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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Cambridge Systematics, Inc.
1300 Clay Street, Suite 1010
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February 1, 2001

Minnesota Department of Transportation

Transportation Building
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.

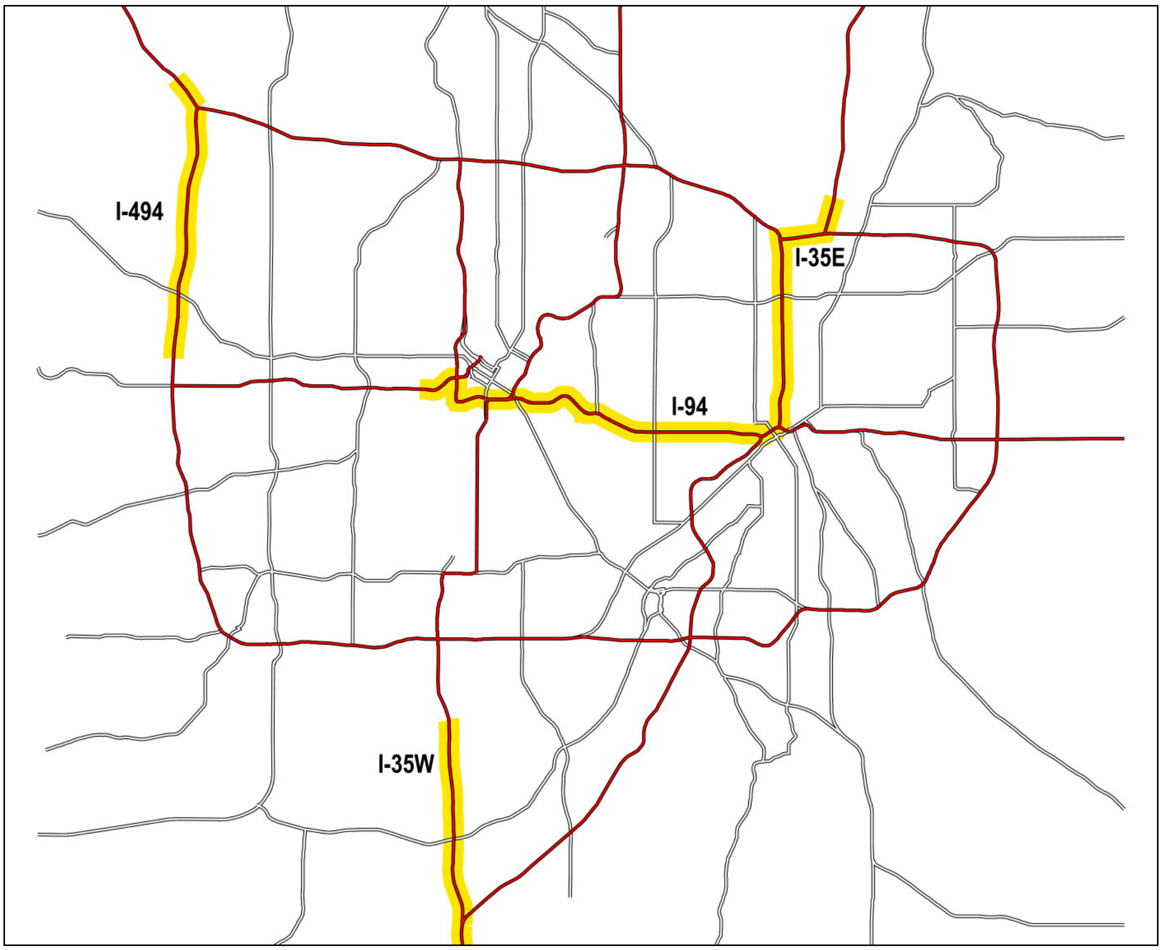
Data related to the measures of effectiveness were collected during two periods in the fall of year 2000. Data collected during the first period were used to assess the baseline or "with ramp meters" scenario. In this scenario, the ramp meters were operated according to established Mn/DOT practices. 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.

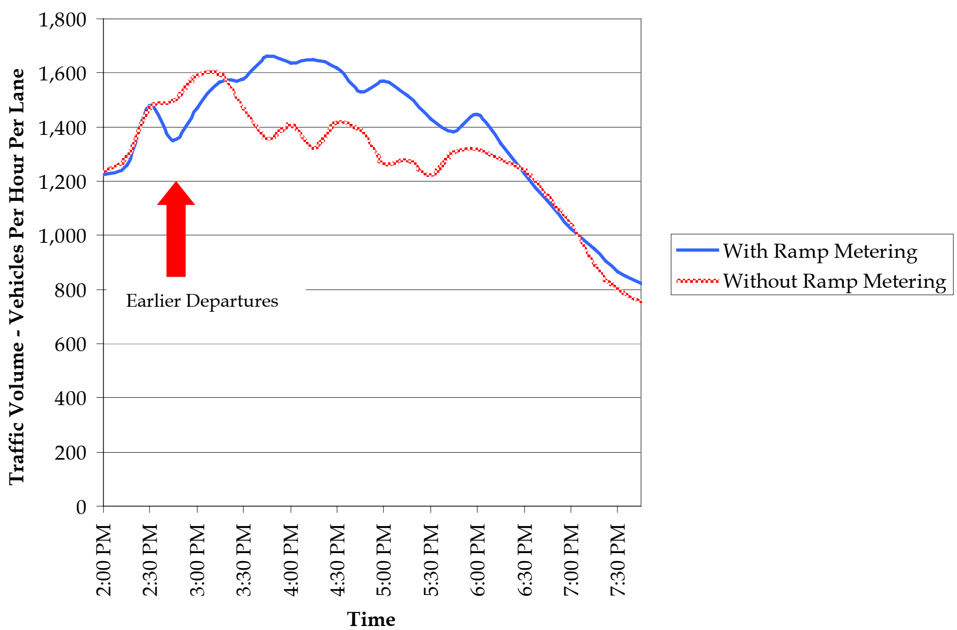
- **Benefit/Cost Analysis:** Ramp metering results in annual savings of approximately $40 million to the Twin Cities traveling public. The benefits of ramp metering outweigh the costs by a significant margin and result in a net benefit of $32 to $37 million per year. The benefit/cost ratio indicates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

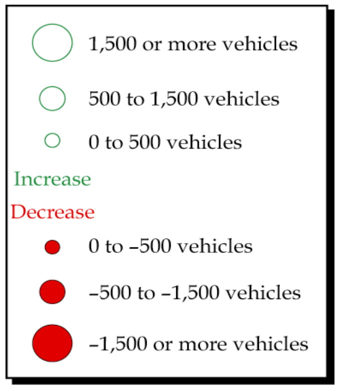
Figure ES.2 I-94 Eastbound Afternoon – Example of Freeway Traffic Volume Reduction and Earlier Departures

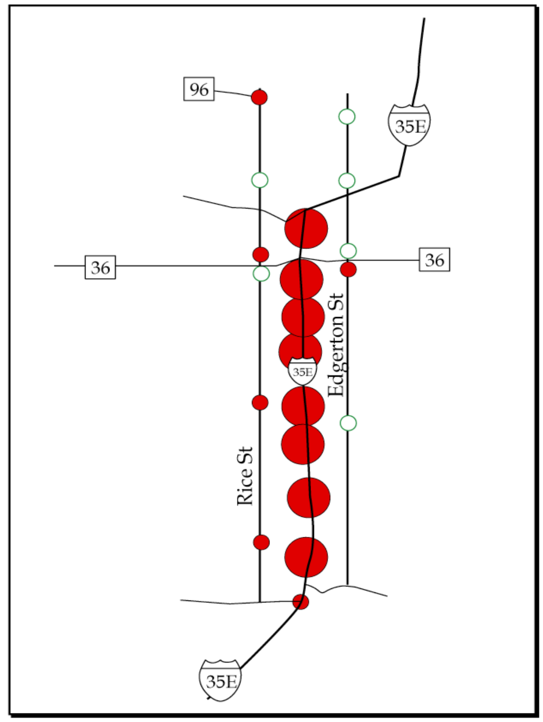


Travel Time

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:

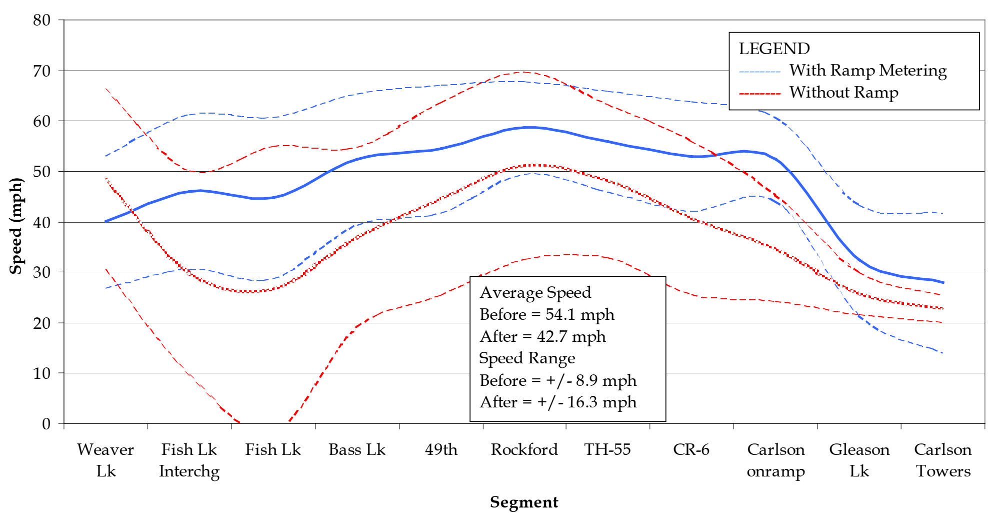
- Not all travelers encountered meters and hence experienced a reduction in travel time due to their absence. Based on the market research data, only 54 percent of peak period travelers in the test corridors routinely encounter an operational (red/green) ramp meter during their commute. The other 46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

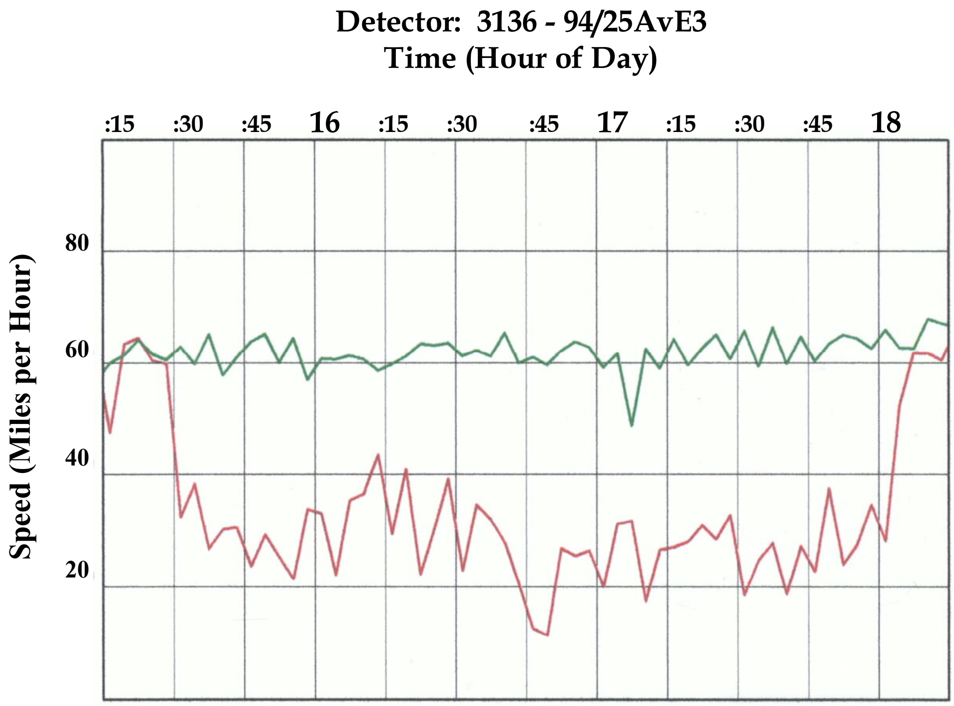


Travel Time Reliability

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)



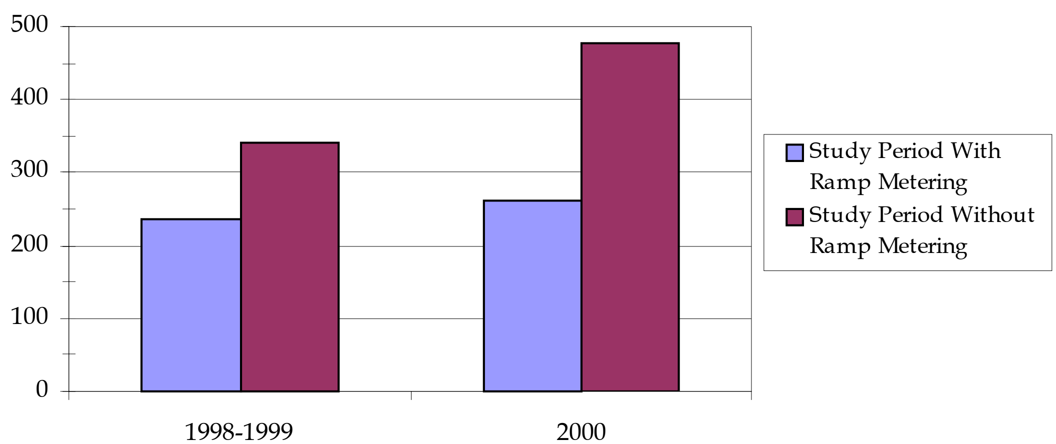
Condition	Date	Field	Sample	Volume
Meters off	Mon, Oct 16, 2000	25′	100%	25,181
Meters on	Mon, Oct 9, 2000	25′	100%	25,294

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.

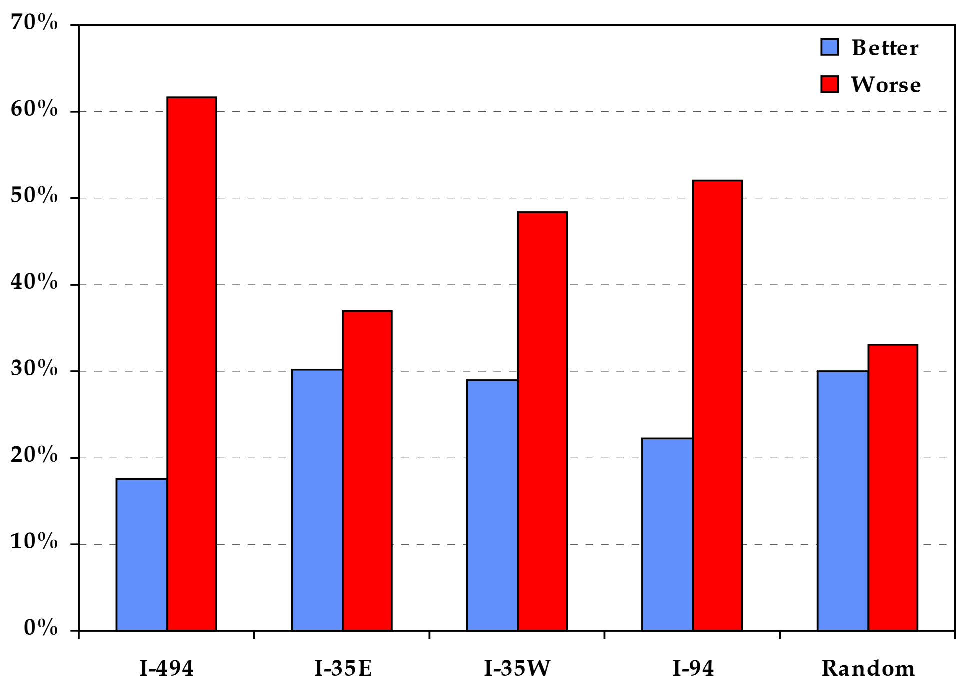
The surveys included both a random sample of area travelers, as well as four corridor-specific samples that focused on the area's freeway corridors for which traffic and travel time data were also collected. These surveys were fielded twice, both before and during the ramp meter shutdown. A total of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

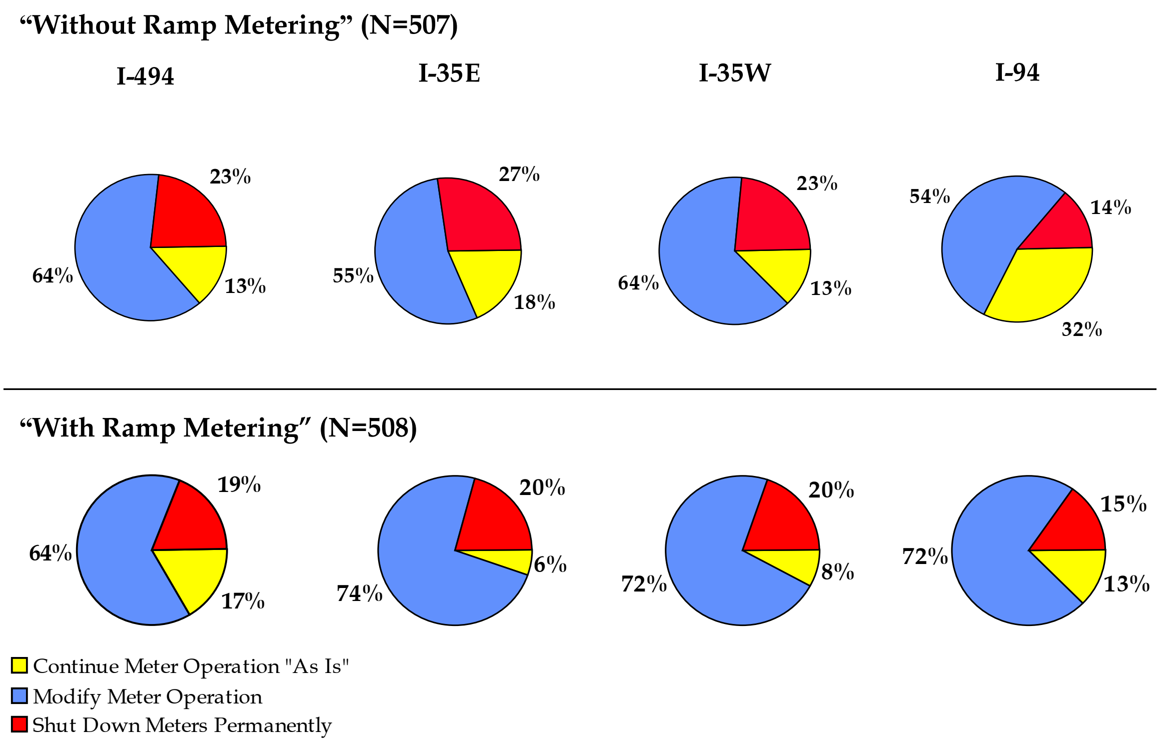
- Findings varied considerably with trip length, consistent with the traffic data. Respondents with origins furthest from the urban core, and with the longest trips, were most likely to believe that traffic conditions got worse during the shutdown. These travelers also had a greater appreciation for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

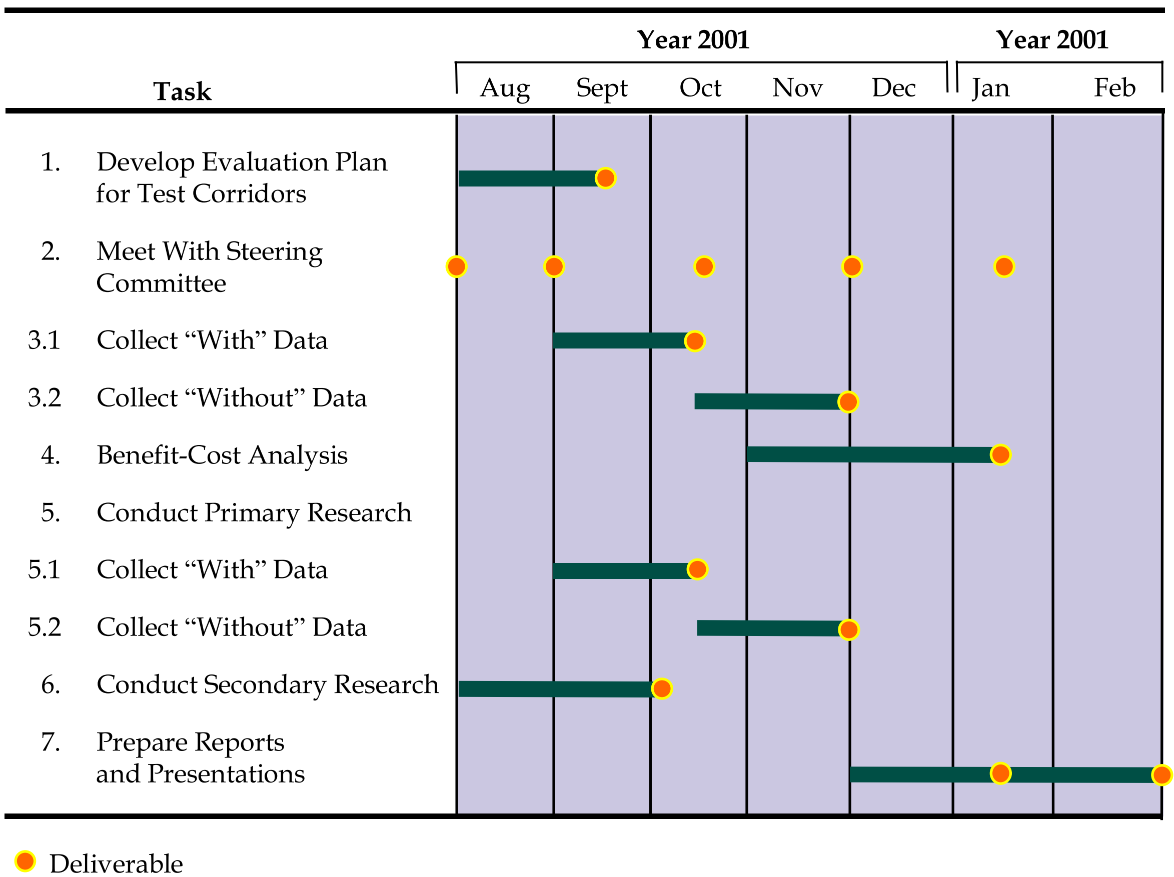
- **Advisory Committee –** Provided policy oversight and input into the consultant selection process, the proposed study work plan, measures of effectiveness, and evaluation measures.

- **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.

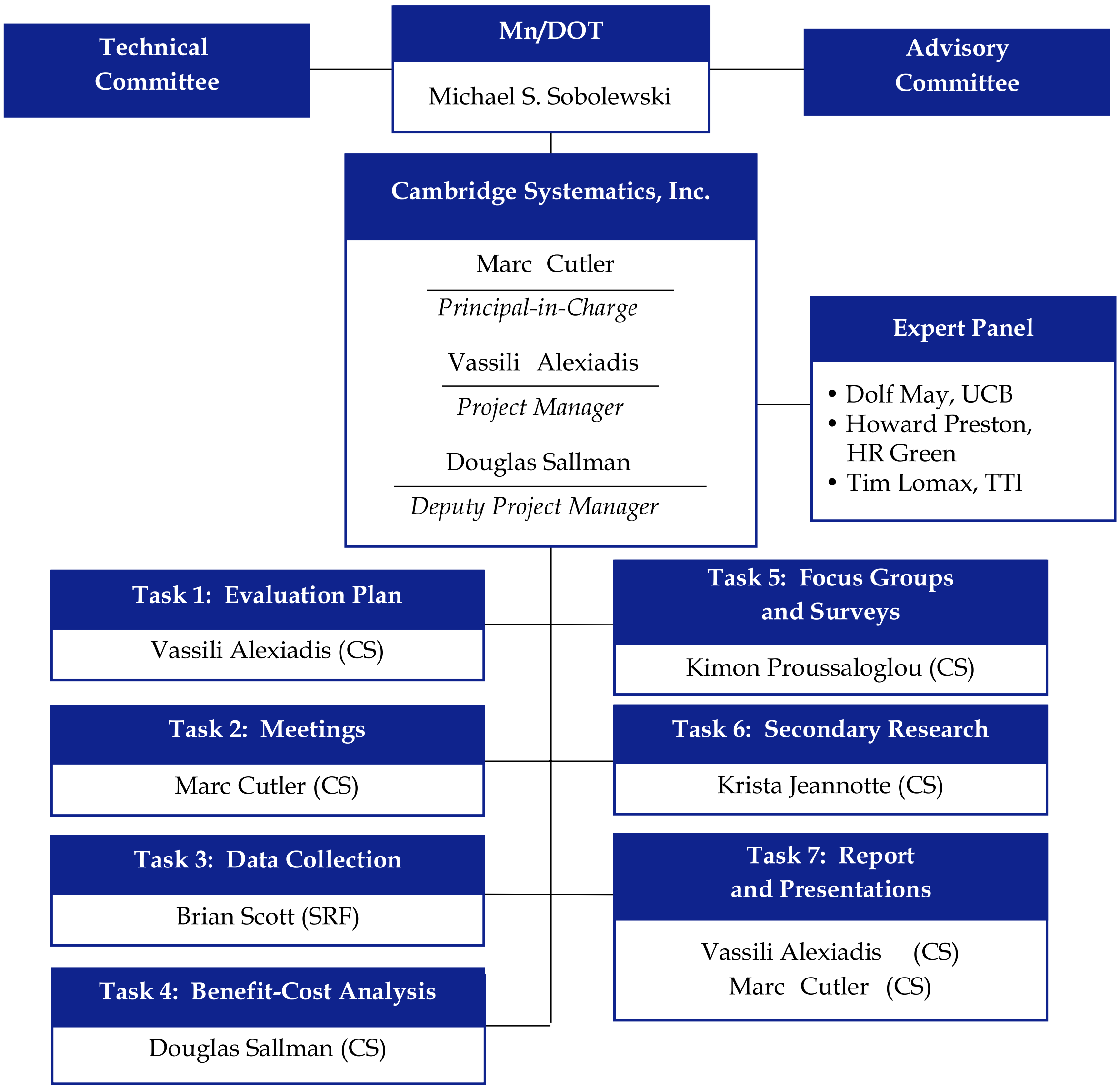
Michael Sobolewski was the Mn/DOT Project Manager selected to provide day-to-day management of the project and provide coordination between the Advisory and Technical Committees and the consultant team.

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.

4.0 Evaluation Methodologies

The evaluation goals, objectives, and performance measures presented in the previous section provided the framework for the evaluation. This section presents an overview of the methodologies that were employed to collect and analyze data for the study. The entire *Evaluation Plan* is included as Appendix L.

4.1 Overview of Evaluation Methodologies

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 systemwide*. 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, during the ramp meter deactivation period, all other congestion management systems were fully operational, including incident detection and camera surveillance.

Although all ramp meters throughout the system were deactivated during the test, the data collection effort was focused on four selected corridors. These corridors were selected as representative of other corridors throughout the metropolitan region. Other systemwide data were collected during this period to allow for the normalization of data collected in the selected corridors.

In parallel with the field traffic data collection, a series of market research tasks 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 public was informed on October 9th that the ramp meters were to be deactivated the following Monday, October 16th.

The goals of the data collection schedule were:

- To provide adequate time for the collection of the "with ramp meters deactivation" data;
- To provide the public with adequate notice of the impending change in traffic operations such that they have time to plan changes in their travel routines should they be interested in doing so; and
- To not provide so much advance notice that the resulting induced behavioral change would in some way taint the data collection following the deactivation of ramp meters.

The ramp meters remained deactivated from October 16th through November 17th, thereby enabling data collection to conclude prior to the onset of the Holiday shopping season.[1] Following the conclusion of the "without" scenario test, data analysis was conducted to isolate the incremental impact observed between the two scenarios during this time. These incremental impacts were then extrapolated and combined with other data to support the regionwide 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 parallel data collection and analysis activities are summarized as follows.

- **Corridor Selection (Section 4.2) –** In this effort, the evaluation team defined corridor selection criteria and selected corridors for data collection.
- **Field Data Collection for Selected Corridors (Section 4.3) –** In this effort, the evaluation team collected field data at selected corridors.
- **Market Research (Section 4.4) –** This activity involved focus group and survey data collection.
- **Benefit/Cost Analysis (Section 4.5) –** In this activity, data collected for the selected corridors were extrapolated to develop estimates of regionwide impacts.
- **Secondary Research (Section 4.6) –** In this effort, the evaluation team conducted research to compare and contrast the ramp metering system in the Twin Cities with systems in other national and international locations.

Subsequent sections in this section provide detail on the methodology employed in each activity and provide specifics on the conduct of the various evaluation tasks.

[1] The meters remained deactivated until December 8th, during which time Mn/DOT conducted an interim policy review and then reactivated the meters in a modified operating mode.

4.2 Corridor Selection

Collecting field data on the entire Twin Cities transportation system would have required an extraordinary amount of resources. In order to make better use of evaluation resources and meet the demanding schedule requirements of the project, the evaluation team instead focused the field data collection on several select corridors that are representative of other corridors throughout the entire system. These data were then extrapolated to the entire system.

The key to corridor selection was to select study corridors that are representative of most of the freeway corridors in the Twin Cities Metropolitan Area so that the results could be extrapolated to the entire freeway system. The first task in the corridor selection was to classify the Twin Cities Metropolitan Area freeways into four corridor types. Each freeway corridor type represents a number of freeway sections within Twin Cities Metropolitan Area. This "categorization" of freeway sections allowed the CS team to extrapolate the measured impacts of the four study corridors to the rest of the Twin Cities Metropolitan Area freeway system to provide systemwide evaluation results.

The four basic types of freeway corridors are defined as follows:

1. **Type A –** Freeway section representing the I-494/I-694 beltline, which has a high percentage of heavy commercial and recreational traffic. The commuter traffic on the corridor type is generally from suburb to suburb.

2. **Type B –** Radial freeway outside the I-494/I-694 beltline with a major geographic constraint that does not allow for alternate routes (i.e., major freeway river crossing).

3. **Type C –** Intercity connector freeway corridor that carries traffic moving between major business and commercial zones. This type of freeway has a fairly even directional split of traffic throughout the a.m. and p.m. peak periods.

4. **Type D –** Radial freeway inside the I-494/I-694 beltline that carries traffic to/from a downtown or suburban work center.

Next, a three-step process was used to select the four study corridors. Process steps are listed below and defined in greater detail in the following pages:

1. Identify the corridor selection criteria;
2. Identify candidate corridors; and
3. Apply corridor selection criteria and select corridors to be studied.

4.2.1 Corridor Selection Criteria

In coordination with the Technical and Advisory Committees, the CS team developed the criteria for corridor selection. The criteria account for the types of freeway corridors, philosophy for metering the different types of freeway corridors, variations in traffic demand on the corridors, lane drops, interchange or geometric constraints, ease of data collection, HOV facilities and transit services in the corridor, unmetered ramps along corridor, etc. The corridor selection criteria were ranked as shown in the following list, with the first four criteria being the primary criteria used for the initial corridor screening:

- Availability and type of alternate routes;
- Level of congestion;
- Geographic representation and balance within the Twin Cities Metropolitan Area;
- Construction activity on freeway and alternate routes;
- HOV lanes and bypass ramps;
- Transit service on corridor;
- Geometric constraints;
- Traveler market segments; and
- Representative corridor length.

4.2.2 Identification of Candidate Corridors

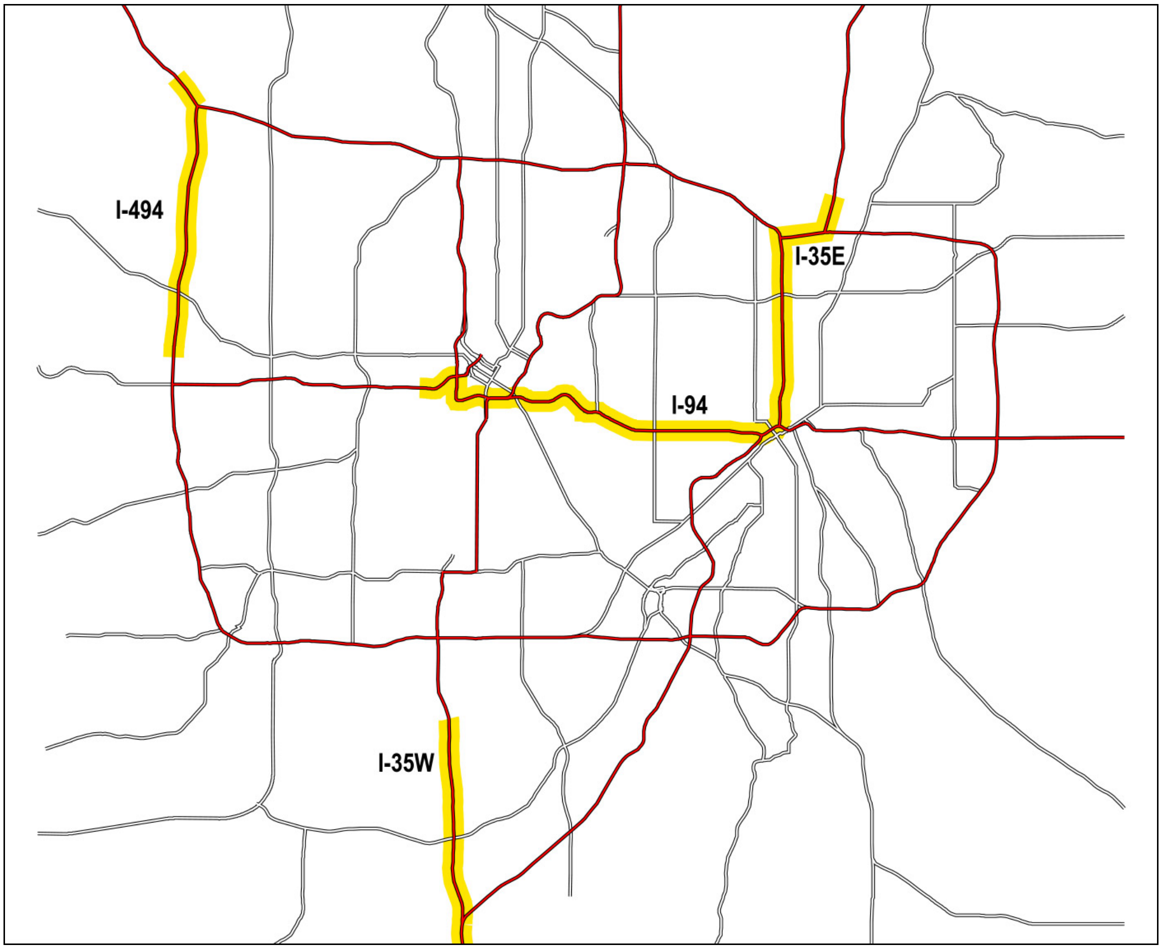
The CS team applied the corridor selection criteria to freeway sections throughout the Twin Cities Metropolitan Area and identified an initial list of 11 freeway corridors that adequately met the primary selection criteria. The entire study *Evaluation Plan* (September 20, 2000) is presented as Appendix G and provides details on the traffic and geometric characteristics of these candidate corridors. Next, the CS team gathered detailed information on the 11 candidate corridors and applied the selection criteria to these corridors, resulting in the selection and presentation of nine candidate freeway corridors for review by the Technical and Advisory Committees.

4.2.3 Selection of Corridors To Be Studied

The CS team presented the candidate corridors to the Technical and Advisory Committees and facilitated the discussion and final selection of the four corridors to be studied in detail. The four corridors selected for the study provide geographic balance within the Twin Cities Metropolitan Area. The four corridors selected for the study are shown in Figure 4.1 and described as follows:

1. **I-494 Corridor –** As shown in Figure 4.2, this corridor serves traffic from outside the Twin Cities Metropolitan Area and commuter traffic between the residential area north of the corridor and employment destinations to the south.
2. **I-35W Corridor –** As shown in Figure 4.3, this corridor serves commuter traffic between the residential communities south of the Minnesota River (e.g., Burnsville and Lakeville) and employment destinations north of the river.

Figure 4.1 Twin Cities Corridors Selected for Detailed Evaluation



3. **I-94 Corridor –** As shown in Figure 4.4, this corridor serves traffic demand between downtown Minneapolis and downtown St. Paul.
4. **I-35E Corridor –** As shown in Figure 4.5, this corridor serves commuter traffic between the northern residential communities and various employment destinations further south.

4.3 Field Data Collection

The premise of the field data collection was to measure the transportation system impacts of the ramp metering system in the Twin Cities Metropolitan Area. This task involved an extensive "with ramp metering" and "without ramp metering" traffic data collection program to address the impacts on traffic operations and safety. Traffic data were collected at specific ramps and along selected corridors within the region over several weeks for both

