Mn/DOT Ramp Meter Evaluation

Phase II Evaluation Report

prepared for

Minnesota Department of Transportation

prepared by

Cambridge Systematics, Inc.

May 10, 2002

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Table of Contents

Table of Contents
(continued)

List of Tables

List of Figures

List of Figures
(continued)

1.0 Project Background and Summary

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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 metropolitan 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.

In 2000, a bill passed by the Minnesota Legislature required Mn/DOT to study the effectiveness of ramp meters in the Twin Cities Region. As a result, a ramp meter evaluation study was conducted in the fall of 2000, with its results presented to the Legislature and the public in February 2001. This "Phase I" evaluation consisted of field observations and traveler surveys/focus groups "with" and "without" ramp metering. The Phase I field evaluation's findings included:

- ***Traffic volumes and throughput:*** After the meters went off there was an average nine percent traffic volume reduction on freeways and no significant traffic volume change on parallel arterials. Also, during peak traffic conditions, freeway mainline throughput declined by an average of 14 percent in the meters-off condition.

- ***Travel time:*** With meters on, improved travel speeds on freeway facilities more than offset ramp delays. This resulted in annual systemwide savings of 25,121 hours of delay.

- ***Travel time reliability:*** Without ramp metering freeway travel time was found to be almost twice as unpredictable as with ramp metering. This produced annual savings of 2.6 million hours of unexpected delay.

- ***Safety:*** Ramp metering resulted in annual savings of over 1,000 crashes or approximately four crashes per day. In the absence of metering and after accounting for seasonal variations, peak period crashes on metered freeways and ramps increased by 24 percent.

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

- ***Fuel consumption:*** Ramp metering resulted in an annual disbenefit of 22,246 gallons of fuel.

- ***Benefit/cost analysis:*** Ramp metering resulted in annual savings of approximately $40 million to the Twin Cities traveling public. The benefits of ramp metering outweighed the costs by a significant margin and resulted in a net benefit of approximately $32 million per year. The benefit/cost ratio indicated that benefits are approximately five times greater than the cost of the system.

In parallel to the field evaluation, the Phase I evaluation included traveler surveys and focus groups to identify traveler's perceptions of ramp metering. The results of these market research efforts are summarized as follows:

- Respondents reported experiencing average wait times at ramps "with meters" of four to nine minutes depending on the corridor, but mainly between five to six minutes.
- Respondents in the "without meters" survey tended to believe that traffic conditions overall had become worse with the meters off. These findings were generally consistent with the traffic data, which indicated that travel conditions had on the whole deteriorated.
- 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.
- The most commonly supported modifications to the Twin Cities metering system 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.

The Phase I evaluation suggested that ramp metering is an overall cost-effective investment of public funds for the Twin Cities area. This finding notwithstanding, the Twin Cities users of the highway system supported the need for modifications toward an efficient but more publicly acceptable operation of ramp meters. The combination of these two factors pointed 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."***

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 Phase I evaluation data collection was completed, including reduced operating timeframe of ramp meters, allowing meters to change more quickly from red to green, and keeping several meters at flashing yellow. When the ramp meter shutdown study ended on December 8, 2000, several interim changes to the ramp metering system occurred, including:

- A number of meters were left turned off;
- Ramp meter operations were limited to four hours each day; and
- Faster metering rates were used.

Until a policy for optimizing ramp meter operation was developed, Mn/DOT continued to voluntarily monitor ramp wait times, freeway travel time and its reliability and crashes, and conducted market research to identify changing traveler perceptions. The Phase II evaluation's objectives were to:

- Enable the development of a policy for optimizing ramp meter operations based on lessons-learned from Phase I of the ramp meter evaluation study; and
- Capture and evaluate the public and system impacts of short- and long-term ramp meter strategies.

The "Phase II" evaluation's methodology and results are presented in this report. The Phase II evaluation concluded that traffic operations and safety continued to experience the degraded performance which was documented during the ramp meter shutdown. The Phase II evaluation's findings include:

- Crash rates increased by 15 percent when comparing the first seven months of years 1998 to 2000 (fully metered) and year 2001 (interim metering operation).
- Freeway speeds in 2001 varied from corridor to corridor, but were consistently five to 10 percent slower than in 2000.
- Freeway travel times also varied from corridor to corridor, with results showing them to be consistently five to 10 percent longer in 2001 than in 2000.
- Freeway traffic volume throughput declined by five percent since the Fall of 2000.
- University Avenue speed was about 11 to 17 percent slower compared to the Fall 2000 speed.
- Phase II market research showed strong support for modification of the system. A major market research finding shows that 60 percent of commuters polled support modification of the ramp metering system. About one-quarter (26 percent) believe that the system should continue to operate as is, while 14 percent believe that the meters should be shutdown completely. These percentages are similar to those expressed during the pre-shutdown condition, except support for a complete shutdown has declined significantly from 21 percent previously.

Based on the Phases I and II evaluations and in coordination with key stakeholders, Mn/DOT defined a new set of objectives, constraints, and criteria for ramp meter application and operation. This policy was based on a thorough investigation of efficiency, equity, and other criteria for the evaluation of ramp metering strategies. Criteria involve variables, such as ramp wait times and ramp storage capacities, target freeway peak-period speeds, and maximum metering rates in the Twin Cities metropolitan area. The goals of the new ramp metering system are:

- To reduce delays caused by congestion and crashes;
- To reduce the number of crashes caused by congestion;
- To provide travelers with more reliable travel times; and
- To manage ramp meter wait times.

A key aspect of the new responsive ramp metering system is the addition of an automated system that will monitor wait times at meters so they can be adjusted as needed by Mn/DOT's traffic management center computers. The new system will provide real-time information about ramp delays and will limit wait times based on ramp conditions, as well as freeway conditions. Specific system features include:

- Ramp meter waits will be no more than four minutes on local ramps and no more than two minutes on freeway-to-freeway ramps;
- Vehicles waiting at meters will not back up onto adjacent roadways;
- Meter operation will respond to congestion and only operate when needed; and
- A number of current ramp meters will be removed; these meters are not currently used and, based upon traffic projections, will not be needed in those areas for at least five years.

