of Minneapolis;
- Metro Transit;
- Ramsey County Department of Public Works; and
- Federal Highway Administration.

The relation of the Advisory and Technical Committee to the overall evaluation team is shown in Figure 2.1.

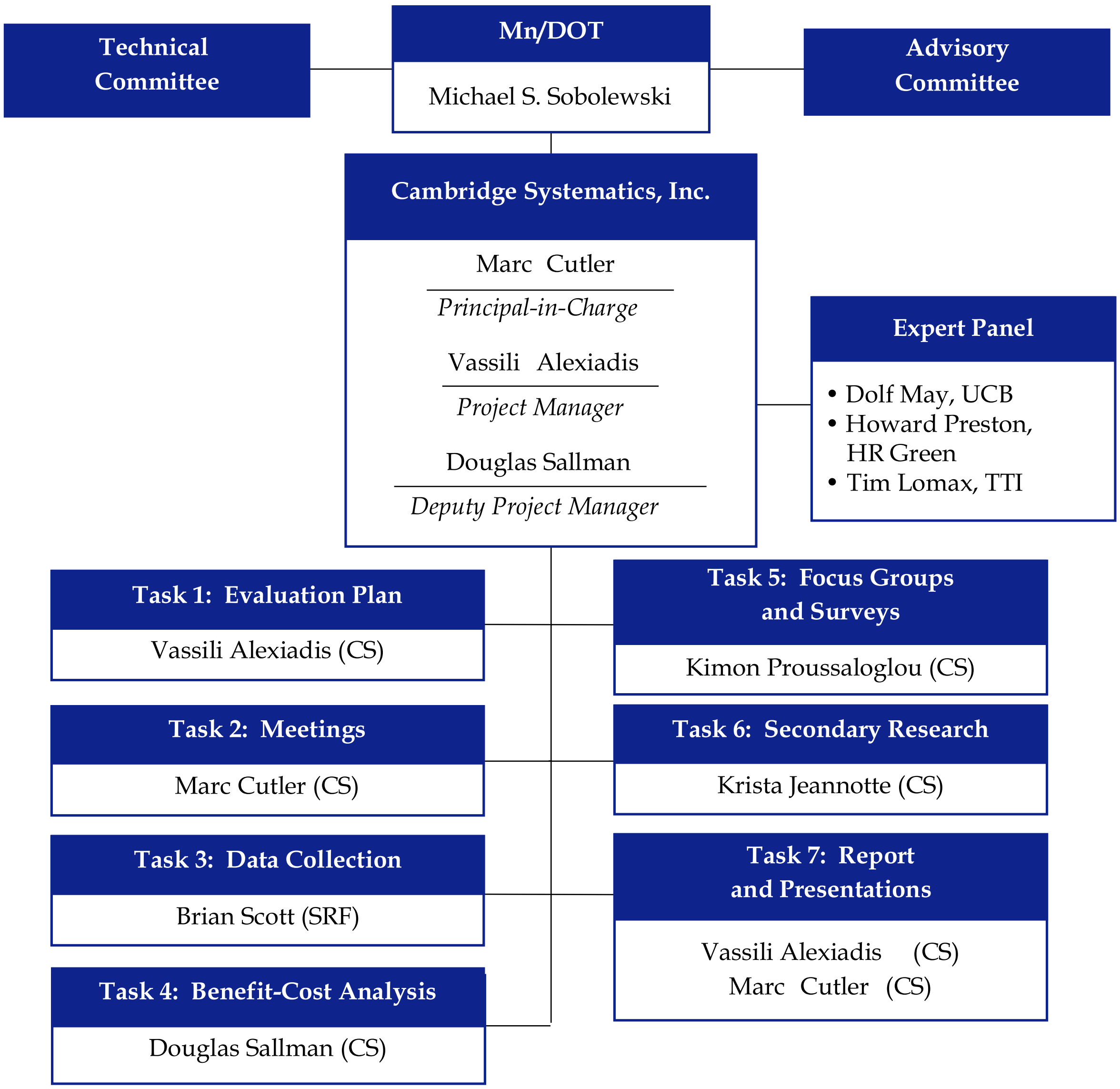
Michael Sobolewski was the Mn/DOT Project Manager selected to provide day-to-day management of the project and provide coordination between the Advisory and Technical Committees and the consultant team.

The consultant team conducting the study was led by Cambridge Systematics, which was responsible for overall project management, as well as the conduct of several specific work tasks (including the development of the evaluation plan, the design and implementation of focus groups and survey market research, the conduct of the benefit/cost analysis, and research of secondary data sources). SRF Consulting assisted Cambridge Systematics in the traffic data collection design and implementation tasks. N.K. Friedrichs Consulting assisted with the market research tasks.

Marc Cutler and **Vassili Alexiadis** of Cambridge Systematics served as the evaluation team's Principal-in-Charge and Project Manager, respectively. They were assisted by **Douglas Sallman** of Cambridge Systematics as Deputy Project Manager and individual Task Managers. These Task Managers provided focused expertise on individual aspects of the workscope. This management approach was developed to adequately support the diverse tasks required of the study, while meeting the rigid time schedule presented by the legislative mandate.

The consultant team was also assisted by an expert panel consisting of individuals selected by the consultant team and by the Advisory and Technical Committees. These nationally-recognized experts provided technical input to the study approach and critical review of deliverables, and helped ensure a credible and objective evaluation. The expert panel comprised of Dolf May from the University of California at Berkeley, Tim Lomax from the Texas Transportation Institute, and Howard Preston from Howard R. Green Company.