Figure 4.2 I-494 Corridor

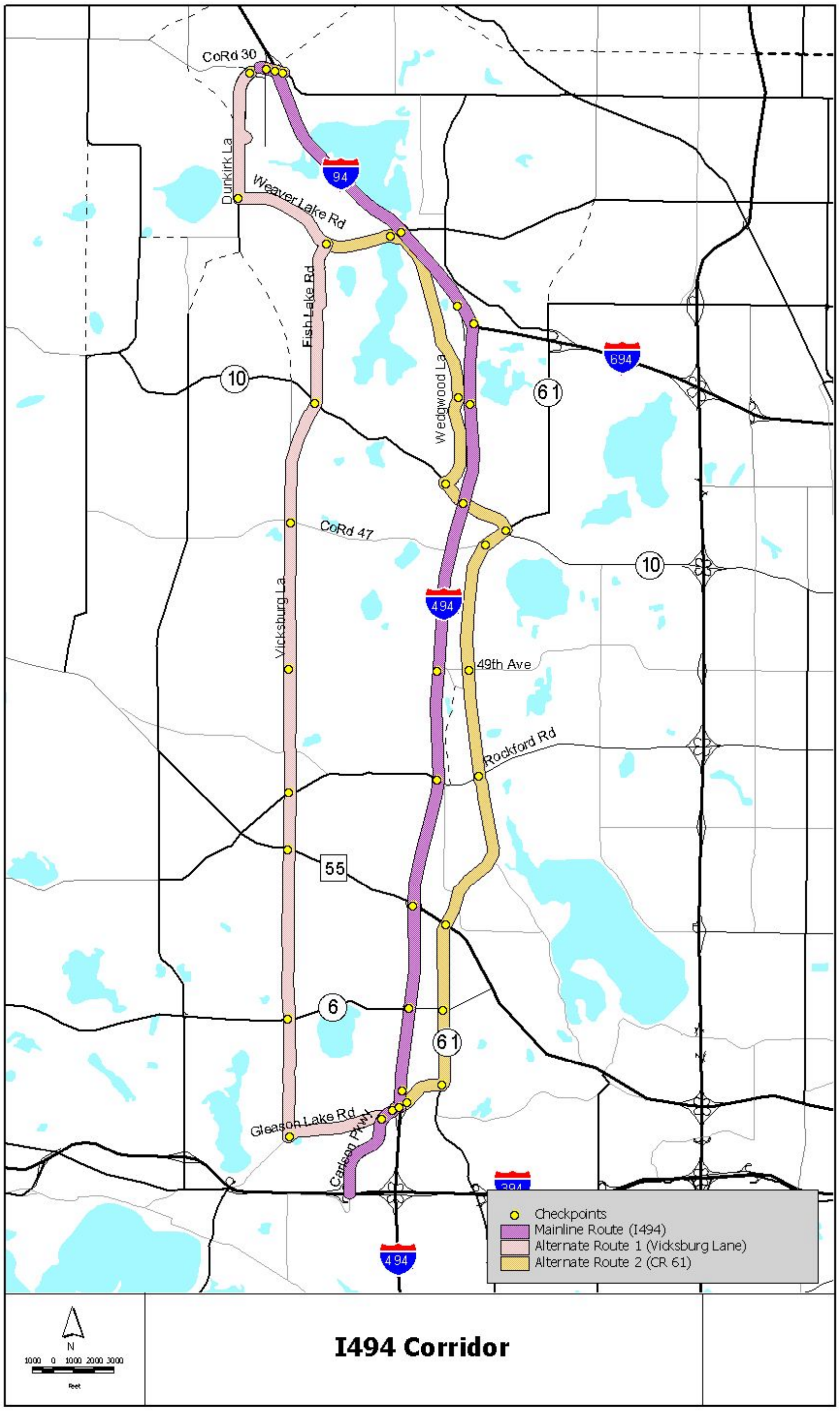


Figure 4.3 I-35W Corridor

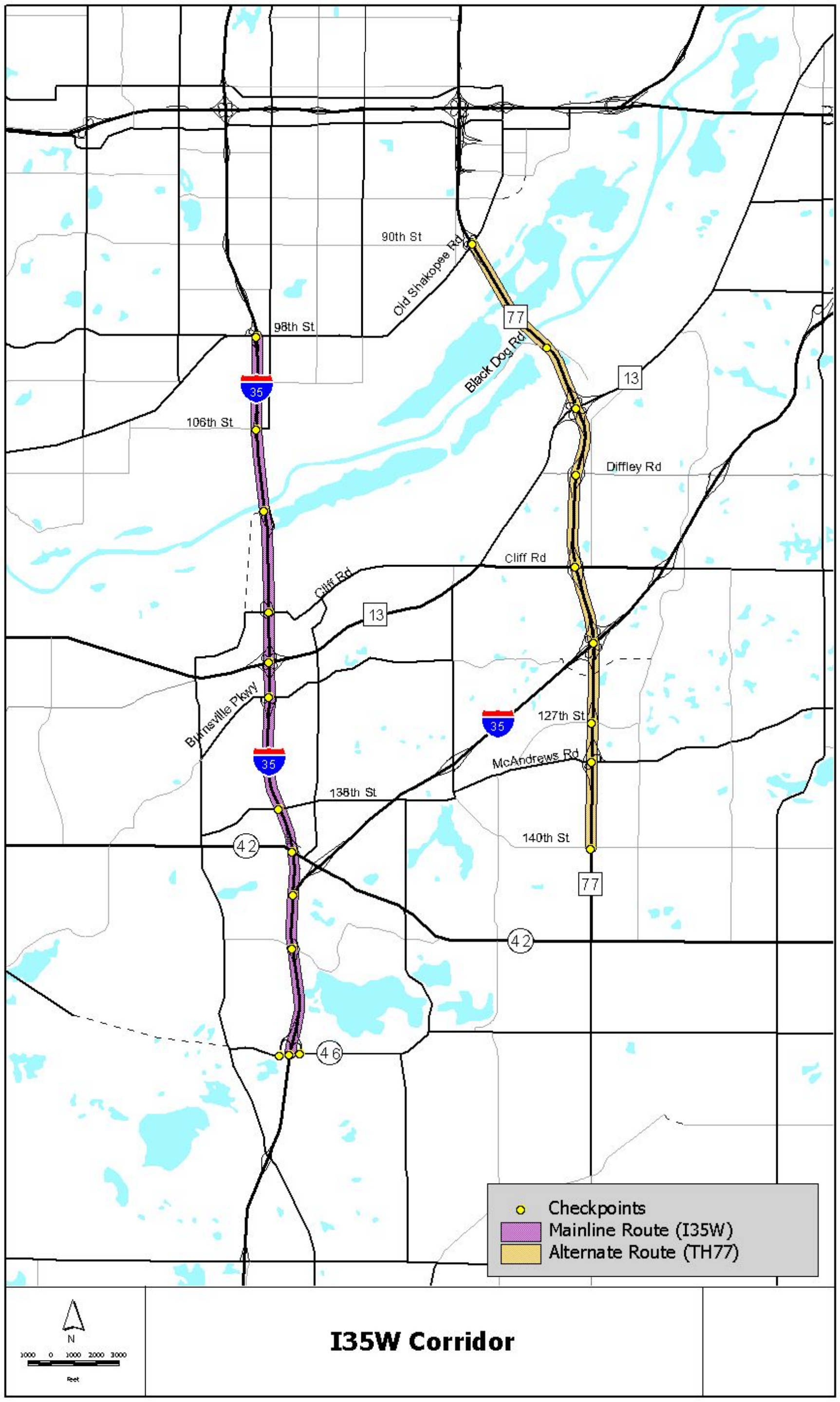


Figure 4.4 I-94 Corridor

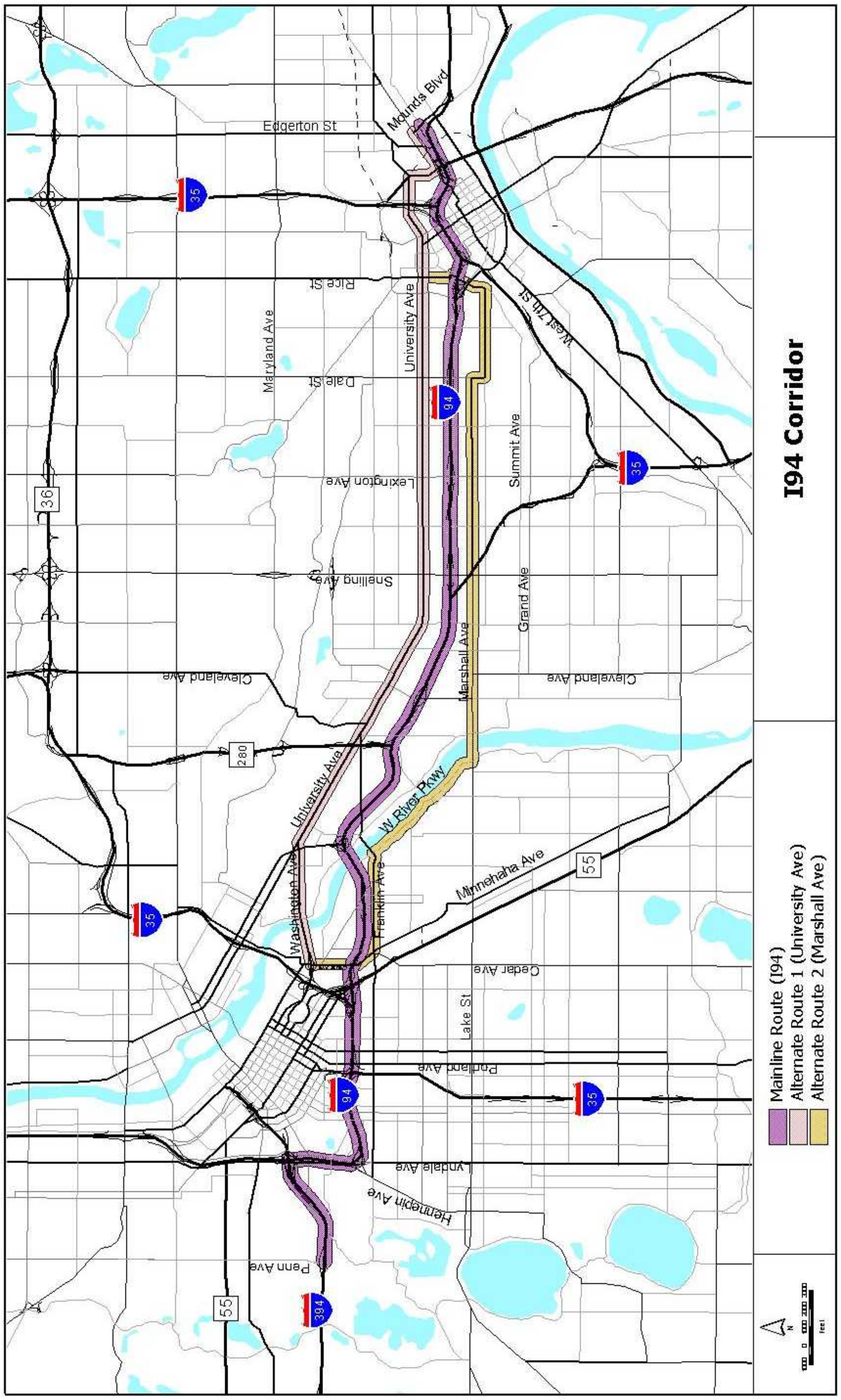
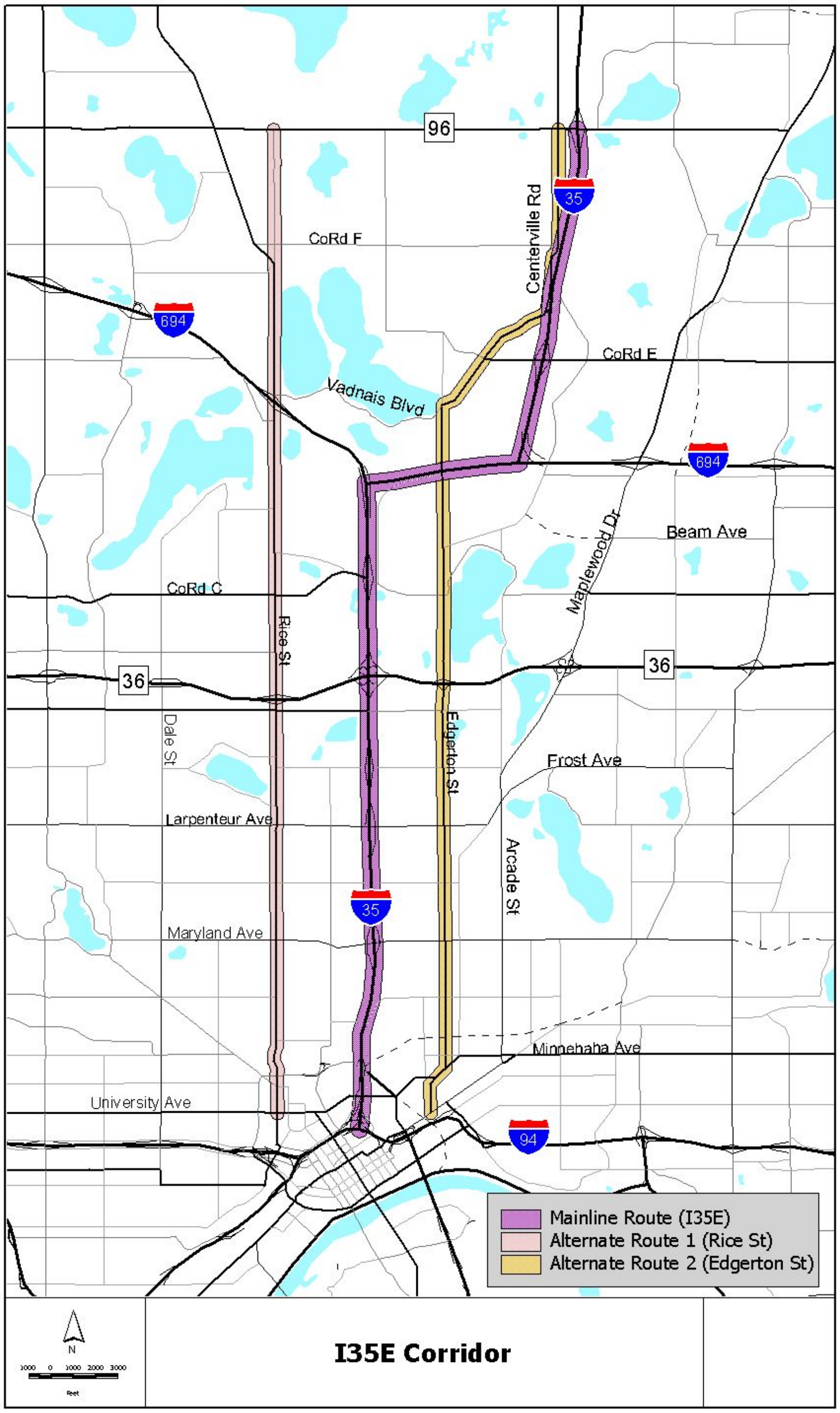


Figure 4.5 I-35E Corridor



the "with" and "without" ramp metering evaluation scenario. Data collection occurred during the morning and afternoon peak periods for approximately 3.5 hours per peak period from Monday through Friday within the evaluation timeframe. Ramp operational studies were conducted during hours the ramps are metered. Subsets were created for Monday and Friday data, and for Tuesday through Thursday data.

The following types of field data were collected to evaluate and quantify the transportation system impacts with and without the ramp metering system:

- Traffic flow data;
- Travel time data;
- Ramp impact data;
- Crash data; and
- Transit usage data.

The main external influences on the system's performance were weather, changes in the transportation system (lane closures, repairs, etc.), incidents causing traffic delays (crashes, stalled vehicles, etc.), and major events. During both the "with" and the "without" study periods all data collected on bad weather days (rain/snow), bad incident days, and dark versus light conditions were flagged. The data were then grouped and analyzed in separate categories. If a statistically significant difference was found between groups, the data were analyzed separately and comparisons were made for data under similar weather/light/incident conditions. Also, the data were analyzed across groups to identify differences in the effectiveness of ramp metering under the varying conditions. Finally, all data were analyzed to measure the effects of peak-period spreading. The following subsets were created with the data:

- **Pavement condition:** Dry, Wet, or Snow Covered;
- **Presence of incidents along corridor:** Yes or No;
- **Light condition:** Light (sunrise to sunset) or Dark (sunset to sunrise); and
- **Day of the week:** Monday, Friday, or Tuesday through Thursday.

A very large amount of data were collected over the course of this evaluation. The following steps were taken to ensure that the data is reliable and secure:

- Data collection personnel were trained by data collection supervisors;
- Data collection supervisors made periodic spot checks on personnel in the field;
- Data were inspected on a daily basis to ensure that the data was reasonable; and
- In the event that equipment problems were encountered, backup data collection equipment was deployed, whenever possible.

Specific measures of effectiveness and their corresponding data sources are presented in the sections that follow for each of the five data types.

4.3.1 Traffic Flow Data

Traffic flow data were collected to examine the traffic flow impacts of the ramp metering system. These data included traffic volume and occupancy data from freeway mainline detector stations and volume data from alternate routes. Two different data collection methods were used including existing freeway loop detectors and portable counting devices (road tubes). Further detail on each type of data and data source is provided below.

Freeway Mainline Traffic Volume and Occupancy – Data from the Mn/DOT Traffic Management Center (TMC) freeway loop detector stations were collected along each of the corridors under evaluation. The following information pertains to freeway data:

- **Sample Size:** Thirty-second traffic volume data per lane, 24-hours per day. Data were aggregated to 15-minute periods during the a.m. and p.m peak periods. Data were also aggregated to daily totals. Four-hour peak periods selected to allow analysis of any peak-period spreading.

- **Data Collection Methods and Tools:** Detector data were downloaded remotely/electronically from the Mn/DOT TMC. The evaluation team run daily automated checks of the data. Spreadsheets and databases were be used to process the data.

Alternate Route Traffic Volumes – Road tubes were used to collect traffic volume data along each of the arterial corridors under evaluation. The following information pertains to alternate route data:

- **Sample Size:** Fifteen-minute volumes per lane during the a.m. and p.m. peak periods. Data were also aggregated to daily totals.

- **Data Collection Methods and Tools:** Arterial route data were collected during the same period as the corresponding freeway route. Spreadsheets and databases were be used to process the data.

4.3.2 Travel Time Data

These data were collected to examine the travel time impacts of the ramp metering system. Statistically significant samples of actual running speeds over the four freeway corridors and corresponding alternate routes were collected. Travel times and distances were recorded from probe vehicles driven along the corridor by members of the evaluation team. The "floating car" method was used, whereby the probe vehicle driver estimates the median speed of the traffic flow by passing and being passed by an equal number of vehicles.

Four Geographic Positioning System (GPS)-equipped vehicles were used to capture the travel time profiles at discrete intervals. One GPS-equipped vehicle was used on each freeway (and alternate route) corridor. Three additional vehicles were equipped with traditional distance measuring instruments (Jamar™) to gain enough travel time data to produce results meeting a 95 percent confidence interval. The specified measuring error was +/-two mph for freeways, and +/-one mph on the alternate routes.

Data were collected in both directions of travel along the corridor. In selecting the alternate route travel time, traffic flow patterns were examined to identify routes that would be used during periods of congestion on the freeway. Further detail on the travel time data collection approach is provided below:

- **Sample Size:** The first step in determining the sample size was to identify the desired level of accuracy. The bounds of statistical error were selected based on the Institute of Transportation Engineers (ITE) Traffic Engineering Manual (pages 95 to 96). With ramp meters/without ramp meters evaluation studies typically allow for speed data accuracy of +/-one mph to +/-three mph. A Confidence Interval of 95 percent is typically used for traffic studies. A sample size of approximately 21 travel time runs in the a.m. and p.m. peak periods each were required in order to obtain a statistically significant sample size.

- **Data Collection Methods and Tools:** The data collection team used a total of seven probe vehicles equipped with GPS and Jamar™ equipment. Probe vehicle drivers recorded weather, pavement conditions, light conditions, construction activity, and incidents; this enabled the isolation of anomalous data which might result from a day of severe weather, or the short-term effects of the start of Standard time at the end of October which falls in the middle of the "without meters" evaluation period.

An overview of the travel time routes along each of the corridors is provided below:

- **I-494 Corridor –** This corridor serves traffic coming from outside the Twin Cities Metropolitan Area, as well as commuter traffic between the residential area on the north end of the corridor and employment destinations on the southern end. Travel time runs were conducted between I-94/County Road 30 in Maple Grove and the Carlson Towers in Minnetonka. Traffic flow has a directional split with southbound congestion occurring in the a.m. peak period and northbound congestion occurring in the p.m. peak period. There are two alternate routes for this corridor. To the west of I-494 Vicksburg Lane, Weaver Lake Road and Dunkirk Lane are used between I-94/County Road 30 and Carlson Parkway. Various roadways (mainly County Road 61) are used for the route primarily to the east of I-494 between I-94/County Road 30 and Carlson Parkway.

- **I-35W Corridor –** This corridor serves commuter traffic between the residential communities south of the Minnesota River (e.g., Burnsville and Lakeville) and employment destinations north of the river. Travel time runs were conducted between Old Shakopee Road in Bloomington and County Road 46 (162nd Street West) in Lakeville. Traffic flow has a heavy directional split with northbound congestion occurring in the a.m. peak period. Data were only collected in the northbound (a.m. period) along this route. The Minnesota River crossing creates a bottleneck in this corridor. The alternate route for this corridor is Trunk Highway (TH) 77 between Old Shakopee Road in Bloomington and County Road 38/140th Street in Apple Valley.

- **I-94 Corridor –** This corridor serves traffic demand between downtown Minneapolis and downtown St. Paul. The western end of the travel time runs passed through the Lowry Hill Tunnel with a turn-around made via I-394 and Penn Avenue in Minneapolis. The eastern turn-around was at Mounds Boulevard in St. Paul. Traffic flow is primarily bi-directional with congestion experienced in both directions during both the morning and afternoon peak periods. There are two alternate routes for this corridor. To the north of I-94, University and Washington Avenues are used between Cedar Avenue in Minneapolis and Mounds Boulevard in St. Paul. To the south of I-94, Franklin, West River Parkway and Marshall Avenue are used between Cedar Avenue in Minneapolis and Rice Street/University Avenue in St. Paul.

- **I-35E Corridor –** This corridor serves commuter traffic between the northern residential communities and various employment destinations further south. Travel time runs were conducted between County Road 96 in White Bear Lake and Wacouta Street in downtown St. Paul. Traffic flow has a directional split with southbound congestion occurring in the a.m. peak period and northbound congestion occurring in the p.m. peak period. There are two alternate routes for this corridor. To the west of I-35E, Rice Street (TH 49) is used between County Road 96 and University Avenue. Primarily to the east of I-35E, Edgerton Street and Centerville Road are used between County Road 96 and 7th Street West in downtown St. Paul.

4.3.3 Ramp Impact Data

A variety of techniques were used to assess the operational impacts of ramp metering at freeway on-ramps. Ramp traffic volume data and ramp meter turn-on times were readily available from the TMC system. Data collected at metered ramps include ramp queue length and delay, HOV lane usage and ramp meter violations, frequency of the ramp queue backing into intersection, and quality of merge.

- **Sample Size:** Data were collected at ramps within the defined test corridors during the a.m. and p.m. peak periods Monday through Friday. All data were collected in 15-minute intervals.

- **Data Collection Methods and Tools:** Jamar equipment were used to record when vehicles entered and exited the ramp queue. At least two observers were positioned at each ramp. The Jamar software was used to calculate queue length and vehicle delay at the ramp. Spreadsheets and databases were be used to process the data.

4.3.4 Safety Impact Data

Crash data were assembled to examine the safety impacts of the ramp metering system. The TMC incident logs were reviewed to collect the number and duration of incidents on those freeway corridors selected for evaluation. In addition, the automated Mn/DOT crash log system was reviewed to collect the number of crashes within the Twin Cities Metropolitan Area. This data were used to directly measure the number of crashes in the "with ramp metering" and "without ramp metering" condition on a systemwide basis. In addition, historical crash data were collected and analyzed as described below.

- **Data Collection Methods and Tools:** TMC incident log data were assembled for the four study corridors; the TMC documents number and duration of incidents on freeways that are monitored by the traffic management system. Metro-wide crash data were collected from Mn/DOT's automated crash log system. Crash data were also assembled for the previous two years.

- **Analysis Methods:** Crash data were separated by different facility types; by metered versus unmetered freeways; by crash type (rear-end, side-swipe, etc.); by crash severity (property damage only – PDO, injury, fatality); and by time of day (crash data while meters are in operation versus data in the off-peak while meters are off-line). Spreadsheets and databases were be used to process the data.

4.3.5 Transit Impact Data

These data were collected to examine the impacts to transit caused by the ramp metering system. Numerous data sources were used and performance measures were collected.

Transit Vehicle Travel Times and Transit Ridership Data

Transit vehicle travel times and ridership data were collected on a sample of transit routes running on the mainline and alternate travel routes on three of the four selected corridors including I-94, I-35E and I-35W. No transit data were collected on the I-494 corridor due to a lack of suburb-to-suburb transit service.

- **Sample Size:** Transit data were collected on a sampling of transit routes on the mainline and/or alternate travel routes for one week within three of the four selected corridors during the a.m. and p.m. peak periods.

- **Data Collection Methods and Tools:** Metro Transit used AVL-equipped buses to collect travel time data on I-94. Metropolitan Council used radio checks and field observations to collect travel time data on I-35E. Minnesota Valley Transit Authority used radio checks to collect travel time data on I-35W. Metro Transit, Metropolitan Council and Minnesota Valley Transit Authority collected transit ridership data using both electronic farebox data and manual driver tally sheets.

Park-and-Ride Facility Usage

Park-and-ride utilization data were collected at a sample of facilities serving transit routes on three of the four selected corridors including I-94, I-35E and I-35W. Utilization data at 12 park-and-ride facilities were collected on three days over a one-week period during both the with ramp meters and during periods. Morning peak period auto travel time data collection personnel manually collected these data through field observations directly after completion of the a.m. peak travel runs. Data included a count of the park-and-ride lot occupancy count.

4.4 Focus Groups and Traveler Survey Methodology

As part of the primary market research task, a qualitative and a quantitative approach to evaluating travelers' attitudes toward ramp metering was adopted. The objective of the qualitative research was to elicit travelers' overall reactions to the operation of ramp meters in the Minneapolis/St. Paul area roadway system and the expected impact of shutting down the ramp meters on travelers' general travel patterns. The qualitative market research was structured to provide:

- Insights into ramp metering issues as viewed by individual travelers,
- Input into the design of the "with ramp meters" and "without ramp meters" surveys, and
- Measures of effectiveness and ways to reach non-technical audiences.

The quantitative market research was based on the design, fielding, and statistical analysis of an extensive set of surveys from travelers in the Minneapolis/St. Paul metropolitan area. These 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 after the experimental ramp metering shutdown resulting in a set of five "with ramp meters" and five "without ramp meters" survey samples. The quantitative market research gathered socioeconomic, travel, and attitudinal information that was analyzed to assess:

- Travel behavior and ramp usage patterns, as well as differences between the "with ramp meters" and "without ramp meters" surveys that reflect the impacts of the ramp metering shutdown,
- Changes in travelers' "with ramp meters" and "without ramp meters" attitudes toward ramp meters that could be attributed to the ramp metering experiment, and
- Differences in travel patterns and attitudes that could be attributed to the different corridors under study and the various segments of the market.

This section discusses in some detail the individual elements of the evaluation approach. It documents the objectives, recruitment criteria, and moderator guide that were used during the focus groups that were conducted to obtain qualitative insights into travelers' behavior and perceptions both before and after the shutdown (Section 4.4.1). It then summarizes the license plate data collection effort that provided the sampling frame for both waves of the corridor surveys (Section 4.4.2).

Sections 4.4.3 and 4.4.4 outline the contents and discuss the elements of the survey instruments used for the random sample and corridor samples in each survey wave. It first presents in detail the survey design for the "with ramp meters" wave of data collection and then focus on the differences in survey design that were incorporated in the "without ramp meters" data collection.

4.4.1 Focus Group Methodology

The main purpose of the qualitative research was to gather information from freeway travelers both "before" and then several weeks "after" ramp meters were shutdown. Additionally, the research was conducted to address a number of specific issues for each of the two evaluation periods:

"With Ramp Meters" Evaluation

- What are travelers' general attitudes and perceptions toward the use of ramp meters?
- Which ramp meter performance measures and issues should be included in a more quantifiable and representative survey to capture travelers' perceptions?

"Without Ramp Meters" Shutdown Evaluation

- What are travelers' general attitudes and perceptions toward the ramp meter shutdown experiment?
- What changes, if any, would travelers like to see done to the way ramp meters are operated as a consequence of the shutdown?

On September 12 ("with ramp meters") and November 14, 2000 ("without ramp meters"), two focus group sessions were held in Bloomington, MN for each of the two evaluation periods. A screener questionnaire was developed and used for the recruitment of focus group participants that met the selection criteria described below. Appendix K presents a technical report detailing recruitment techniques and focus group methodology.

Four focus group sessions were held among individuals who traveled on one or more of the following routes: I-94 east or westbound in Minneapolis or St. Paul, I-494 northbound and southbound between I-94 and I-394, I-35W north toward Minneapolis, and I-35E northbound or southbound in St. Paul and areas north of the city. These routes constituted the experimental corridors for the ramp meter shutdown. In order to qualify for participation, individuals had to travel these routes during weekday hours from either 6:00 a.m. to 9:00 a.m. or 3:00 p.m. to 6:00 p.m. Additionally, separate focus groups were conducted based on the frequency of travel as follows:

1. **Light Ramp Users –** Travelers who make a total of one to five trips per week on average; and
2. **Heavy Ramp Users –** Travelers who make a total of six or more trips per week on average.

Also, an effort was made to insure that about a third of the participants in the heavy ramp users group traveled these routes for commercial/work reasons. Further, each of the two groups (heavy and light ramp users) contained an equal mixture of participants who resided in either an urban or suburban area, and who used roadways that had a "convenient" or "non-convenient" alternate route as defined by travelers.

Finally, there was an equal mixture of both male and female travelers between 18 and 65 years of age in each session. Despite efforts to recruit participants who traveled on the designated test routes from throughout the region, the location of the focus group facility in Bloomington introduced a slight bias toward participants with urban and inner suburban work locations and residences. These areas, relative to outer suburbs, were more likely to benefit from the ramp meter shutdown. This experience is reflected in the comments of the participants. There were no major differences in the comments of the light and heavy ramp user groups.

4.4.2 Sampling Frame and Survey Logistics

During each of the data collection waves, before and after the ramp metering shutdown, two types of telephone surveys were conducted. A random sample of respondents in the seven-county metropolitan area was drawn along with four targeted samples of corridor users along each of the four corridors under study. This section describes the process of drawing the random and corridor samples, discusses the sample sizes for each type of survey, and outlines the survey implementation process.

Sampling Frame. The random sample was developed by means of random digit dialing and included all travelers who traveled during the a.m. peak period between 6:00 and 9:00 a.m. or during the afternoon peak period between 4:00 and 7:00 p.m. The sampling frame included Minnesota residents in the seven-county Minneapolis/St. Paul metropolitan area. Respondents working for state and local transportation agencies, media outlets, and market research firms were excluded from the sample.

The corridor-specific samples were based on license plate data collected at locations along each of the test corridors (Table 4.1). License plate data were collected over the course of seven workdays days using a total of nine staff members. A total of 58,000 license plate numbers were collected, a sample size that proved adequate for sampling purposes for both “with ramp meters” and “without ramp meters” corridor surveys.

The representativeness of the corridor sample was supported by the variety of locations in which license plate numbers were collected (Appendix A). A total of 92 shifts were spread over 45 locations in the four corridors under study. During the second day of data collection, the location of a staff member by the freeway during the evening peak period may have caused delays to I-94 users. Because of this early problem with that specific location, the data collection plan was modified to include a mix of freeway locations and ramp entrances to the corridors.

The corridor sample was limited to automobile drivers and passengers in the designated corridors. The license plate numbers were then processed by the Department of Public Safety (DPS) so that they could be converted to Minnesota residential telephone numbers and names. This database was subsequently used to contact I-494, I-35E, I-35W, and I-94 corridor users within the study area.

Table 4.1 Distribution of Survey Returns for "With Ramp Meters" and "Without Ramp Meters" Surveys

	I-494	I-35W	35E	I-94	Random Sample
"With ramp meters" Corridor Surveys					
Refused to be interviewed	25	28	36	32	133
Has not driven in corridor	91	125	145	161	–
Terminated on security	5	9	7	12	22
Has not driven on a weekday or during peak	30	55	33	27	63
Terminated during interview	6	4	10	14	19
Completed interview	126	125	125	133	253
Total	**283**	**346**	**356**	**379**	**490**
"Without ramp meters" Corridor Surveys					
Refused to be interviewed	18	15	39	29	136
Not aware of shutdown	11	12	16	31	56
Has not driven in corridor	90	152	91	122	–
Terminated on security	9	7	17	8	19
Has not driven on a weekday or during peak	15	33	18	17	52
Terminated during interview	3	5	6	4	15
Completed interview	128	128	127	127	252
Total	**274**	**352**	**314**	**338**	**530**

At the outset of the project, the issue of targeting some aspect of the primary research (either the qualitative or quantitative) to specific market subgroups, such as commercial vehicle operators or transit riders, was discussed. While it was recognized that such groups have unique concerns and issues, it was decided not to dilute the general random sample by targeting such groups since all vehicles and passengers experience similar traffic conditions; therefore, the conclusions which emerge from the general random samples can be applied to all travelers. The desirability of including Wisconsin residents in the I-94-corridor sample was also discussed and rejected. It was the preference of the Advisory Committees to limit the sample to residents of the seven county metro area. In addition, inclusion of Wisconsin residents would have complicated the data conversion process since assistance would have been required from the Wisconsin Department of Public Safety. Since the inclusion of Wisconsin residents would have lengthened the average commuting distance of the I-94-corridor sample, their exclusion could have had some impact on the results for this one corridor given the differences in attitudes which emerged based on average trip length. However, the impact of this variable was well captured by the existing data.

Sample Sizes. A total of 1,520 telephone surveys were collected for purposes of this analysis. The total sample size was equally split between the two waves of "with ramp meters" and "without ramp meters" data collection. The sample sizes by type of survey and by data collection wave were distributed by corridor and for the entire study area as follows:

- A "with ramp meters" random digit-dial sample for the seven-county metropolitan area before the ramp meter shutdown (N = 253);
- Four "with ramp meters" random samples of travelers in each of the four corridors under study with approximately 125 observations per corridor and a total of 507 observations across the four corridors distributed as follows:
  - 126 observations for I-494 users,
  - 125 observations for I-35W users,
  - 125 observations for I-35E users, and
  - 131 observations for I-94 users.
- Five "without ramp meters" surveys were completed as part of the survey effort following the ramp meter shutdown resulting in a total sample size of 760 observations distributed as follows:
  - 252 observations for the random sample,
  - 127 observations for I-494 users,
  - 127 observations for I-35W users,
  - 127 observations for I-35E users, and
  - 127 observations for I-94 users.

Survey Implementation. The survey design was extensively tested during its development starting with informal testing in the office of the various pencil and paper versions of the survey as it evolved into its final form. Testing also continued during the conversion of the survey from a paper and pencil format to a computer-aided programmed telephone interview. The survey design was thoroughly reviewed by the project's Advisory Committees. Formal pre-testing was also conducted on 38 surveys, resulting in the elimination of 10 surveys from the sample. Finally, throughout the survey data collection effort, three monitoring stations staffed by senior staff members were used to ensure the quality of the survey effort.

A special effort was also made to keep the length of the survey as short as possible to maximize participation rates. The objective was to structure the survey so that all of the relevant information could be collected, while maintaining the interest of the respondent by keeping the length of the survey less than 20 minutes. The average length of the survey for the corridor sample was 15 minutes while the average length of the random sample survey was 12 minutes.

The response rates were very satisfactory as shown in Table 4.1 with a very high cooperation rate obtained from respondents. The refusal rate was an extremely low 8.8 percent. Another indicator of the cooperation of the respondents was the lack of missing responses across all variables in the survey. Even for the traditionally sensitive question related to respondents' income levels, only 9.4 percent of the responses were missing, indicating respondents' interest in the survey topic and their high level of cooperation. This response rate is indicative of the high level of interest in the ramp metering study in the metro region.

4.4.3 Design of the "With Ramp Meters" Surveys

An important component of the survey design was the reliance on respondent-friendly wording of questions to ensure that traffic engineering concepts were successfully communicated to travelers. Surveys were customized for each corridor and the survey questions were customized to each respondent's travel pattern to increase the realism of the survey to individual respondents and to enhance the response rate.

To avoid any ordering biases, individual questions within a sequence of questions were also rotated randomly across respondents. Furthermore, the attitudinal questions were worded using a mix of positive and negative wording for questions related to metering to minimize any response biases that could be attributed to wording. Finally, the surveys were programmed and data were collected using a computer-aided telephone survey to minimize data entry and processing errors and to facilitate the tabulations of "with ramp meters" and "without ramp meters" for statistical analysis.

The structure of the "with ramp meters" telephone survey included the following groups of questions (Appendix 4A):

- **Screener questions** that included the identification of travel in one of the corridors of interest, the direction of travel in the corridor, and the time of day that this trip is taking place. Respondents traveling in the peak direction between 6:00 and 9:00 a.m. and/or between 3:00 and 6:00 p.m. were selected for the interview. Interviews with respondents working for Mn/DOT, planning agencies, media outlets, and city/county public works departments were discontinued.
- Information on the characteristics of the last typical **peak period trip** on the freeway corridor, including the following:
  - Trip purpose, origin, and destination both at the town/suburb level and at the intersecting street level of detail;
  - Vehicle occupancy and by-pass lane usage;
  - Estimated total travel time and freeway travel time;
  - Ramp entrance and exit to/from the freeway of interest;
  - Wait time at ramp entrance meter and at any other freeway-freeway meter(s);
  - Frequency of using the freeway during a week;
  - Experience with longer ramp wait times and willingness to wait at a ramp; and
  - Experience with alternate routes, shifts in departure time, and use of alternate ramps.

- A battery of **attitudinal statements** regarding their travel experiences in general and their experience with ramp meters in particular. Ramp-related questions included travelers' attitudes toward ramp wait times, safety considerations, predictability of travel, and the usefulness of ramp by-pass lanes.

- **Demographic** information that was used to control for potential differences among respondents.

- A **polling** question that asked respondents their opinion whether the meter system should be kept "as is," modified in some way, or shut down permanently and the suggestions respondents had if they thought that modifications were needed.

4.4.4 Design of the "Without Ramp Meters" Surveys

The sampling frame, survey design, and data collection effort for the telephone surveys that were distributed after the ramp meter shutdown followed the process adopted for the "with ramp meters" surveys. The intent was to replicate as closely as possible all elements of the survey process to ensure that the resulting two sets of databases were comparable.

The differences between the "with ramp meters" and "without ramp meters" survey instruments reflected the changes that were introduced by the ramp meter shutdown experiment. The differences between the "with ramp meters" and "without ramp meters" surveys can be summarized as follows:

- All questions related to ramp **meter wait times** were dropped, since meters were not in operation during the without period.

- A set of **retrospective questions** was added to assess whether travelers felt they were better or worse off in the absence of ramp metering. Respondents were asked if their total travel time, freeway travel time, and traffic conditions had improved; stayed the same; or deteriorated as a result of the meter shutdown.

- The battery of **attitudinal questions** that assess travelers' perceptions of the ramp meter system in the "without ramp meters" survey were worded in the past tense to make reference to the impact of the shutdown. An introductory statement was also added to aid travelers in their response.

- A question to address whether there was a potential **media bias** in reporting the shutdown was also included in the survey.

4.5 Benefit/Cost Analysis

The benefit/cost analysis extrapolated the findings from the field data for the selected corridors and market research to produce estimates of regionwide impacts. A traditional spreadsheet benefit/cost model was used to conduct the regional extrapolation of data and benefit/cost analysis.

The analysis method involved the use of spreadsheet models to extrapolate data from the four selected corridors to the regional scale. All regional corridors were classified similar to the selected corridors. Metered corridors in the Twin Cities metropolitan area were categorized based on the following criteria:

- Geographic location and roadway attributes,
- Level of congestion and directionality of traffic,
- Geometric constraints and availability of alternative routes, and
- Traveler market segments based on the traveler survey results.

Corridors not fitting completely within a single category were assigned to two or more categories using percentages. Table 4.2 shows the corridor categorization scheme used in the benefit/cost analysis.

Observed traffic flow impacts from the selected corridors were then applied to all ramp metered corridors according to their specific corridor type. Impact values were applied to the resulting performance measures and formed the basis for the benefit/cost analysis. This methodology is well accepted for conducting analysis of this type and was applied in an expedient manner suitable to the project schedule requirements.

In developing an estimate of system costs associated with ramp metering, the CS team considered equipment and other costs directly associated with ramp metering, as well as portions of the supporting infrastructure. The cost analysis methodology accounted fully for costs directly attributable to the ramp metering system (e.g., ramp signals); and also accounted for a proportion of costs for supporting deployments based on percentage of overall functions devoted to ramp metering. This approach provides a full accounting of equipment without accruing costs attributable to unrelated systems. Other costs incorporated in the analysis include:

- Operational costs (electricity, communications, etc.);
- Operational personnel costs;
- Maintenance costs (replacement equipment, etc.);
- Maintenance personnel costs;
- Management costs; and
- Research and development costs (ramp meter wait time indicators, evaluation studies).

In order to ensure a conservative approach, all costs related to the operation of the entire congestion management system (CMS) in the Twin Cities region were then measured against the estimated benefits of only ramp metering. This study did not take into account benefits resulting from the operation of other CMS components, including incident management, changeable message signs, and camera surveillance equipment, which remained fully operational throughout the study.

Table 4.2 Categorization of Metered Corridors in the Twin Cities

Corridor	Between	Corridor Type A	Corridor Type B	Corridor Type C	Corridor Type D	
I-35E	I-35 Junction and TH77		60%		40%	
I-35E	TH77 and I-494		60%		40%	
I-35E	I-494 and Downtown St. Paul			10%	90%	
I-35E	Downtown St. Paul and I-694				100%	*
I-35W	I-35 Junction and I-494		100%			*
I-35W	I-494 and Downtown Minneapolis			30%	70%	
I-35W	Downtown Minneapolis and I-694			10%	90%	
I-35W	I-694 and Lexington		80%		20%	
I-94	Century Avenue and Downtown St. Paul		10%	10%	80%	
I-94	Downtown St. Paul and Downtown Minneapolis			100%		*
I-94	Downtown Minneapolis and I-694			30%	70%	
I-94 (I-694)	I-694 Junction and CR30	100%				
I-394	Downtown Minneapolis and TH100			60%	40%	
I-394	TH100 and TH169			30%	70%	
I-394	TH169 and I-494			10%	90%	
I-494	Mississippi River and TH54	90%		10%		
I-494	TH5 and TH169	25%		75%		
I-494	TH169 and I-394	80%		20%		
I-494	I-394 and I-94 Junction	100%				*
I-694	I-35W and I-94 Junction	100%				
TH10	University and Round Lake (Anoka Co.)		80%		20%	
TH36	I-35E and I-35W	10%		20%	70%	
TH62	TH55 and I-35W	10%		70%	20%	
TH62	I-35W and TH100	10%		70%	20%	
TH62	TH100 and I-494	20%		70%	10%	
TH77	I-35E and I-494		100%			*
TH77	I-494 and TH62			10%	90%	
TH100	I-494 and TH62			70%	30%	
TH100	TH62 and I-394			70%	30%	
TH169	I-494 and TH62			40%	60%	
TH169	TH62 and I-394	5%		40%	55%	
TH169	I-394 and I-94/I-694	15%		20%	65%	

Type A = Freeway section representing the I-494/I-694 beltline (commuter, heavy commercial, and recreational traffic);

Type B = Radial freeway outside the beltline (with a major geographic constraint presenting limited alternative routes);

Type C = Intercity connector; and

Type D = Radial freeway.

*Denotes actual test corridors.

To annualize ramp meter costs, the evaluation team developed a current year snapshot cost estimate of all equipment currently deployed. This annual cost estimate includes:

- Capital costs of equipment based on total cost divided by the anticipated equipment life, and
- Annual operation and maintenance costs added to average annual capital cost to calculate total annual cost.

This method provides a snapshot of costs for the current year suitable for comparison with the estimation of benefits for the same year. The Technical and Advisory Committees provided significant input in the development of the cost analysis methodology.

4.6 Secondary Research

The purpose of this activity was to review and summarize other relevant research regarding the benefits and costs of ramp metering and to identify ramp metering strategies employed in other comparable metropolitan areas. The CS team reviewed, verified, and validated a currently unpublished Texas Transportation Institute (TTI) ramp meter comparison study. Activities in this task included:

- A comparison of Minnesota's ramp metering system to other deployments in metropolitan areas across the country, including the total number of ramp meters; the type of deployment (pre-set, traffic actuated, centrally controlled); hours of operation; ramp configuration strategies (with or without HOV lanes, etc.); benefit-cost; environmental and safety studies undertaken; outreach and educational efforts; user feedback; and plans for expansions or new ramp metering deployments.
- A summary of the trends of ramp metering strategies and use.
- A summary of the benefits, impacts, and costs of ramp metering from studies done across the country.

The CS team also identified and searched ITS and other transportation agency web sites and relevant domestic and international transportation trade press to find ramp metering information that is current and relevant, including:

- Traffic Technology International,
- Roads and Bridges,
- The Journals of the Association of Metropolitan Planning Organizations,
- The Institute of Transportation Engineers (ITE) and American Public Works Association,
- U.S. DOT's electronic data library,

- U.S. DOT's ITS costs and benefits database, and
- State and other transportation agency DOT web sites.

The CS team also interviewed and/or surveyed individuals from two metropolitan areas with ramp meters to fill in any missing gaps in the TTI study. The two telephone interview sites included Phoenix, AZ; and Seattle, WA. The two sites were selected so as to represent different ramp metering strategies across the United States.

5.0 Field Evaluation Results

5.1 Travel Performance Data Analysis

This section presents the results of the field data collection and evaluation. Focused data collection efforts were targeted at gathering comprehensive traffic performance data for representative corridors during both the "with" and "without" study periods. Four primary study corridors were selected, as described in Section 4.0, and data was collected for periods corresponding with the times when the corridors were metered. The study corridors were metered in the following directions during the following time periods:

- I-494 Northbound (NB) p.m. peak,
- I-494 Southbound (SB) a.m. peak,
- I-35W Northbound a.m. peak,
- I-94 Eastbound (EB) p.m. peak,
- I-94 Westbound (WB) a.m. and p.m. peaks,
- I-35E Northbound p.m. peak, and
- I-35E Southbound a.m. peak.

Data collection methods included:

- Travel time runs to capture the speed, travel time, and travel time variability on the freeways, ramps, and adjacent parallel arterials;
- Traffic volume counts on freeways, ramps, and arterials; and
- Ramp delay studies to measure the delay imposed by the meters and the queue spillover effects onto the adjacent streets.

Table 5.1 summarizes the corridor travel time, travel time reliability, speed, mainline volume, ramp volume, and ramp travel time observed at the various study corridors during both the "with" and "without" periods.

5.1.1 Statistical Significance Tests

Before studying the impacts observed in the "with" and "without" periods, statistical analysis was conducted on the observed data to:

Table 5.1 Summary of Freeway and Ramp Evaluation Results

	I-494		I-35W	I-94			I-35E		Average Across All Corridors
	NB p.m.	SB a.m.	NB a.m.	EB p.m.	WB a.m.	WB p.m.	NB p.m.	SB a.m.	
Freeway Speed Average									
With (mph)	61.44	54.12	52.71	49.81	51.68	54.42	53.87	49.86	53.49
Without (mph)	53.95	42.73	50.66	44.45	44.02	45.45	50.32	37.03	46.08
Difference (%)	-12%	-21%	-4%	-11%	-15%	-16%	-7%	-26%	-14%
Difference (mph)	-7.50	-11.39	-2.05	-5.35	-7.66	-8.97	-3.55	-12.83	-7.41
Freeway Speed Standard Deviation[1]									
With (mph)	4.54	8.90	13.66	7.23	5.76	4.46	9.34	12.20	8.26
Without (mph)	5.99	16.25	16.50	9.70	8.88	8.08	7.53	12.68	10.70
Difference (%)	32%	82%	21%	34%	54%	81%	-19%	4%	36%
Difference (mph)	1.45	7.34	2.85	2.48	3.12	3.63	-1.80	0.47	2.44
Freeway Travel Time Average									
With (min)	8.8	10.4	7.4	14.8	14.1	13.3	8.1	9.1	10.77
Without (min)	10.1	15.3	8.2	17.4	17.1	16.4	8.6	12.7	13.22
Difference (%)	15%	47%	10%	18%	21%	23%	6%	40%	22%
Difference (min)	1.30	4.89	0.78	2.60	2.95	3.04	0.45	3.61	2.45
Freeway Travel Time Standard Deviation[1]									
With (min)	0.7	2.8	2.5	2.5	1.7	1.2	1.9	3.2	2.07
Without (min)	1.2	7.9	3.7	6.3	3.7	3.1	1.5	4.5	3.97
Difference (%)	64%	180%	46%	153%	114%	154%	-23%	41%	91%
Difference (min)	0.47	5.04	1.15	3.78	1.99	1.89	-0.42	1.30	1.90
Freeway Volume Average									
With	11,810	11,010	11,093	18,359	16,082	17,657	14,974	14,552	14,442
Without	11,840	10,047	10,042	17,386	15,284	16,437	12,165	12,140	13,168
Difference (%)	0%	-9%	-9%	-5%	-5%	-7%	-19%	-17%	-9%
Difference (veh)	30	-963	-1,051	-973	-798	-1,220	-2,809	-2,412	-1,275
Ramp Travel Time Average[2]									
Ramp Vol per Corr	6,872	7,659	7,526	23,099	20,898	26,010	7,844	7,486	13,424
With (min/veh)	4.0	3.1	3.3	1.6	1.8	3.3	1.4	2.5	2.6
Without (min/veh)	0.25	0.31	0.24	0.35	0.49	0.49	0.20	0.26	0.33
Difference (min/veh)	-3.7	-2.8	-3.1	-1.3	-1.3	-2.8	-1.2	-2.2	-2.3
Ramp Travel Time Standard Deviation[1,2]									
With (min/veh)	2.4	2.9	2.8	1.1	1.6	1.9	0.9	2.0	1.9
Without (min/veh)	0.03	0.16	0.11	0.13	0.11	0.09	0.03	0.09	0.09
Difference (min/veh)	-2.4	-2.7	-2.7	-1.0	-1.5	-1.8	-0.9	-1.9	-1.8

1 Standard Deviation is defined as the measure of distribution of travel time around an average value.

2 Ramp travel time consists of time it takes to travel the length of the ramp, meter delay time, and queue delay time.

- Identify any anomalies in the data that may introduce bias into the analysis of travel conditions; and

- Identify the statistical significance of differences observed in the "with" and "without" study periods.

Statistical Analysis of Field Conditions

Statistical tests were conducted on all data to identify any external factors that might introduce bias to the data. During the data collection for both the "with" and "without" study periods, all data collected on Mondays, Fridays, bad weather days (rain, snow), major incident days, and "dark" versus "light" conditions were flagged. Statistical significance tests ("t-tests") were then applied to the data to determine if these external factors resulted in data that were significantly different from other collected data.

Table 5.2 summarizes the results of the t-tests for all study corridors. Statistically significant data sets are shown in *italics*. In most instances, the variability in days of the week, weather, sunlight, or incidents were not statistically significant from each other to warrant separate analysis of the data. Therefore, all valid observations were grouped and analyzed together throughout this study.