An additional objective of this report is to identify, evaluate, and recommend methods for developing and testing long-range ramp meter strategies. To this end, Sections 4.0 and 5.0 contain descriptions of the use of various spreadsheet tools developed for the Phase I evaluation. Section 7.0 presents detailed instructions on how to conduct benefit-cost analysis using a spreadsheet tool developed for the Phase I evaluation; this tool can readily be used in future evaluations of ramp metering or other traffic management strategies. Section 8.0 presents an evaluation of other planning and micro-simulation tools that can be used in the context of a ramp metering deployment plan.

This document is organized as follows:

- Phase II Evaluation Objectives (Section 2.0);
- Phase II Performance Measures and Evaluation Overview (Section 3.0);
- Phase II Field Data Collection Plan (Section 4.0);
- Results of the Phase II Field Evaluation (Section 5.0);
- Phase II Traveler Surveys (Section 6.0);
- Benefit/Cost Analysis Methodology (Section 7.0); and
- Planning for Future Ramp Meter Deployments (Section 8.0).

2.0 Phase II Evaluation Objectives

2.0 Phase II Evaluation Objectives

The goals and objectives for evaluating ramp meter effectiveness in the Twin Cities Metropolitan Region were designed to investigate system performance and public acceptance of the new ramp metering strategy. Implemented following the shutdown – as described in Section 1.0, page 1-2. The Phase II evaluation goals include:

1. To evaluate whether the benefits of the new ramp metering strategy outweigh the impacts and associated costs;
2. To identify the impacts of the new ramp metering strategy at selected surface streets; and
3. To evaluate the impacts of the new metering strategy on freeway-to-freeway ramps.

For each of the broad evaluation goals, several detailed evaluation objectives were identified. These evaluation objectives provided the framework for conducting the evaluation. Table 2.1 presents the evaluation objectives as they relate to each of the evaluation goals. The following sections describe in greater detail the tasks required to fulfill each of the evaluation's three main goals and associated objectives.

Table 2.1 Phase II Evaluation Goals and Objectives

Evaluation Goal	Evaluation Objectives
Evaluate whether the benefits of the new ramp metering strategy outweigh the impacts and associated costs	• Quantify ramp traffic flow impacts/benefits (positive and negative) of the new metering strategy at selected corridors • Quantify freeway mainline traffic flow impacts/benefits (positive and negative) of the new metering strategy at selected corridors • Quantify safety impacts/benefits (positive and negative) of the new metering strategy at selected corridors
Identify the impacts of the new ramp metering strategy at selected surface streets	• Identify ramp metering impacts on selected local streets • Document additional ramp metering benefits/impacts observed during the study
Evaluate the impacts of metering freeway-to-freeway ramps	• Quantify impacts/benefits (positive and negative) of freeway-to-freeway ramp metering at one location

3.0 Phase II Evaluation Performance Measures and Overview

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The goals and objectives presented in the previous section provide the framework for the Phase II evaluation. This section presents the particular measures of effectiveness evaluated during the study. These evaluation measures build on the evaluation objectives and are designed to provide for a comprehensive analysis of the evaluation goals. This section also presents an overview of the methodologies employed to collect and analyze data for the study.

3.1 Evaluation Measures

For each of the evaluation objectives identified in Section 2.0, one or more measures of effectiveness have been identified to provide an assessment of the objective. Where possible, these evaluation measures are expressed in quantitative terms; however, many of the measures are more appropriately expressed in qualitative terms. The evaluation measures selected for each evaluation objective are presented in Table 3.1.

The measures of effectiveness are not mutually exclusive and, in some cases, the same measure is used to test several objectives. The evaluation measures are 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 may be either positive or negative, depending on the impacts observed during the two scenarios. Outcomes may also be *both* positive and negative in that results may vary geographically across the selected corridors, market segments, or timeframes.

Section 3.2 presents an overview of the methodology employed in evaluating these measures. The remaining sections of this document provide greater detail on the data collection and analysis methodologies.

Table 3.1 Phase II Evaluation Measures

Evaluation Objective	Measures of Effectiveness
1. Quantify ramp traffic flow impacts/benefits (positive and negative) of new metering strategy at selected corridors	• Changes in traffic volume for on-ramps at selected corridors • Queue lengths at the ramps • Changes in customer attitudes/satisfaction levels toward the new metering strategy at selected corridors • Perceived ramp delay and ramp travel time reliability changes at selected corridors
2. Quantify freeway mainline traffic flow impacts/benefits (positive and negative) of new metering strategy at selected corridors	• Changes in traffic volume, travel time, travel speed, and travel time reliability for freeways at selected corridors • Changes in customer attitudes/satisfaction levels toward freeway operations at selected corridors • Perceived changes in travel time and travel time reliability at selected corridors
3. Quantify safety impacts/benefits (positive and negative) of new metering strategy at selected corridors	• Changes in the number and severity of crashes occurring at selected corridors • Perceived changes in safety of travel in selected corridors
4. Quantify impacts/benefits (positive and negative) of freeway-to-freeway ramp metering at one location.	• Changes in traffic volume, travel time, travel speed, and travel time reliability for the freeway • Changes in traffic volume, travel time, travel speed, and travel time reliability for the on-ramp • Changes in customer attitudes/satisfaction levels toward freeway-to-freeway metering • Perceived ramp delay and ramp travel time reliability changes at selected corridors • Perceived changes in safety of travel in selected corridors
5. Identify impacts of ramp metering on local streets	• Change in travel time for alternative travel route in a selected corridor • Change in travel speed for alternative travel route in a selected corridor • Change in traffic volume for alternative route in a selected corridor
6. Document additional ramp metering benefits/impacts observed during the study	• Documentation only

3.2 Overview of Evaluation Methodologies

Data related to the evaluation measures of effectiveness were collected in the Fall of 2001, between September 10 and September 28, 2001. In this scenario, the ramp meters were operating at a reduced metering capacity from the strategy evaluated in the fall of 2000. To identify impacts of ramp metering away from the affected ramps and freeway sections, an evaluation study was conducted on one selected parallel arterial. Also, to analyze the impacts of freeway-to-freeway metering, an evaluation study was conducted at one of the freeway-to-freeway ramps. Furthermore, traveler surveys were conducted to provide additional information to help in the identification and development of appropriate modifications to the metering strategy.