Figure 2.1 Evaluation Team



3.0 Evaluation Objectives and Performance Measures

The goals and objectives of conducting the evaluation of ramp meter effectiveness in the Twin Cities Metropolitan Region were designed to meet the mandate of the legislature's bill. Three evaluation goals for the Ramp Meter Study were identified, including:

- Evaluate whether the benefits of ramp metering outweigh the impacts and associated costs;
- Identify other ramp metering impacts on surface streets and transit operations; and
- Identify how the Twin Cities' ramp metering system compares and contrasts with other national and international ramp meter systems in other areas.

For each of the broad evaluation goals, several detailed evaluation objectives were identified. These evaluation objectives provide the framework for conducting the evaluation. Table 3.1 presents the evaluation objectives as they relate to each of the evaluation goals.

For each of the evaluation objectives, one or more measures of effectiveness were identified to provide an assessment of the objective. Where possible, these evaluation measures were expressed in quantitative terms; however, many of the measures are more appropriately expressed in qualitative terms. Appropriate data were collected relating to each of these measures to provide the opportunity for assessment against the evaluation objectives and goals.

The evaluation measures selected for each evaluation objective are presented in Table 3.2. The measures of effectiveness are focused on the incremental change observed between the two evaluation scenarios – "with ramp meters" and "without ramp meters." By focusing on the change occurring between the two scenarios, the evaluation team was better able to isolate the particular benefit/impact. The measures of effectiveness are not mutually exclusive and, in some cases, the same measure was used to test several objectives. The evaluation measures were also designed to be "neutral" and not pre-suppose any outcome of the ramp meter test. In all cases, the outcome of the particular measure could be either positive or negative, depending on the impacts observed during the two scenarios. Outcomes could also be *both* positive and negative, in that results could vary geographically across the selected corridors, market segments, or timeframes.

Table 3.1 Evaluation Goals and Objectives

Evaluation Goal	Evaluation Objective
Evaluate whether the benefits of ramp metering outweigh the impacts and associated costs.	• Quantify ramp metering safety impacts (positive and negative) for selected corridors. Extrapolate ramp metering safety impacts to the entire system. • Quantify ramp metering traffic flow impacts (positive and negative) for selected corridors. Extrapolate ramp metering traffic flow impacts for the entire system. • Estimate ramp metering impacts (positive and negative) on energy consumption and the environment. • Compare the systemwide ramp metering benefits with the associated impacts and costs. • Identify (both quantitatively and qualitatively) public attitudes toward ramp metering for both the selected corridors and the region as a whole.
Identify other ramp metering impacts on surface streets and transit operations.	• Identify ramp metering impacts on local streets. • Identify ramp metering impacts on transit operations. • Document additional ramp metering benefits/impacts observed during the study.
Identify how the Twin Cities' ramp metering system compares and contrasts with ramp meter systems in other areas.	• Identify similarities and differences between the Twin Cities' ramp metering system and other metropolitan areas in terms of ramp meter operation strategy employed, and ramp configuration strategy. • Identify national and international trends regarding the use of ramp metering as a traffic management strategy. • Identify benefits/impacts of ramp metering systems documented in other national and international studies.

Table 3.2 Evaluation Measures

Evaluation Objective	Measures of Effectiveness
1. Quantify ramp metering safety impacts for selected corridors and the entire system.	• Change in the number and severity of crashes occurring in selected corridors and the entire system. • Estimated change in the regional crash rate for different facility types. • Change in the number of traffic conflicts (non-crashes) occurring at specific corridor locations (ramp merge and adjacent intersections). • Change in HOV lane violations. • Perceived change in safety of travel in selected corridors and the entire system.
2. Quantify ramp metering traffic flow and travel time impacts for selected corridors.	• Change in travel time for primary and alternative travel routes in selected corridors. • Change in travel speed for primary and alternative travel routes in selected corridors. • Change in traffic volume for primary and alternative travel routes in selected corridors. • Change in travel time reliability for selected corridors. • Change in traffic volume, travel time, travel speed, and travel time reliability for on-ramps in selected corridors. • Perceived change in travel time and travel time reliability for selected corridors.
3. Identify ramp metering impacts on local streets.	• Change in traffic volumes on local streets in selected corridors. • Change in the length and severity of ramp queue spillover onto adjacent intersections in selected corridors.
4. Extrapolate ramp metering traffic flow and travel time impacts (positive and negative) for the entire system.	• Estimated regional change in travel time, travel time reliability, travel speed, vehicle miles traveled for different facility types. • Perceived regional change in travel time. • Perceived regional change in travel time reliability.
5. Estimate ramp metering impacts (positive and negative) on energy consumption and the environment.	• Estimated regional change in emissions by pollutant and by facility type. • Estimated regional change in fuel consumption by facility type.

Table 3.2 Evaluation Measures (continued)

Evaluation Objective	Measures of Effectiveness
6. Compare the systemwide ramp metering benefits with the associated impacts and costs.	• Change in the number and severity of crashes occurring systemwide. • Change in systemwide travel times. • Change in the total number of trips. • Change in travel time reliability. • Change in fuel use and other user paid costs. • Change in vehicle emissions levels. • Estimated change in DOT operating costs. • Estimated change in operating costs of other agencies (e.g., State Patrol, transit agencies, local jurisdictions, etc.) • Capital and operating costs of ramp metering system.
7. Identify ramp metering impacts on transit operations.	• Change in transit travel times for selected corridors. • Change in transit ridership levels for selected corridors. • Estimated change in operating costs for transit providers.
9. Document additional ramp metering benefits/impacts observed during the study.	• Documentation only.
10. Identify similarities and differences between the Twin Cities' ramp metering system and other metropolitan areas in terms of ramp meter operation strategy employed, and ramp configuration strategy.	• Documentation only.
11. Identify national and international trends regarding the use of ramp metering as a traffic management strategy.	• Documentation only.
12. Identify benefits/impacts of ramp metering systems documented in other national and international studies.	• Documentation only.