Table 5.2 Field Condition T-Test Results Across All Corridors

Comparison	Travel Time	Speed
Tuesday-Thursday vs. Monday	1.11	1.72
Tuesday-Thursday vs. Friday	1.33	1.26
Monday vs. Friday	0.19	0.37
Light vs. Dark	1.64	0.54
Dry vs. Wet	1.95	*3.35*
Incidents vs. Not	*3.47*	*3.85*

Note: Statistically significant differences in *italics*.

Statistical Analysis Between "With" and "Without" Meter Study Periods

Once the data was categorized and grouped, another t-test procedure was performed on the "with" and "without" data sets to determine whether or not the observed data statistically supports the hypothesis that ramp metering makes a significant impact on travel speeds and traffic volume.

Table 5.3 summarizes the comparisons between "with" and "without" data sets. Except for a few isolated instances, statistically significant differences were observed in speed and volume on all study corridors.

Table 5.3 "With" Versus "Without" T-Test Results

	I-494		I-35W	I-94			I-35E		
With vs. Without t-test	**NB p.m.**	**SB a.m.**	**NB a.m.**	**EB p.m.**	**WB a.m.**	**WB p.m.**	**NB p.m.**	**SB a.m.**	**All Corridors**
Speeds	*8.07*	*4.25*	1.55	*5.86*	*4.65*	*7.14*	*2.47*	*5.94*	*4.99*
Volumes	0.82	*5.69*	*4.62*	*2.71*	*2.33*	*3.99*	*18.33*	*21.16*	*7.46*

Note: Statistically significant differences in *italics*.
EB = Eastbound, NB = Northbound, SB = Southbound, and WB = westbound.

5.2 Travel Performance Results

5.2.1 Travel Time and Travel Speed

Once the statistical significance of the data sets were confirmed, detailed analysis was conducted to identify the impacts (both positive and negative) attributable to the ramp metering system.

Freeway mainline travel times were observed to be lower in the "with metering" study period for all study corridors and directions. On average, mainline travel time was 22 percent or 2.5 minutes less with metering. The highest travel time improvement occurred on I-494 SB in the a.m. peak period, improving from 15.3 minutes (without metering) to 10.4 minutes (with metering).

Without metering, the reliability of travel time was also observed to decrease by an average of 91 percent as reflected by an increase in the range of travel time. This finding was supported by observations of highway patrol personnel who reported an increase in the duration of accidents due to longer time required for emergency personnel to access the scene of the accidents. The highest travel time reliability percentage increase occurred on the I-494 SB a.m. peak period corridor (increasing from 2.8 to 7.9 minutes), I-94 WB p.m. peak period corridor (increasing from 1.2 to 3.1 minutes), and I-94 EB p.m. peak period corridor (increasing from 2.5 to 6.3 minutes).

Similarly, travel speeds on the freeway mainlines improved with metering by an average of 14 percent or 7.4 miles per hour (mph). The largest speed improvement was observed on southbound I-35E and I-494 during the a.m. peak period (26 percent or 12.8 mph, and 21 percent or 11.4 mph, respectively). I-35W NB a.m. and I-35E NB p.m. showed the least amount of speed improvements (only four percent and seven percent, respectively).

Figures 5.1 through 5.8 illustrate the travel speeds observed on the study corridors for all weekdays. Appendix B contains travel speed results categorized by the different days of the week. The solid lines indicate average speeds, while the dashed lines represent the

Figure 5.1 I-494 NB Afternoon Speed and Speed Variability

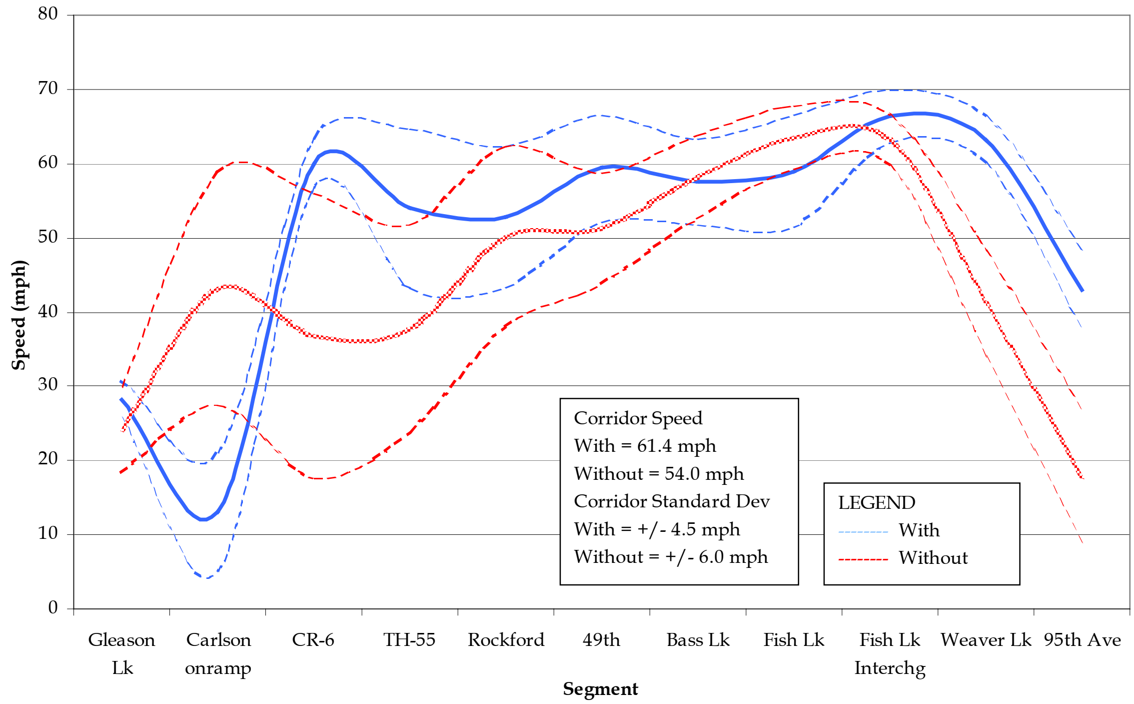


Figure 5.2 I-494 SB Morning Speed and Speed Variability

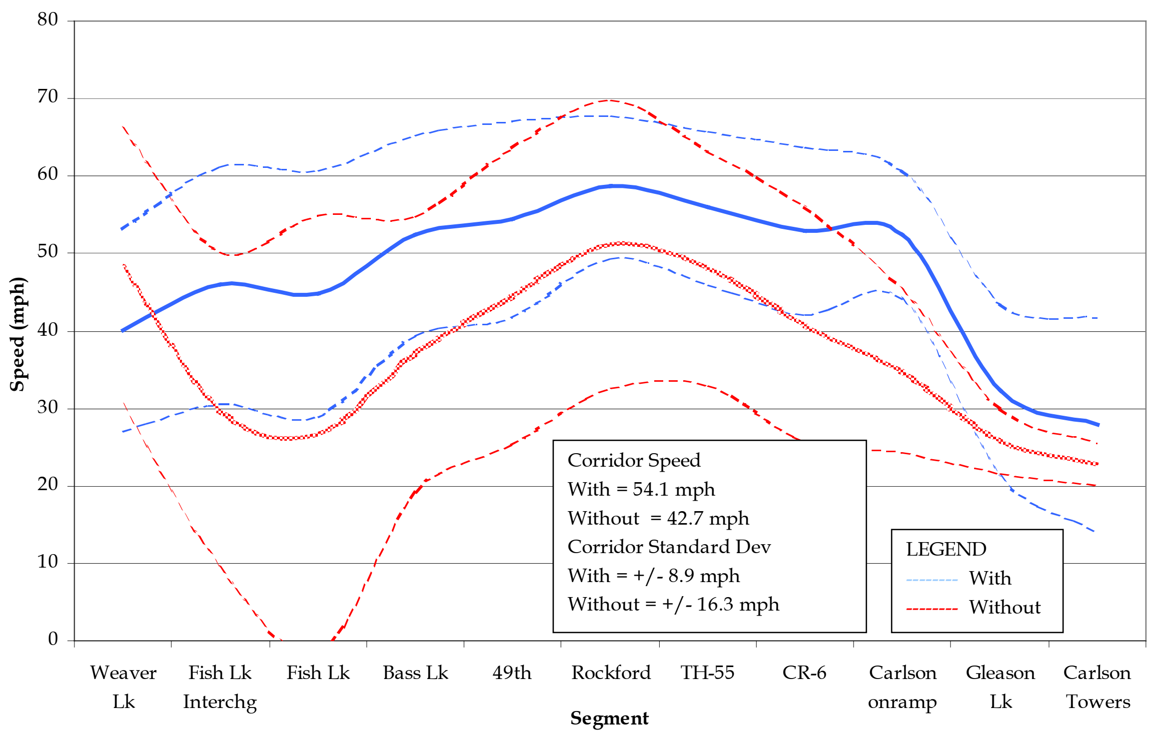


Figure 5.3 I-35W NB Morning Speed and Speed Variability

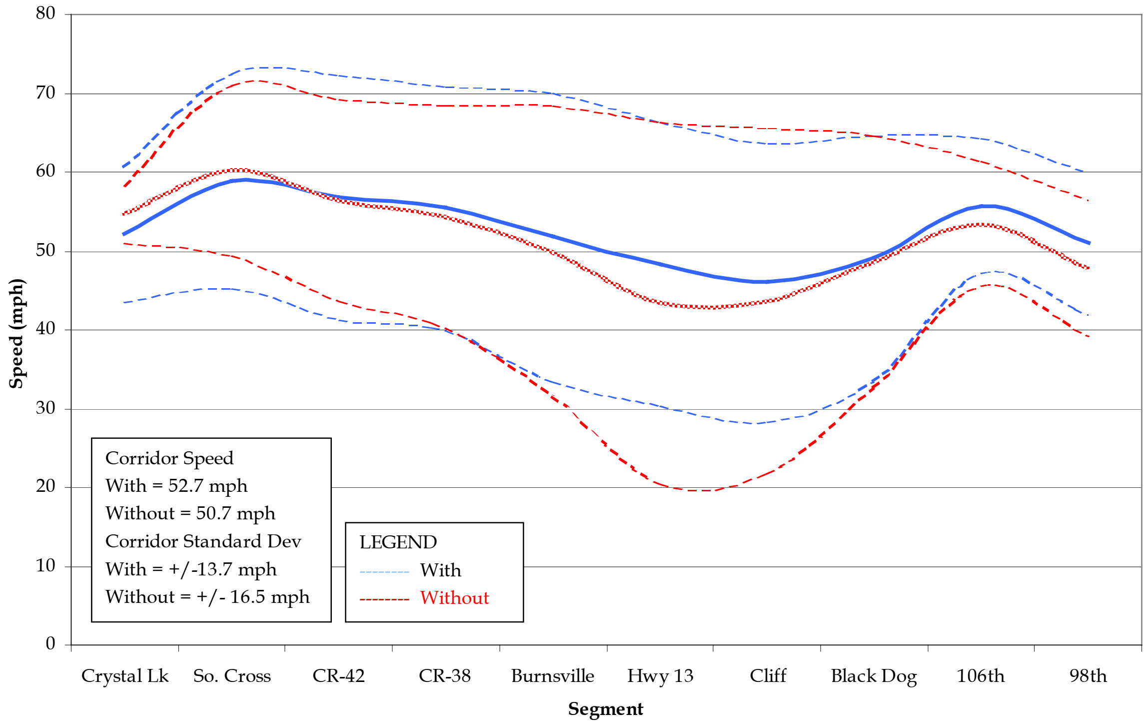


Figure 5.4 I-94 EB Afternoon Speed and Speed Variability

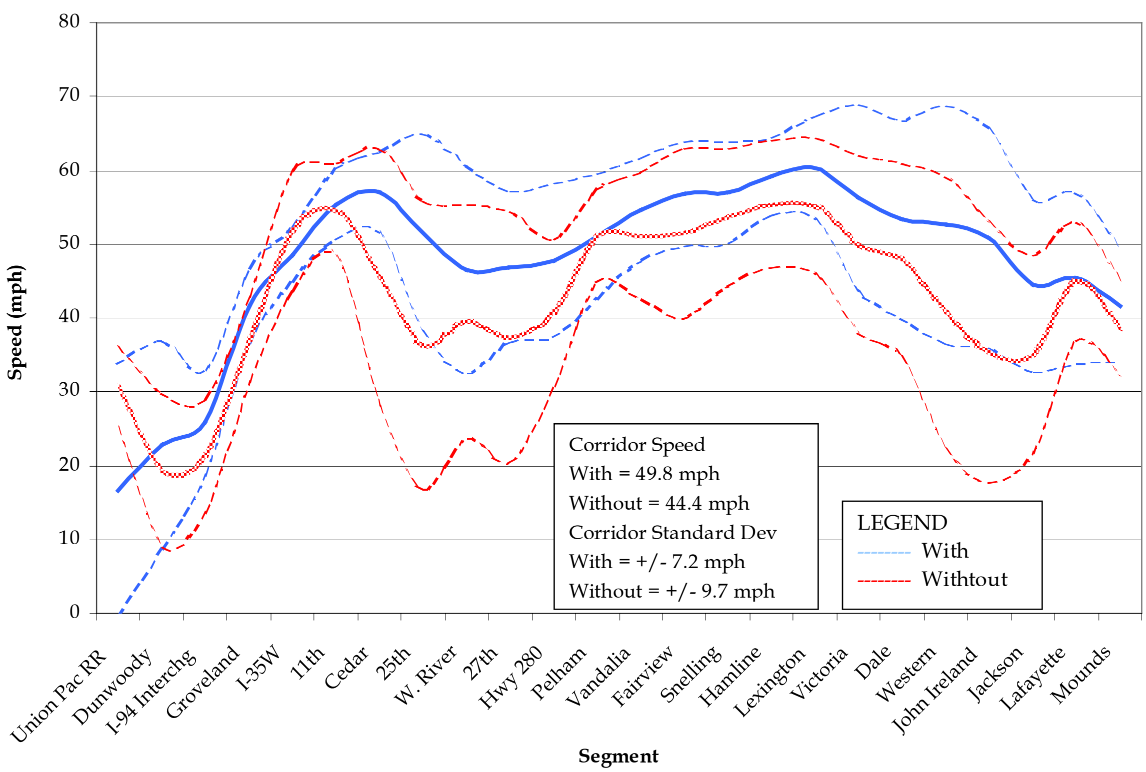


Figure 5.5 I-94 WB Morning Speed and Speed Variability

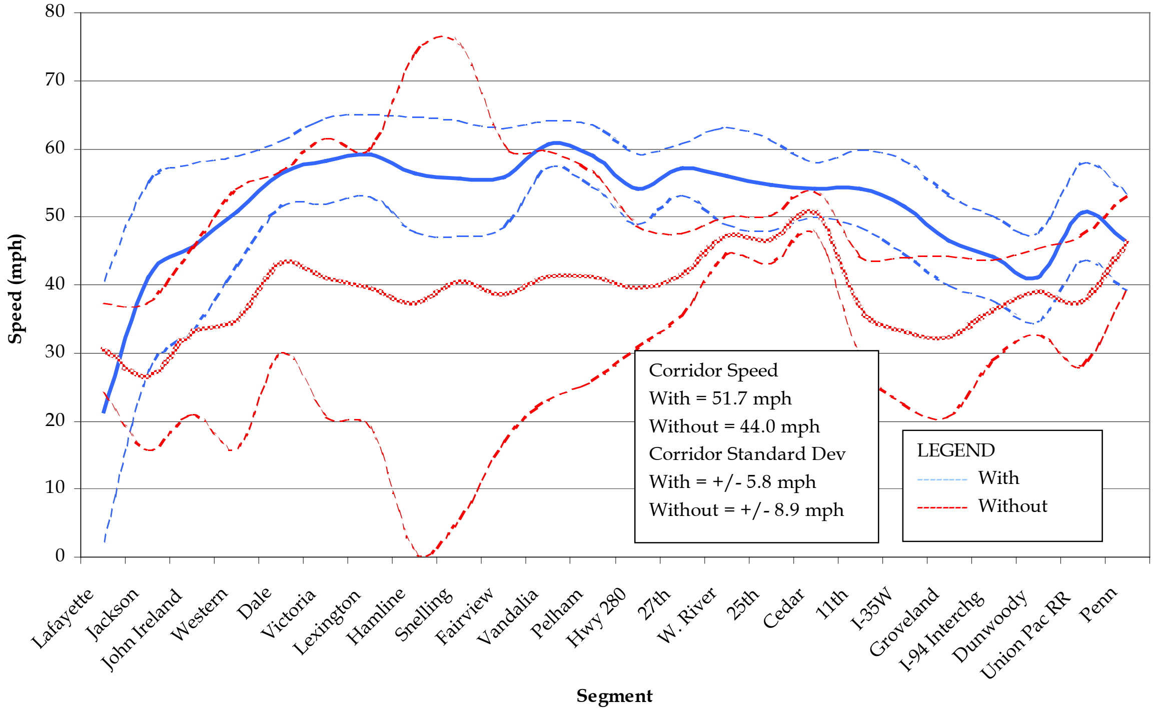


Figure 5.6 I-94 WB Afternoon Speed and Speed Variability

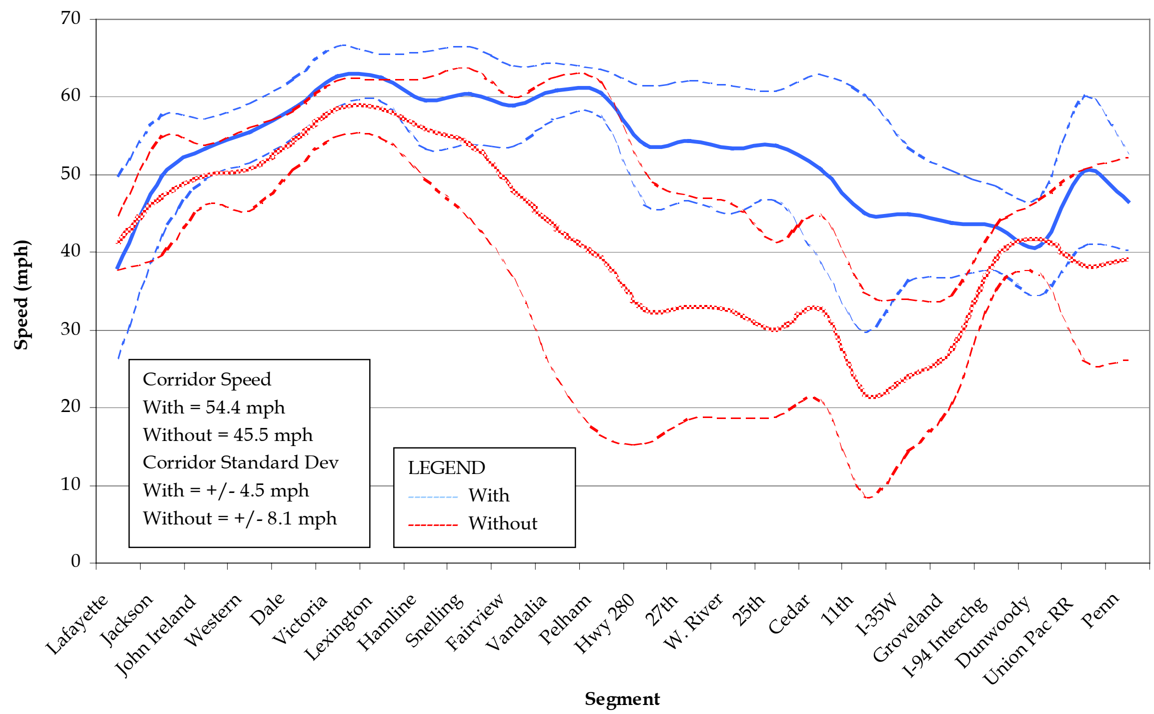


Figure 5.7 I-35E NB Afternoon Speed and Speed Variability

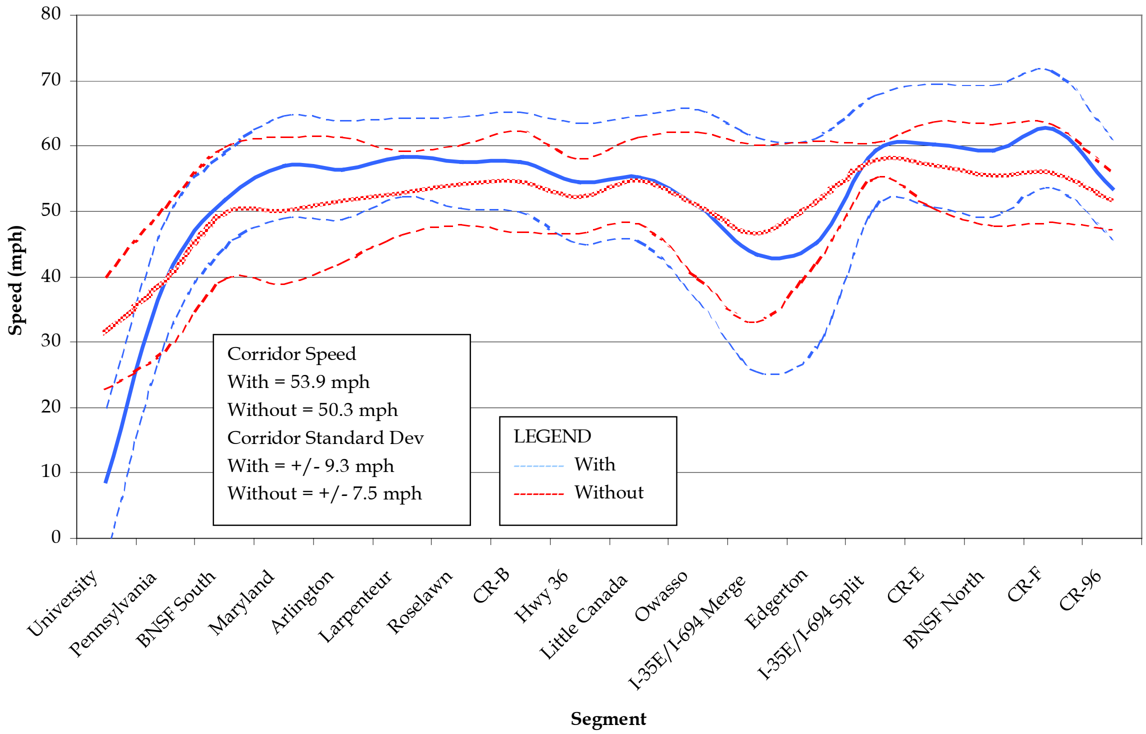
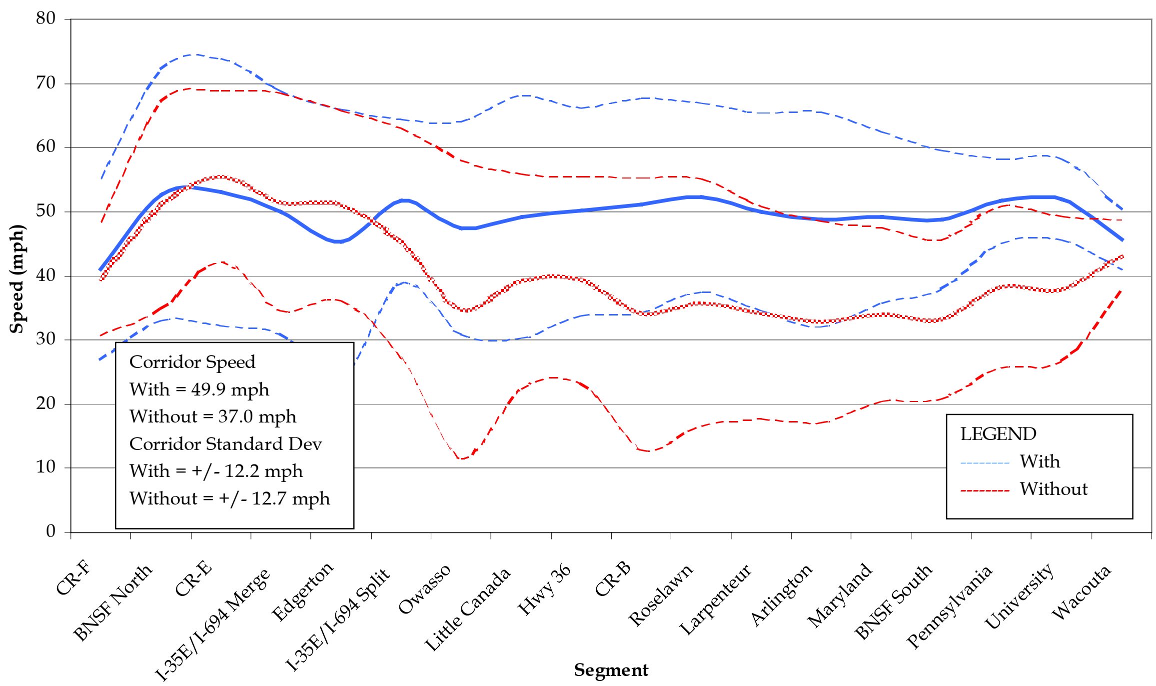


Figure 5.8 I-35E SB Morning Speed



upper and lower ranges of the average speeds. In this report, the range is defined as one standard deviation above and below the average value, which covers approximately 70 percent of all observations (blue lines represent the "with" study period, red lines represent the "without" study period). The larger the distance between a solid line and its corresponding dashed lines, the larger the speed variability observed (i.e., travel time is less reliable). Conversely, tighter sets of lines indicate that the speeds do not deviate as greatly from the average, and travel speed is more predictable.

Figure 5.9 illustrates the relationship between speed and throughput as recorded by a station detector on I-94 EB p.m. The lower chart shows that speed was consistently lower in the "without" period (red line) than the "with" period (green line). The jaggedness of the red line also indicates that the speed variability was increased in the absence of ramp meters. Although not as dramatic as the speed difference, the freeway traffic flow (volume) during the metered condition was also generally higher than its non-metered counterpart.

In general, parallel arterial speeds stayed the same "with" and "without" metering. Table 5.4 summarizes the changes in speeds and their standard deviations at selected arterials paralleling the study corridors. The speed stability in the two study periods may be attributed to the fact that traffic signals control many of the intersections along the arterials; unless there are significant changes in arterial volumes that cause gridlock at intersections, speeds along the arterials would be expected to remain relatively unchanged.

According to the traffic volume analysis presented in the next section, there were no changes in traffic volumes on the arterials segments of sufficient magnitude to cause the failure of arterial signal systems or a significant degradation of travel time. Figures 5.10 and 5.11 illustrate examples of travel speeds along CR-61 NB p.m. and Vicksburg NB p.m., arterials that parallel the I-494 study corridor. Appendix B shows the remainder of the arterial speed figures.

5.2.2 Freeway Traffic Volume and Throughput

With the meters off, a peak period volume traffic reduction of about nine percent was observed for all study corridors, or approximately 1,200 vehicles per corridor. The largest volume reduction was observed on I-35E NB p.m. (2,800 vehicles), while I-494 NB p.m. experienced virtually no changes in traffic volumes. There was minimal traffic diversion onto the studied parallel arterials due to the shutdown. In fact, an average decrease of 56 vehicles per studied parallel arterial was observed in the "without" period (refer to Table 5.4 for details). The observed reduction in traffic volumes in the "without" study period supports the notion that ramp metering results in greater throughput capacity on freeway facilities.

Figures 5.12 through 5.19 show the traffic volume differences at the freeway corridors, as well as their corresponding parallel arterials. Larger circles represent higher volume differences between the metered and non-metered conditions. For the actual traffic volumes at all corridors and arterials, refer to Appendix C.

Figure 5.9 Detector Reading – Example of Changes to Speed and Speed Variability

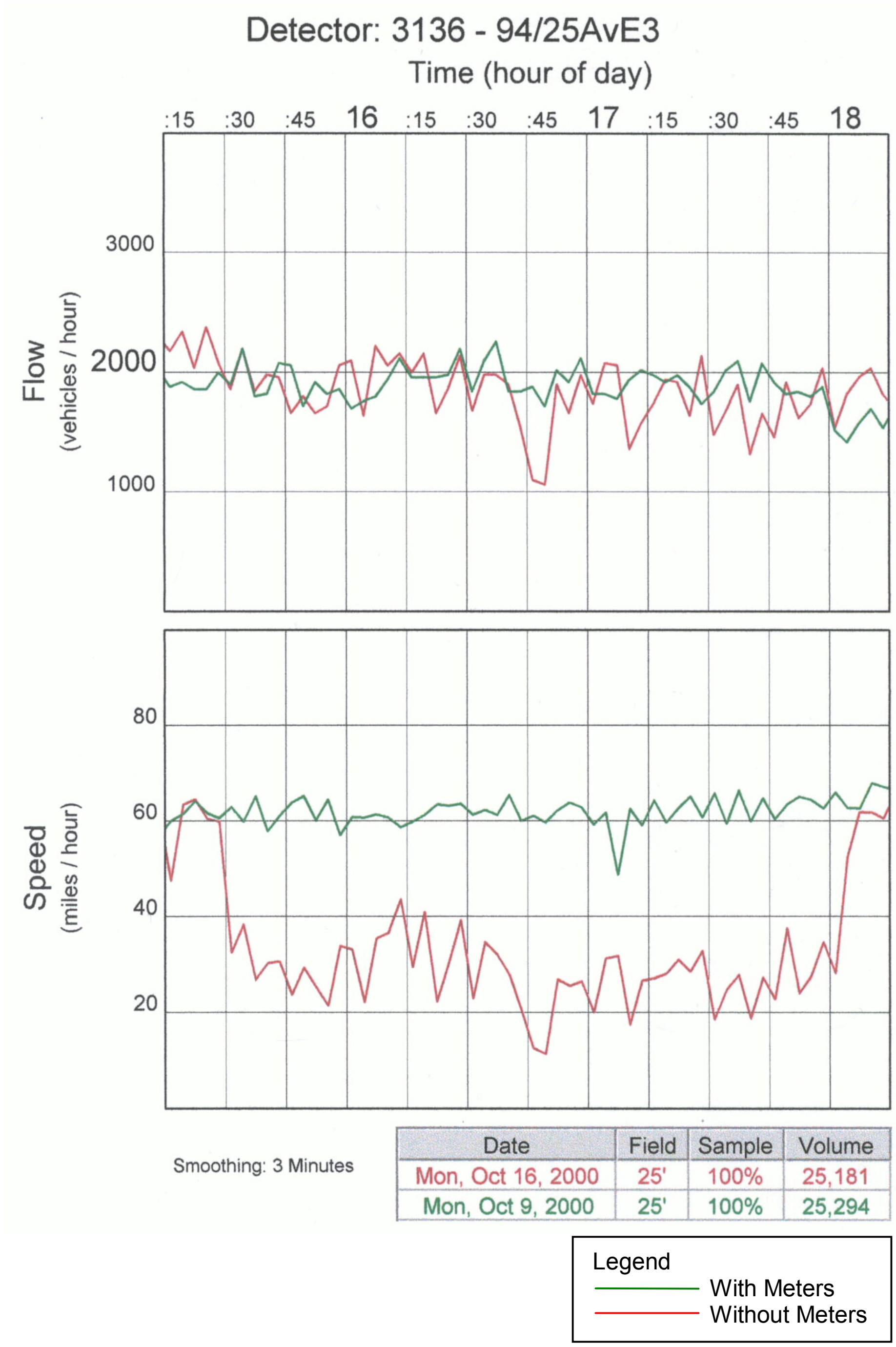


Table 5.4 Summary of Arterial Evaluation Results

	CR-61		Vicksburg		TH-77	University			Marshall			Rice		Edgerton		All Arterials
	NB p.m.	SB a.m.	NB p.m.	SB a.m.	NB a.m.	EB p.m.	WB a.m.	WB p.m.	EB p.m.	WB a.m.	WB p.m.	NB p.m.	SB a.m.	NB p.m.	SB a.m.	
Arterial Speed Average																
With Metering (mph)	31.02	32.48	31.27	32.78	59.88	22.08	25.13	23.81	18.85	22.40	21.30	25.58	18.18	27.84	26.53	27.94
Without Metering (mph)	31.33	31.20	31.92	31.53	60.91	21.47	24.93	23.32	22.12	22.36	23.19	26.76	28.57	28.34	27.61	29.04
Difference (%)	1%	-4%	2%	-4%	2%	-3%	-1%	-2%	17%	0%	9%	5%	57%	2%	4%	6%
Difference (mph)	0.30	-1.28	0.65	-1.24	1.03	-0.61	-0.19	-0.50	3.26	-0.03	1.88	1.18	10.39	0.50	1.08	1.09
Arterial Speed Std Dev																
With Metering (mph)	6.05	6.69	4.00	4.44	8.11	5.51	5.78	6.50	4.95	4.55	4.37	5.87	4.65	3.54	4.41	5.29
Without Metering (mph)	5.38	5.54	3.45	5.04	7.23	5.98	5.84	5.79	4.49	4.67	4.14	5.28	5.46	3.17	6.27	5.18
Difference (%)	-11%	-17%	-14%	13%	-11%	9%	1%	-11%	-9%	3%	-5%	-10%	18%	-10%	42%	-1%
Difference (mph)	-0.68	-1.15	-0.55	0.59	-0.88	0.48	0.06	-0.70	-0.46	0.11	-0.23	-0.59	0.82	-0.36	1.86	-0.11
Arterial Vol Average																
With Metering	2,573	2,138	1,762	1,484	11,092	2,921	1,592	2,299	1,622	1,084	1,312	2,141	1,652	1,811	1,395	2,458.50
Without Metering	2,406	1,913	1,433	1,366	10,141	2,793	2,057	2,521	2,265	646	1,364	2,129	1,538	1,713	1,742	2,401.81
Difference (%)	-6%	-11%	-19%	-8%	-9%	-4%	29%	10%	40%	-40%	4%	-1%	-7%	-5%	25%	0%
Difference (veh)	-166	-225	-329	-118	-951	-128	465	52	-12	-438	222	643	-114	-98	347	-56.69
Arterial With vs. Without T-Test																
Speed	0.71	0.82	0.72	1.49	0.29	0.17	0.14	1.61	6.86	0.62	3.82	2.55	1.52	1.44	0.38	

Figure 5.10 CR-61 NB Afternoon Speed and Speed Variability

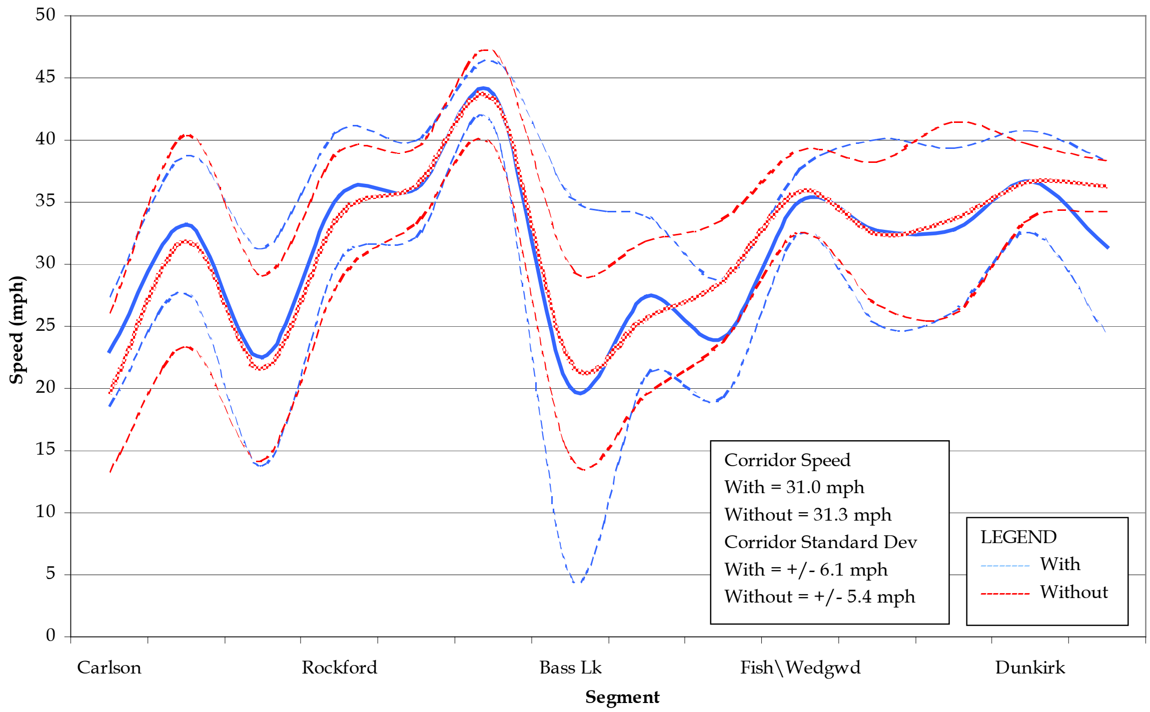


Figure 5.11 Vicksburg Avenue NB Afternoon Speed and Speed Variability

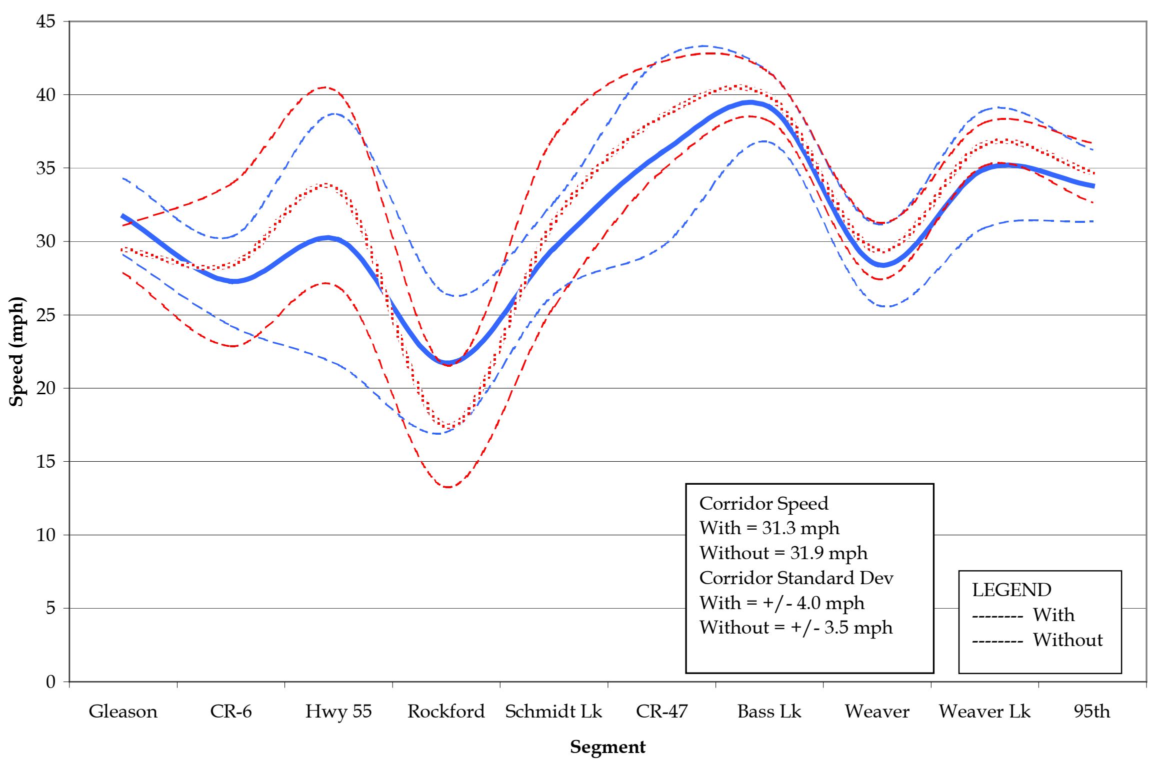
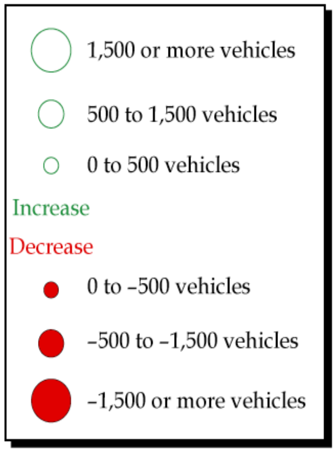
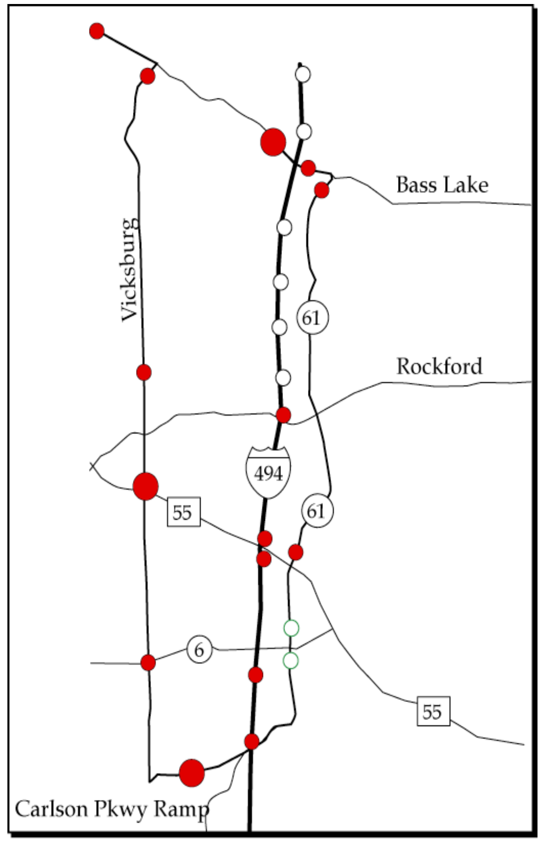


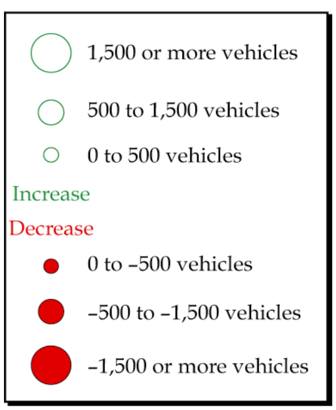
Figure 5.12

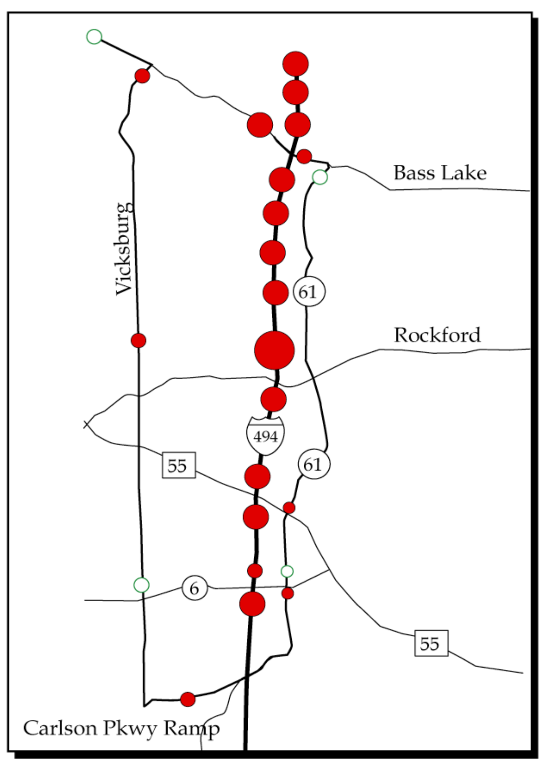




Average Volumes	I-494	CR-61	Vicksburg
With Metering	11,810	2,573	1,762
Without Metering	11,840	2,406	1,433

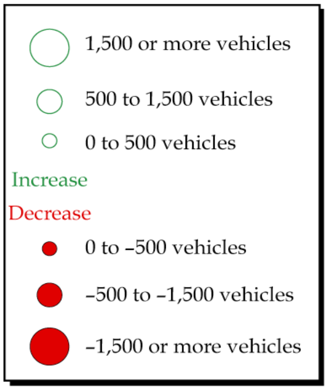
Figure 5.13 I-494 SB A.M. Traffic Volume Differences



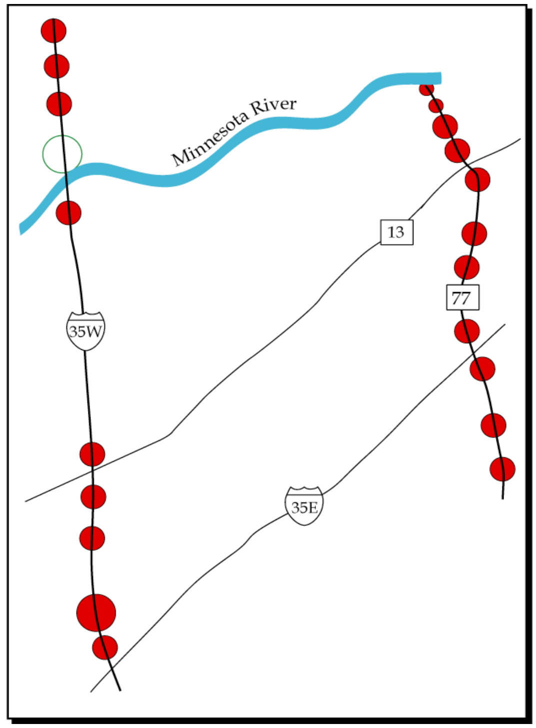


Average Volumes	I-494	CR-61	Vicksburg
With Metering	11,010	2,138	1,484
Without Metering	10,047	1,913	1,366

Figure 5.14 I-35W NB A.M. Traffic Volume Differences



Average Volumes	I-35W	TH-77
With Metering	11,093	11,092
Without Metering	10,042	10,141



Analysis on the temporal distribution of traffic showed limited peak spreading outside the peak periods (6:00 to 9:00 a.m. or 3:00 to 6:00 p.m.). In some cases, slight shifts were observed in traffic volumes away from the peak period towards earlier or later departure times in the off-peak period.