To support the evaluation, individual test plans were developed to guide the collection and analysis of different types of data. Each test plan provided detailed instructions for conducting a specific aspect of the study. Yet, all the individual test plans were carefully linked to provide coordination between the different analysis efforts. The individual test plans developed for this study include:

- **Field data collection plan for selected freeways and one alternative arterial –** The plan identifies selected corridors, and the field data collected and analyzed (Section 4.0); and

- **Market research test plan –** The plan defines the telephone survey data collection tasks performed and presents the methodology used (Section 5.0).

The following sections present the individual test plans that provide specifics on the conduct of the various evaluation tasks.

4.0 Field Data Collection Plan

4.0 Field Data Collection Plan

The objective of the field data collection portion of this study was to measure the impacts of ramp metering on a host of transportation variables over different types of freeway corridors. The results of these corridor-specific data and analysis were used to report the effects of the new ramp metering strategy on each corridor studied.

■ 4.1 Study Areas

All Phase I study corridors were used again as study areas for the Phase II evaluation. In addition, a new corridor, TH-10, was included in this evaluation. University Avenue (paralleling I-94), was the only parallel arterial studied, because in the Phase I evaluation it was the only arterial to show a statistically significant change in traffic patterns as a result of the meter shutdown. The corridors, arterial, and freeway-to-freeway ramp selected for the study are listed in Table 4.1. Market research was also conducted to gather public opinion and preferences on the modified ramp meter strategy.

Table 4.1. Phase II Study Area Extents

Corridor	When	Boundaries
I-494	NB p.m. peak	TH-62 to Bass Lake
	SB a.m. peak	Weaver Lake (I-94) to TH-62
I-35W	NB a.m. peak	Crystal Lake to 98th (Old Shakopee)
I-94	EB p.m. peak	I-394 to TH-52 (Lafayette)
	WB a.m. peak	TH-52 (Lafayette) to I-394
	WB p.m. peak	TH-52 (Lafayette) to I-394
I-35E	SB a.m. peak	Little Canada to I-94
TH-10	EB a.m. peak	TH-169 to TH-610

■ 4.2 Field Data Collection Plan

The premise of the field data collection test plan was to measure the transportation system impacts of the new ramp metering strategy at the selected corridors. This task involved an extensive Fall 2001 traffic data collection program to address the impacts on traffic operations and safety by means of on-the-ground collection of empirical data about the non-metered and metered systems.

4.2.1 Field Data Sources

Most of the field data were supplied by the routine automated data collection systems used by Mn/DOT to monitor traffic flow, such as freeway and ramp loop detectors. Arterial traffic volumes, speed, and travel time data were collected separately through road tubes and travel time runs, while incident data are gathered from the Department of Public Safety's (DPS) incident database. Lastly, manual observations by the Traffic Management Center (TMC) staff were used to assess ramp meter violation rates, spillover frequency, and traffic conflicts. Table 4.2 summarizes the performance measures and data sources used in the field data collection.

Table 4.2 Summary of Performance Measures and Data Sources

Objective		Performance Measures		Data Source
1	Assess traffic flow impacts	1.1	Freeway volume	TMC station detectors
		1.2	Freeway occupancy	TMC station detectors
		1.3	Alternate route volume	Road tubes
2	Assess travel time impacts	2.1	Freeway speed	TMC station detectors
		2.2	Alternate route speed and travel time	GPS- and Jamar™-equipped vehicles
3	Assess ramp impacts	3.1	Ramp volume	TMC ramp detectors
		3.2	Ramp queue length	TMC ramp detectors
		3.3	Ramp queue delay	TMC ramp detectors
4	Assess safety impacts	4.1	Incidents on freeway corridors and ramps within study area	DPS/TMC incident logs

4.2.2 Data Collection

This section provides additional detail on the format, assumptions, and collection methods used in gathering data to allow the evaluation of the new ramp metering strategies.

Freeway Mainline Traffic Volume, Speed, and Occupancy

Data from the Mn/DOT TMC freeway loop detector stations were collected along each of the corridors under evaluation. Travel times were derived based on the collected speed and occupancy data. The following information pertains to freeway data:

1. Sample size:
   - Thirty-second traffic volume data per lane, 24-hours per day;
   - Data aggregated to 15-minute periods during the four-hour a.m. and four-hour p.m. peak periods;
   - Four-hour peak periods selected to allow analysis of any peak-period spreading;
   - Data aggregated to daily totals;
   - Five days of data per week (Monday through Friday); and
   - Data collected from the detector stations within the corridor study limits.
2. Data collection methods and tools:
   - Spreadsheet and/or database tools were used to process data.

Alternate Route Traffic Volume

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:

1. Sample size:
   - Fifteen-minute volumes per lane during the four-hour a.m. and four-hour p.m. peak periods;
   - Daily volume totals; and
   - Five days of data per week (Monday through Friday).
2. Data collection methods and tools:
   - Collect data on arterial routes during the same period as the corresponding freeway route;
   - Road tubes were used to collect the data; and
   - Spreadsheet and/or database tools were used to process the data.

Alternate Route Speed and Travel Time

Geographic Positioning System (GPS)- or Jamar™-equipped vehicles were used to capture the travel time profiles at discrete intervals. Data were collected in both directions of travel along the arterial. Further details on the data collection approach are provided below.