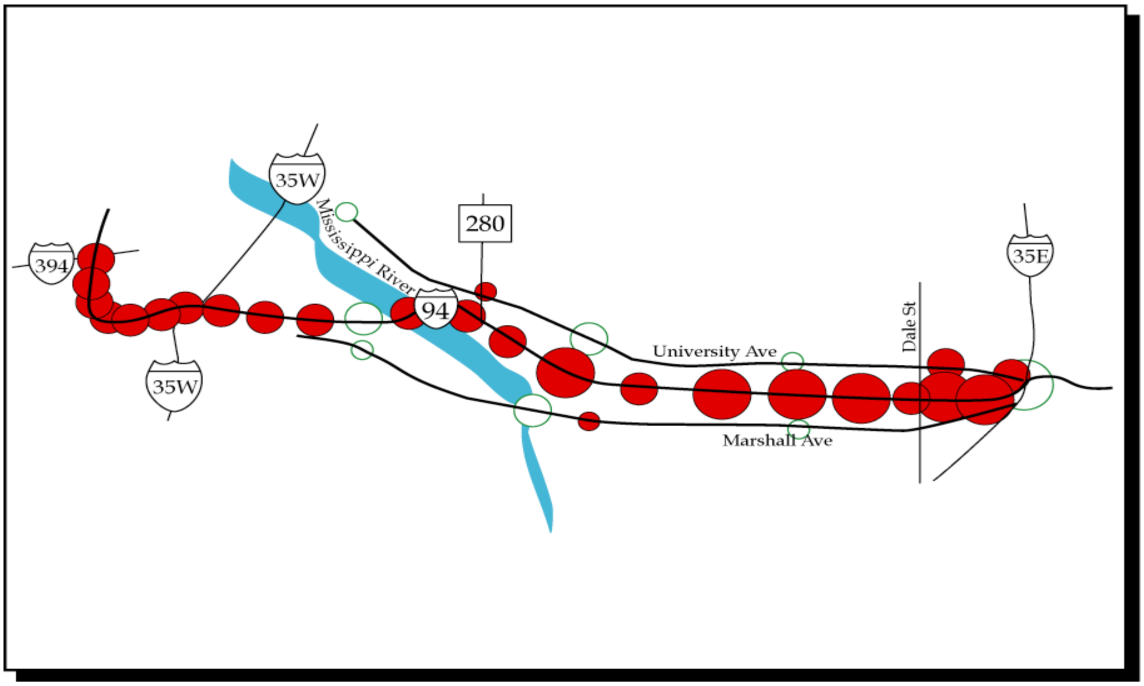
Figure 5.20 illustrates an example of this peak period shift observed on I-94 EB p.m. Between 2:30 and 3:15 p.m., higher traffic volumes were observed in the "without" case than in the "with" case, indicating that some commuters were leaving earlier to avoid peak period congestion.

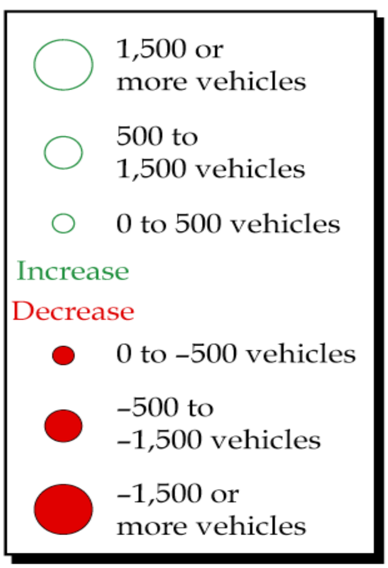
The studied parallel arterials experience virtually no volume changes between the two study periods, indicating that the remaining volume reductions from the freeways may have diverted to arterials that were not included in this study, or shifted out of the peak periods entirely. This could also suggest that the increased freeway congestion resulted in some travelers foregoing their normal trips.

5.2.3 Ramp Traffic Volume and Ramp Travel Time

While the meters were on, each ramp carried an average of 1,500 vehicles per peak period, ranging from 1,121 vehicles per ramp on I-35E NB p.m. to 2,001 vehicles per ramp on I-94 WB p.m.

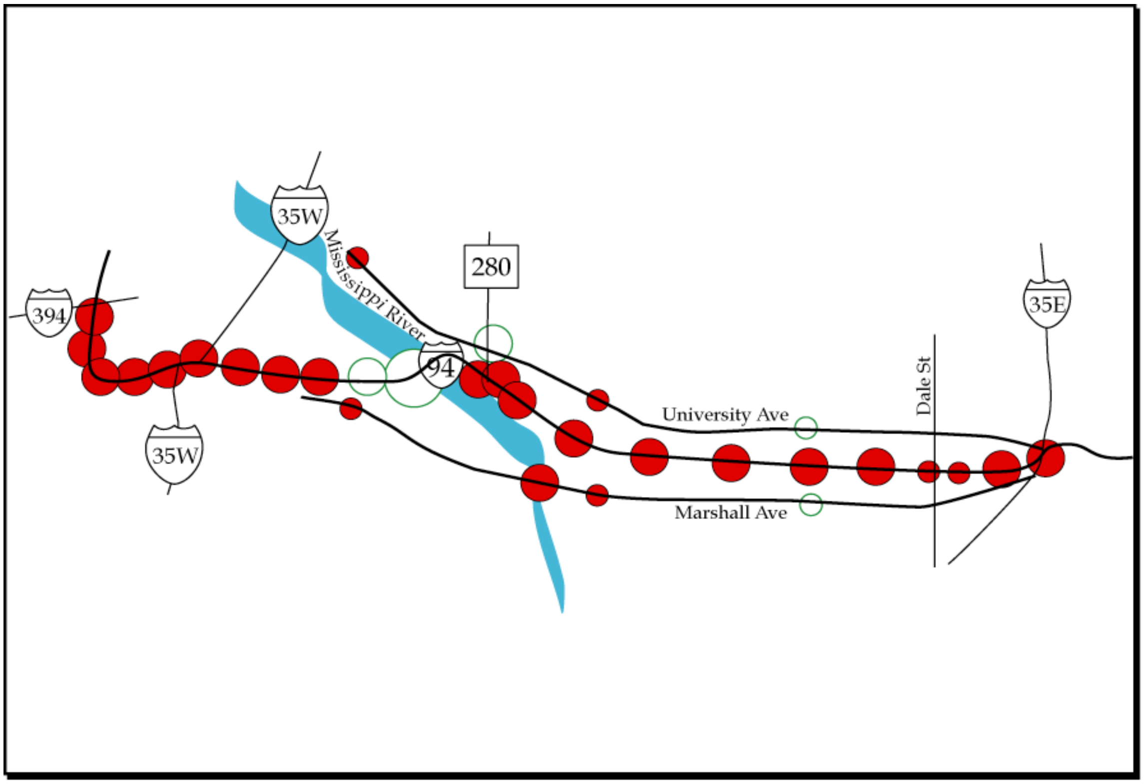
Figure 5.15 I-94 EB P.M. Traffic Volume Differences

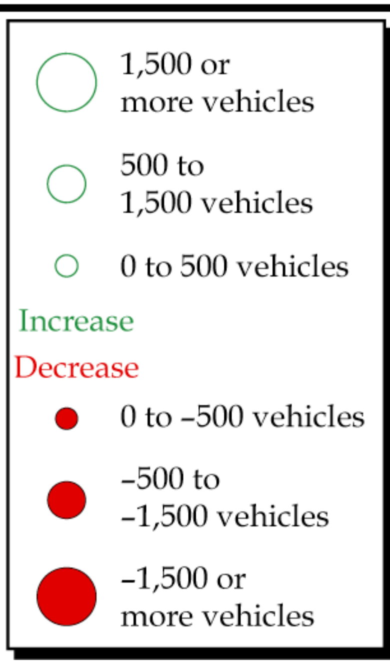




Average Volumes	I-94	University	Marshall
With Metering	18,359	2,921	1,622
Without Metering	17,386	2,793	2,265

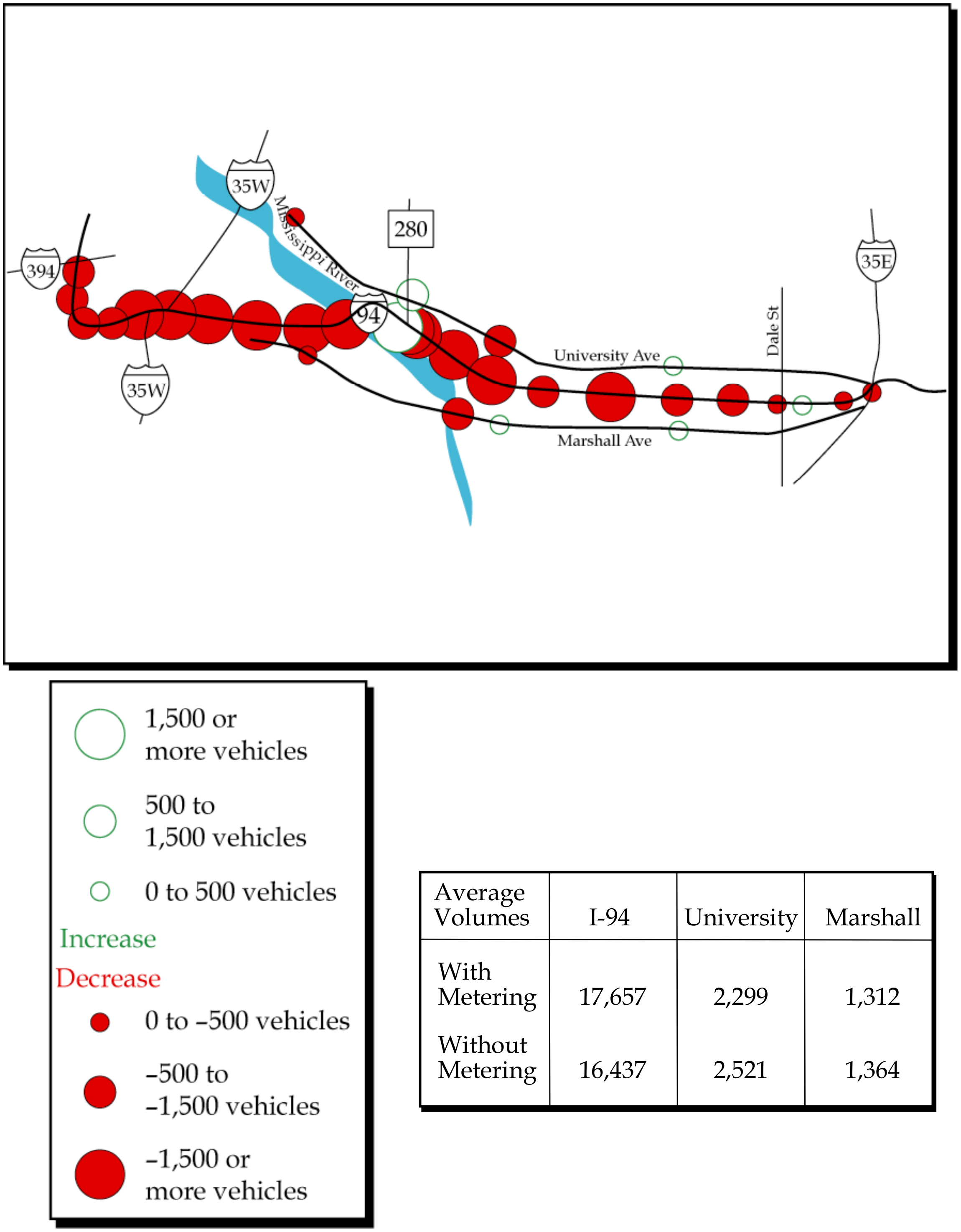
Figure 5.16 I-94 WB A.M. Traffic Volume Differences





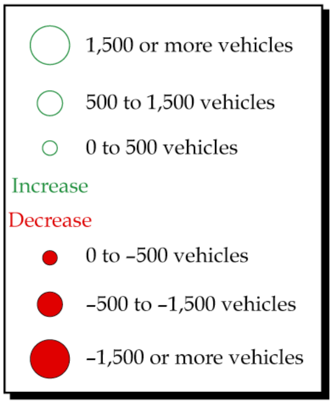
Average Volumes	I-94	University	Marshall
With Metering	16,082	1,592	1,084
Without Metering	15,284	2,057	646

Figure 5.17 I-94 WB P.M. Traffic Volume Differences



Average Volumes	I-94	University	Marshall
With Metering	17,657	2,299	1,312
Without Metering	16,437	2,521	1,364

Figure 5.18 I-35E NB P.M. Traffic Volume Differences



Average Volumes	I-35E	Rice	Edgerton
With Metering	14,974	2,141	1,811
Without Metering	12,165	2,129	1,713

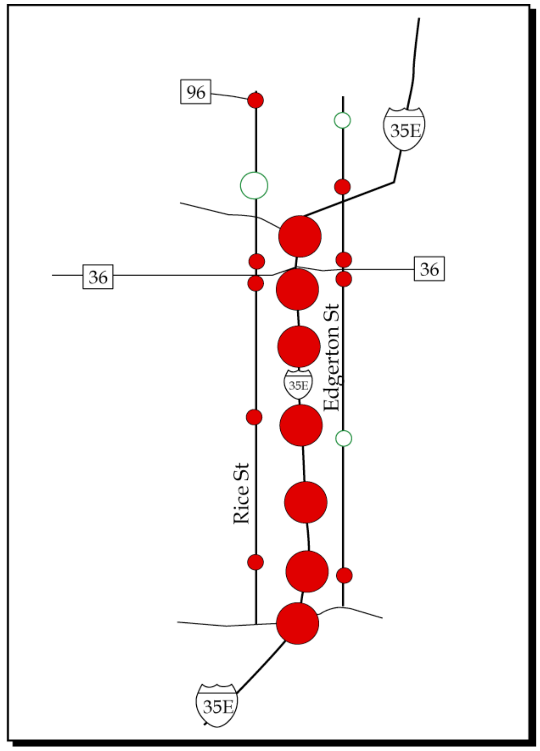
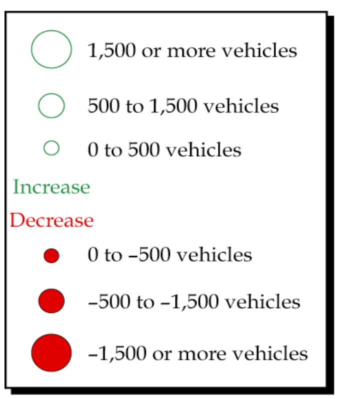


Figure 5.19 I-35E SB A.M. Traffic Volume Differences



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

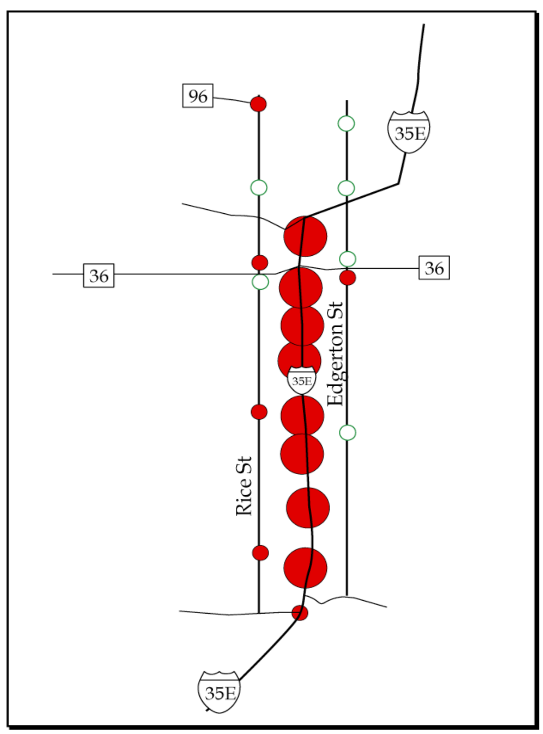
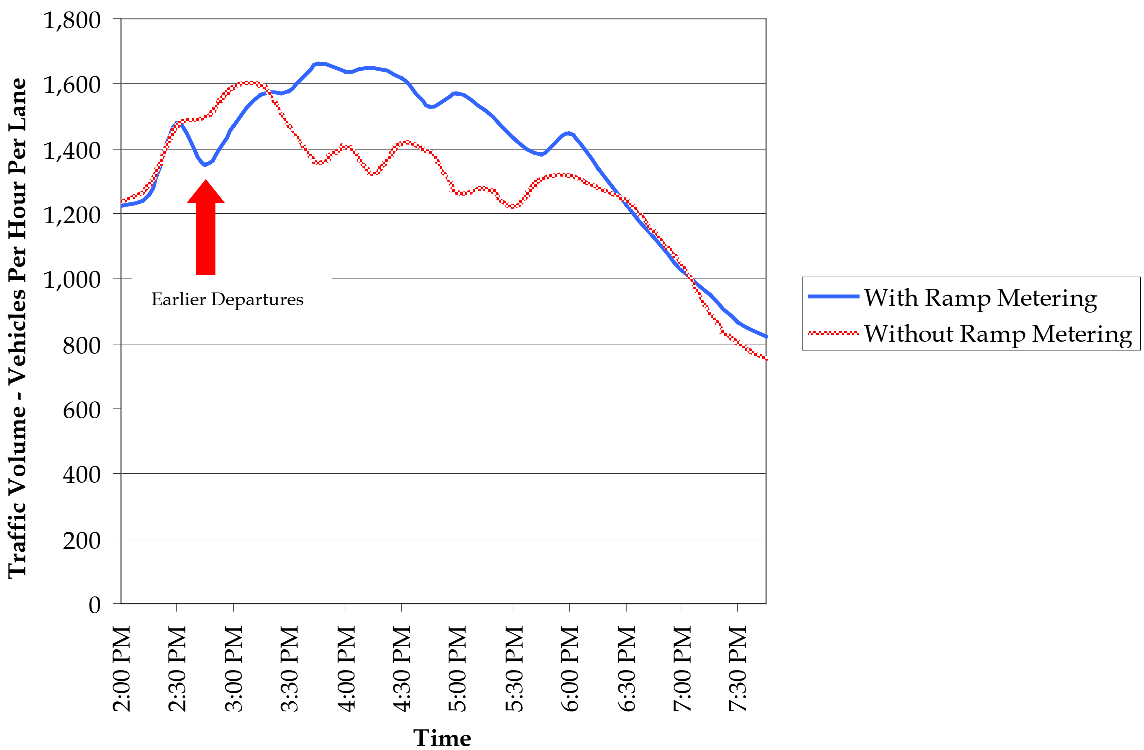


Figure 5.20 I-94 EB Afternoon Volume Spread



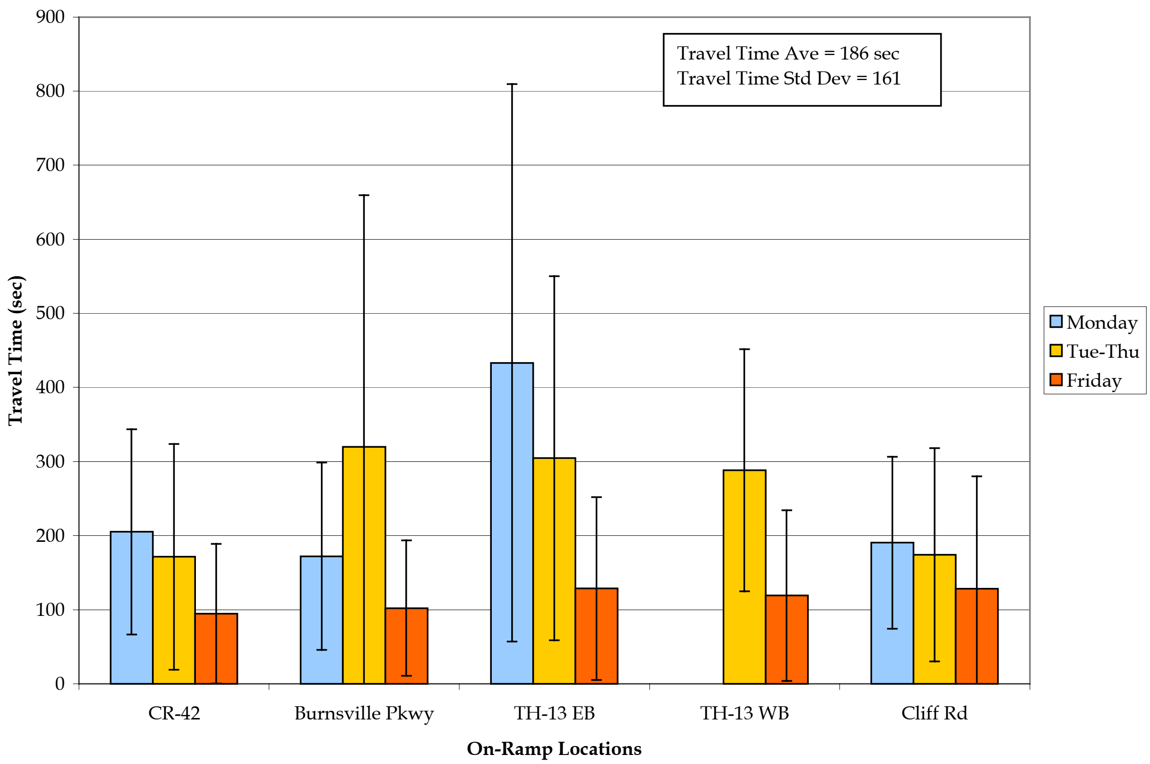
Without metering, vehicles may enter the freeway without delay at the meter. The ramp travel time in the absence of metering was calculated based on the time it takes to travel the length of the ramp, assuming that the average speed on the ramp is approximately the same as the mainline right lane speed).

With metering, ramp travel time includes the meter delay and the queue delay, in addition to the distance travel time. With meters on, the average ramp travel time in all studied corridors was 158 seconds or 2.6 minutes.

Metering also resulted in increased travel time variability at the ramps. Based on the collected data, ramp travel time variability was about 117 seconds (almost two minutes) when the meters were on, compared to only six seconds without the meters.

Figure 5.21 illustrates the ramp travel times observed at I-35W NB a.m. with the meters on. The travel times are categorized into three different sets according to the day of the week (e.g., Mondays, Tuesdays through Thursdays, and Fridays). The vertical lines indicate the variability in the travel times. At this particular corridor, the average ramp travel time was 200 seconds (3.3 minutes), with an average variability of 168 seconds (2.8 minutes). The remainder of the ramp travel time figures categorized by different days of the week can be found in Appendix D.

Figure 5.21 I-35W NB Morning Ramp Travel Time



Figures 5.22 through 5.30 illustrate the comparison of ramp travel times between the "with" and "without" study periods. For simplicity, data from different days of the week were grouped together. Overall, the observed data indicate that ramp travel time was reduced by 139 seconds (2.3 minutes), and travel time reliability was improved by 111 seconds (1.9 minutes) in the "without" study period.

5.2.4 Freeway Mainline Versus Ramp Travel Times

From the freeway mainline perspective, ramp metering was shown to improve travel time by an average of 2.5 minutes and improve travel time reliability by 1.9 minutes for the average nine-mile segment observed by the evaluation team. These improvements on the freeway mainline are balanced against a worsening of conditions at the ramp facilities. Metering imposed an average of 2.3 minutes of additional delay at the ramps and reduced the ramp travel time reliability by an average of 1.85 minutes.

Direct comparison of the observed impacts suggests that ramp metering results in a net travel time benefit for the study corridors. The corridor mainline freeways carried an average of 14,400 vehicles during the peak period, which translated to about 590 hours of time savings on average per peak period. The ramps for each corridor carried an average

Figure 5.22 I-494 NB Afternoon Ramp Travel Time

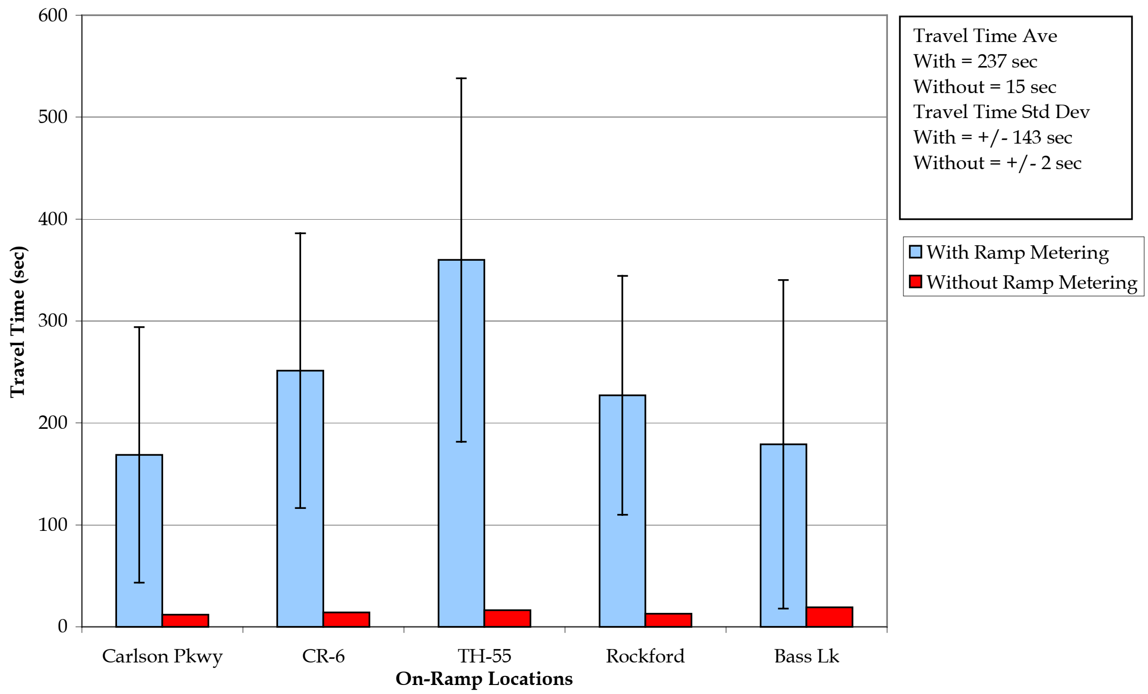


Figure 5.23 I-494 SB Morning Ramp Travel Time

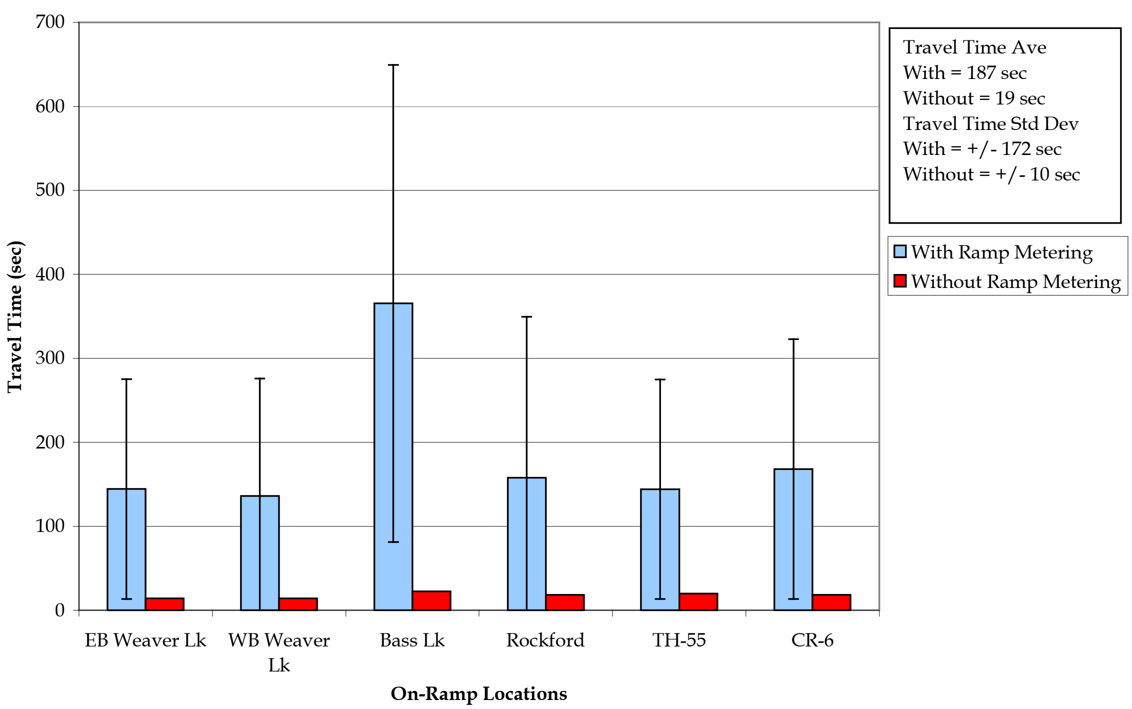


Figure 5.24 I-35W NB Morning Ramp Travel Time

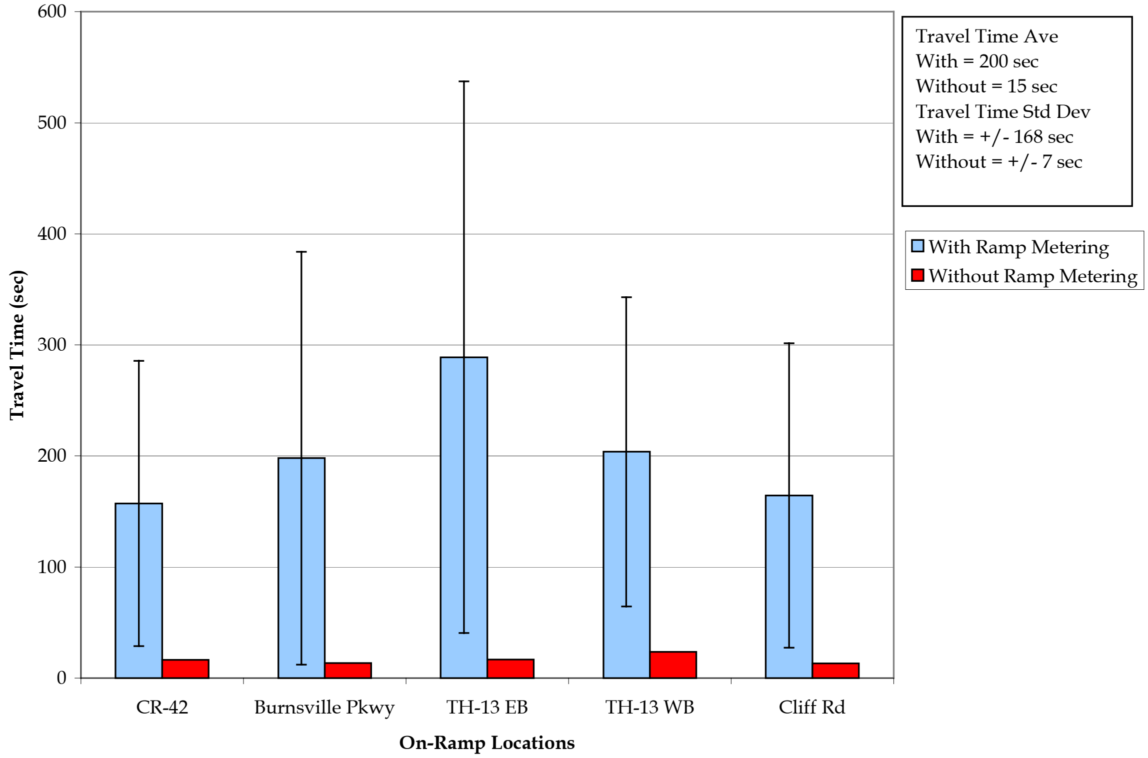


Figure 5.25 I-94 EB Afternoon Ramp Travel Time

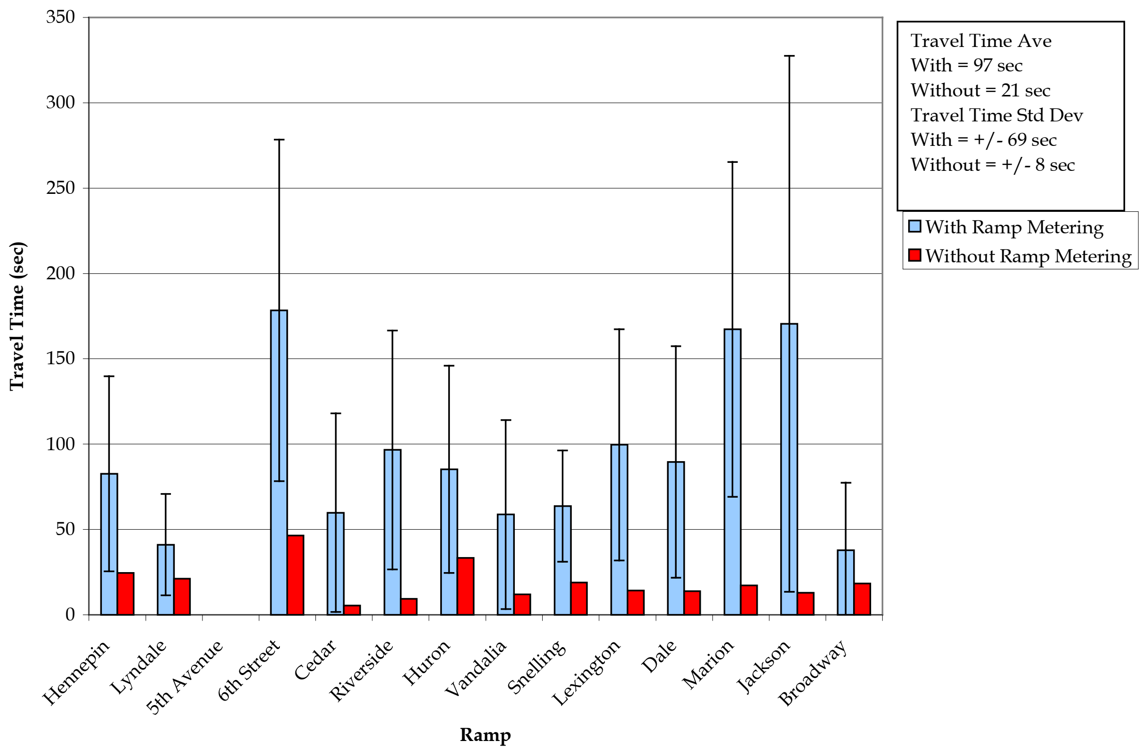


Figure 5.26 I-94 WB Morning Ramp Travel Time

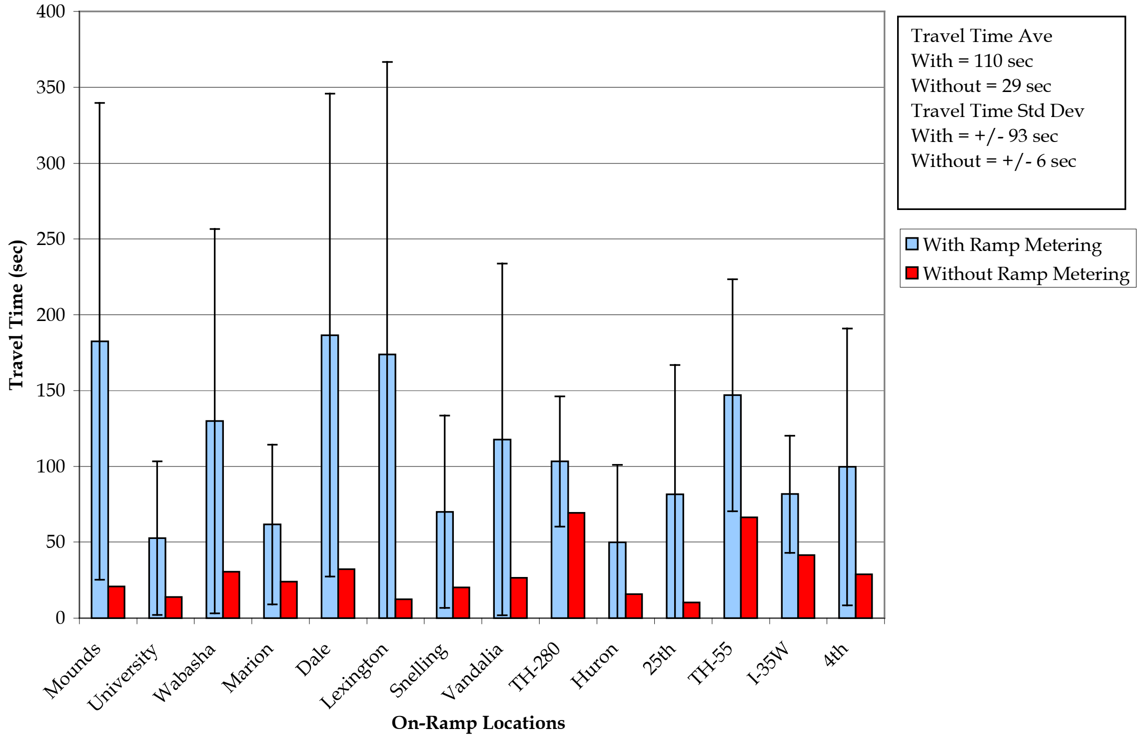


Figure 5.27 I-94 WB Afternoon Ramp Travel Time

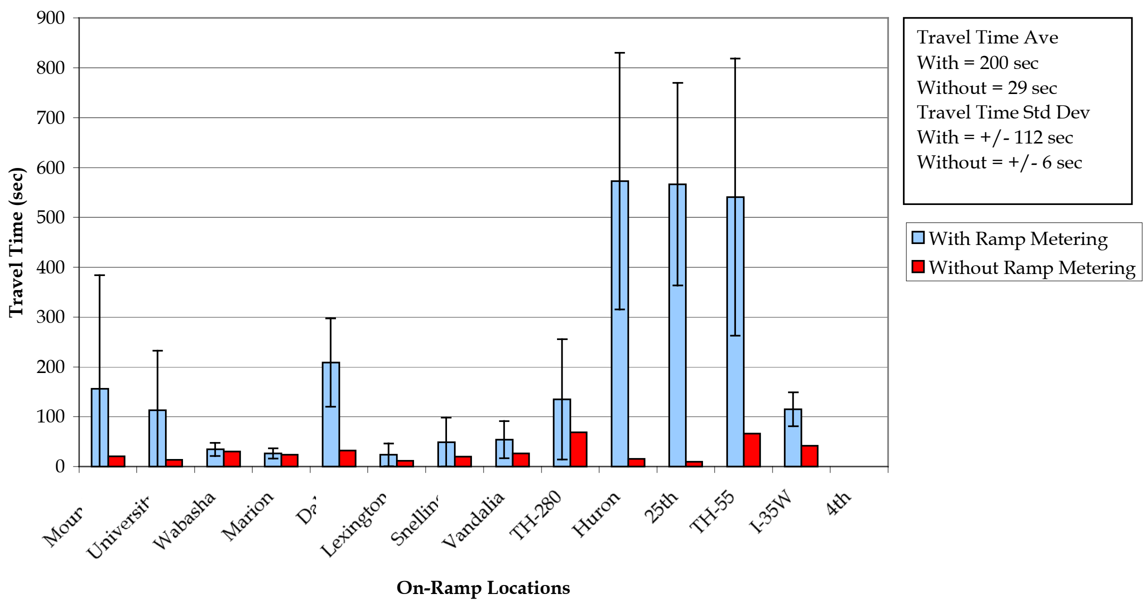


Figure 5.28 I-35E NB Afternoon Ramp Travel Time

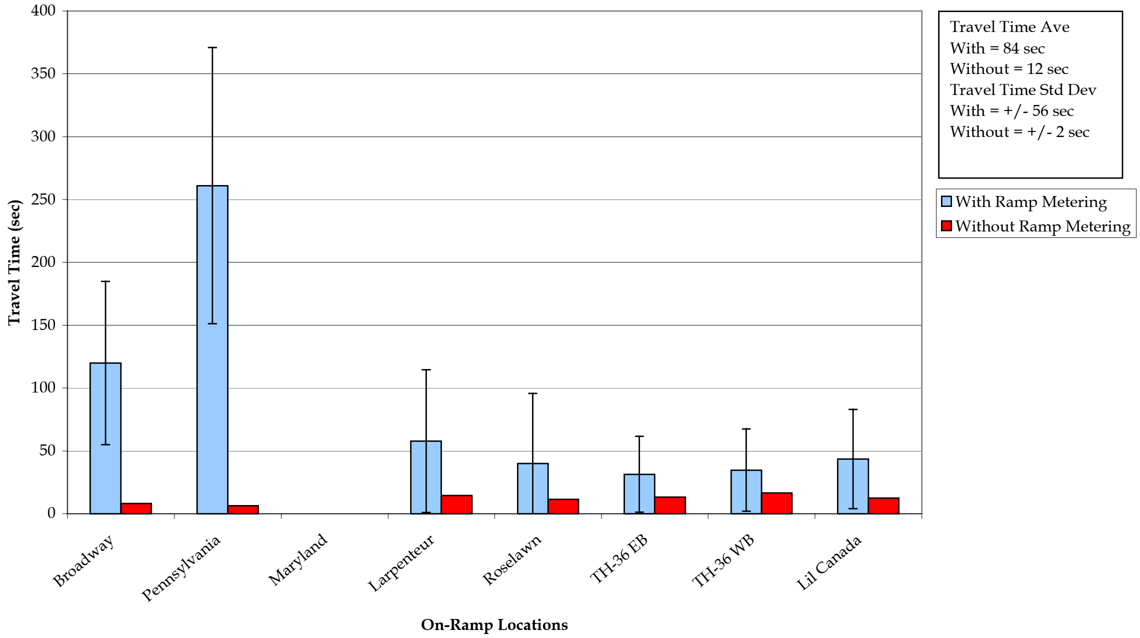


Figure 5.29 I-35E SB Morning Ramp Travel Time

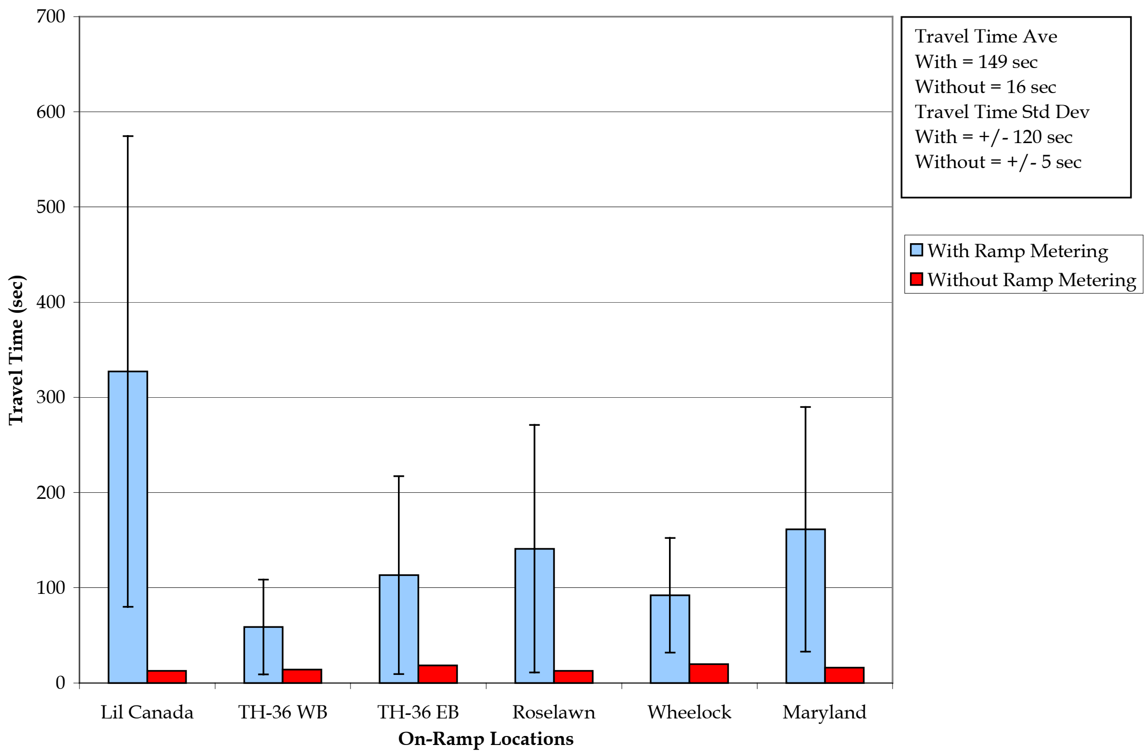
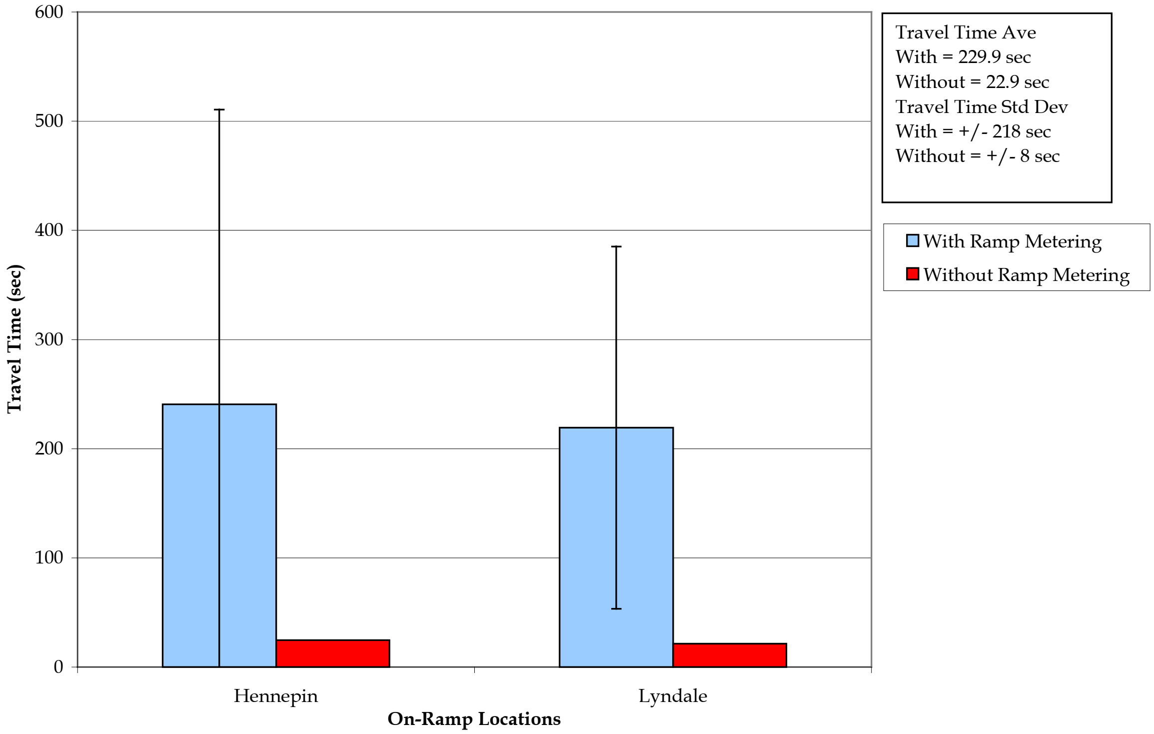


Figure 5.30 I-94 EB Morning Ramp Travel Time



of 13,400 vehicles per peak period and experienced 2.31 minutes of greater delay per vehicle. This equates to 516 hours of ramp delay on average per peak period. An example of this calculation, based on averages across all corridors, is presented in Table 5.5.

Table 5.5 Calculation of Net Travel Time for Selected Corridors During a 3.5-Hour Peak Period

Average Corridor Freeway Volume	14,442 vehicles
Average Travel Time Change on Freeway Segments	2.45 minutes
Subtotal Freeway Travel Time Change	*589.7 hours saved*
Average Corridor Ramp Volume	13,424 vehicles
Average Travel Time Change on Ramps	2.31 minutes
Subtotal Ramp Travel Time Change	*-516.4 hours spent*
Net Travel Time Change	**73.5 hours saved**

Table 5.5 provides an example calculation only, based on observed average impacts. In the calculation of travel time changes in the benefit/cost analysis, the specific impacts

observed for each individual corridor and time period was extrapolated to the appropriate similar corridors to estimate changes in freeway and ramp travel times.

5.3 Safety Impacts

Crash data were collected for both the "with" and "without" metering periods to analyze any changes occurring in the number and severity of crashes. Detailed crash data were obtained from the Twin Cities crash database maintained by the Department of Public Safety and Mn/DOT. This crash database provided a record for each crash, including information on:

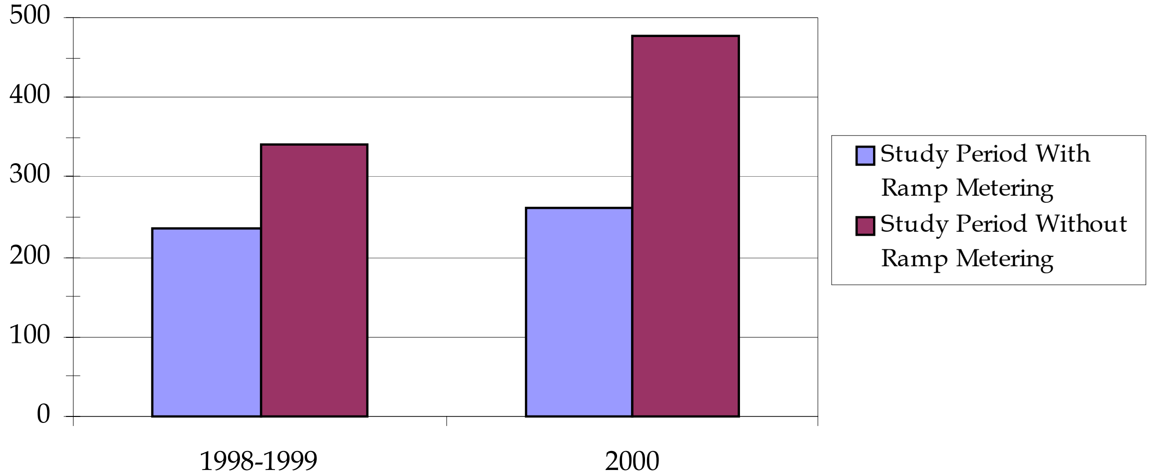
- Crash severity (fatality, injury, property damage);
- Type of crash (rear-end, side-swipe, etc.);
- Location of the crash;
- Facility type;
- Time of crash; and
- Other factors, including pavement condition, lighting, weather, etc.

In addition to collecting these data for the study period, the evaluation team analyzed the identical crash data for the equivalent periods in 1998 and 1999. These historical data were used to control for any seasonal variation typically occurring between the two study periods. The three years of data were then statistically analyzed to identify any change in crash rates resulting from the ramp metering shutdown.

The analysis found that there is typically a seasonal increase in the number of crashes observed between the two study periods. The crash rates on metered freeways during the peak periods were specifically analyzed to isolate any seasonal variation between the two study periods. The results showed that, on average, there was an increase from 236 to 341 crashes observed between the equivalent "with" and "without" study periods in 1998 and 1999 – representing an overall 44.5-percent increase in the number of crashes.

An analysis of the crashes occurring on metered freeways during the peak periods during the ramp metering evaluation showed an increase from 261 to 476 crashes, or an 82 percent increase, as shown in Figure 5.31. Based on historical seasonal variations, 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 on metered freeways.* This finding is consistent with accident reduction observed on metered facilities documented in an evaluation of conditions with and without ramp metering in the Phoenix metropolitan region. The observed increase in crashes is supported by data from the Mn/DOT incident management center which reported 60 percent more incidents (crashes plus disablements) during the "without" period.

Figure 5.31 Comparison of Crash Occurrence in the "With" and "Without" Study Periods (for Metered Freeways in the Morning and Afternoon Peak Periods)



The crash severity from the "with" and "without" periods was analyzed and compared with historical averages. Fortunately, no fatality crashes were reported during either the "with" or "without" study period. Injury crashes were shown to increase by approximately three percent over the seasonally adjusted rate; however, the sample size of crashes is generally too small to draw any firm conclusions. Property damage crashes, which did have a significant sample size, increased by 33 percent above the seasonally adjusted estimate.

Analysis of Crash Types

Table 5.6 shows the results of an analysis of the seasonally adjusted number of crashes by type occurring on metered freeways in the peak period. Rear-end, side-swipe, and ran-off road crashes are the most typical types of crashes reported near ramp merge locations. All these crash types show significant increases in the "without" study period.

Table 5.6 Comparison of Crash Occurrence by Crash Type (for Peak Period Metered Freeways)

Crash Type	Percent Change in the Absence of Metering
Rear-end	+15%
Side-swipe	+200%
Ran off road	+60%
Other crashes	+9%

5.4 Transit and Park-and-Ride Impacts

Performance data from regional transit providers was analyzed for the "with" and "without" study periods to evaluate the impacts of ramp metering on transit. No overall change in transit ridership was observed during the "without" study period. Generally, transit impacts were minor with no overall statistically significant changes being noted in the brief "without" period. The net transit ridership increase between the two study periods was only 1.1 percent (about 300 additional riders out of 30,000 from 18 bus lines). This increase was well within the expected seasonal variation. Park-and-ride usage increased by 6.4 percent, or approximately 300 more vehicles out of 3,000 at 18 park-and-ride lots. The summary of the transit impacts analysis is provided in Tables 5.7 and 5.8.

Transit operators provided useful information, based on operational analysis and the experience of transit drivers during the two study periods. Some of the major findings reported are shown in Table 5.9.

Table 5.7 Transit Ridership Summary

Route	With Meters	Without Meters	Difference	% Difference
431	144	125	-19	-13.1%
440	362	301	-61	-16.9%
442	1,197	1,133	-64	-5.4%
444	2,073	2,105	31	1.5%
35M	2,333	2,352	18	0.8%
35N	3,600	3,688	88	2.4%
35R	333	369	37	11.0%
35T	3,846	3,922	76	2.0%
35V	404	435	32	7.8%
35Y	652	649	-4	-0.5%
37W	2,066	1,967	-99	-4.8%
445/6	1,246	1,240	-6	-0.5%
77A	3,368	3,467	99	2.9%
77BC	1,716	1,823	107	6.2%
77PV	2,192	2,215	23	1.0%
77S	275	264	-11	-4.1%
77T	2,348	2,364	16	0.7%
77W	1,031	1094	62	6.0%
Total	**29,185**	**29,509**	**324**	**1.1%**

Table 5.8 Park-and-Ride Usage

Corridor	With Meters	Without Meters	Difference	% Difference
I-35E	534	532	-2	-0.4%
I-35W	1,965	2,129	164	7.7%
I-94	437	462	25	5.3%
All Corridors	**2,936**	**3,123**	**187**	**6.4%**

Table 5.9 Impacts of Ramp Metering Shutdown Reported by Transit Providers

Positive or Neutral Impacts	Negative Impacts
Metro Transit did not observe significant systemwide delays.	Longer distance express routes had more difficulty with on-time performance than Minneapolis express routes.
Traffic through downtown and on local arterials appeared to move better, improving the operation of some routes.	Due to congestion, buses were reported to use bus-only shoulders more frequently during the meter shutdown.
	Metro Transit's Transit Control Center indicated that bus operators experienced higher instances of automobile drivers intentionally blocking bus-only shoulders to keep the bus from passing their vehicles.

The transit providers also noted that, although no significant ridership impacts were observed, the "without" metering period was too brief to evaluate any long-term impacts. Transit operators were concerned that the reduction in the transit travel time advantage over single-occupancy vehicles, attributable to the elimination of ramp queues, may eventually promote greater use of automobiles by current transit users.

6.0 Traveler Surveys and Focus Groups

6.1 Analysis Objectives

The primary objective of the market research analysis was to assess changes to the individual traveler perspective on ramp metering following the ramp meter shutdown. Insights on travelers' behavior and attitudes toward ramp metering would help to identify the strengths and weaknesses of the ramp metering system as viewed by individual travelers. Such insights would support the design of the system and the decision-making process regarding its future.

The survey data collection and the statistical analysis approach were structured to obtain the socioeconomic, travel, and attitudinal information that would most effectively allow the evaluation team to "listen to consumers" and quantify their reactions to ramp metering. The analysis tried to answer the following questions:

- What is the socioeconomic profile of travelers in the random sample and the respondents in each of the corridor samples?
- Are there any important differences in the socioeconomic characteristics of respondents in the "with ramp meters" and "without ramp meters" surveys that require us to treat the two waves as different?
- What are the travel characteristics of respondents in each survey and how do they differ across the four corridors and between the "with ramp meters" and "without ramp meters" survey waves?
- Did the ramp metering shutdown have an impact on travelers' everyday travel patterns? Has the shutdown caused a shift in respondents' travel patterns and has it also affected the way they view the usefulness of the ramp meters?
- What are travelers' attitudes toward their everyday commute and, in particular, how do travelers view the ramp metering system and its impact on their everyday travel? Are travelers' attitudes consistent with their own travel experiences with ramp metering and are they in agreement with the traffic and travel time data?
- Following the ramp meter shutdown, do travelers believe they are better or worse off regarding the total origin-destination travel time, the time spent on the freeway, and the overall traffic conditions that they face?

- How has the meter shutdown affected travelers' attitudes toward ramp meter operations? Are there any important differences by market segment and by corridor indicating different reactions to the ramp meter shutdown that need to be taken into account?

- What are travelers' opinions about the ramp meter operations? Do travelers want to see the system operating "as is," modified in some way, or shut down permanently? Has their opinion changed after their experience with the ramp meter shutdown?

The second objective of the market research effort was to complement the traffic and travel time analysis described in earlier sections of this report. The collection of survey data was conducted along the same freeway corridors for which traffic and travel time data were collected (see Figure 4.1). Therefore, the joint analysis of the surveys and the traffic and travel time sources allows the market research findings to support the interpretation of the traffic and travel time analysis findings.

To meet these objectives, the data collection and analysis approach consisted of the following steps that are described in detail in this section:

- **Focus groups** of area residents were conducted to obtain qualitative insights into travelers attitudes toward ramp metering and to help design the surveys;

- **The sampling frame** consisted of a random sample of residents in the seven-county metro area and a collection of license plate numbers from users of the four corridors under study – two separate samples were developed for the before and after surveys;

- **Traveler surveys** were designed to extract the travel patterns, attitudes, and suggestions of area travelers using a combination of a random sample and four corridor-specific samples;

- A **"with/without" comparative** analysis was made possible by collecting data on traveler behavior, attitudes, and suggestions both before and after the ramp meter shutdown; and

- The **statistical analysis** of the two survey waves emphasized the identification and measurement of statistically significant "with/without" differences across corridors and market segments.

6.2 Section Outline

This section discusses in detail the statistical analysis and interpretation elements for each of the steps in the market research effort. This discussion builds on the evaluation methodology described in Section 4.3 that outlined the focus group structure, summarized the sampling frame for the surveys, and presented the design of the "with ramp meters" and "without ramp meters" surveys.

The focus group findings are summarized in Section 6.3.1. The discussion is structured around the objectives of each focus group, the questions that were addressed, and the conclusions that were reached during each phase.

Section 6.3.2 focuses on the quantitative market research task by discussing briefly the statistical analysis tools and tests that were used to identify and measure the statistical significance of differences uncovered during the analysis. Section 6.3.3 concludes the analysis approach by outlining the research questions that were explored. This set of research hypotheses serves as an introduction to the empirical analysis that is described in this section.

Section 6.4 provides the first set of empirical results from the traveler survey analysis. The focus is on the descriptive analysis of the socioeconomic characteristics and the identification of differences both across corridors and across the two waves of the analysis. A similar approach is undertaken for the analysis of travel patterns under Section 6.5.

Summaries of travel behavior characteristics for the random sample and across the different corridors are provided to help understand the different travel contexts faced by travelers. A comparison of respondents' travel patterns before and after the shutdown and travelers' own assessment of how the shutdown experiment affected the travel times and traffic conditions they face helps to identify whether the ramp meter shutdown had a significant impact on traveler behavior. An in-depth analysis of travelers' experiences, specifically with the ramp meters, is provided under Section 6.6. Travelers' average wait time at the meters and their willingness to wait are addressed.

Section 6.7 presents the analysis of traveler attitudes toward their overall travel and then focuses on traveler attitudes that are directly related to ramp metering. Statistically significant differences are identified across market segments and corridors. Section 6.9 discusses differences that are attributable to the ramp meter shutdown experiment by combining the corridor and market segment comparisons with a "with/without" analysis of travelers' attitudes.

The analysis concludes in Section 6.10 by assessing travelers' preferences toward the continuation of the ramp meter system operation. Travelers' response to a polling question that examined whether respondents supported the continuing operation of the ramp meter system is summarized, along with respondents' suggestions for changes to the ramp meter system that they would like to see implemented in the future.

6.3 Overview of the Analysis Approach

6.3.1 Focus Group Findings

The discussion in this section summarizes the synthesis of the results emanating from qualitative research conducted among freeway travelers within the Minneapolis/St. Paul metropolitan area. These results provided an initial understanding of travelers' attitudes toward the ramp meter shutdown, and inputs to the survey design and statistical analysis.

These augmented our understanding of travelers' attitudes toward the operation of ramp meters in the region's freeway system, including travelers' opinions about ramp meters in general; the types of benefits ramp meters may or may not provide; and how the existence of ramp meters affects route, mode, and departure time choice decisions. An extensive discussion and presentation of the qualitative research findings from the focus groups is included in Appendix I.

During each focus group session, the moderator introduced topics, probed for comments, and elicited reactions from all of the participants, while maintaining a non-directive style of interviewing to avoid biasing any discussions. Participants were encouraged to speak freely, interact, and offer dissenting opinions, whenever possible, on each of the issues. The sessions were conducted at a professional focus group facility with a one-way mirror to permit the observation of participants by members of the Technical and Advisory committees, consultant staff, and Mn/DOT staff.

6.3.1.1 "With Ramp Meters" Focus Groups

The discussion topic guide that was developed included the following general topics for discussion during each focus group:

- Introduction by the moderator of the purpose of the discussion and the ground rules for participation in the discussion,
- General perceptions toward ramp meters,
- Awareness of ramp meter benefits,
- Evaluation of ramp meter performance and measures of effectiveness,
- Attitudes and expectations toward the ramp meter shutdown, and
- Information needs for the ramp meter shutdown.

General Ramp Meter Perceptions

The mention of ramp metering was initially met with considerable negative reaction, although participants made a distinction between their experiences waiting at ramp meters and traveling on the region's freeway systems. They believed that there were too many ramp meters in the metro area and were frustrated with the long wait times at the meters. Participants appeared resigned to the fact that metering has become a way of life for travel in the region, and recognized that the traffic on freeways flowed much better in the Twin Cities area potentially as a result of ramp metering. Ramp metering was perceived as making travel more predictable in terms of the time it took to get to their destination once on a freeway, although the wait times at the meter and the back-up occurring on the ramps themselves were considered to be the most unpredictable portion of any given trip.

Travelers were very knowledgeable about the roadway network and very adept in terms of planning which specific routes to take during peak morning and afternoon travel periods and often relied on traveler information from radio or television. Their experience with the behavior of specific ramp meters at different times of the day had a direct impact on travelers' route choice.

Awareness of Ramp Meter Benefits

Participants in both groups were unable to remember when ramp meters were first installed and the rationale behind their installation. There was a significant lack of justification for ramp metering, since it seemed to have occurred long ago and was not perceived as helping to increase the "quality of commuting life." When participants in the two groups were able to cite specific benefits associated with ramp metering, the majority of comments given pertained to "reducing congestion" and "safety" issues. Specifically, it was mentioned that metering served to help traffic flow on the freeways, which, in turn, allowed motorists to maintain adequate speeds and distances between vehicles. Also, meters appear to decrease the potential for accidents, since they provide a means to ease the merging of ramp traffic entering the freeway.

However, when specific benefits were provided on an aided basis (i.e., provided by the moderator), most participants agreed that the meters were indeed very beneficial to travelers. The benefits that resulted in the most positive reactions related to:

- Aids in merging traffic onto a freeway in a safe and orderly manner,
- Serves to increase speeds and the flow of traffic once on the freeway,
- Helps to conserve gas and expenses,
- Improves air quality and the environment, and
- Reduces roadway stress and anxiety once on the freeway.

Interestingly enough, there was considerable debate over the merits of the last three benefits cited above and participants made a clear distinction between the potential for reducing road rage on the freeways, but not always on the ramps, since wait times could be very frustrating for most travelers. After discussing these specific benefits, participants felt a little better and perhaps less negative about ramp metering in general.

Ramp Meter Performance Measures

None of the participants mentioned having problems with the actual operation of ramp meters since they were perceived as being well-maintained and fully operational most of the time. However, participants thought that the time spent waiting at a ramp meter had no association with the amount of traffic on the freeway itself. There appeared to be no degree of consistency between the wait times experienced even across adjacent meters, and there didn't seem to be a clear relationship between freeway traffic and ramp meter wait times. Given this apparent inconsistency, it was not clear to participants whether the wait times were centrally controlled and adjusted.

Overall, waiting times of two to five minutes were very acceptable to most participants, with wait times of five to eight minutes still tolerable, and anything over 10 minutes considered to be quite frustrating. In addition to problems with wait times, back-ups on many of the more heavily-traveled ramps meters were also cause for concern and were viewed as yet another source of frustration. Travelers would like to have either longer ramps or some advanced notification of wait times before entering a ramp. This latter idea was very appealing to participants since it provided them with information that could be used to make a decision about using a particular ramp meter just as long as an electronic message sign was located a sufficient distance before the entrance.[1] Lastly, the use of by-pass lanes for high-occupancy vehicles (HOVs) (or commonly referred to as "sane lanes") as a means to avoid ramp meters altogether was not considered to be very useful by the majority of participants.

Attitudes Toward the Ramp Meter Shutdown

At the time, most of what participants had heard about the shutdown came from articles in the newspaper or by word-of-mouth. Among those participants who remembered hearing or reading something about the shutdown, the media's description of it was felt to be more factual in content rather than opinioned and biased.[2]

Participants were also asked what concerns, if any, they would have about such a shutdown of the region's ramp meters. The most common reaction was that it would wreak havoc on travel in the region. Most participants stated that, except for leaving a little earlier in the morning, they would not change their travel routes or stay at home during the first few days of the experiment should it actually occur. They indicated that they would continue with their usual routines and wait to see what happens before making plans to use alternate routes. Also, when asked whether they would be more likely to rideshare or take public transportation, they stated that they would be highly unlikely to do so.

Information Needs for Ramp Meter Shutdowns

In an effort to understand how information about the impending shutdown should be conveyed to the general public, participants were asked what they would like to know about it and the best way to inform them. Participants generally agreed that they would like to be notified anywhere from 10 to 14 days in advance of the event in order to make adjustments to their schedules.

With regard to what information they would like to have available from Mn/DOT to be able to judge the impact of such a shutdown, participants were very clear about their needs. Interestingly, information pertaining to traditional traffic performance measures

[1] In 1998-1999, Mn/DOT conducted a test of ramp meter wait signs which provided real time estimates of wait times at ramps where travelers would not be able to see the length of the queue. These signs were deployed by the Orion Program to test the costs and benefits of new forms of Intelligent Transportation Systems (ITS) technologies. An evaluation conducted by Cambridge Systematics, Inc. for Mn/DOT found wide consumer acceptance and enthusiasm for the signs and, in some cases, use of the information to adjust route choice. Further deployment of the signs has been deferred due to operational issues.

[2] The focus group was conducted in September 2000. While there had been considerable general discussion in the media for the previous several months following the enactment of legislation in the spring of 2000 mandating the shutdown, no specific information regarding the timing or details of the shutdown had yet been released by Mn/DOT.

would be viewed as carrying more weight than either direct feedback from the general public or statements made by politicians and Mn/DOT officials. As such, they would like an unbiased analysis from a third party to provide them with information, such as:

- Travel times by time of day;
- Accident occurrences before and during the experiment; and
- Surveys of travelers to assess their opinions about the shutdown.

The findings from this initial qualitative process suggested the following actions:

- Develop programs (media and outreach) that can be used to educate the general public about the benefits and rationale of ramp metering;
- Post average waiting times on an electronic display located well before the entrance to a ramp to allow travelers to make decisions about using alternate routes; and
- Provide a degree of consistency between waiting times for adjacent ramp meters where wait times are adjusted for the amount of actual congestion on a roadway.

6.3.1.2 "Without Ramp Meters" Focus Groups

A discussion topic guide similar to the "with ramp meters" focus group was developed and included, the following general topics for discussion:

- General reactions toward the ramp meter shutdown;
- Impact of ramp meter shutdown on travel behavior;
- Media coverage of ramp meter shutdown;
- Evaluation of ramp meter shutdown experiment; and
- Preferences for alternative ramp meter solutions.

<u>General Reactions Toward the Ramp Meter Shutdown</u>

Given the negative attitudes of travelers toward ramp meters evidenced in the "with ramp meters" focus group, it was not surprising that reactions were quite positive about the shutdown experiment. Overall, participants' experiences traveling on freeways in the Twin Cities region were favorable since most felt that their commutes were now faster than before, and travel on the region's freeways did not appear to be any less safe than before. Further, once on the freeways, they did not experience any more back-ups than was typically the case before the shutdown. However, when probed, they did tend to concede that the freeways had become more congested. Overall, this situation was very surprising to some of the travelers who believed that there would be severe problems traveling in the region after the shutdown occurred.

In terms of their experiences on the ramps themselves, travelers' levels of frustration had completely vanished. Wait times at even moderately congested ramps disappeared and became a non-issue. Several travelers went on to mention that, instead of using alternate routes and back roads just to avoid the meters, they were now more likely to use a direct route, which meant using a once congested ramp to get onto the freeway. Thus, short trips, which were previously diverted away from freeways by ramp meters, were now re-attracted to the freeways.

Similar to what was heard in the "with ramp meters" groups, travelers would rather be moving, albeit even at slower speeds, than enduring long waits at meters. Also, some travelers appeared not to mind the perceived increase in congestion on the freeway, since being in "control" and having the "freedom" to make decisions about which routes to use made the situation tolerable. For example, if they found a freeway to be too congested, they could exit at the next ramp. In contrast, if they entered a ramp with a long queue, they were stuck. Thus, travel on the freeways was viewed as being even more predictable, since they did not have to anticipate the length of the wait at meters. Finally, merging into the freeway was brought up as something that needed to be improved. It was noted that many drivers in the region had been accustomed to a "managed" form of merging controlled by the meters and did not know how to aggressively merge in an "unmanaged" situation.

Impact of Ramp Meter Shutdowns on Travel Behaviors

Consistent with the "with ramp meters" focus group, very few travelers mentioned that they had actually modified their travel behavior or route taken to get to a particular destination. Except for a few travelers who were now more willing to use the freeways instead of taking alternate routes, they continued to use the same ramp entrances and routes as before.

Travelers were pleased that no new bottlenecks were created aside from the ones that existed before the experiment, which everyone in both traveler groups already knew about. Therefore, it appeared that their tolerance levels for such congestion even at bottlenecks had risen dramatically, since the single most common source of their frustrations (ramp meters) had been removed.

However, even though wait times and back-ups at ramps were substantially reduced or eliminated altogether, there was still a feeling that it would be necessary for some ramp meters to remain operational. This sentiment was based on the awareness that certain areas of the freeway system are still heavily congested and in need of metering to help alleviate such congestion. Therefore, in these cases, metering made sense.

Media Coverage of Ramp Meter Shutdowns

Travelers' expectations about what would happen after ramp meters were shutdown did not materialize. The expectation was that travel in the area would be difficult during the initial period of the experiment, and then taper off gradually to where it would become tolerable again. Consistent with this observation, travelers were very vocal about the way various media sources depicted the shutdown experiment both before and during its occurrence. In their view, the media made a big deal over nothing and tended to exaggerate the situation, making it more newsworthy than it should have been. Therefore, travelers tended to discount these stories and placed more importance on what they saw rather than what they heard.

All travelers mentioned that they were given sufficient information in a timely manner by Mn/DOT. When asked about the lead time given for when the shutdown actually would occur, travelers indicated that they knew about it anywhere from three to four weeks in advance. (In reality, Mn/DOT provided one week notification of the exact date of the shutdown.) Also, the various dissemination sources (television, radio, and newspapers) used were more than adequate in making sure the general public knew of the specific details of the shutdown.

Evaluation of Ramp Meter Shutdown Experiment

Similar to the "with ramp meters" focus groups, participants were very clear about the types of information they would like to have available from Mn/DOT to be able to judge the impact of the shutdown experiment. Again, information pertaining to traditional traffic performance measures would be viewed as carrying more weight than either direct feedback from the general public or statements made by politicians and Mn/DOT officials. As such, they would like to have traffic performance data, such as:

- Travel time by time of day; and
- Accident occurrences before and during the experiment.

However, unlike the previous sessions, they had very mixed feeling about what sources should be used to make these evaluations, and who should be responsible for sharing the outcome. Some participants thought that the funds could be better spent improving the freeway system in the region than in hiring an outside consultant to conduct the evaluation. However, many others were not as skeptical suggesting that an unbiased source should perform the evaluation.

Also, when it came to informing the public about the outcome of the shutdown experiment, participants in the "without ramp meters groups" were unanimous in their feelings that the information should come directly from Mn/DOT officials. Specifically, they mentioned that the best way to inform the public about the outcome and the future status of the experiment would be through a series of short announcements conducted with the media (primarily television and newspapers). They wanted to be able to hear the criteria that MN/DOT would be using to make its decisions about the status of metering, so that they could form their own opinions about the reliability and credibility of such performance measures.

Preferences for Alternative Ramp Meter Solutions

Prior to asking travelers what they would like to see done to improve ramp metering in the Twin Cities region, a vote was taken where they had to choose between three different outcomes based on their experiences with the recent shutdowns. The options included:

1. Re-open the ramp meters the way they were before,
2. Keep the ramp meters permanently closed, or
3. Keep ramp meters but change the way they operate.

Interestingly, no one chose to operate the meters the way they were before. However, travelers were equally split between shutting meters off and modifying their operation. Although they would like to have a source of frustration disappear, they believed that ramp metering does help to alleviate traffic congestion for certain areas of the region's freeway system. Travelers believed that Mn/DOT should try as many solutions as possible to improve traffic flow on the freeways.

In keeping with this attitude, travelers were given a series of potential ramp meter solutions to evaluate, which included:

- Keeping some meters open and others closed based on the degree of freeway congestion,
- Adjusting wait times at meters so that queues are shorter,
- Installing "smart" meters that adjust wait times to actual traffic congestion and queue lengths,
- Providing signage/displays at ramp meter entrances that post average wait times, and
- Shortening the hours of ramp metering during peak morning/afternoon travel.

Across both groups, travelers were very much in favor of either keeping some meters open and closing others, or installing "smart" meters to adjust waiting times to reflect a variety of traffic conditions. These two solutions were cited most often, followed by two others that included displaying wait times at ramp meter entrances and shortening the hours of ramp meter operations (especially turning them off earlier at night rather than turning them off later in the morning). Again, these solutions were in keeping with many of the opinions discussed during the sessions and provided acceptable courses of actions for Mn/DOT to take, if the decision is made to continue the experiment.

The "without ramp meters" group sessions suggest that the public wishes to have Mn/DOT continue to evaluate acceptable ramp metering solutions rather than merely turning them back on or keeping them permanently off. Specifically, these recommendations reflect the need to make changes in both travelers' driving behaviors and habits, and the actual operations of the ramp meters themselves as follows:

- Develop driver education programs that can be used to "train" travelers about appropriate ramp merging behaviors and freeway etiquette;
- Monitor ramp meters one at a time to evaluate whether it should be opened or permanently closed based on traffic conditions and the alleviation of congestion; and
- Install "smart" meters on those ramps that have been found to require metering, so that wait times reflect actual traffic conditions on the ramp at the time.

6.3.2 Statistical Analysis Methods

The objective of the statistical analysis was to quantifiably identify, measure, and interpret the impact of the ramp meter shutdown on travelers' behavior and their attitudes. To accomplish that, the statistical analysis focused on the sources of variation in the data to identify those statistically significant differences that could explain variations in the data by corridor, market segment, and whether the survey was taken before or after the experimental shutdown of the ramp meter system.

Another aim of the analysis was to present the results in a manner that was easy to communicate to the public about how ramp metering was perceived. Therefore, the statistical analysis and the presentation of the key findings encompasses a variety of methods that range from summary statistics, such as mean values of key variables, to tables and graphs that illustrate key differences, and to analysis of variance methods that identify statistically significant differences across survey waves and market segments.

- **Summary Statistics –** Means and distributions of key variables were used to build a snapshot picture of travelers' profile, travel behavior, and perceptions. The analysis included differences by corridor and market segment, as well as a comparative profile before and after the meter shutdown.

- **Tabulations and Graphs –** Groupings and tabulations of key variables, along with bar charts and pie graphs, highlight important differences in traveler profile, travel behavior, and attitudes by survey wave, corridor, and market segment in a manner that can be best communicated to the public.

- **T-Statistic Test –** Differences between mean values for a particular variable, such as travelers' attitudes before and after the shutdown, were assessed through the use of the t-statistic test. This test statistic takes into account the mean values for the variable under study, the variance of each variable, and the sample sizes. Statistically significant differences suggest that the observed change in attitudes is not a random variation, but can be attributed to the meter shutdown.

- **Chi-Square Test –** Differences between distributions of a particular variable are assessed by using the chi-square test. This test statistic is used to evaluate whether variables, such as socioeconomic characteristics with multiple categories (e.g., age and education), differ across corridors or between the two survey waves. Statistically significant differences indicate that there is a systematic difference that is not attributable solely to variation in the data.

- **Analysis of Variance (ANOVA) –** This statistical analysis method was used as an extension of the t-test approach. The objective of using this multivariate method is to identify whether there are statistically significant differences that can be explained by more than one factor simultaneously. An example is the identification of significant differences between the two waves of surveys, while controlling for differences due to the various market segments.

  The analysis of the random sample survey and the four corridor-specific surveys focused on "with ramp meters/without ramp meters" comparisons of travelers' travel behavior and attitudes toward travel in the Minneapolis/St. Paul metro area and toward ramp metering in particular. The statistical analysis identified important differences that are statistically significant at a 95-percent confidence level. To enhance the validity of these "with ramp meters/without ramp meters" comparisons the analysis also takes into account other factors that may have an impact on travelers' attitudes, such as:

- Their frequency of travel during a typical week;
- Socioeconomic characteristics of respondents;
- Differences in respondents' travel patterns; and
- The differences across the four freeway corridors under study.

- **Geographic Information Systems (GIS) –** Finally, the analysis has also been supported by the spatial comparison capabilities offered by GIS. The use of GIS tools allowed us to geocode and map the origins and destinations, and O-D travel patterns of travelers in the study area to ensure that:
  - They properly represented each corridor under study;
  - They collectively provided a representative sample of metro area travelers; and
  - There were no significant differences between the two survey waves ensuring the similarity and comparability of the two samples.

6.3.3 Steps in the Survey Analysis

The questions that have been addressed in the analysis include the following:

- What is the socioeconomic profile of travelers in the random and the corridor samples and how do these characteristics differ by corridor? Are there any important differences in the socioeconomic characteristics of respondents in the "with ramp meters" and "without ramp meters" survey samples that require them to be treated as different? (Section 6.4)

- What are respondents' overall travel patterns, what is travelers' experience with ramp metering, and how do travel patterns and experience with metering differ by survey type and by corridor? (Section 6.5)

- What has been the impact of the ramp metering shutdown on travelers' everyday travel patterns? How do travelers view the changes in travel time and traffic conditions that have resulted from the shutdown? (Section 6.5)

- What is travelers' experience with ramp wait times, how does that experience differ by corridor, and what is travelers' maximum willingness to wait at a ramp meter? (Section 6.6)

- What are travelers' attitudes toward their everyday commute and in particular, how do travelers view the features of the ramp metering system and its impact on their everyday travel? (Section 6.7)

- Has the shutdown affected the way travelers view the usefulness of the ramp meters? Are changes in traveler attitudes consistent across corridors and do they agree with changes reflected in the traffic and travel time data? (Section 6.8)

- Are there any important differences by market segment and by corridor that suggest that different types of commuters have different reactions to the ramp meter shutdown that need to be taken into account? (Section 6.8)

- Would travelers like to maintain the metering system, introduce changes to it, or shut if off after their experience with the experimental shutdown? What types of changes would they like to see introduced? (Section 6.10)

6.4 Socioeconomic Characteristics

The socioeconomic characteristics of each respondent were collected to develop a user profile across the different types of surveys and survey waves, and to control for potential differences by corridor that could affect the way respondents perceive the features of the ramp metering system. The information that was collected to build respondents' socio-economic profile included respondents' gender, age, education level, household size, car ownership, and household income. A detailed listing of the distribution of each socioeconomic variable by survey wave, type of survey, and by individual corridor is shown in Appendix E.

Traveler Profile – The socioeconomic profile of the typical commuter in the Minneapolis/ St. Paul area is provided by the random sample survey in each wave of the analysis (Table 6.1). Overall, respondents in the random sample have a high level of education and almost 70 percent of them are employed full time. Car ownership and incomes are also relatively high with more than 30 percent of the households in the random sample owning three or more cars, and with almost 30 percent of households having annual incomes of $80,000 or more.

The contrast between the corridor sample as a whole and the random sample exhibited some interesting differences in each of these socioeconomic characteristics. Corridor users were more likely to be college graduates, to own three or more cars, and to be employed full time compared to respondents in the random sample. Furthermore, corridor users were also found to be more likely to live in larger households and to have an average income that was higher than the income of respondents in the random sample.

Differences by Corridor – The contrast among the four corridor-specific samples showed some interesting socioeconomic differences that are summarized in Table 6.1. Commuters on the I-494 corridor were much more likely to be employed full time, to live in larger households, and to have a higher average income than commuters in other corridors. Corridor I-94 respondents had a higher education level, a much lower level of car ownership, and a high income that was comparable to I-494 users. In general, commuters on the I-35E and I-35W corridors either fell in the middle of the range defined by the I-94 and

I-494 corridor users, or were more closely comparable to the characteristics of the random sample respondents.

Table 6.1 Overview of Socioeconomic Characteristics in the "With Ramp Meters" Survey

	I-494	I-35E	I-35W	I-94	Random
College/post-graduate	52%	46%	42%	71%	48%
Three or more cars	38%	35%	36%	26%	31%
Full-time employment	88%	72%	76%	72%	68%
Three or more HH members	67%	62%	55%	54%	47%
Income > $80,000	39%	22%	26%	40%	27%

"With Ramp Meters/Without Ramp Meters" Comparisons – A total of 30 "with ramp meters/without ramp meters" comparisons for the socioeconomic characteristics were made taking into account the distributions of each of the six socioeconomic attributes across the four corridors and the random sample. As shown in Figures 6.1 and 6.2, the education and age characteristics of respondents in the sample track very closely in the "with ramp meters" and "without ramp meters" surveys. Out of the total of 30 comparisons, only two proved to be statistically significant at the 95-percent confidence level using the chi-square test, suggesting some differences in the income distributions of I-35E commuters and the random sample respondents in the "with ramp meters" and "without ramp meters" samples.

The detailed comparisons for each socioeconomic characteristic for each type of survey and the before and after survey waves are provided in Appendix E. Across the random sample surveys and across each corridor sample there is a similarity between the "with ramp meters" and "without ramp meters" survey samples illustrated in Tables E.1 through E.6 of the Appendix E. These 30 comparisons taken together support the high degree of similarity between the "with ramp meters" and "without ramp meters" sub-populations sampled in each of the four corridors and in the random sample. Therefore, differences in the responses of the "with ramp meters" and "without ramp meters" survey samples noted in the sections below are unlikely to be due to differences in the composition of the sample populations themselves.

Figure 6.1 Educational Profile of Respondents

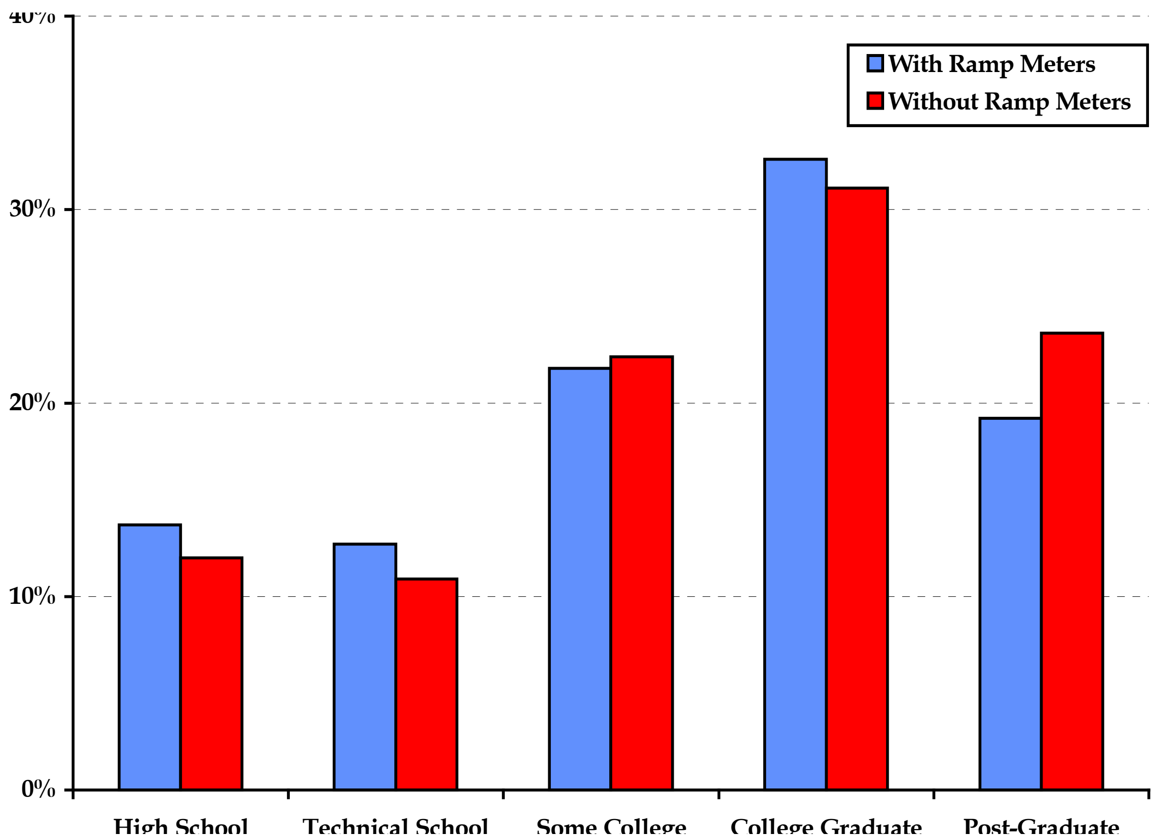
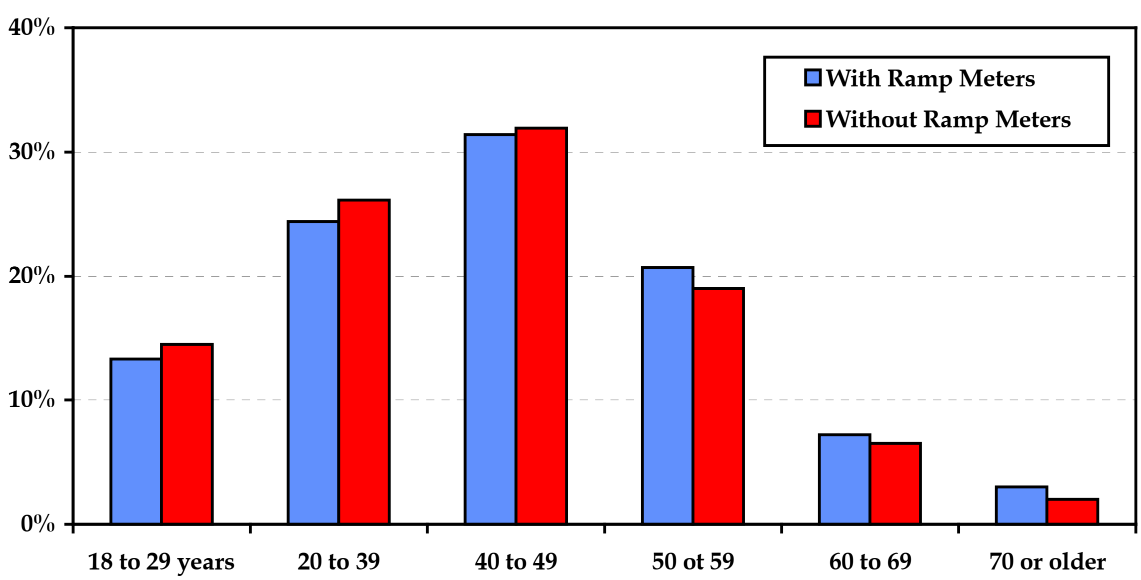


Figure 6.2 Age Profile of Respondents



6.5 Travel Patterns

6.5.1 Overall Travel Profile

As part of the survey, travelers framed their experience with ramp metering within the characteristics of their everyday travel. Respondents were asked to provide their origin, and destination, their estimates of total origin-destination travel times, and their estimates of time spent traveling on the freeway. Although these measures are not expected to be as accurate as the detailed travel time runs collected in each corridor, they provide benchmarks used by commuters in evaluating their travel experience across the corridors for both the before and after the shutdown conditions.