1. Assumptions:
    - Four-hour morning period is 5:00 to 9:00 a.m.;
    - Four-hour afternoon period is 3:00 to 7:00 p.m.; and
    - Monday through Friday data collection days.
2. Data collection methods and tools:
    - Floating Car Method was used to collect travel time data – with this method the probe vehicle driver estimated the median speed by passing and being passed by an equal number of vehicles;
    - GPS or Jamar™ data collection tools were used to collect travel time data in three of the probe vehicles;
    - Travel time data were collected in both the peak and non-peak direction; and
    - Probe vehicle drivers recorded weather, pavement conditions, light conditions, construction activity, and incidents to enable the isolation of anomalous data.

Ramp Volume, Queue Length, and Delay

Ramp volume data (ramp merge detector data) and ramp meter turn-on times were readily available from the TMC system.

1. Sample size:
    - Collect data for every on-ramp within the defined test corridors;
    - Five days of peak-period counts per site; and
    - Data collected in 15-minute intervals.
2. Tools:
    - Spreadsheets and/or databases tools were used to process the data.

Safety Impacts

The DPS incident database was used to assess safety impacts at selected corridors and on-ramps.

1. Sample size:
    - At corridors and on-ramps within study area; and
    - TMC documents number and duration of incidents on freeways that are monitored by the traffic management system.
2. Tools:
    - DPS incident database; and
    - TMC incident log for study corridors.

3. Analysis:
   - Separate data by freeway corridor;
   - Separate data for non-metered versus metered conditions;
   - Identify crashes by type (rear-end, side-swipe, etc.);
   - Separate data by crash severity (property damage only (PDO), injury, fatality); and
   - Separate data by time of day: crash data while meters are in operation versus data in the off-peak while meters are off-line.

■ 4.3 Evaluation Methodology

A database contains the Fall 2001 peak-period performance characteristics for each of the study corridors during meter-operational time periods. The studied alternative arterial was analyzed in a similar fashion to examine whether or not the ramp meter strategy change affected its operation.

4.3.1 Freeway, Ramp, and Arterial Data Evaluation Methodology

Performance measures extracted from the TMC and field data include:

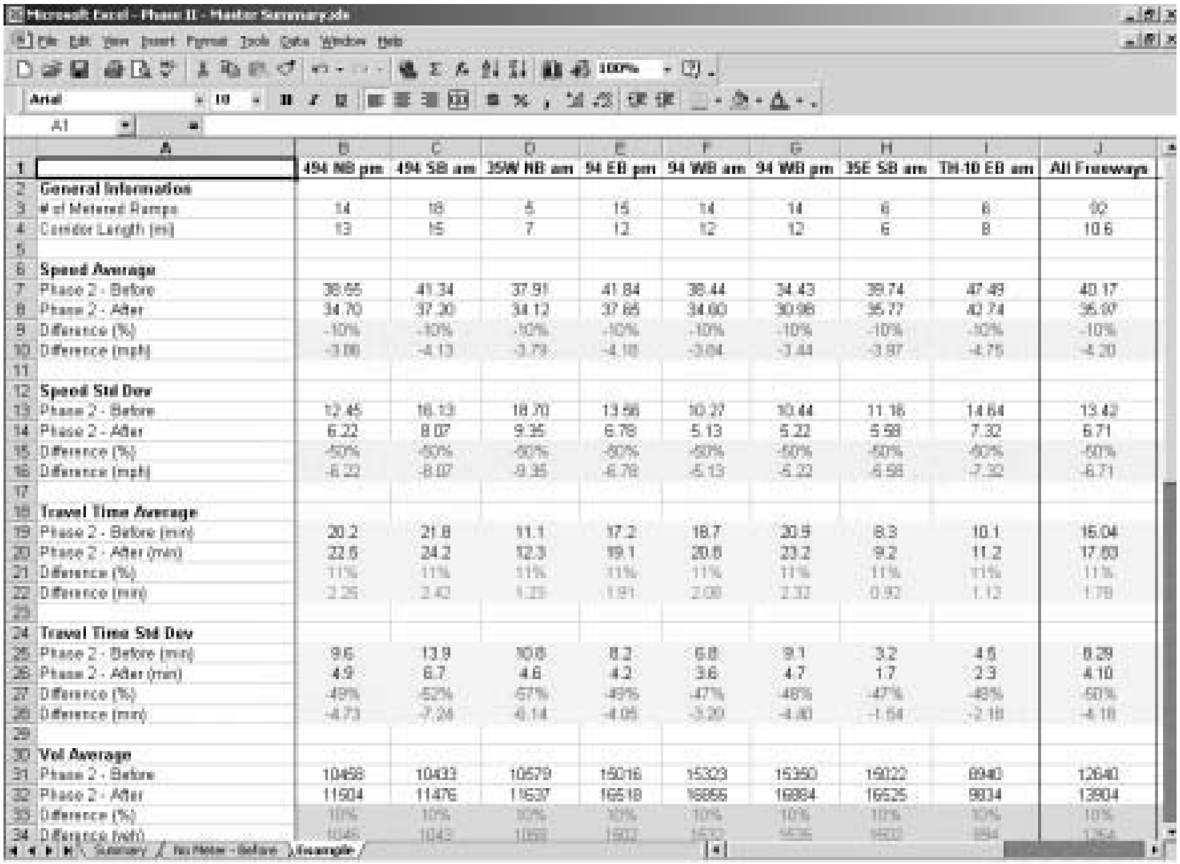
- Average freeway mainline speeds;
- Standard deviation of mainline speeds;
- Average mainline volumes;
- Standard deviation of mainline volumes;
- Average on-ramp delay per vehicle;
- Standard deviation of ramp delay per vehicle;
- Average ramp volumes; and
- Standard deviation of ramp volumes.