Geographic Distribution: A comparison of the geographic distribution of respondents' origins, destinations, and O-D travel patterns was made to ensure that there was an adequate dispersion of origins and destinations in the study area and to check the consistency of this pattern between the "with ramp meters" and "without ramp meters" survey samples. This comparison was made possible by the geocoding of the respondents' detailed origin and destination information provided in the survey. A detailed technical discussion of the methodology and software used in the geocoding process is provided in Appendix F.

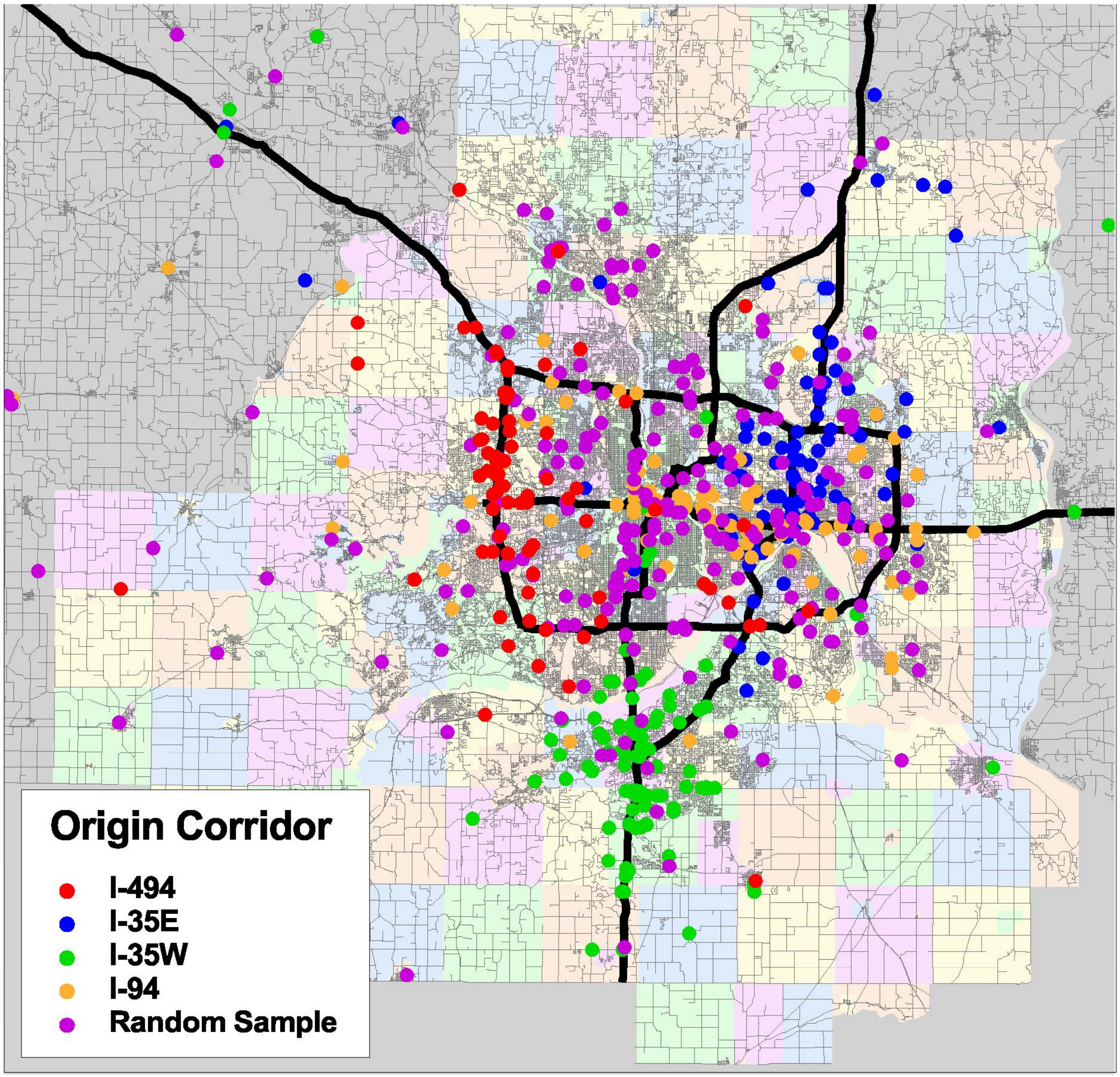
A comparison of travelers' origins in the "with ramp meters" and "without ramp meters" surveys is illustrated in Figures 6.3 and 6.4. These distributions suggest the dispersions of origins throughout the study area, as well as the great degree of similarity in the origins of respondents in both survey waves. The distributions of the origin-destination pairs shown in Figure 6.5 further underlines the widespread distribution of travel patterns in the area in the "without ramp meters" survey, a pattern that was again very similar to the distribution of O-D pairs in the "with ramp meters" survey.

Total and Freeway Travel Times – Respondents in the "with ramp meters" random sample reported an average total travel time of 28 minutes compared to an average of 34 minutes reported by corridor users. Freeway travel times were also lower among random sample respondents, an average of 20 minutes, compared to an average time of 24 minutes spent on the freeway by corridor users.

As shown in Figure 6.6, the distribution of travel times in the random survey was concentrated in the low end of the range with trips up to 25 minutes, while the travel times in the corridor sample were concentrated and evenly distributed between 20 minutes and one hour. The distributions of freeway travel times were comparable in the random and corridor samples with the exception of the predominance of short trips lasting less than 15 minutes in the random sample (Figure 6.7). The random sample undoubtedly captured more travelers making short local trips, while the corridor travelers tended to be making longer commuter types of trips.

The travel times by corridor highlight the similarities across the I-35E, I-35W, and I-94 corridors with "with ramp meters" freeway travel times of roughly 21 minutes, compared to the I-494 users who spent 50 percent longer on the freeway for an average of 32 minutes.

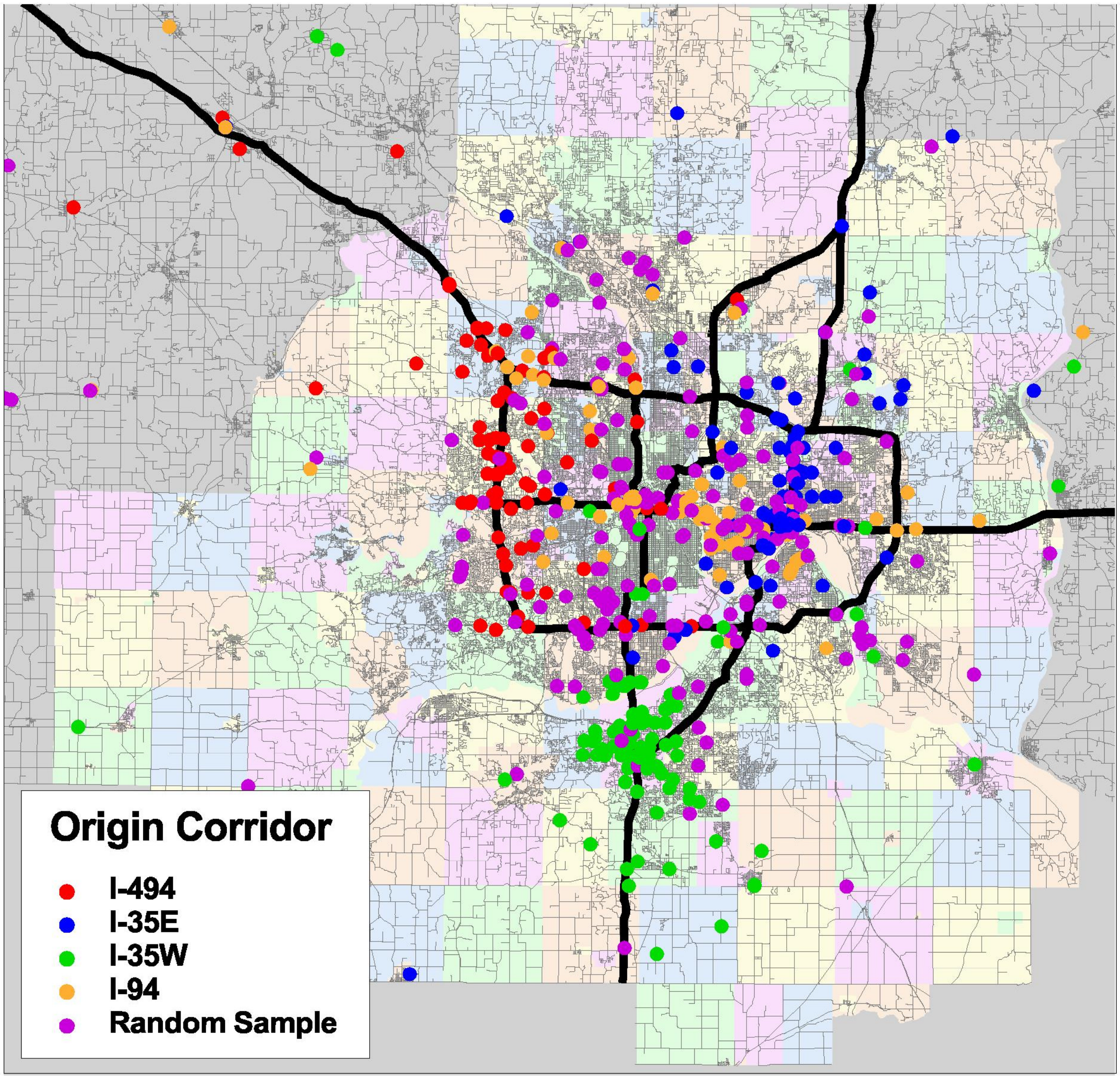
Figure 6.3 Origins of Travelers – "With Ramp Meters" Surveys



The same pattern holds for the total O-D travel times with I-494 users spending a total of 45 minutes on the road, 50 percent more than the 30-minute total travel time experienced by users of the other three corridors (Table 6.2). This difference between the I-494 corridor sample and the other corridor samples is important in explaining attitudinal differences described in the following sections.

"With Ramp Meters" and "Without Ramp Meters" Comparisons – A comparison of the "with ramp meters" and "without ramp meters" total travel times and freeway travel times (both for the random and for the corridor-specific samples) indicate an interesting and consistent pattern of travel time differences.

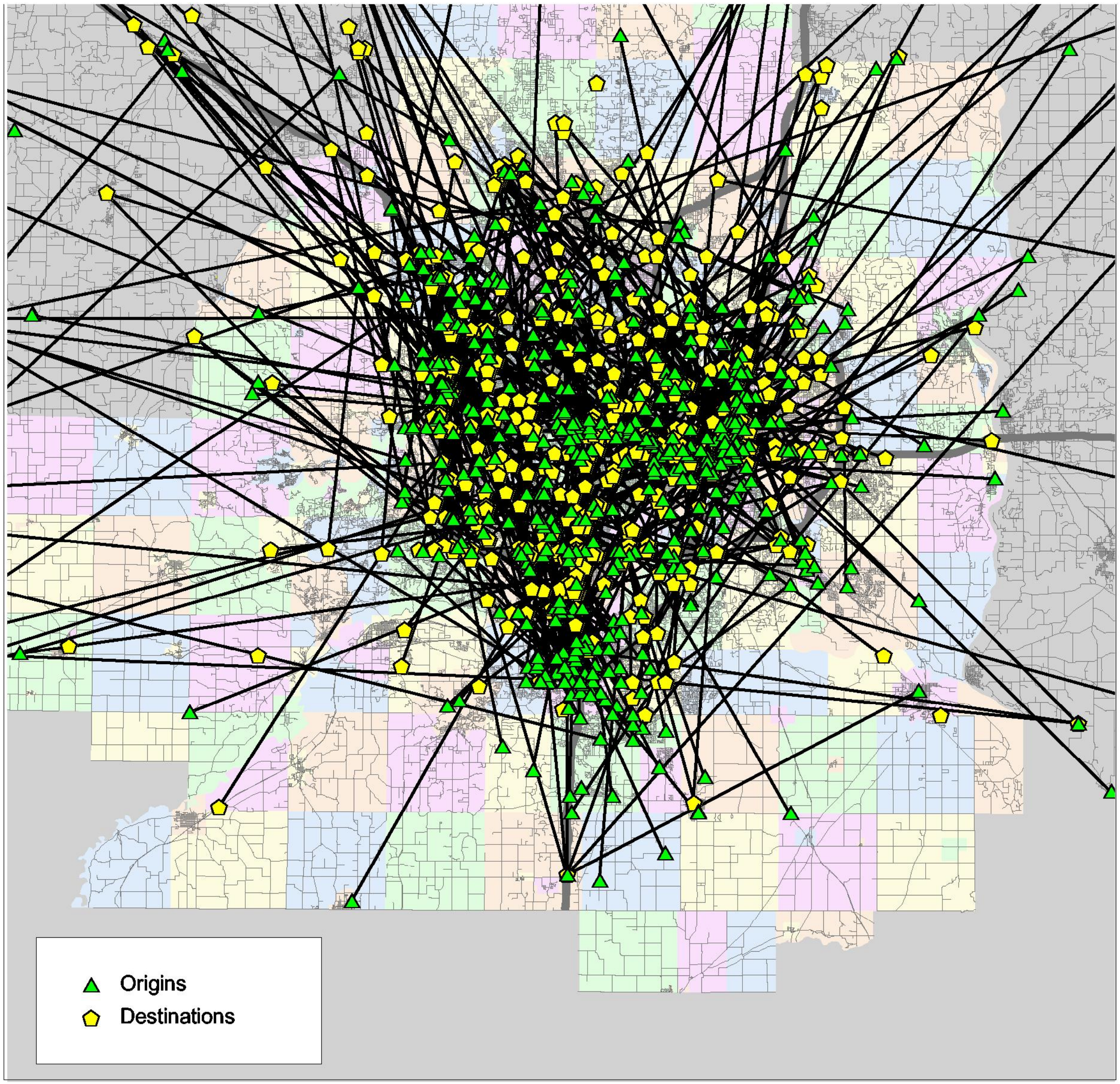
Figure 6.4 Origins of Travelers – "Without Ramp Meters" Surveys



Although some of the differences may be attributable to the slightly different mix of "with ramp meters" and "without ramp meters" origin-destination travel patterns within each corridor, there is a consistent pattern of increasing travel times shown in Table 6.2. Both the total travel times and freeway travel times have increased following the shutdown, a pattern that is consistent both in the random sample and in each of the four corridor samples.

The difference in the total travel time ranges from only a marginal increase in the random sample to a six- and eight-percent increases, respectively, in the I-35W and I-94 corridors, to a high of a 15-percent increase in travel time in the I-35E corridor. There is a similarly consistent pattern of increases in the time spent traveling on the freeway. Increases in

Figure 6.5 Origin-Destination Patterns – "Without Ramp Meters" Surveys



freeway time range from a low of 2.5 percent for the I-35W corridor, to a 17 percent increase for the I-94 corridor, and to a high of 35 percent in freeway travel time in the I-35E corridor sample.

Comparison with Travel Time Data – This empirical analysis is consistent with the travel time findings summarized in Section 5.2. According to the travel time comparisons, the percentage change in travel time in the I-35E southbound a.m. corridor was 40 percent, one of the highest increases among the studied corridors. This suggests that I-35E travelers' reported travel times properly reflect the changes in travel times.

Figure 6.6 Origin-Destination Total Travel Times – "With Ramp Meters" Surveys

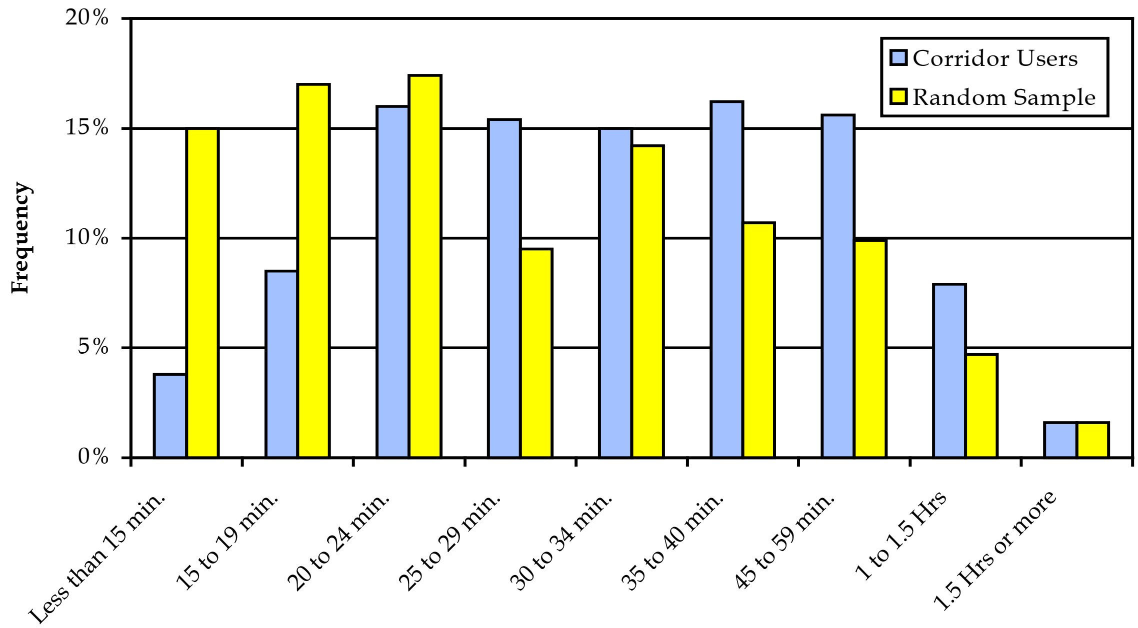


Figure 6.7 Freeway Travel Times – "With Ramp Meters" Surveys

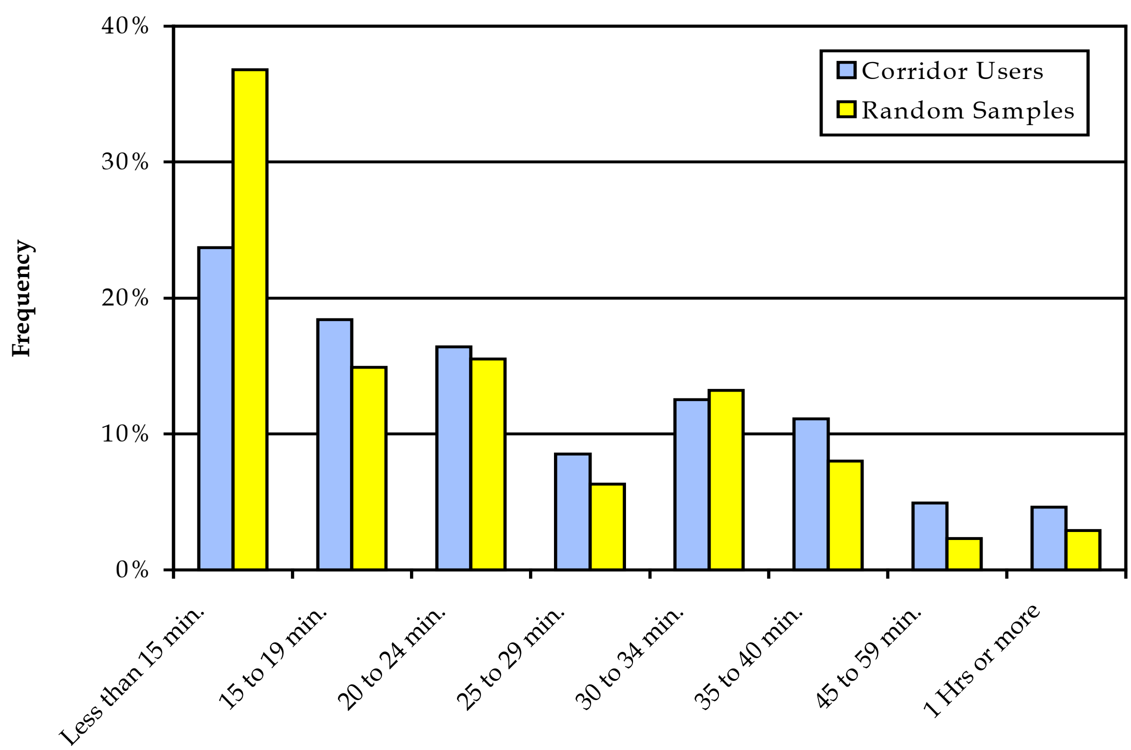


Table 6.2 Total and Freeway Travel Times Reported in the Surveys

	Total Travel Time (minutes)			Freeway Travel Time (minutes)		
	With Ramp Meters Survey	Without Ramp Meters Survey	Percentage Change	With Ramp Meters Survey	Without Ramp Meters Survey	Percentage Change
Random Sample Survey	28.0	28.1	0.4%	20.4	22.4	9.8%
I-494 Corridor Survey	45.4	46.2	1.8%	31.9	34.3	7.5%
I-35E Corridor Survey	30.7	35.5	15.6%	21.5	29.2	35.8%
I-35W Corridor Survey	31.1	33.1	6.4%	21.9	22.5	2.7%
I-94 Corridor Survey	29.9	32.2	7.7%	21.3	24.9	16.9%

6.5.2 Time-of-Day and Route Diversion Patterns

One of the questions that was of interest to the ramp metering analysis was the extent to which travelers would divert to different routes, use different ramps to enter the freeway, or shift to another time of day to avoid congestion as soon as the ramp meter system was turned off. These likely diversion patterns were addressed both in the "with ramp meters" and in the "without ramp meters" surveys and are summarized in this section.

"With Ramp Meters" Diversion Patterns – In the "with ramp meters" survey, respondents were asked whether they were familiar with alternate routes to their destination and with different entrance ramps to the freeway system. Combined with a question on whether travelers were likely to shift to an earlier or later departure time to avoid congestion on the freeway, these questions served as general indicators of travelers' propensity to divert to different routes and times of day.

The analysis of the "with ramp meters" random and corridor surveys indicates that travelers in the Minneapolis/St. Paul area are generally familiar with both route and time-of-day diversions (Table 6.3). Travelers are more likely to leave at a different time of day to avoid congestion and to use a different ramp entrance to avoid back-ups, rather than use a different route altogether. This pattern was similar for the random and the individual corridor samples with the users of the I-35W corridor being considerably more likely to shift their departure time to avoid congestion in the I-35W corridor.

"Without Ramp Meters" Diversion Patterns – In the "without ramp meters" survey, respondents who frequently used a particular freeway were asked whether following the ramp meter shutdown they experimented with different routes, and whether they left earlier or later to avoid traffic congestion. Roughly a quarter of the random survey respondents experimented with either route or time-of-day diversions. This percentage was larger in the corridor surveys where respondents were more likely to experiment with different options (Table 6.4).

Table 6.3 Diversion Patterns in the "With Ramp Meters" Surveys

	Random Sample	I-494 Corridor	I-35E Corridor	I-35W Corridor	I-94 Corridor
Route Diversion					
Sometimes use alternate routes to avoid waiting at ramp meters	68.8%	71.4%	72.0%	72.0%	71.0%
No	31.2%	28.6%	28.0%	28.0%	29.0%
Total	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**
Time-of-Day Diversion					
Sometimes leave earlier or later to avoid traffic congestion	78.7%	75.4%	78.4%	85.6%	74.8%
No	21.3%	24.6%	21.6%	14.4%	25.2%
Total	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**
Ramp Diversion					
Sometimes avoid a ramp that is backed up with traffic and use a different ramp to enter a freeway	75.1%	77.0%	76.0%	80.0%	79.4%
No	24.9%	23.0%	24.0%	20.0%	20.6%
Total	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**

Table 6.4 Diversion by Frequent Freeway Users in the "Without Ramp Meters" Surveys

	Random Sample	I-494 Corridor	I-35E Corridor	I-35W Corridor	I-94 Corridor
Route Diversion					
Tried other routes since the ramp meter shutdown	23.3%	45.3%	36.0%	35.7%	41.9%
Always used the same route since the ramp meter shutdown	76.7%	54.7%	64.0%	64.3%	58.1%
Total	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**
Time-of-Day Diversion					
Sometimes left earlier or later to avoid traffic congestion	25.6%	40.2%	33.9%	41.7%	33.1%
Did not leave earlier or later to avoid congestion	74.4%	59.8%	66.1%	58.3%	66.9%
Total	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**

A comparison of the diversion patterns across corridors also shows some interesting corridor-specific patterns. Users of the I-494 corridor showed a greater degree of experimentation than users of the other corridors with 45 percent experimenting with alternate routes compared to a third among I-35E and I-35W commuters and 40 percent of I-94 users. Similarly, 40 percent of I-494 users and 42 percent of I-35W users tried a different time of day to avoid congestion compared to a third of commuters using the I-35E and I-94 corridors (Table 6.4). This willingness to experiment is consistent with the generally longer commutes experienced by the I-494 users.

6.5.3 Retrospective Evaluation of Traffic Conditions

As part of the "without ramp meters" survey, respondents were asked to evaluate any changes in the traffic conditions that they faced in their everyday commute as a result of the ramp meter shutdown. Two questions also addressed their experience with the total travel time and the time they spent on freeways during their everyday travel. Specifically, respondents were asked the following set of questions that were adjusted for the random sample and the corridor surveys and were also customized to each respondent's travel experience:

> *"You said that your last trip took ___ minutes to travel from ___ (your origin) to ___ (your destination). Was this time longer or shorter than when you made this same trip before the meters were turned off?"*

> *"You say that on your last trip you spent ___ minutes driving on any freeways. Was this time longer or shorter than when you made this same trip before the meters were turned off?"*

> *"Since the ramp meter shutdown, do you think traffic conditions on ___ freeway are better or worse than before the shutdown?"*

Tables 6.5 to 6.7 suggest a balanced response to all three questions among the sample random respondents. Travelers in the "without ramp meters" random sample were more or less equally split among those believing they were better off than before, worse off than before, and those who didn't perceive any big changes due to the shutdown.

In contrast, the analysis of the same three questions across the four corridors identified some revealing differences with I-494 users showing up as different than commuters in the other three corridors. More than half of the I-494 users responded that their trip took longer following the meter shut off with only a quarter of the respondents experiencing an improvement (Figure 6.8). The same pattern was true for the travel time spent on the freeways with only 18 percent of the I-494 corridor users considering their current commute an improvement in terms of travel time spent on the freeway.

Finally, an equally strong pattern was reflected in I-494 users' assessment of the overall traffic conditions. Sixty percent of the I-494 users believe that they are worse off with the meters shut down, compared to just 17 percent who see the meter shutdown as an improvements in traffic conditions (Figure 6.9). These responses are in agreement with

Table 6.5 Reported Changes in Total Travel Time: "Without Ramp Meters" Surveys ***(Freeway Users Who Made Same Trip Before Ramp Meter Shutdown)***

	Percentage				
	Random Sample	**I-494 Corridor**	**I-35E Corridor**	**I-35W Corridor**	**I-94 Corridor**
Recent trip was longer than before meters were turned off	25.8%	54.1%	33.1%	30.4%	33.9%
Recent trip was shorter than before meters were turned off	31.3%	26.2%	31.5%	42.4%	34.7%
Recent trip was about the same	43.0%	19.7%	35.5%	27.2%	31.5%
Total	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**

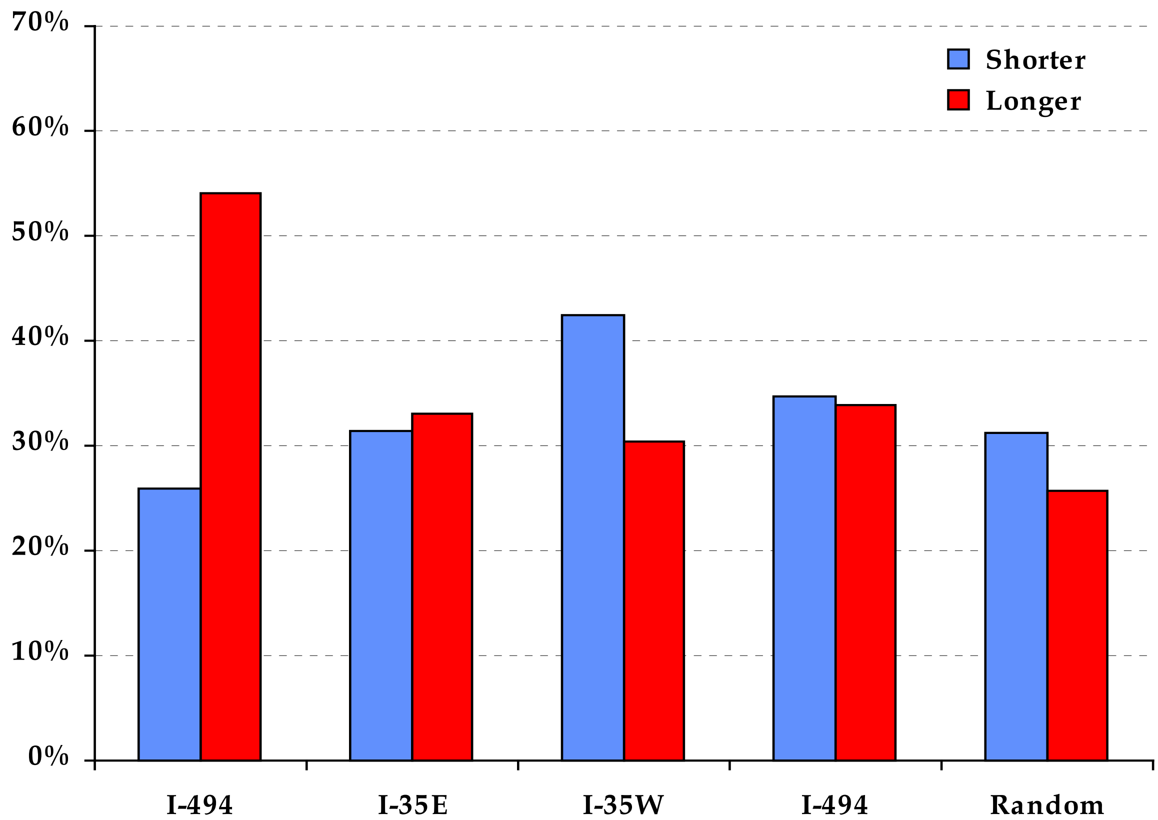
Table 6.6 Reported Changes in Freeway Travel Time: "Without Ramp Meters" Surveys ***(Freeway Users Who Made Same Trip Before Ramp Meter Shutdown)***

	Percentage				
	Random Sample	**I-494 Corridor**	**I-35E Corridor**	**I-35W Corridor**	**I-94 Corridor**
Freeway travel time was longer than before meters were turned off	30.7%	50.4%	33.6%	34.7%	39.5%
Freeway travel time was shorter than before meters were turned off	23.6%	18.2%	26.4%	20.2%	25.8%
Recent freeway travel time was about the same	45.7%	31.4%	40.0%	45.2%	34.7%
Total	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**

Table 6.7 Reported Changes in Traffic Conditions: "Without Ramp Meters" Surveys ***(Freeway Users Who Made Same Trip Before Ramp Meter Shutdown)***

	Percentage				
	Random Sample	**I-494 Corridor**	**I-35E Corridor**	**I-35W Corridor**	**I-94 Corridor**
Traffic conditions better now than before meters were turned off	29.9%	17.5%	30.3%	48.4%	52.1%
Traffic conditions worse now than before meters were turned off	33.1%	61.7%	36.9%	29.0%	22.3%
Traffic conditions are about the same	37.0%	20.8%	32.8%	22.6%	25.6%
Total	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**

Figure 6.8 Reported Changes in Travel Times After the Shutdown "Without Ramp Meters" Surveys

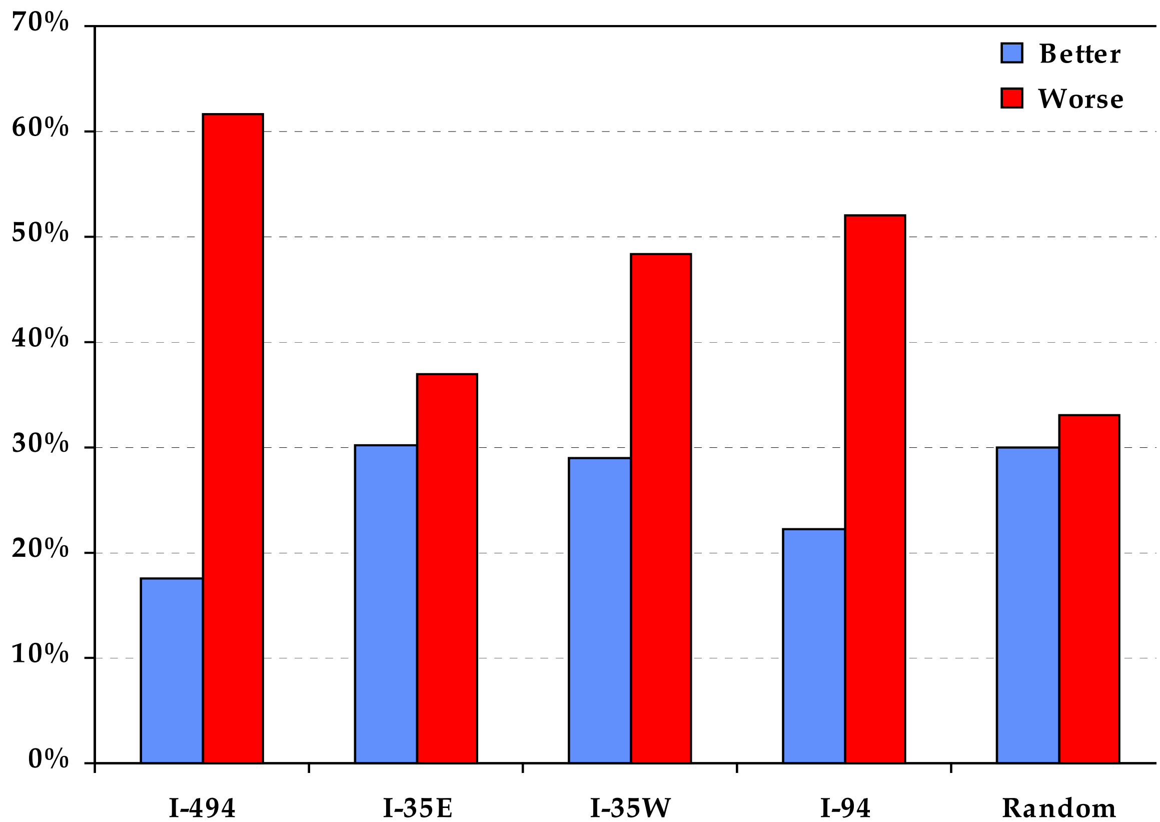


the traffic and travel time data discussed in Section 5.2 that showed decreases of 12 percent and 21 percent (northbound p.m. and southbound a.m., respectively) in the average speed in the I-494 corridor and an increase in the variability of I-494 freeway speeds. These responses also support the supposition that ramp metering is most beneficial to long distance commuters with origins in the outlying regions of the metro area, such as those surveyed in the I-494 corridor.

Unlike their I-494 counterparts, commuters on the I-35E and I-94 corridors were more ambivalent regarding the changes in their total and freeway travel times (Tables 6.5 and 6.6). Roughly one-third of I-35E and I-94 respondents believed that they were worse off, one-third believed that they were better off, and the other third believed that there was not much change since the shutdown. Although I-35W commuters were also in a three-way tie regarding their evaluation of the total O-D commute time, most of them thought that travel time on I-35W and the other freeways they use in their everyday travel had increased as a result of the shutdown.

Finally, the assessment of overall traffic conditions was again a little different than the evaluation of travel times (Table 6.7). Although respondents using the I-35E corridor were in a three-way tie, almost 50 percent of users on I-35W and on I-94 thought that they now faced worse overall traffic conditions as a result of the shutdown.

Figure 6.9 Reported Changes in Traffic Conditions After the Shutdown "Without Ramp Meters" Surveys



Comparisons with Travel Time and Speed Variability Data – These responses are in agreement with the traffic and travel time data discussed in Section 5.2 that showed a decrease of four percent in the average speed in the I-35W corridor. Meanwhile, I-94 eastbound p.m., I-94 westbound a.m., and I-94 westbound p.m. commuters experienced speed reductions of 11 percent, 15 percent, and 16 percent, respectively. In all cases, variability of speeds increases, especially on I-94.

■ 6.6 Ramp Wait Times

Since one of the primary objectives of the market research study was to assess travelers' attitudes toward ramp metering, survey respondents were asked to estimate their typical ramp wait times. These wait times reported by individual travelers were analyzed to better understand the context which travelers face in their everyday commute, since ramp wait times affect their travel behavior and their attitudes toward ramp metering.

During the description of their typical commute trip, respondents were asked a battery of detailed questions related to the ramp they used to enter the freeway and their corresponding experience at the ramp meter. A series of questions was used to identify the following types of information for each traveler:

- The ramp entrance travelers used to enter the freeway, the time of day they entered the ramp, and the existence of an operating meter on each ramp;
- Vehicle occupancy to distinguish between travelers who avoided a ramp meter by carpooling and using the by-pass lane, and those who had to wait at a meter;
- The number of ramp meters that each traveler encountered during his/her trip to reflect any additional wait times due to freeway-to-freeway ramp metering;
- The reported ramp meter wait time at each metered ramp encountered in their trip;
- Their experience with encountering longer ramp meter wait times than those encountered during their last typical trip; and
- Their maximum willingness to wait at a ramp beyond which they wish they had used an alternate route or ramp entrance.

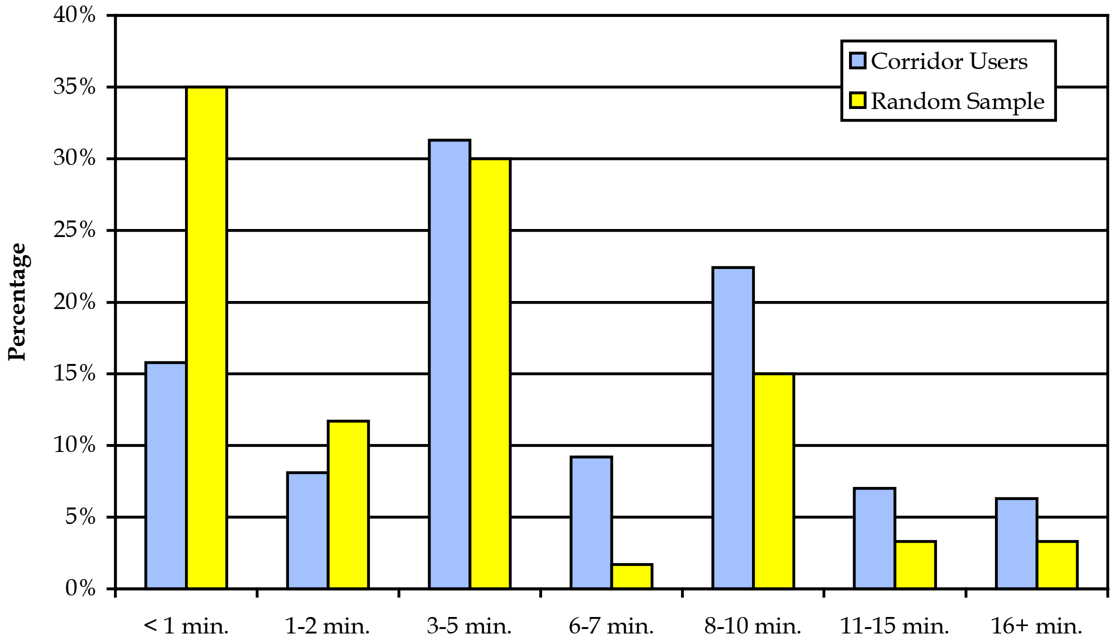
Affected Population – An analysis of the ramp usage patterns in the "with ramp meters" survey suggests the frequency with which travelers in the metro area need to wait at a ramp meter and provides an estimate of the population affected by ramp metering on a typical day.

In the "with ramp meters" random sample, a total of 61 respondents representing 24 percent of the sample had to wait at a ramp meter during their typical commute trips. In contrast, the targeted sample of "with ramp meters" corridor users shows that 208 respondents (40 percent of the sample) had to wait at a ramp meter. This difference underlines the much lower incidence of ramp meter waiting in the population as a whole, when compared to freeway corridor users.

Furthermore, the percentage of respondents who had to wait at two or more ramp meters during their commute was much lower. Only four percent of the random sample respondents and nine percent of the respondents in the "with ramp meters" corridor sample had to wait at two or more meters. Again, this pattern underscores the different experience of all travelers in the Minneapolis/St. Paul area as compared to the experience of freeway users.

Ramp Wait Times – The distribution of ramp wait times experienced by metered users and grouped together in two- to five-minute intervals is shown in Figure 6.10. This figure again distinguishes between travelers in the random and the corridor samples, and includes only those respondents who entered a freeway from an entrance controlled by an operating ramp meter. On average, respondents in the random sample reported that they waited an average of 4.5 minutes, while respondents across the four corridors reported an average wait time of 6.7 minutes.