Quantitative performance measures were used to estimate the positive and negative impacts of the new ramp metering strategy, including travel time, travel time reliability, and safety. Changes between each quantitative performance measure at each corridor were calculated to measure the impacts of the new ramp metering strategy at each corridor. Only corridor segments and travel directions having operating ramp meters were included in the analysis for each of the peak periods. No impacts were applied to non-metered segments. Qualitative performance measures and anecdotal information were documented and used to support the hard data in determining the effectiveness of the new metering strategy.

Use of the Spreadsheet Tool

A summary spreadsheet tool, developed in Microsoft Excel™, was used to calculate quantitative performance measure changes between the two study periods. Figure 4.1 presents a sample view of the summary worksheet. The user may enter the speed and volume averages and standard deviations of the collected field data for each corridor, time period, and direction. The tool automatically calculates the differences, as well as the travel time average and its standard deviation.

Figure 4.1 Sample View of the Field Data Summary Worksheet



	A	B	C	D	E	F	G	H	I	J
1		494 NB pm	494 SB am	35W NB am	94 EB pm	94 WB am	94 WB pm	35E SB am	TH-10 EB am	All Freeways
2	**General Information**									
3	# of Metered Ramps	14	18	5	15	14	14	6	6	92
4	Corridor Length (mi)	13	15	7	12	12	12	6	8	10.6
5										
6	**Speed Average**									
7	Phase 2 - Before	38.65	41.34	37.91	41.84	38.44	34.43	39.74	47.49	40.17
8	Phase 2 - After	34.70	37.30	34.12	37.66	34.60	30.98	35.77	42.74	35.97
9	Difference (%)	-10%	-10%	-10%	-10%	-10%	-10%	-10%	-10%	-10%
10	Difference (mph)	-3.86	-4.13	-3.79	-4.18	-3.84	-3.44	-3.97	-4.75	-4.20
11										
12	**Speed Std Dev**									
13	Phase 2 - Before	12.45	16.13	18.70	13.56	10.27	10.44	11.16	14.64	13.42
14	Phase 2 - After	6.22	8.07	9.35	6.78	5.13	5.22	5.58	7.32	6.71
15	Difference (%)	-50%	-50%	-50%	-50%	-50%	-50%	-50%	-50%	-50%
16	Difference (mph)	-6.22	-8.07	-9.35	-6.78	-5.13	-5.22	-5.58	-7.32	-6.71
17										
18	**Travel Time Average**									
19	Phase 2 - Before (min)	20.2	21.8	11.1	17.2	18.7	20.9	8.3	10.1	16.04
20	Phase 2 - After (min)	22.6	24.2	12.3	19.1	20.8	23.2	9.2	11.2	17.83
21	Difference (%)	11%	11%	11%	11%	11%	11%	11%	11%	11%
22	Difference (min)	2.25	2.42	1.23	1.91	2.08	2.32	0.92	1.12	1.78
23										
24	**Travel Time Std Dev**									
25	Phase 2 - Before (min)	9.6	13.9	10.8	8.2	6.8	9.1	3.2	4.6	8.29
26	Phase 2 - After (min)	4.9	6.7	4.6	4.2	3.6	4.7	1.7	2.3	4.10
27	Difference (%)	-49%	-52%	-57%	-49%	-47%	-48%	-47%	-48%	-50%
28	Difference (min)	-4.73	-7.24	-6.14	-4.05	-3.20	-4.40	-1.54	-2.18	-4.18
29										
30	**Vol Average**									
31	Phase 2 - Before	10458	10433	10579	15016	15323	15350	15022	8940	12640
32	Phase 2 - After	11504	11476	11637	16518	16855	16884	16525	9834	13904
33	Difference (%)	10%	10%	10%	10%	10%	10%	10%	10%	10%
34	Difference (vph)	1046	1043	1058	1502	1532	1535	1503	894	1264

4.3.2 Crash Data Evaluation Methodology

Detailed crash data, maintained by the DPS and Mn/DOT, were obtained for the study area during the appropriate study periods. The crash database contained information for each crash, including information on:

- Crash severity (fatality, injury, property damage);
- Type of crash (rear-end, side-swipe, etc.);

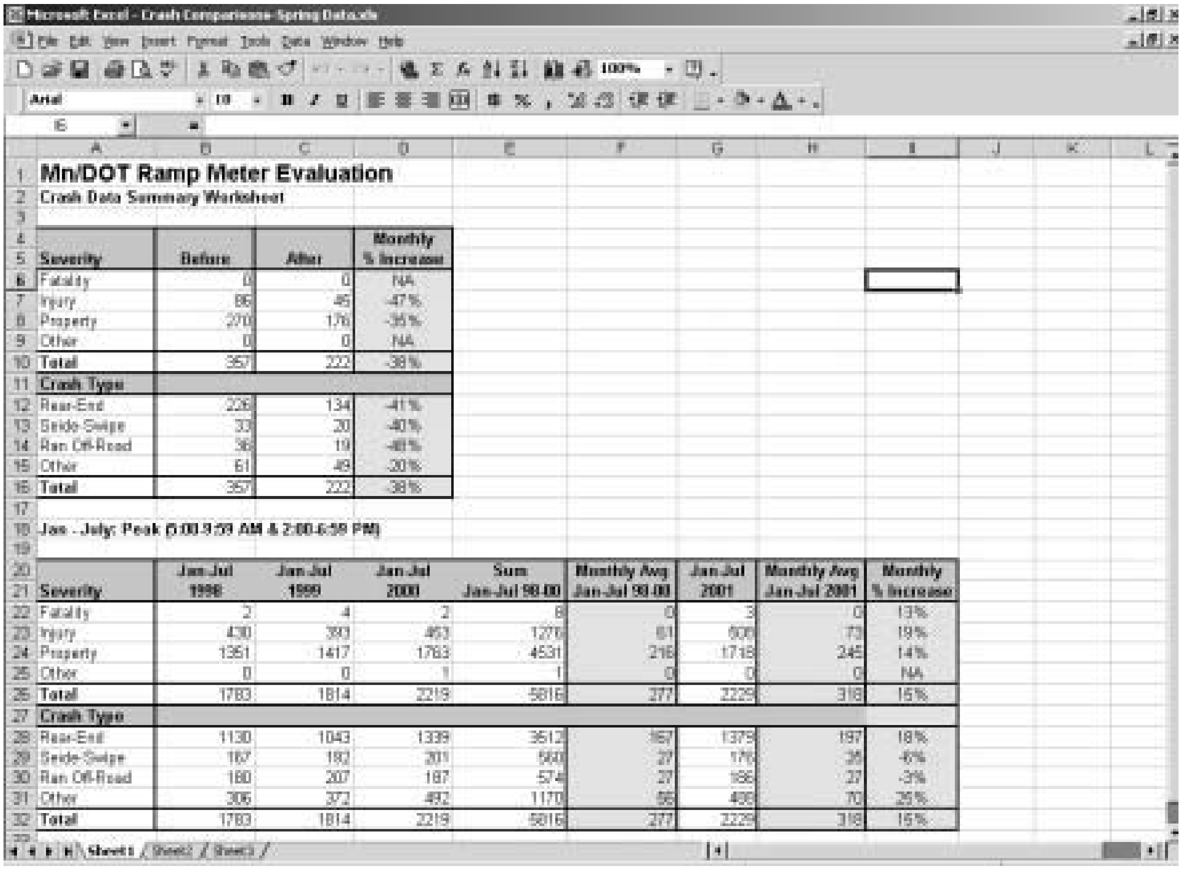
- Location of the crash;
- Facility type;
- Time of crash; and
- Other factors, including pavement condition, lighting, weather, etc.

In addition to collecting these data for the study periods, the evaluation team analyzed crash data for the first seven months (January through July) of years 1998 through 2001. These historical data were used to identify any changes in crash rates resulting from the changed ramp metering strategy in the fall of 2000, and to identify the seasonal impacts of safety in the Twin Cities region.

Use of the Spreadsheet Tool

Similar to the field data summary spreadsheet, the crash data summary sheet was developed in Microsoft Excel™. Figure 4.2 presents a sample view of the crash summary worksheet. The analyst may enter the number of crashes for each type and severity from the DPS database within the boundaries of the study area and time periods. Once these figures are entered into the worksheet, the changes in crashes are automatically calculated.

Figure 4.2 Sample View of the Crash Data Summary Worksheet



Mn/DOT Ramp Meter Evaluation

Crash Data Summary Worksheet

Severity	Before	After	Monthly % Increase
Fatality	0	0	NA
Injury	86	46	-47%
Property	270	176	-35%
Other	0	0	NA
Total	357	222	-38%
Crash Type			
Rear-End	226	134	-41%
Seide-Swipe	33	20	-40%
Ran Off-Road	36	19	-48%
Other	61	49	-20%
Total	357	222	-38%

Jan - July: Peak (5:00-9:59 AM & 2:00-6:59 PM)

Severity	Jan-Jul 1998	Jan-Jul 1999	Jan-Jul 2000	Sum Jan-Jul 98-00	Monthly Avg Jan-Jul 98-00	Jan-Jul 2001	Monthly Avg Jan-Jul 2001	Monthly % Increase
Fatality	2	4	2	8	0	3	0	13%
Injury	430	393	453	1276	61	508	73	19%
Property	1351	1417	1763	4531	216	1718	245	14%
Other	0	0	1	1	0	0	0	NA
Total	1783	1814	2219	5816	277	2229	318	15%
Crash Type								
Rear-End	1130	1043	1339	3512	167	1379	197	18%
Seide-Swipe	167	192	201	560	27	176	25	-6%
Ran Off-Road	180	207	187	574	27	186	27	-3%
Other	306	372	492	1170	56	488	70	25%
Total	1783	1814	2219	5816	277	2229	318	15%

5.0 Results of the Phase II Field Evaluation

5.0 Results of the Phase II Field Evaluation

This section presents the results of the Fall 2001 ramp metering field data collection conducted between September 10 and September 28, 2001. Evaluation data were collected for periods corresponding with the times when the corridors were metered. Table 5.1 summarizes the average travel time, travel time reliability, speed, mainline volume and ramp delay observed at the various study corridors for the Fall 2001 study period.

Table 5.1 Summary of Freeway and Ramp Evaluation Results – Fall 2001

	I-494		**I-35W**	**I-94**			**I-35E**	**TH-10**
	NB **p.m.**	**SB** **a.m.**	**NB** **a.m.**	**EB** **p.m.**	**WB** **a.m.**	**WB** **p.m.**	**SB** **a.m.**	**EB** **a.m.**
Corridor length (miles)	13	15	7	12	12	12	6	8
Freeway speed average (mph)	38.55	41.34	37.91	41.84	38.44	34.43	39.74	47.49
Freeway speed standard deviation[1] (mph)	12.45	16.13	18.70	13.56	10.27	10.44	11.16	14.64
Freeway travel time average (min)	20.2	21.5	11.1	17.2	18.7	20.9	8.3	10.1
Freeway travel time standard deviation[1] (min)	9.6	13.3	10.8	8.2	6.8	9.1	3.2	4.5
Freeway volume average	10,458	10,433	10,579	15,016	15,323	15,350	15,022	8,940
Ramp delay average (sec)	0	0	0	0	0	0	0	0

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

■ 5.1 Freeway Travel Time and Travel Speed

Freeway mainline travel speeds were observed to range between 35 miles-per-hour (mph) and 47 mph during the three-hour peak period, with an average of 40.25 mph. Mainline travel time averaged 1.5 minutes per mile, ranging from 1.26 minutes to 1.74 minutes per mile. Travel time reliability averaged 48 seconds per mile, with TH-10 eastbound during the a.m. peak as the most time-reliable corridor at 34 seconds per mile, and I-35W northbound during the a.m. peak as the least time-reliable corridor (92 seconds per mile).