Figure 6.10 Distribution of Ramp Wait Times Among Metered Users "With Ramp Meters" Corridor and Random Sample Surveys



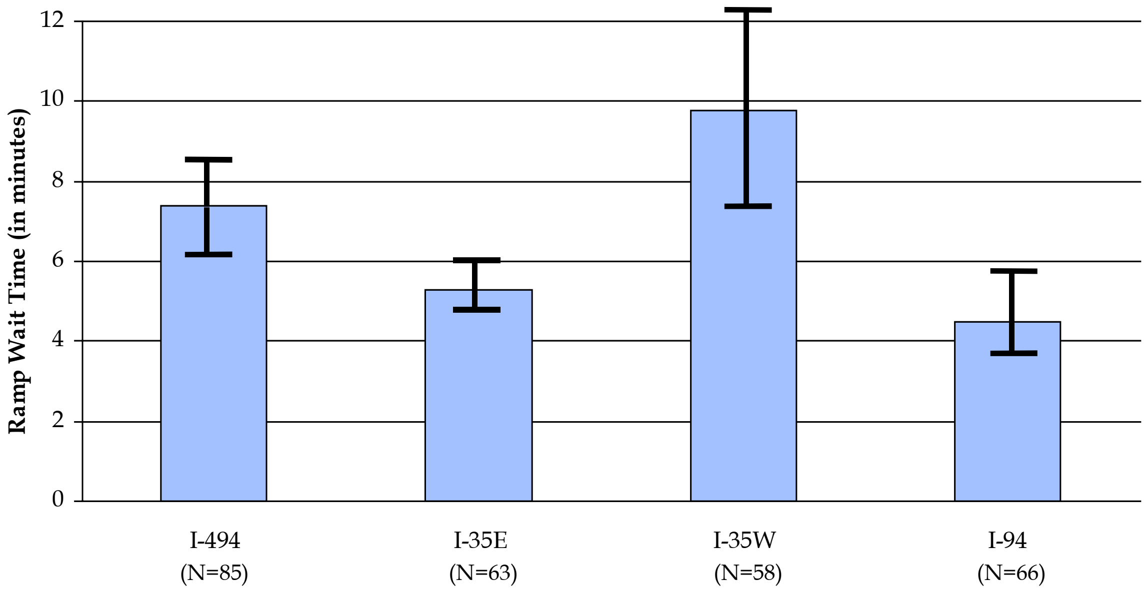
The most frequent wait time reported by the random sample respondents was less than one minute, with more than 75 percent of the wait times being five minutes or less. In contrast, only 15 percent of the corridor users reported wait times of one minute or less, and roughly 50 percent reported wait times of five minutes or less. This pattern further differentiates the two samples with the freeway corridor users more likely than the population at large to:

- Encounter a wait at the ramp meter, and
- Have to wait longer at the ramp meter.

Differences by Corridor – An analysis of the average ramp wait times across corridors shown in Figure 6.11 also illustrates some interesting differences across corridors. The average wait time reported by I-35W corridor users was the highest at 9.8 minutes with almost 30 percent of the respondents reporting ramp wait times of 11 minutes or longer. It should be noted also that I-35W users had the greatest variability in reported ramp wait times compared to the other three corridors, indicating either a wide range of perceived times or a great variation in ramp wait times by time of day.

The second highest average wait time was reported by I-494 users, who believed that on average they had to wait at a ramp for 7.4 minutes. The commuters on I-35E reported an average wait times just above five minutes while the lowest wait time was reported by I-94 users who thought that they waited at a ramp 4.5 minutes on average.

Figure 6.11 Average Ramp Wait Times Among Metered Users "With Ramp Meters" Corridor Surveys



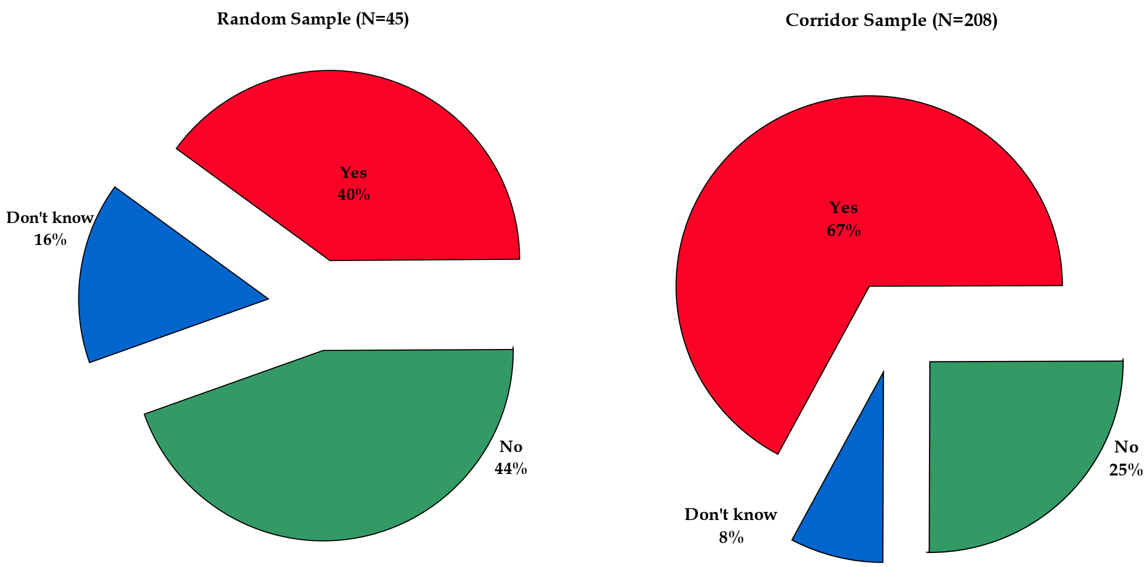
In comparison to the traffic data presented in Section 5, average perceived wait times are about equal to actual wait times for the peak hour only. In comparison to the total peak period, perceived wait times are about twice as high as actual wait times (roughly five to six minutes compared to two to three minutes). It is typical for travelers to perceive wait times of all kinds (waiting for a bus, etc.) to be about twice as long as reality. This highlights the importance of ramp wait time in travelers evaluation of their travel experience and the role of ramp meters.

Experience with Longer Wait Times – In addition to travelers' experience with their last typical trip, the survey examined the overall experience of travelers with ramp wait times. Travelers' experience with wait times longer than those reported for their last typical trip was obtained by asking respondents the following question:

> *"Considering all your trips when you use the freeway and wait at the ramp meters, do you find that any of your trips are 10 or 15 minutes longer because of longer wait times at the ramp meters?"*

The results summarized in Figure 6.12 suggest another important difference between the population at large included in the random sample as compared with the corridor-specific samples. In the random sample, 40 percent of respondents reported that they had experienced 10- to 15-minute additional delays due to ramp wait times. In contrast, two out of three respondents using the four corridors reported that, in their experience, they had suffered similar delays due to ramp metering.

Figure 6.12 Experience of Longer Ramp Wait Times



Maximum Willingness to Wait: Finally, respondents in both samples were asked about their tolerance for ramp wait times. The question was phrased as follows:

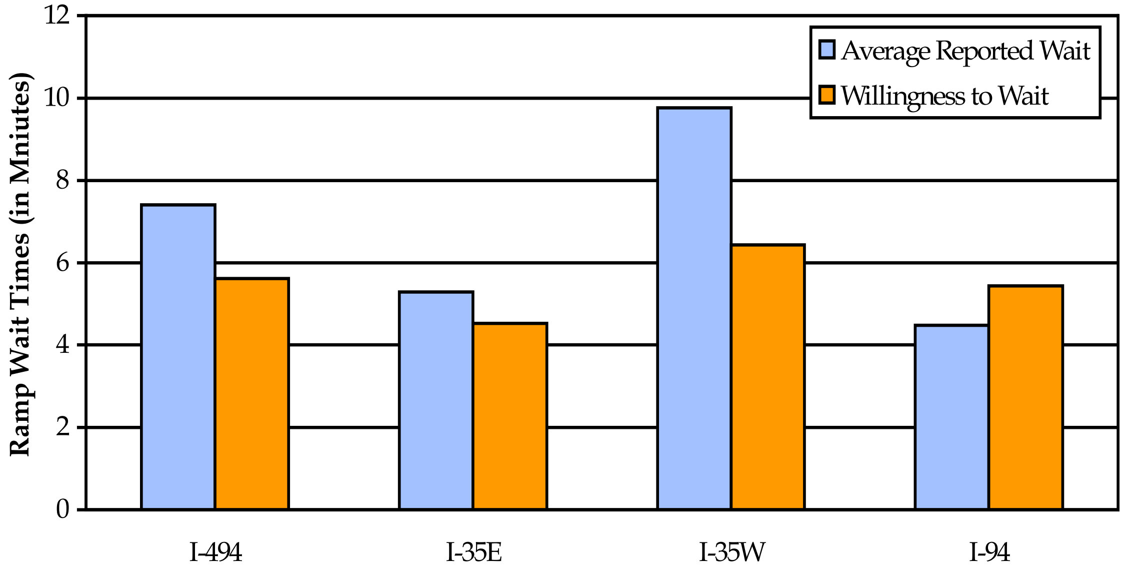
> *"How many minutes are you willing to wait at a ramp meter before you wish you had used a different route?"*

The responses to this question can be interpreted as a threshold beyond which respondents view ramp wait times as unreasonably long. The average maximum acceptable wait time was 5.0 minutes among random sample respondents, and somewhat higher for an average of 5.5 minutes among corridor users.

As shown in Figure 6.13, there were also differences in the stated maximum willingness to wait at a ramp meter among commuters in each of the four freeway corridors. These differences highlight a greater tolerance toward ramp meter wait times among I-35W corridor users, while commuters on I-35E appear to be the least tolerant of long ramp wait times.

Travelers' tolerance limits are consistent with the highest perceived wait times that were experienced by corridor for I-35W users and the lowest average perceived times experienced by I-35E users (Figure 6.13). Travelers are willing to wait at a ramp but clearly not beyond the reasonable bounds of their everyday travel experience. Furthermore, these findings are also consistent with the detailed estimates of ramp wait times by corridor reported in Section 5.0.

Figure 6.13 Maximum Willingness to Wait at a Ramp "With Ramp Meters" Corridor Surveys (N=507)



6.7 Attitudes Toward Ramp Metering

The patterns of travelers' ratings of highway level of service and ramp meters in the Minneapolis/St. Paul area generally reflect the qualitative insights gained from the focus groups. During the "with ramp meters" focus groups, participants' comments signaled a clear overall dislike of the concept of ramp meters. Participants expressed their frustration with the large number of ramps in the area, the long waiting times at the meters, the backups of the ramp queues onto the local streets, and the perceived lack of consistency between waiting times and level of freeway congestion.

These qualitative insights were translated into a set of questions that elicited travelers' attitudes toward their overall travel in the area, as well as specific attributes of their travel experience that are affected by ramp operations. Respondents rated the statements on a scale of one to 10, with a rating of one – meaning that respondents strongly disagreed with a statement, and a rating of 10 – suggesting that they strongly agreed. The wording of the attitudinal statements was intentionally mixed with both positively and negatively worded statements to control for any wording biases. The order of the statements was also randomized to avoid any ordering biases. Table 6.8 provides a detailed list of the attitudinal questions that respondents were asked as part of "with ramp meters" surveys.

Figures 6.14 and 6.15 show the average ratings for the attitudinal statements from the "with ramp meters" corridor survey. These graphs illustrate generally low ratings for ramp-related performance measures and somewhat higher ratings for overall network

Table 6.8 Attitudinal Statements for Freeway and Ramp Meter Performance

Now I would like you to think about your normal day-to-day travel throughout the Minneapolis-St. Paul metro area. I will read some statements that may or may not describe your travel experience. As I read each statement, please use a scale of one to 10 to tell me how much you agree with the statement. One means you disagree strongly and 10 means you agree strongly. The first statement is – **READ STATEMENTS, ONE AT A TIME**:

> **REPEAT AS NEEDED**: One means you disagree strongly and 10 means you agree strongly.
> **ROTATE STATEMENTS A THROUGH D AND ROTATE F THROUGH S.**
> **RECORD RESPONSE OF 1-10.**

A. I feel safe from car crashes when driving on freeways.

B. A special lane on the freeway for buses and carpools is a waste of freeway space.

C. The Minneapolis-St. Paul metro area has a good freeway network to move traffic.

D. When I travel during peak traffic hours, my travel time is predictable so I can plan to arrive on time.

E. Overall I am satisfied with the ramp meter system.

F. The length of time that I wait at ramp meters is usually too long.

G. I never know how long I will have to wait at a ramp meter.

H. I feel safe when leaving a ramp meter and merging into freeway traffic.

I. Ramp meters improve the area's overall traffic flow.

J. The cost of ramp meters is a good value for taxpayers.

K. Ramp meters shorten my travel time overall.

L. Ramp meters reduce car crashes.

M The ramp by-pass lanes are of benefit to people like me.

N. Some meters may not be necessary since I never have to wait at those meters during the peak traffic hours.

O. Buses and car pools should have the advantage of using ramp by-pass lanes.

P. Sometimes I need to wait at a ramp meter for a long time even when the highway traffic seems to be moving well.

Q. I wish there were more alternate routes that I could use to avoid ramp meters.

R. Ramp meters often cause congestion on local streets when the wait lines extend for one or more city blocks.

S. There should be an electronic sign before each ramp, telling the wait time at the ramp meter.

Figure 6.14 General Attitudes Toward Travel "With Ramp Meters" Corridor Surveys (N=500)

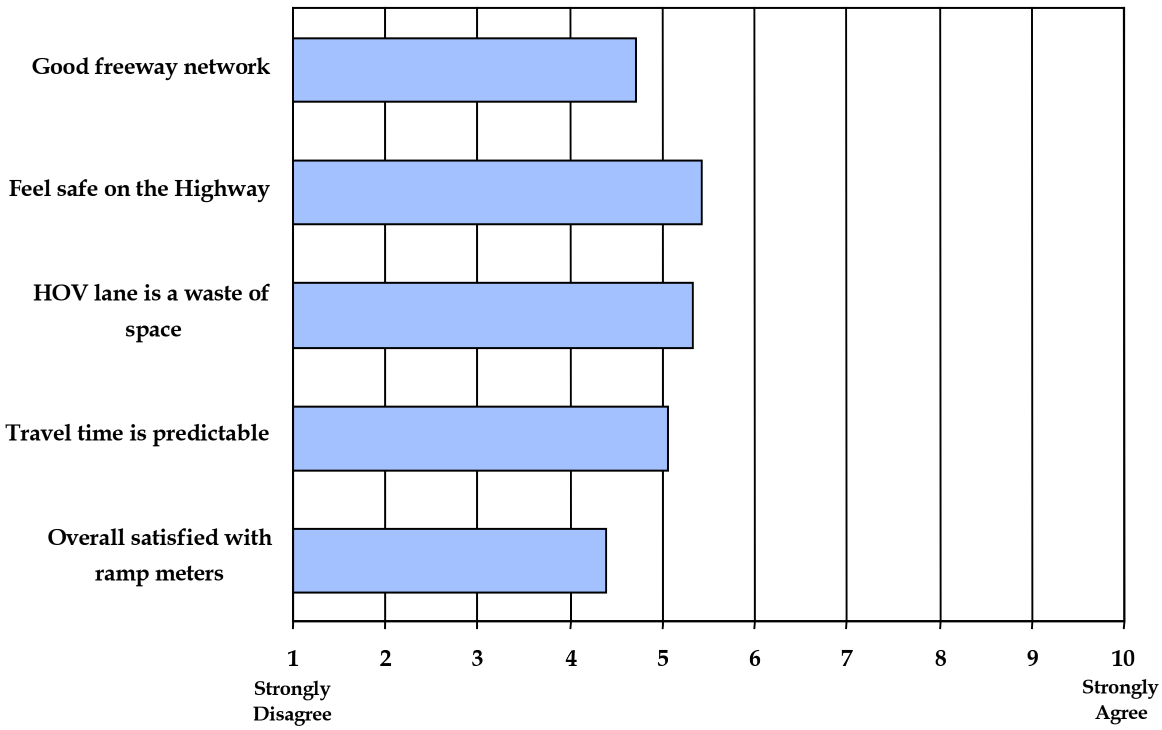
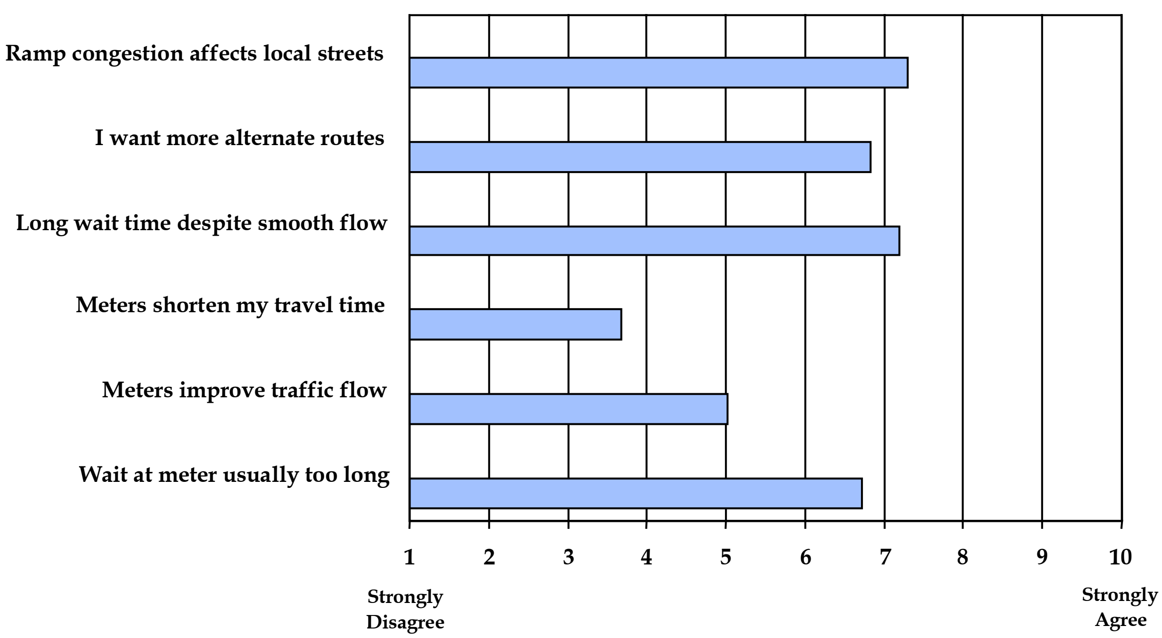


Figure 6.15 Attitudes Toward Ramp Metering "With Ramp Meters" Corridor Surveys (N=507)



performance. This pattern is consistent with the insights from the focus groups, where participants were dissatisfied mostly with ramp meters, rather than with their overall travel experience.

Overall, the responses to the attitudinal questions in the random survey were comparable to the corridor survey, although the random survey ratings were generally a little more positive toward ramp metering. A detailed list of average ratings for the random sample and the four corridor surveys is provided in Appendix H.

Differences by Corridor: There were some interesting differences in the perceptions of commuters using different corridors with I-94 commuters being the most positive about metering, and commuters on I-35W being the most vocal against the metering system.

- I-494 users generally "felt safe driving on the freeway," but
  - Didn't believe that "during peak traffic their travel times were predictable,"
  - Thought that the wait time at the meters was too long, and
  - Gave the lowest rating for "overall satisfaction with ramp metering."
- Commuters on I-35E stated that they "never know how long to wait" and gave lower ratings to "feeling safe when merging with freeway" and "feeling safe when leaving the ramp to merge."
- Users of the I-35W corridor
  - Gave the lowest ratings for "overall satisfaction with ramp metering";
  - Believed strongly that "ramp meters affect local streets," that they "never know how long they'll wait," and that "wait times at meters are too long";
  - Wished they had "more alternate routes to avoid ramp metering," and were much less receptive to the usefulness of HOV lanes; and
  - Disagreed more than the other corridor users with the statement that "ramp meters reduce crashes" and that they "feel safe when merging with freeway."
- Finally, commuters on the I-94 corridor generally provided positive feedback for the ramp meter system since they:
  - Believed that the "cost of ramp meters is a good value";
  - Agreed more than the rest that "meters improve overall traffic flow" and that "meters shorten my travel time"; and
  - Were less likely to believe that they "had to wait at a ramp even when freeway traffic was moving smoothly," while they were more receptive to HOV lanes.

Differences by Market Segment – In addition to the identified differences by corridor, an effort was undertaken to identify differences by market segments. Both socioeconomic and travel-related variables were used to examine whether some of the observed differences by survey wave could be attributed to differences by underlying market segments.

The socioeconomic variables that were tested included respondents' gender, age, education, employment status, household size, and household income. The travel-related variables that were tested included frequency of travel, travel in the a.m. versus the p.m. peak period direction, reported wait times at the ramp, and total and freeway travel time.

The most important statistically significant differences that could be attributed to socioeconomic and travel characteristics related to the length of the total origin-destination trip. Travelers with longer travel times of 45 minutes or more:

- Provided lower ratings for the statement that "during peak traffic hours my travel time is predictable";
- Were more satisfied with the "overall operation of ramp meters" and were less in agreement with the statements that "the wait at ramp meters is usually too long," and that "sometimes I need to wait at a ramp meter for a long time even when the highway traffic seems to be moving well";
- Believed that "ramp meters improve overall traffic flow" and that "meters shortened their travel time"; and
- Although they felt less "safe from crashes on the freeways," they agreed that "meters reduce car crashes" and that the ramp meter system was a good value.

The longer wait times experienced at ramp meters helped to explain respondents' lower ratings for the "freeway network in the Minneapolis/St. Paul area," their disagreement with the statement that "meters reduce my travel time," and their lower level of "overall satisfaction with ramp metering."

Finally, there were also some important gender-specific differences that related to ramp meter operations. In particular, women:

- Felt less "safe from crashes on the freeway";
- Agreed less than men with the statement that they "felt safe when leaving the ramp to merge into the freeway";
- Believed more than men that "meters reduce car crashes";
- Agreed more strongly than men that "meters improve traffic flow"; and
- Were more receptive to the concept of a changeable message sign before the ramp entrance providing information about the expected ramp wait time.

6.8 Differences in Attitudes Following the Shutdown

The primary objective of the comparative analysis of traveler's ratings of highway performance before and after the experimental shutdown of ramp meters was to evaluate whether and how the experiment had affected travelers' attitudes. The first step in the analysis was to examine whether the ramp metering shutdown experiment had affected respondents' general perceptions about travel in the study area and, more specifically, how it had affected their perceptions about ramp meter performance. The second step was to identify whether the experiment had affected various market segments in different ways. To examine that, the analysis also focused on identifying corridor-specific and travel-related influences on travelers' changing attitudes.

This section presents and discusses only those differences that are statistically significant at the 95-percent confidence level. The t-statistic test and analysis of variance methods were used to identify those differences that were statistically significant.

Table 6.9 summarizes the statistically significant differences that were identified for respondents' "with ramp meters/without ramp meters" attitudes in the random sample and across corridors. Appendix H includes five tables that show each individual rating in the "with ramp meters" and "without ramp meters" surveys in the random sample and the four corridors along with the corresponding t-statistic values. This section provides an overview of the results of the random sample survey and then focuses on the corridor-specific differences that have emerged.

The changing pattern of attitudes shown in Figure 6.16 highlights the impact of the ramp meter shutdown on travelers' perceptions. These statistically significant differences from the corridor sample underscore the strengthening of the already negative perceptions toward ramp metering among the corridor users.

Random Sample Survey – The "with ramp meters/without ramp meters" changes in ratings presented in Table 6.9 strongly suggest that randomly selected respondents in the Minneapolis/St. Paul metro area:

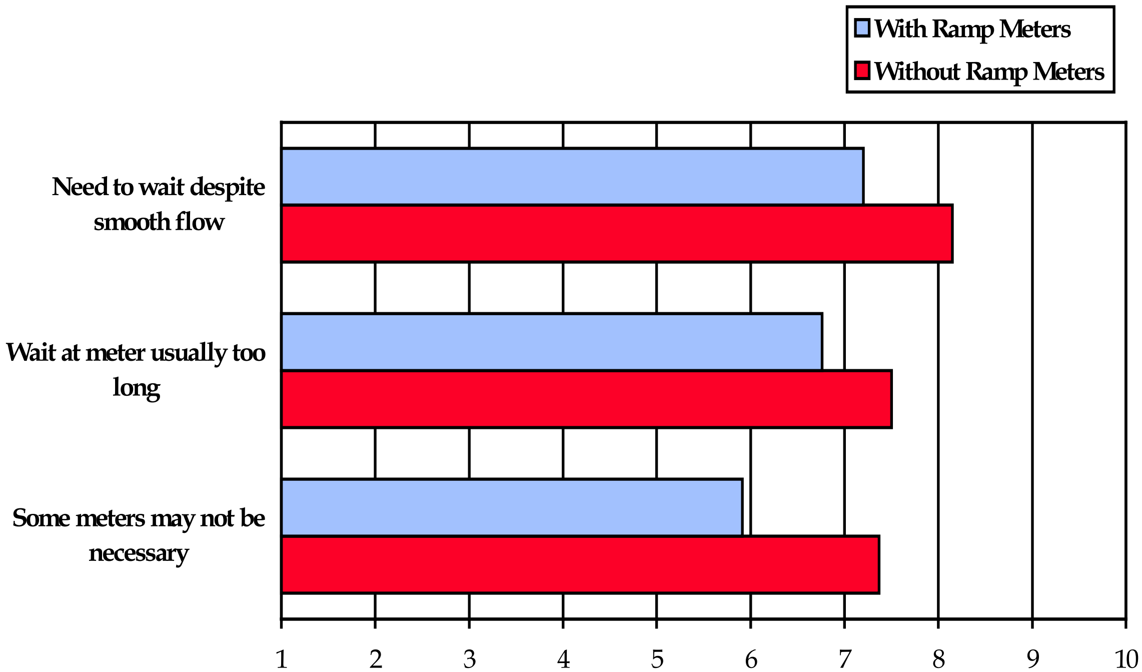
- Have reinforced their negative perceptions that "the length of ramp meter wait times was too long";
- Are more convinced than they used to be before the shutdown that "some meters may not be necessary";

Table 6.9 Statistically Significant Differences in Travelers' Attitudes N=250 in Each Corridor and N=500 in the Random Sample

	Random	I-494	I-35E	I-35W	I-94
Need to wait despite smooth flow	+0.8	+0.3	+0.9*	+1.3	+1.5
Wait at meters is too long	+0.7	-0.1	+1.0	+0.7	+1.4
Some meters not necessary	+1.5	+0.6	+1.6	+1.8	+1.6
Travel time is predictable	+0.2	+0.1	+1.1	+0.6	-0.3
Congestion more tolerable	+0.7	+0.3	+2.1	+1.0	0.0

*Note: Statistically significant differences in red. It should be noted that tests of statistical significance involve several measures of variance across the sample. Thus, a change of 1.0 could be statistically significant in one case, but not in another.

Figure 6.16 "With Ramp Meters/Without Ramp Meters" Wait Time Attributes and Need for Meters – N=906 for Corridor Surveys



- Believe firmly now that "they had to wait too long at a ramp even when freeway traffic was moving smoothly";

- Believe that the "level of congestion" that they face in their after commute after the shutdown is more tolerable than before the meter shutdown; and

- Seem to agree less than they used to about the value of the "VMS signs informing them of the expected ramp wait times."

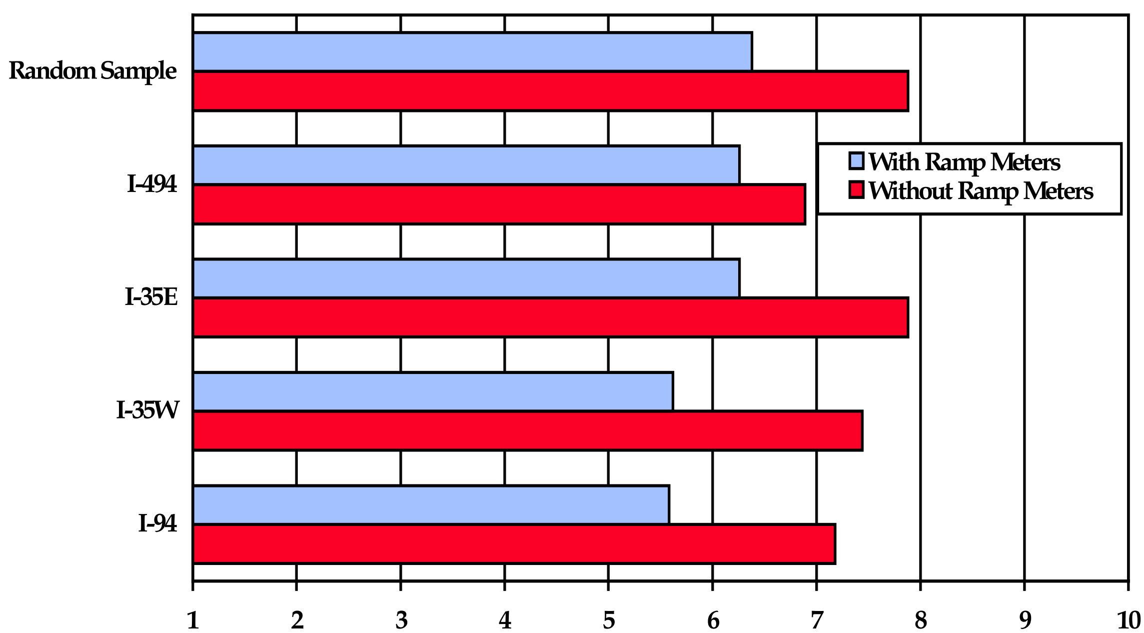
These findings most likely reflect the relatively smooth operation of the freeway system during the experimental shutdown. Despite the increase in travel times and the change in accident rates, the ramp meter shutdown did not cause a major gridlock in the area and traffic continued to flow reasonably well without the need to wait at ramp meters.

Differences by Corridor – The analysis of the attitudinal ratings across the four corridors provided some interesting insights. Since the picture that emerged was quite different across the four corridors, the following discussion focuses on the statistically significant differences for each corridor while a detailed listing of all attitudinal differences is provided in Appendix H.

Commuters using the I-35E, I-35W, and I-94 corridors were in agreement among themselves, but in sharp contrast to I-494 users. The "without ramp meters" ratings provided by commuters on the I-35E, I-35W, and I-94 corridors, when compared with their "with ramp meters" ratings, clearly suggest that the experiment has reinforced their negative perceptions about ramp meter operations (Table 6.9). In particular, commuters on each of these three corridors were in agreement with the random sample respondents since:

- They became more convinced that "some meters may not be necessary" (Figure 6.16);
- They believed strongly that "the length of ramp meter wait times was too long."
- They now believed firmly that when the meters were in operation they had to wait too long even when freeway traffic was moving smoothly.
- The pattern of "with ramp meters/without ramp meters" differences by corridor for each of these statements is the same as the pattern shown in Figure 6.17. In addition, commuters on I-35E and I-35W also believed that:
  - The predictability of their commute had improved significantly during the experimental meter shutdown, and
  - Their commute on I-35W and I-35E was considerably more tolerable than it used to be when the ramp meters were in operation.

Figure 6.17 Differences in "Some Meters May Not Be Necessary" by Corridor N=250 in Each Corridor and N=500 in the Random Sample



Finally, there was an interesting finding regarding corridor I-35W that was not consistent with I-35E corridor users' overall negative view of ramp meters. As shown in Table 6.10, I-35W commuters appreciated the safety aspects associated with ramp metering. In particular:

- They believed that the operation of ramp meters made them "feel safe when leaving a ramp meter and merging into freeway traffic"; and

- They agreed with the statement that "ramp meters reduce car crashes."

As part of the safety analysis, it would be very interesting to identify whether there was a higher incidence of accidents on I-35W that could be attributed to the ramp meter shut-down, and whether the configuration of the freeway entrance ramps on I-35W makes merging more difficult in this corridor compared to the rest of the ramps in the study area.

After comparing their prior experience with the operation of the network system with the ramp meters shut down, I-494 commuters believe that they were better off with the ramp meters in operation (Table 6.10). The pattern of responses by I-494 commuters is in sharp contrast to the responses by commuters in the other corridors as described above. In particular:

- I-494 users were more satisfied with the "overall performance of ramp meters."

- They appreciated more the element of safety that ramp meters provide giving higher ratings to the statements "feeling safe when leaving the ramp to merge into the high-way" and "ramp meters reduce car crashes."

Table 6.10 Statistically Significant Differences for I-494 Corridor N=250 in Each Corridor and N=500 in the Random Sample

	Random	I-494	I-35E	I-35W	I-94
Overall satisfied with meters	-0.3	+1.4	-0.2	-0.1	-0.7
Meters improve overall traffic	-0.1	+1.5	+0.2	+0.4	-0.6
Meters shorten travel time	0.0	+2.0	+0.4	0.0	+0.1
Feel safe to merge	+0.3	+0.8	+0.4	+1.4	-0.1
Meters reduce car crashes	+0.1	+0.7	+0.4	+0.7	-0.8

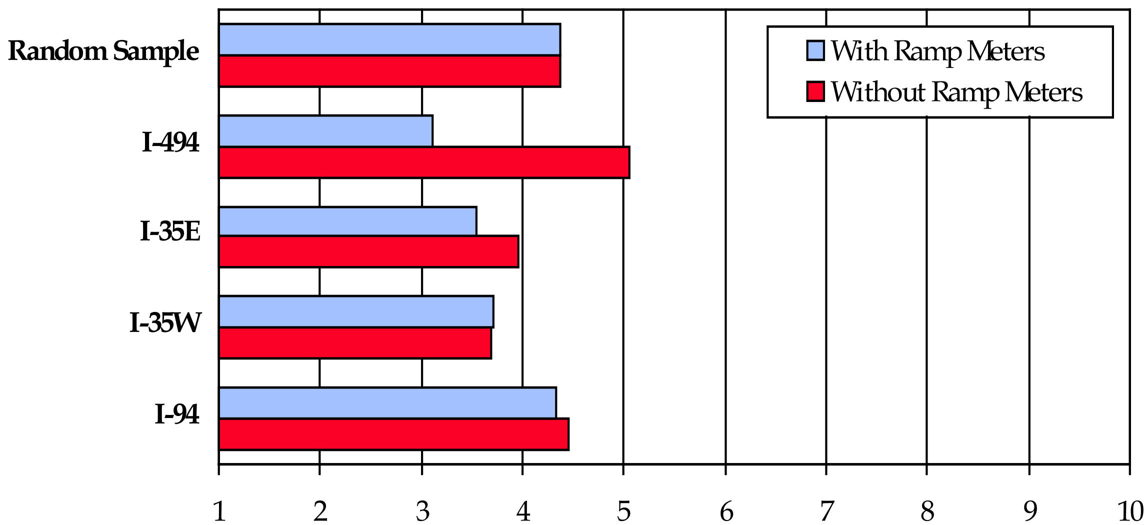
*Note: Statistically significant differences in red.

- They believed more strongly than before that "ramp meters shortened my travel time" as shown in Figure 6.18.

- They agreed more strongly with the statement that "ramp meters improve overall traf-fic flow" in the corridor.

- They didn't believe as strongly any more that "buses and carpools should have bypass lanes." The patterns of attitudinal differences for each of these statements followed the pattern shown in Figure 6.18.

Figure 6.18 Differences in "Meters Shorten my Travel Time" by Corridor N=250 in Each Corridor and N=500 in the Random Sample



The negative experience of I-494 commuters during the meter shutdown and their more positive view of ramp meters is consistent with I-494 users' evaluation of worsening traffic conditions and longer travel times during the shutdown as discussed in Section 6.5. Their perceptions also reflect the increase in travel time in the corridor as measured by the I-494 travel time runs and the higher variability of speeds in the I-494 corridor. These findings are also consistent with the travel pattern profile of I-494 users having longer average trip times than those surveyed in the other corridors, and having origins further from the urban core. These are precisely the groups which would generally be expected to benefit from ramp metering. This premise is further reinforced by the following comparison of attitudes toward ramp metering by trip length across the entire survey sample.

Differences by Travel Attributes – Finally, an examination of the impacts of travel-related attributes on travelers' perceptions uncovered some additional important differences among travelers with commutes of different lengths. In particular, respondents with longer origin-destination travel times changed their perceptions of ramp meter operations differently than respondents who took shorter trips.

In the "without ramp meters" survey, satisfaction with ramp meter operations has increased among travelers with longer commutes. The longer their travel time, the more likely it is that travelers come to realize that they were better off with the meters in operation, a pattern that was the reverse for commuters with short O-D travel times. Two figures are included here as examples of the travel time impact on the change in travelers' perceptions about ramp meters, but the pattern of more positive perceptions is the same and very strong in all five statements:

1. "Overall I am satisfied with the ramp meter system" as shown in Figure 6.19.
2. "Ramp meters shorten my travel time overall" shown in Figure 6.20.

Figure 6.19 "Overall Satisfied With Meters" by Travel Time Market Segments N=903 in the Corridor Sample

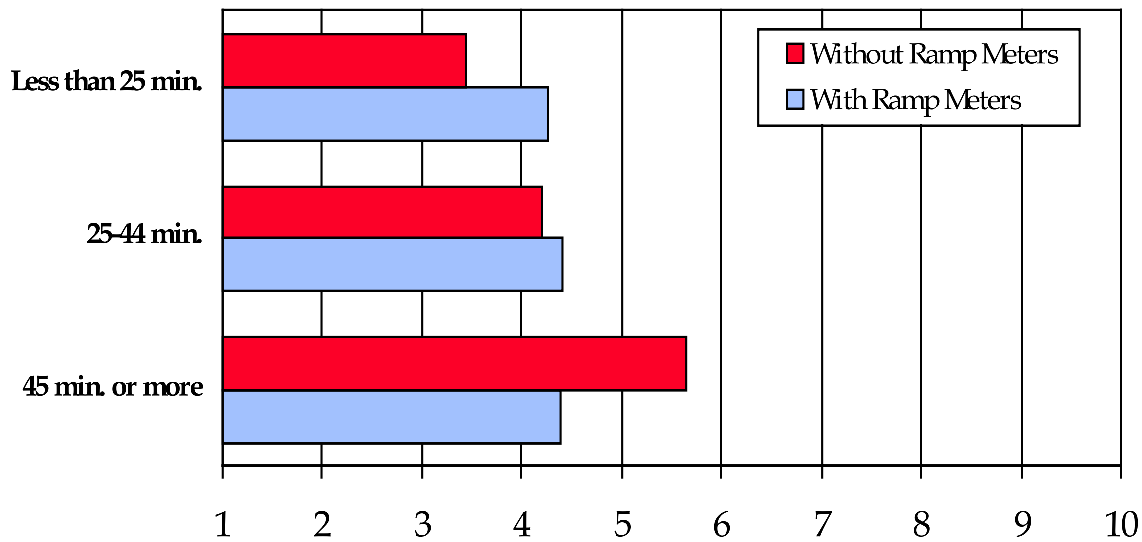
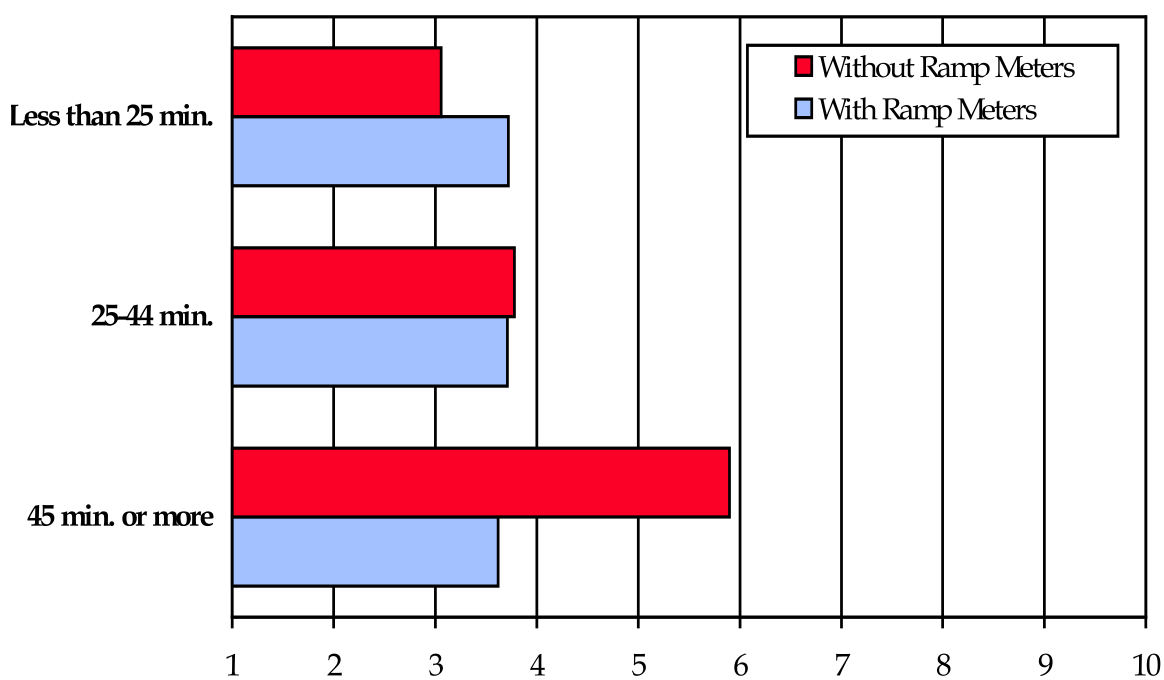


Figure 6.20 "Meters Shorten my Time" by Travel Time Market Segments N=903 in the Corridor Sample



3. "Ramp meters improve the area's overall traffic flow."
4. "The length of the time I wait at meters is usually too long."
5. "The cost of ramp meters is a good value to taxpayers."

These patterns confirm that, although travelers with longer trips were originally more positive toward ramp metering, the experience of the ramp meter shutdown strengthened their positive view of metering even further.

6.9 Travelers' View of the Ramp Metering Future

The final objective of the market research was to assess whether respondents favored changes to the ramp metering system; to identify proposed changes; and to examine differences by survey wave, corridor, and market segment. At the end of both the "with ramp meters" and "without ramp meters" surveys, respondents were asked to evaluate the ramp metering system with the following question:

> *"Given your experience with the ramp meter system in the Minneapolis/St. Paul area, do you think the ramp meter system should be continued as it is now, modified in some way, or shut down permanently?"*

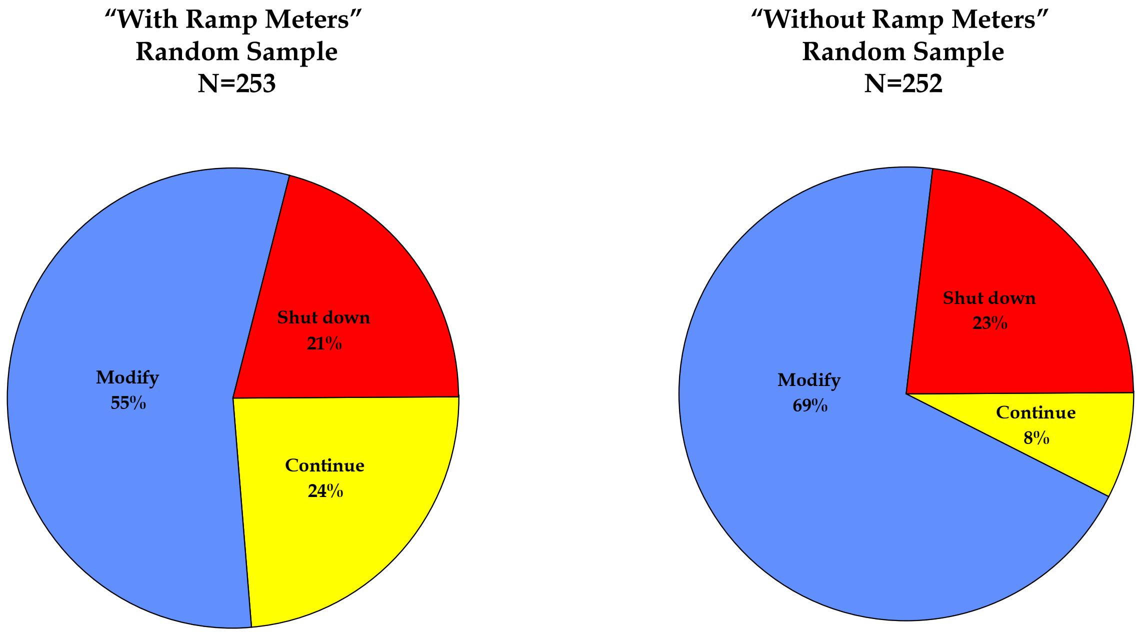
The three responses to the question (status quo versus shutdown versus modifications) were rotated to minimize any response bias that could be attributed to ordering effects.

The analysis of both the "with ramp meters" and "without ramp meters" responses suggests that respondents strongly favor a modified version of the ramp metering system. The differences by survey wave show increasing support for the "modification" option following the shutdown, while differences across corridors and market segments suggest that I-494 users and those making longer trips are more supportive of the pre-shutdown status quo.

Traveler Preferences – As shown in Figure 6.21, prior to the shutdown, more than half of the random sample respondents wanted the ramp meter system modified with the rest split almost equally among those who favored the status quo (24 percent of the total) and those who wanted the system shut down permanently (21 percent of the total). The strongest support for the meter shutdown was among frequent travelers driving alone in the corridor and facing ramp wait times eight minutes or longer.

Following the shutdown, the "modification" option strengthened even further supported by a dominant 69 percent of the random sample respondents. The support for maintaining the meter system status quo was down considerably from 24 percent of the random sample to just eight percent in the "without ramp meters" survey. It should also be noted that the percentage of respondents favoring a permanent shutdown remained more or less constant over the two survey waves.

Figure 6.21 Future of Ramp Metering – Random Sample



Similar patterns were also observed for the corridor survey sample (Figure 6.22). Support for the "modification" option among the four corridor users dominated both survey waves, rising from 59 percent to 70 percent of the sample following the shutdown. Support for the ramp meter status quo dropped over time with only 11 percent of the corridor users supporting it, following their generally positive experiences with the ramp meter shutdown.

Differences by Corridor and Market Segment – The analysis of respondents across the four corridors and across market segments uncovered some additional interesting differences. The common finding was that the majority of corridor users want the system modified in some way, with that option gathering greater support following the shutdown and mostly at the expense of the status quo option.

In three out of the four corridors, support for the ramp meter status quo dropped dramatically following the shutdown (Figure 6.23). In the I-35E corridor, only 5.5 percent of the users want the meters back compared to 18 percent in the "with ramp meters" sample. Similarly, in the I-35W corridor, the support for the status quo drops from 13 percent to eight percent, while in the I-94 corridor from a previous high of 32 percent to 13 percent. In contrast, support for the status quo increased among I-494 users from a previous low of 13 percent to a post-shutdown high of 17 percent.

This pattern was examined further to identify the reasons behind it. As shown in Figure 6.24, total travel time helps to explain the differences in travelers' responses. More than 90 percent of travelers with a typical commute travel time of less than 25 minutes

Figure 6.22 Future of Ramp Metering – Corridor Sample

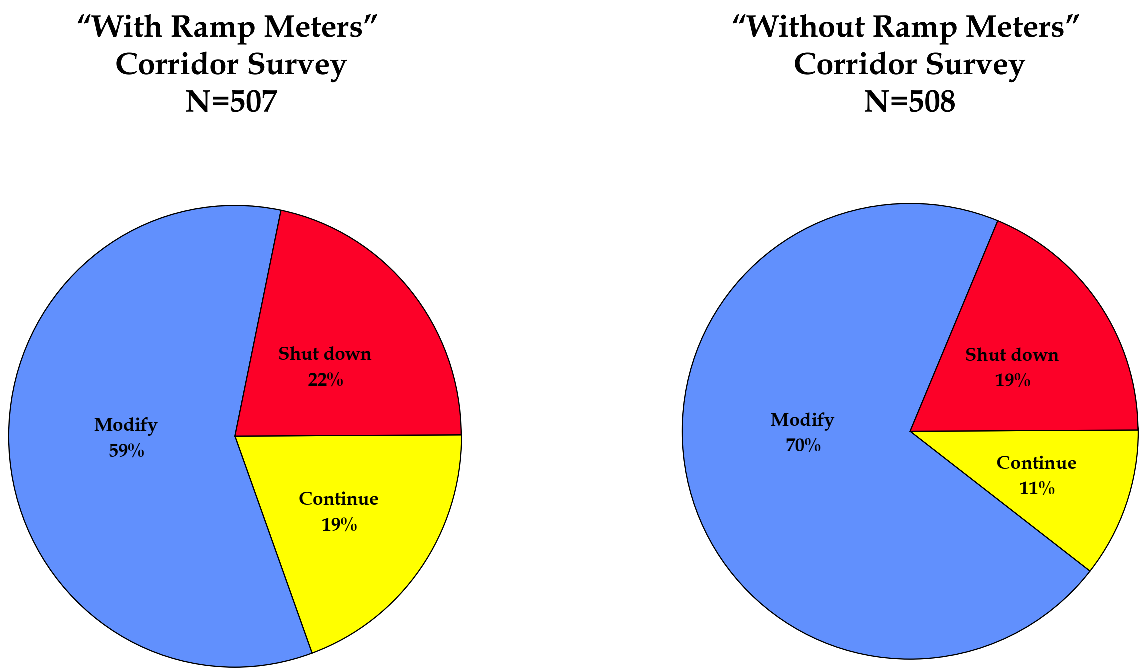


Figure 6.23 Future of Ramp Metering – Random Sample

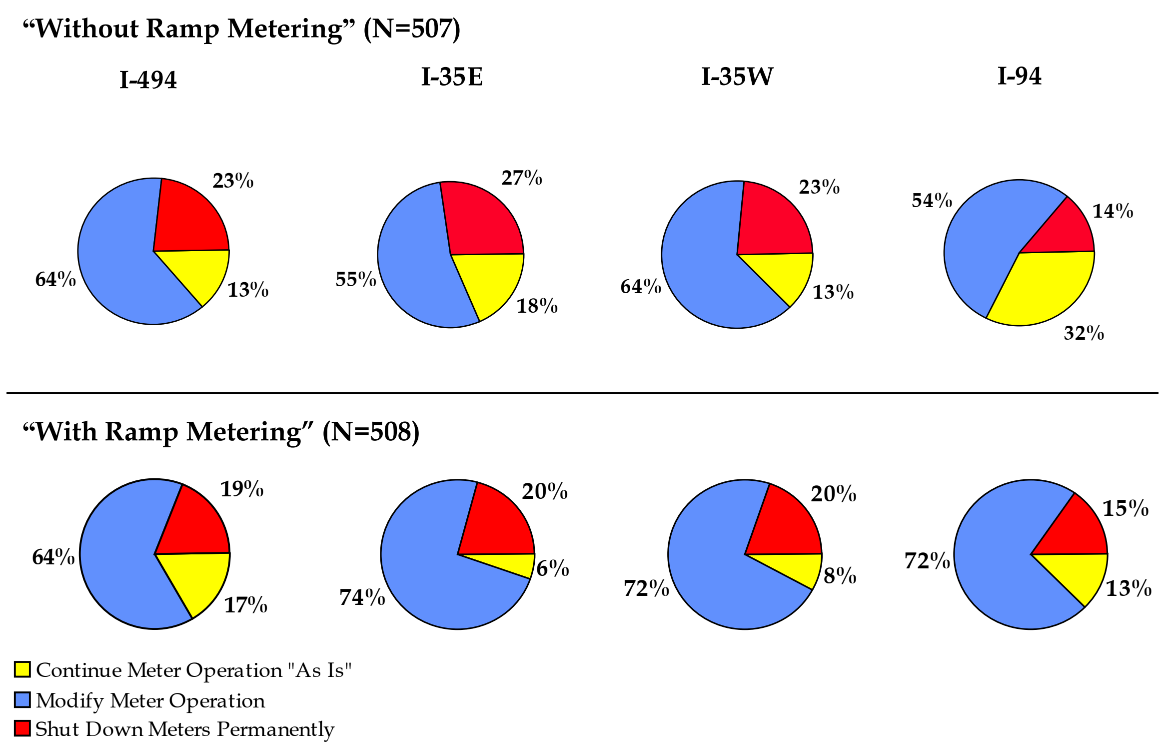
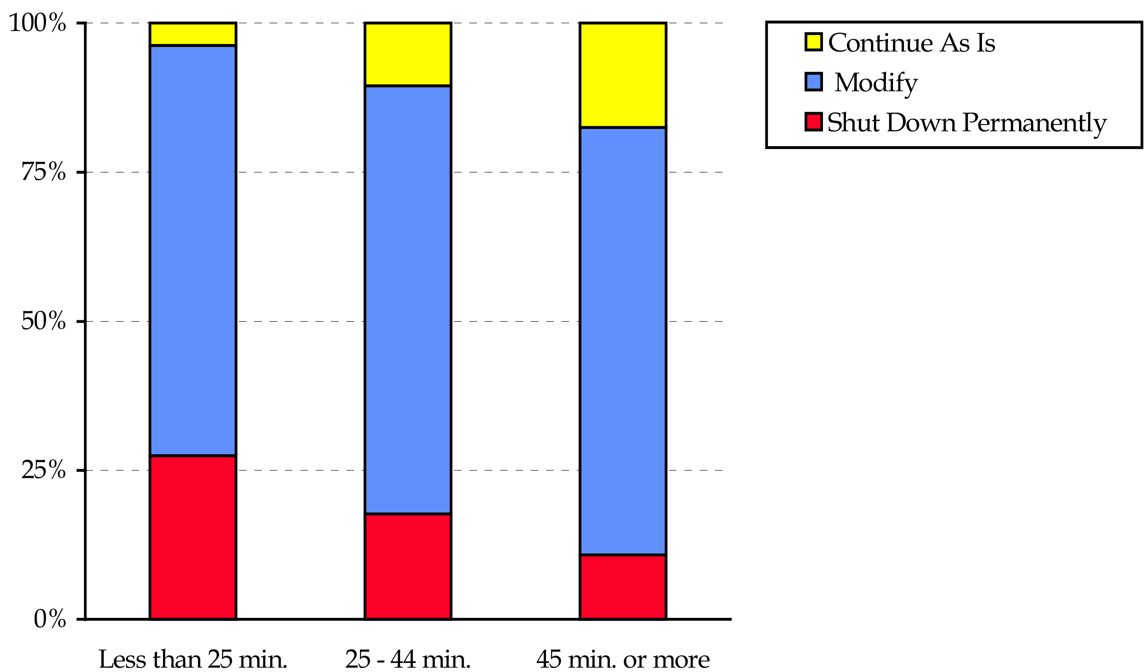


Figure 6.24 Differences in Future of Ramp Metering by Total Travel Time "Without Ramp Meters" Corridor Surveys (N=508)



were strongly opposed to the status quo and wanted the meters either shut off permanently or modified in some way. In contrast, travelers with typical commute times of more than 45 minutes were much more likely to prefer the status quo and much less likely to want the meters shut down permanently. This finding is consistent with the greater support for the status quo among I-494 commuters who experience a longer commute than respondents in the other three corridors.

Suggested Modifications – Finally, respondents who favored a modified version of the ramp meter system were asked to provide their own suggestions. The question was open-ended and respondents could provide one or more suggestions for improvement of the system. These responses were later categorized by the study team to provide an overview of respondents' preferences.

Table 6.11 shows the suggested modifications that were mentioned at least 10 percent of the time in the "with ramp meters" survey. Actions that are related to reducing the wait time experienced at the ramp meters topped the list representing 50 percent of the responses in the "with ramp meters" survey. Shortening the hours of operation and reducing the number of meters keeping meters only in congested areas were also frequently mentioned, followed by the option of providing electronic sign information about ramp delays before the ramp entrance.

Table 6.11 Ramp Metering Modifications – All "With Ramp Meters" and "Without Ramp Meters" Surveys

	With Ramp Meters	Without Ramp Meters
Shorten wait times/turn green faster	26%	25%
Adjust green to light traffic flow	24%	17%
Shorten hours of operation/turn off	16%	14%
Fewer meters/only in congested areas	15%	49%
Sign at ramp entrance	10%	6%

Interestingly, the pattern of responses was somewhat different in the "without ramp meters" survey. The dominant suggestion mentioned almost 50 percent of the time was to reduce the number of meters by focusing only in congested areas. This pattern is consistent with the drop in respondents' preference for the status quo and their increased support for modifications. These patterns are more clearly demonstrated by Table 6.12 which highlights differences by corridor. It is interesting to note that I-494 commuters prefer adjustments to the existing system of ramp meters mostly by suggesting actions that reduce wait times at the meters. In contrast, half or more of the commuters in each of the other three corridors favor a reduction in the meters in operation with ramp metering focused only in areas with existing traffic congestion.

Table 6.12 Ramp Metering Modifications – "Without Ramp Meters" Surveys by Corridor

	I-494	I-35E	I-35W	I-94
Shorten wait times/turn green faster	35%	21%	27%	18%
Adjust green to light traffic flow	28%	10%	16%	16%
Shorten hours of operation/turn off	27%	10%	8%	12%
Fewer meters/only in congested areas	22%	49%	64%	59%

7.0 Benefit/Cost Analysis

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

7.1 Analysis Approach

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

7.1.1 Estimation of Benefits

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

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

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

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

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

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

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

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

7.1.2 Estimation of Costs

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

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

Table 7.1 Impact Value Assumptions

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

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

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

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

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

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

Table 7.2 Congestion Management Subsystems Proportional Support of Ramp Metering

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

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

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

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

■ 7.2 Analysis Findings

7.2.1 Benefits of Ramp Metering

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

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

Travel Time Impacts

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

Travel Time Reliability Impacts

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

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

Safety Impacts

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

Emissions Impacts

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

Fuel Use

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

All Impact Categories

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

Table 7.3 Annual Ramp Metering Benefits

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

7.2.2 Ramp Metering Costs

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

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

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

Table 7.4 Annual Congestion Management and Ramp Metering System Costs

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

*Represents only those research contracts related to ramp metering.

7.2.3 Comparison of Ramp Metering Benefits and Costs

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

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

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

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

Table 7.5 Comparison of Annual Costs and Benefits

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

8.0 Secondary Research

This section summarizes the results of the secondary research conducted for this project. This task involved reviewing and summarizing relevant research regarding ramp metering employed in other metropolitan areas. Traffic operations personnel from two cities (Seattle, Washington; and Phoenix, Arizona) were interviewed to obtain more detailed insight into the objectives, strategies, successes, and issues with their ramp metering systems. Finally, the results from this evaluation effort are compared to studies conducted on the effectiveness of ramp metering systems in other areas. The detailed results of this research are contained in Appendix K.

■ 8.1 Basics of Ramp Metering

In the absence of metering, vehicles usually enter the freeways grouped in platoons, thus creating turbulence at the freeway mainline. When the mainline traffic is already at or near its capacity, such turbulence can cause even more adverse impacts. This turbulence produces stop-and-go traffic, which can lead to rear-end or sideswipe accidents.

Numerous studies have been conducted to evaluate the impacts of ramp metering in a variety of U.S. and international locations. These evaluations suggest that, depending on the type of the hardware, strategies used, and physical ramp/freeway/ alternative arterial configurations, the general benefits of ramp meters are thought to include:

- Increase in freeway productivity, up to 2,700 vehicles per hour per lane (vphpl);
- Reductions in stop-and-go traffic;
- Reductions in sideswipe or rear-end accidents and fatalities;
- Reductions on impacts of recurring congestion due to heavy traffic demand;
- Reductions in fuel consumption from stop-and-go travel;
- Improvements in air quality and other societal goals;
- Breaking up of vehicle platoons;
- Promoting easier and safer merging from ramps; and
- Reducing emergency vehicle response time.

Disadvantages of ramp metering may include:

- Delays and increased emissions at on ramps;
- Queues extending to the arterials;
- Higher volumes on the local arterials;
- Inequity issues (disadvantage to citizens that are traveling on short trips without any alternative routes, and to those living near the city centers); and
- Encouraging longer trips.

8.2 Use of Ramp Metering Across the Country

By 1995, ramp meters had been installed and operated in 23 metropolitan areas in the U.S. Of these, 11 cities have a system of more than 50 ramp meters, including Minneapolis-St. Paul. Los Angeles (CA) has the most ramp meters, with over 1,000 meters in operation. Due to the overall positive benefits and publicized success stories, the number of participating cities is expected to increase.

Historically, freeway sections that warrant ramp metering usually have the following characteristics:

- Peak-period speeds less than 48 kph (or less than 30 mph);
- Vehicle flows between 1,200 to 1,500 vehicles per hour per lane (vphpl);
- High accident rates; and/or
- Significant merging problems.

Ramp meters with controllers other than fixed-time may turn on or off, depending on the traffic volumes or occurrence of accidents/incidents. However, most agencies use standard hours to turn on/off their ramp meters, except in emergencies, for reasons of stability and reliability in the public eye.

In general, most ramp meters across the country operate during the a.m. and p.m. peak periods. However, several exceptions exist. In a busy, freeway-dependent city like Los Angeles, 32 ramp meters are operated at all times. As a result of a compromise between the Washington State Department of Transportation (WSDOT) and local neighborhood groups, a ramp meter in Seattle is only turned on during the p.m. peak. Due to equity issues, Detroit ramps that are close to the city centers are only metered in the off-peak direction. Another ramp meter in Seattle also operates on weekends, as well as weekdays.

Ramp Metering Goals and Strategies

Depending on the goals and objectives of the implementing agency, several types of ramp meter strategies can be pursued. The types of ramp metering strategies include:

1. **Emphasis on Safety –** Under this scenario, metering rates are typically very restrictive (imposing high metering delays). This reduces the traffic flow turbulence, and, therefore, the number of accidents at the merge areas. Often viewed as too restrictive and controversial, currently, there are no agencies adopting this strategy.

2. **Optimize Travel Safety and Efficiency –** Metering rates are less restrictive than Strategy #1, since some emphasis is placed on maximizing freeway productivity. The Twin Cities and San Diego (CA) are the primary cities implementing this strategy.

3. **Minimize Local Street Impacts –** When queue storage is limited, as in the case of Houston and Arlington (TX), more provisions need to be made to ensure that minimal queues develop on the arterials. However, such compromises decrease the traffic management effectiveness of ramp metering. Nevertheless, studies show that some positive benefits are obtained.

4. **Combination of Strategies #2 and #3: Basic Freeway Management.** Most cities adopt this strategy. Since the public is wary of queues and delay at the ramps, metering rates are adjusted at some cost to the freeway and overall transportation system efficiency.

8.3 Keys to a Successful Ramp Metering Program

Based upon the literature review, this section lists some of the strategies for a successful ramp meter program.

- **Select the Right Place –** In order to realize significant benefits, it is necessary to implement ramp metering in freeway sections that actually need it. Locations typically have the following characteristics: peak-period speeds less than 30 mph; flow of 1,200 to 1,500 vphpl; high accident rate; and significant merging problems.

- **Secure Funding –** Before embarking on a ramp metering program, make sure that the local politicians and city officials are committed to funding the program.

- **Good Public Support –** All implementing cities believe that public education and support are critical to the success of their ramp metering programs.

- **Ample Storage Capacity –** Most cities would like to have longer and wider ramps to prevent queues from extending beyond the ramps onto the arterials. If long queues with backups onto the arterials occur on a consistent basis, implementation of queue detection systems and adoption of a more conservative strategy may be necessary.

- **Synergy –** Use other forms of Intelligent Transportation Systems (ITS) to eliminate disadvantages found in ramp metering alone (e.g., couple ramp metering with ramp queue wait time signs or a Traveler Information System that can inform motorists of travel conditions and options for different travel modes, times, or routes).

- **Avoid Conflicting Solutions –** Mainline freeway HOV lanes and ramp meters may not work well together. Without HOV-bypass lanes or direct HOV connectors, metering may impose unnecessary delay to buses and carpools.

- **Eliminate Technical Problems –** Make sure the system is free from technical breakdowns to sustain high public trust and compliance rates.

- **Consistent Enforcement –** Consistent police enforcement, though costly, is the most effective enforcement strategy.

- **Continuous Improvement –** Upgrade the system to central or fuzzy logic controllers. Central control offers monitoring of an entire system, while fuzzy logic eliminates the possibility of processing and applying imprecise or erroneous traffic data.

8.4 Peer City Interviews

Two cities were interviewed to obtain more detailed information regarding their ramp metering strategies, successes, and issues. The two cities included Seattle, Washington; and Phoenix, Arizona.

8.4.1 Seattle, Washington

Seattle started the implementation of ramp meters in 1981, and continues to expand the system today. Currently, the Seattle metro area has 105 metered ramps serving approximately 8,000 lane-miles of freeway. Approximately 85 ramps have HOV-bypass lanes and 20 ramps have dual metered lanes. The average length of the ramps is approximately 750 feet, ranging from 500 to 1,200 feet. The meters are centrally controlled and normally activated during the weekday a.m. and p.m. peak periods (6:30 to 9:00 a.m. and 3:00 to 6:30 p.m.), but few exceptions exist.

Recently, Seattle implemented a new metering algorithm that "adjusts the meters … based on neural network programming." WSDOT claims it to be more responsive, an improvement over previously used algorithms.

According to WSDOT, the objective of Seattle's ramp meter program is to "improve safety and efficiency." WSDOT considers its ramp meter program in Seattle very successful, largely due to coupling this program with a solid HOV program. Integration between metering, mainline HOV and HOV-bypass lanes is done as often as possible. Furthermore, a good amount of time and effort is always invested into working with the communities near a metering system prior to activation. This way, public support has always been excellent, while violation rates remain very low (less than two percent).

Queue lengths are found to be the main constraints to the program. While the ramp metering strategies are area-wide, further refinements are performed at the corridor and community level to address the constraints. Again, good local community relations are necessary to achieve mutual goals between the agency and the citizens.

Currently, Seattle conducts ongoing collision avoidance studies at the freeway merging areas. Since accident reduction studies typically look at crashes that had occurred, collision avoidance studies analyze reductions in "near misses" or almost-accidents. Generally, ramp meters reduce the potential conflicts at the merging areas by about 30 to 60 percent.

8.4.2 Phoenix (AZ)

The Arizona Department of Transportation (ADOT) started to implement stand-alone ramp meters in Phoenix during the mid-1980s, but did not implement any ramp meter systems (series of meters along a given corridor) until 1995. Currently, the Phoenix metro area operates 121 ramp meters, of which 22 ramps have HOV-bypass lanes and 21 ramps have dual lanes. Ramp lengths vary greatly between ramps, all ranging between 500 feet (older ramps) to 1,300 feet (newer ramps).

The majority of the ramp meters are centrally controlled and capable of adapting to traffic patterns, but operate under fixed-time control. Most ramp meters in Phoenix are activated during the a.m. and p.m. peak periods (6:00 to 9:00 a.m. and 4:00 to 7:00 p.m.), except at ramps near freeway construction zones, where meters are turned on 24 hours per day.

ADOT's main objective for the ramp meter program in Phoenix is to improve the current Freeway Management System and to "break up platoons." ADOT believes that its ramp meter program has been a tremendous success in Phoenix, especially because of the city's grid system (one square-mile grids throughout the metro area). Unlike Minneapolis-St. Paul, where often geographical constraints, such as rivers and lakes force commuters to travel on the freeway, Phoenix's grid system provides alternative routes for the short-trip commuters, especially during peak periods.

Like Seattle, queue lengths are found to be the constraints of the program. In the past, queue detectors were placed to detect when and how far queues have extended at (or beyond) the ramps. However, continuous adjustments (week-to-week or month-to-month) and balancing between the city street and freeway volumes have proven to be a more effective method in preventing extended backups. Two full-time technicians have been allocated to manage and maintain all ramp meters in the Phoenix metro area.

ADOT raised an interesting issue with respect to their metered ramps with HOV-bypass lanes. Since the ramps have dual lanes (one for mixed-flow vehicles, the other for HOV or transit only), dual left-turn lanes are often placed at the arterials leading to the ramps. But during the heaviest periods, backups sometimes reach the end of the ramps, even extending towards the left-turn lanes and beyond. Obviously, the HOV-bypass lanes carry less traffic than their counterparts, leading the regular lane to become very congested, while the HOV-bypass lane remains empty. Out of frustration, motorists are found to switch over to the empty left-turn lane and use the HOV-bypass lane illegally. In Phoenix, this situation results in a violation rate of over 45 percent. Under normal circumstances, the ramp meter violation rate is approximately 10 percent. Recently, ADOT passed a legislative effort raising the amount of fines that can be levied against violators, up to $619. The large sum caused uproar among the citizens and in the local media, but early results showed that violation rates have decreased substantially.

As much as possible, ADOT prefers to expand its ramp metering system in Phoenix in conjunction with other freeway management or construction projects. Every system addition requires strong relationships with local city agencies and governments. But so far, there have been few political controversies caused by ramp meters.

8.5 Comparison of Twin Cities Evaluation Findings to Other Ramp Meter Evaluation Studies

Numerous evaluation studies have been performed on ramp metering systems around the world. Depending on the goals and objectives of each program, the performance measures used for each study are different. Table 8.1 summarizes the measures that have been used, along with the impacts resulting from the implementation of ramp metering.

Table 8.1 Changes in Performance Measures Resulting from the Implementation of Ramp Metering

Performance Measures	Change
Freeway mainline speed	Increases
Accident rate/frequency	Decreases
Overall travel time/delay time	Decreases
Freeway mainline volume/flow/stability of flow	Increases and stabilizes
Fuel savings	Increases
Benefit/cost (B/C) ratio	4:1 to 62:1
Ramp delays	Increases
Arterial vehicle volume	Increases, but insignificant

Table 8.2 provides a summary comparison of the Twin Cities ramp meter evaluation to other ramp metering studies that have been conducted dating back to 1975. Where data was available, the table identifies the number of meters, type of control, metering strategy, hours of operation, and the various performance measures. The following conclusions have been observed from the studies:

- Mainline speed, travel time savings, safety (crashes), and vehicle volume (throughput) are the most commonly used measures of effectiveness.

- 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 evaluation'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.

Table 8.2 Comparison of Twin Cities Evaluation Findings to Other Ramp Meter Evaluation Studies

Location	Twin Cities	Abilene	Arlington	Atlanta	Austin	Denver
State/Country	**MN**	**TX**	**TX**	**GA**	**TX**	**CO**
Study Date	**2000**		1999	1996	1997	1982
Number of Ramp Meters in Study	**431**		5	5	3	28
Total Number of Ramp Meters	**431**		26	>50		
Type	**Mostly central control, few fixed**		Fixed, 4 sec cycle	Fixed		Central control
Strategy[1]	**2**		3	2-3		
Hours of Operation	**Varies, peak period**		6:15-8:30 a.m.	3:45-6:30 p.m.	a.m. peak	
Freeway Travel Time Impacts	**-22%**	-13%	-10%	-10%	-37.5%	-26.7% to -37%
Freeway Speed Impacts	**+7 mph**	+22%			+60%	+35.5 to +58%
Impact on Crashes	**-26%**					-5% to -50%
Traffic Volume and Throughput	**+9% to +14%**				+7.9%	+19%
Emissions Impacts	**1,161 tons annually**					+24%
Fuel Impacts	**+22,000 gallons/day**	-6%				
Benefit/Cost Ratio	**5:1 to 15:1**	62:1		4:1 to 20:1		
Average Ramp Delays	**+2.3 min/veh**					
Arterial Volume Impacts	**Insignificant**					+300 vph

Table 8.2 Comparison of Twin Cities Evaluation Findings to Other Ramp Meter Evaluation Studies (continued)

Location	Detroit	Houston	Long Island	Los Angeles	Milwaukee	Minn-St. Paul
State/Country	**MI**	**TX**	**NY**	**CA**	**WI**	**MN**
Study Date		1997	1987 to 1990, 1991	1975	1995	Several, 1975 to 1996
Number of Ramp Meters in Study	28		60	259	6	Varied
Total Number of Ramp Meters	49	<50	75	808	43	431
Type	Central control	Fixed	Traffic responsive and central control	Traffic responsive	Traffic responsive and central control	Mostly central control, few fixed
Strategy[1]		3		2-3	2-3	2
Hours of Operation		6:30-9:30 am, 3:30-6:00 p.m.		Varies, 32 all day	Varies, 6-9 am, 3:00-6:30 PM	
Freeway Travel Time Impacts	-7.4%	-22%	-13% to -20%	-13%		-13.8% to -26.5%
Freeway Speed Impacts	+8%	+29%	+9% to +21%	+15 mph	+3% to +35%	+14% to +60%
Impact on Crashes	-50%		-15%	-20%		-24% to -29%
Traffic Volume and Throughput	+14%		0% to +7%	900 vpd	+22%	+8% to +40%
Emissions Impacts	124,600 tons annually		+17.4% CO, +13.1% HC, -2.4% NOx			2.2 million kg annually
Fuel Impacts			-6.7%	-13%		
Benefit/Cost Ratio						7.3:1
Average Ramp Delays			1.2 to 3.4 vehicles			0.1 to 2.5 minutes
Arterial Volume Impacts	Insignificant			Insignificant		

Table 8.2 Comparison of Twin Cities Evaluation Findings to Other Ramp Meter Evaluation Studies (continued)

Location	Phoenix	Portland	Sacramento	Seattle	Zoetemeer	M6 Motorway
State/Country	**AZ**	**OR**	**CA**	**WA**	**Netherlands**	**England**
Study Date	1989 to 1995	1982	1984	1981 to 87	1995	1986
Number of Ramp Meters in Study	9	16	9	22	9	1
Total Number of Ramp Meters	121	58	19	105		
Type	Fixed	Fixed	Traffic responsive	Central Control, fuzzy logic		Fixed
Strategy[1]	2-3	2-3	2-3	2-3		
Hours of Operation	5:30-9:00 a.m., 2:30-6:30 p. m.	6:30-9:30 a.m., 3:00-6:30 p.m.	7:00-9:00 a.m.	6:30-9:00 am, 3:00-6:30 p.m.		
Freeway Travel Time Impacts		-7.4% to -39%		-47.7% to -91%	-13%	
Freeway Speed Impacts	+5 to +10%	+7.5% to +155%		+20-25%	+15%	
Impact on Crashes		-43%	-50%	-38%		
Traffic Volume and Throughput	+15%	+25%	+3% to +5%	+62% to +86%	+3%	+3.2%
Emissions Impacts						
Fuel Impacts		540 to 700 gal/day				
Benefit/Cost Ratio	5:1 to 10:1			10:1 or more		
Average Ramp Delays				< 3 min	+20 sec	+1.5 min
Arterial Volume Impacts				Insignificant		<5% diverted from fwy

[1]Metering Strategies: 1 = Emphasis on safety; 2 = Optimize Travel Safety and Efficiency; and 3 = Minimize Local Street Impacts.
Abbreviations: sec = seconds, min = minutes, hrs = hours, mph = miles per hour, vph = vehicles per hour, HOV = high-occupancy vehicle, VMT = vehicle miles traveled, fwy = freeway, veh = vehicle, kg = kilograms.

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

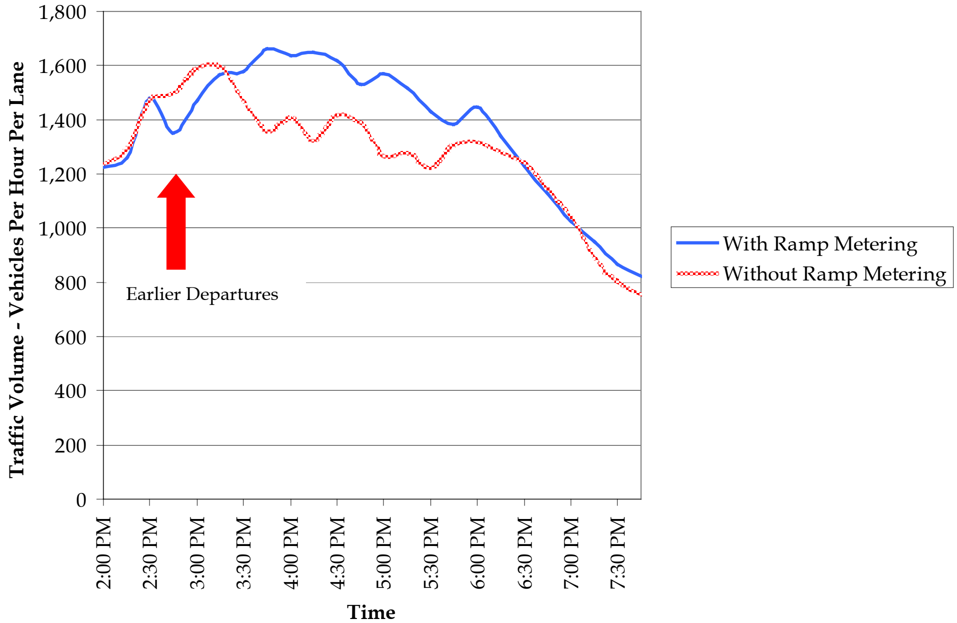
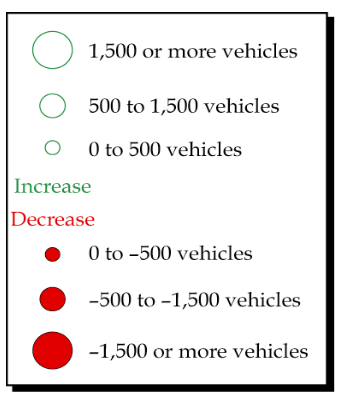
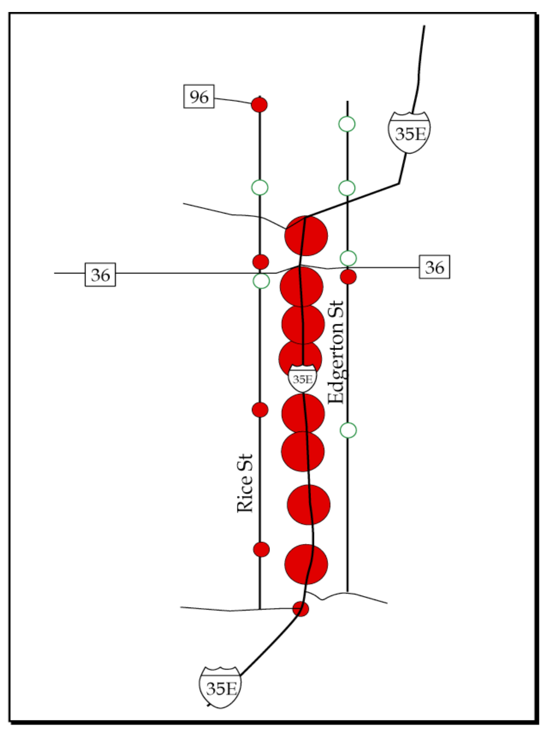


Figure 9.2 I-35E Southbound Morning – Example of Traffic Volume Reduction



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.

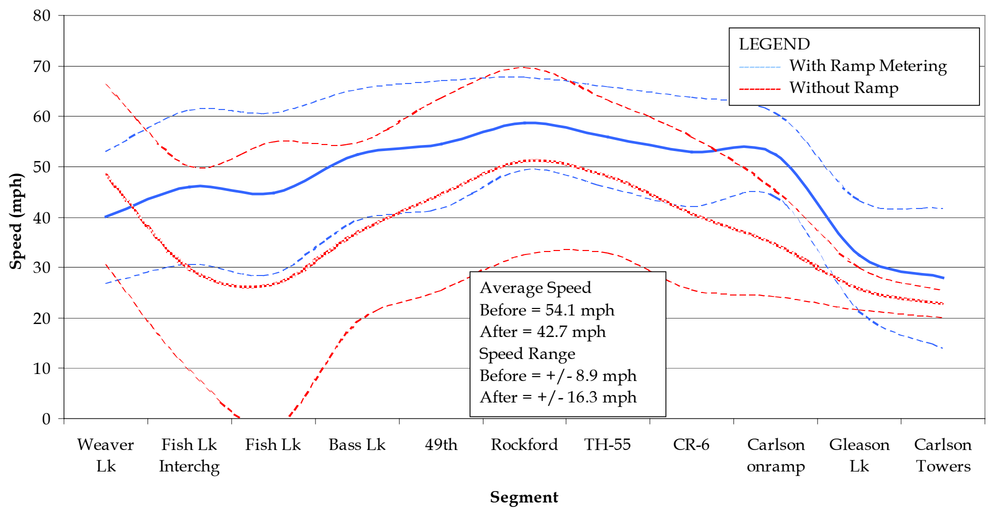
In addition to the increase in travel times observed on the test corridors during the "without meters" period, significant increases in congestion were reported on some non-metered freeways outside of the corridors observed by the evaluation team. This finding is consistent with the travel survey data 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

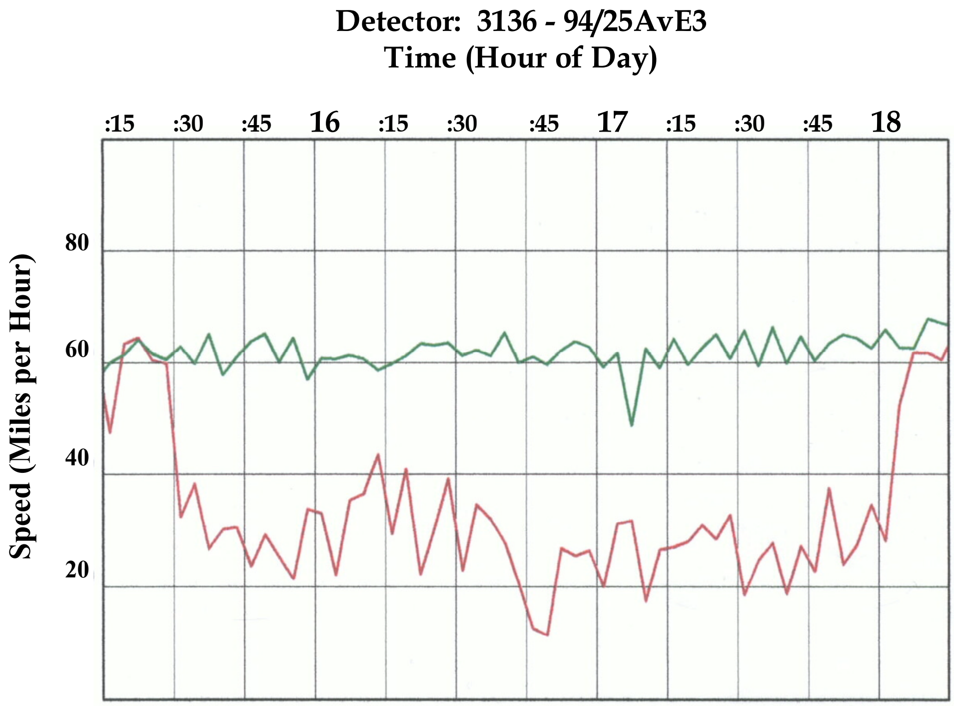


significant benefit to travelers as individuals are better able to predict their travel times and, therefore, budget less time for the trip. While the travel time performance measure presented above quantifies changes in travel time on average or "normal" travel days, travel time reliability is a more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

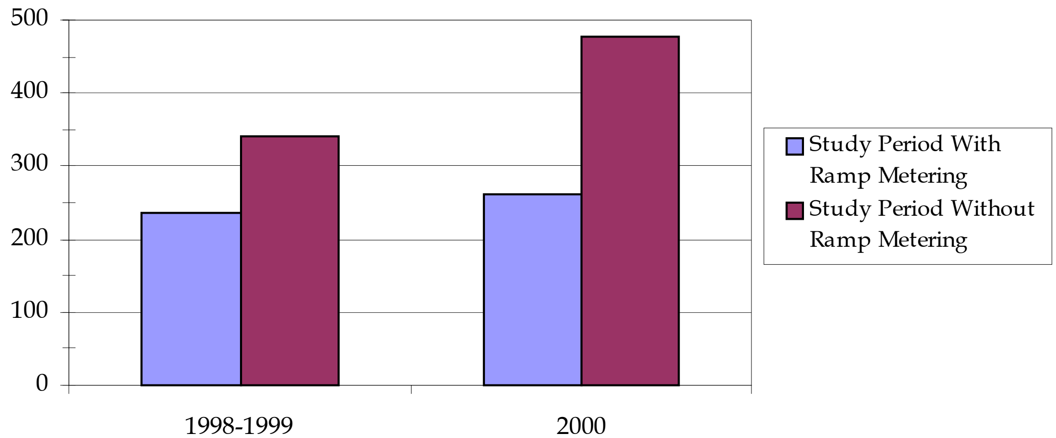


Condition	Date	Field	Sample	Volume
Meters off	Mon, Oct 16, 2000	25′	100%	25,181
Meters on	Mon, Oct 9, 2000	25′	100%	25,294

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.

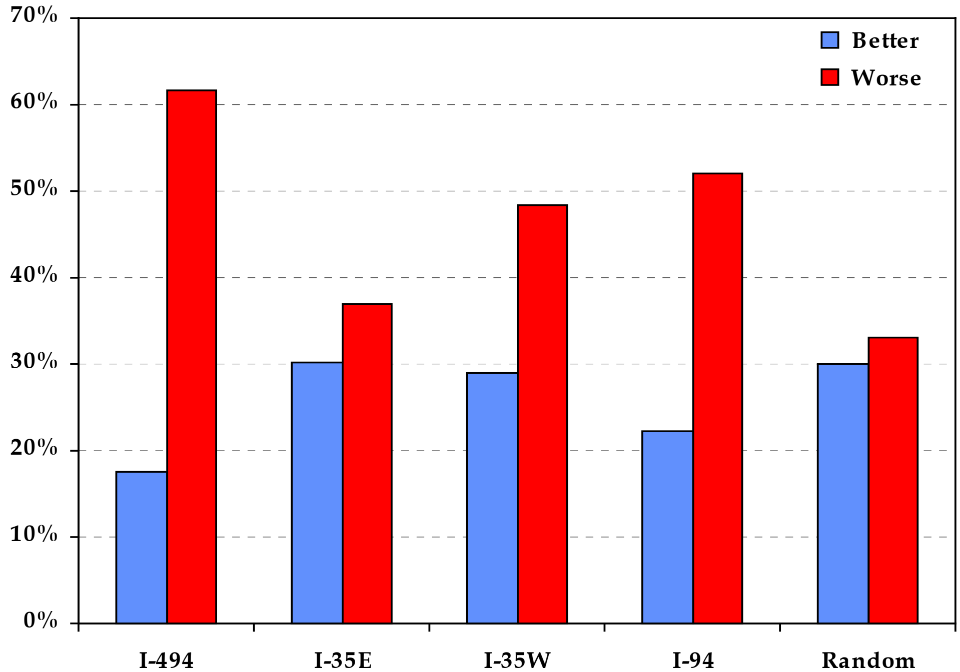
The results from the analysis of the traveler surveys and focus groups are summarized as follows:

- 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

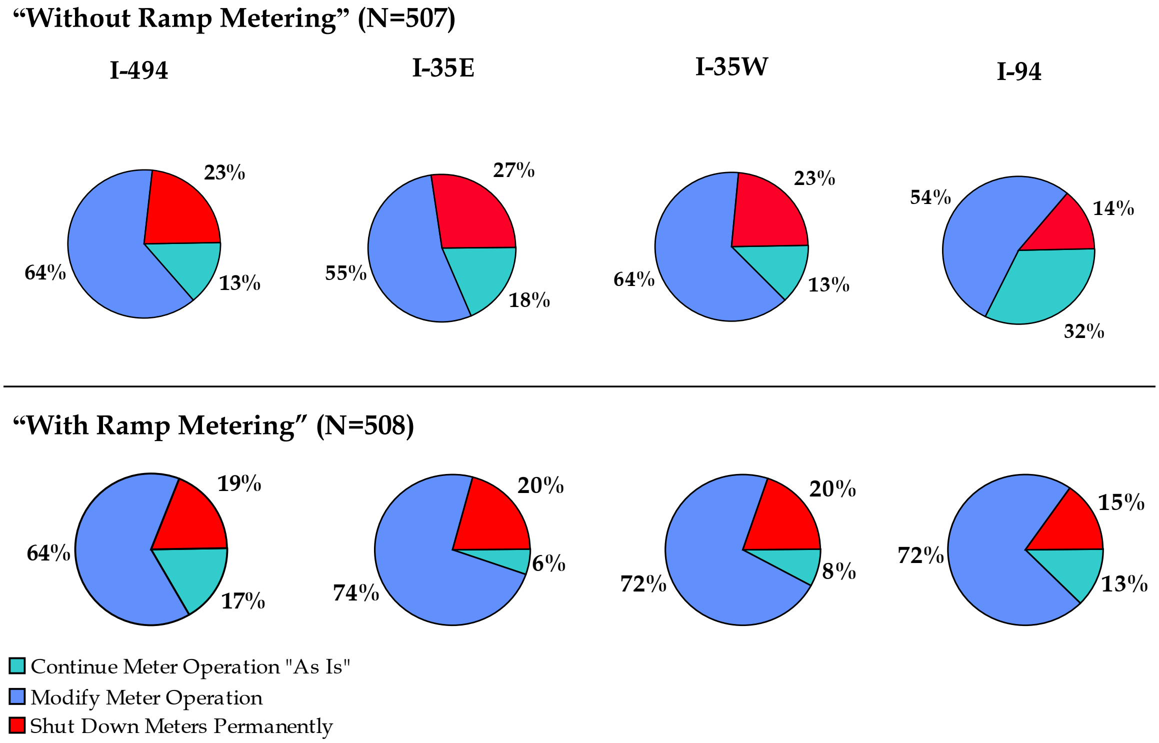


- Findings varied considerably with trip length, consistent with the traffic data. Respondents with origins furthest from the urban core, and with the longest trips, were most likely to believe that traffic conditions got worse during the shutdown. These travelers also had a greater appreciation for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