Figures 5.1 through 5.8 illustrate the travel speeds observed at the study corridors for all weekdays. The solid lines indicate average speeds, while the dashed lines represent the upper and lower ranges of the average speeds – the speed range is defined as one standard deviation above and below the average value, which covers approximately 70 percent of all observations. 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 5.1 I-494 NB P.M. Peak Period Speed and Speed Variability

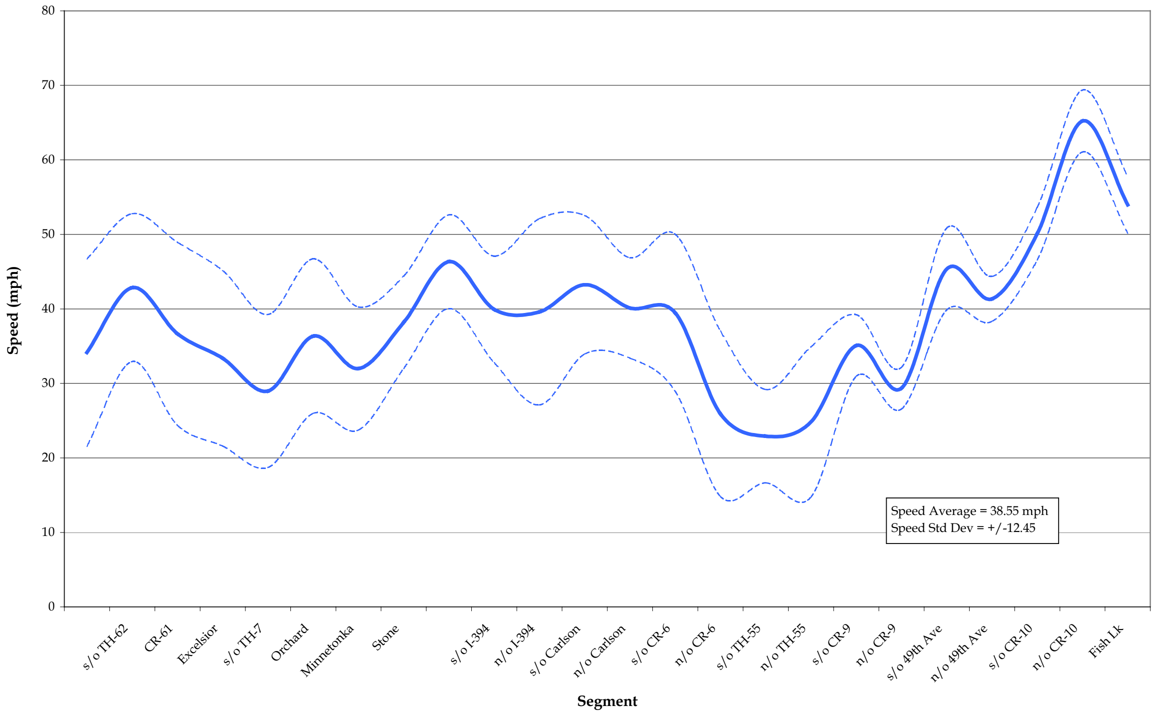


Figure 5.2 I-494 SB A.M. Peak Period Speed and Speed Variability

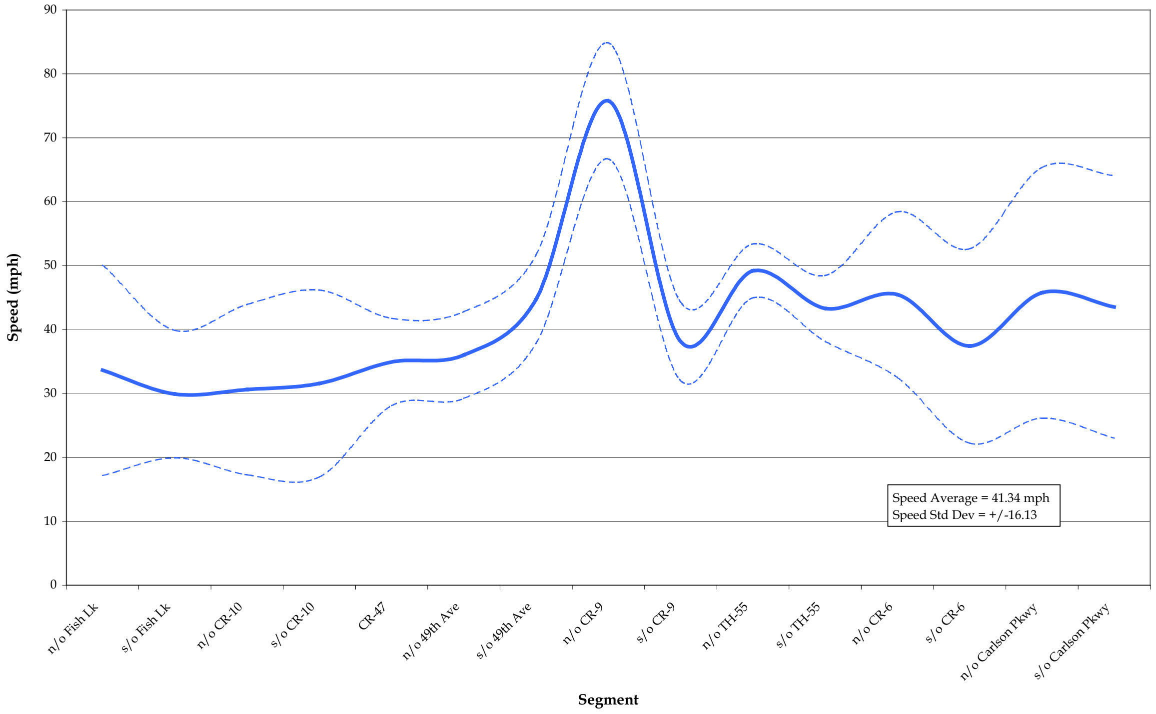


Figure 5.3 I-35W NB A.M. Peak Period Speed and Speed Variability

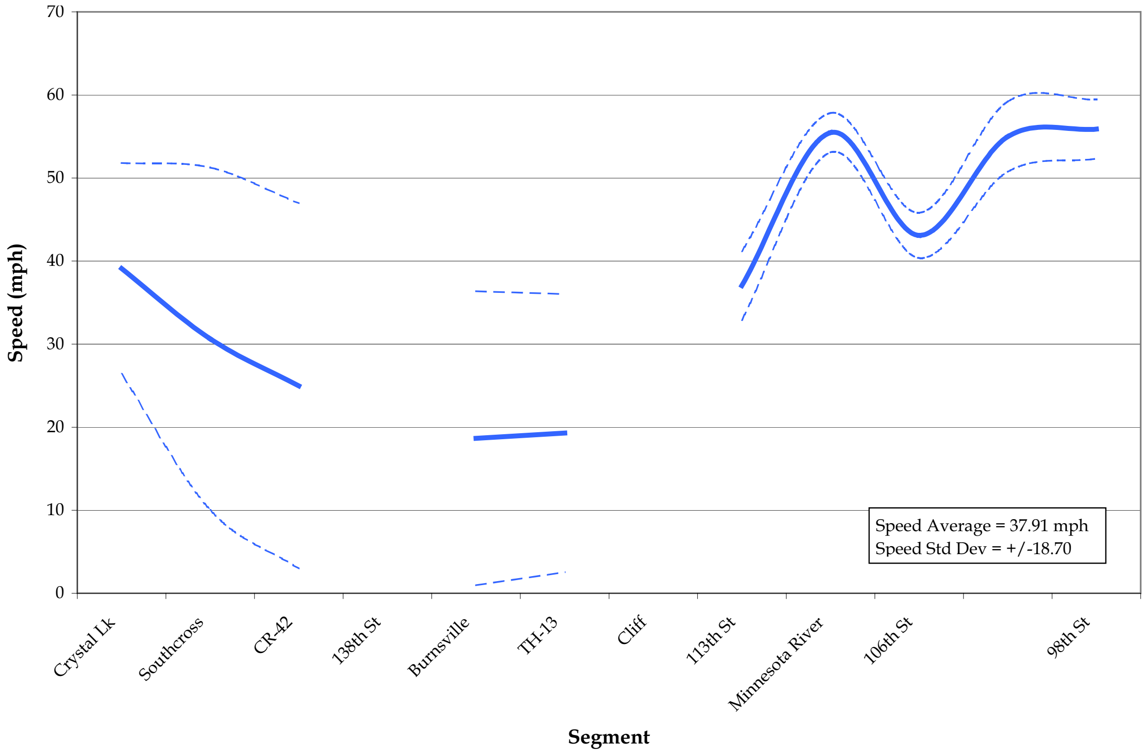


Figure 5.4 I-94 EB P.M. Peak Period Speed and Speed Variability

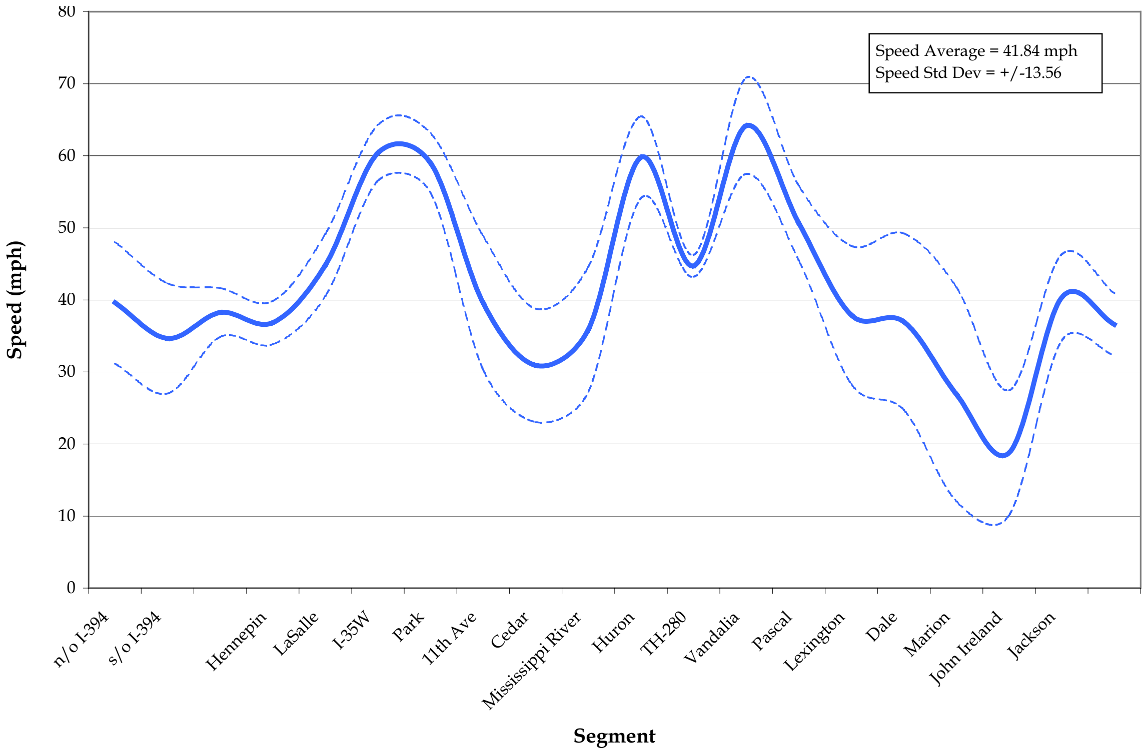


Figure 5.5 I-94 WB A.M. Peak Period Speed and Speed Variability

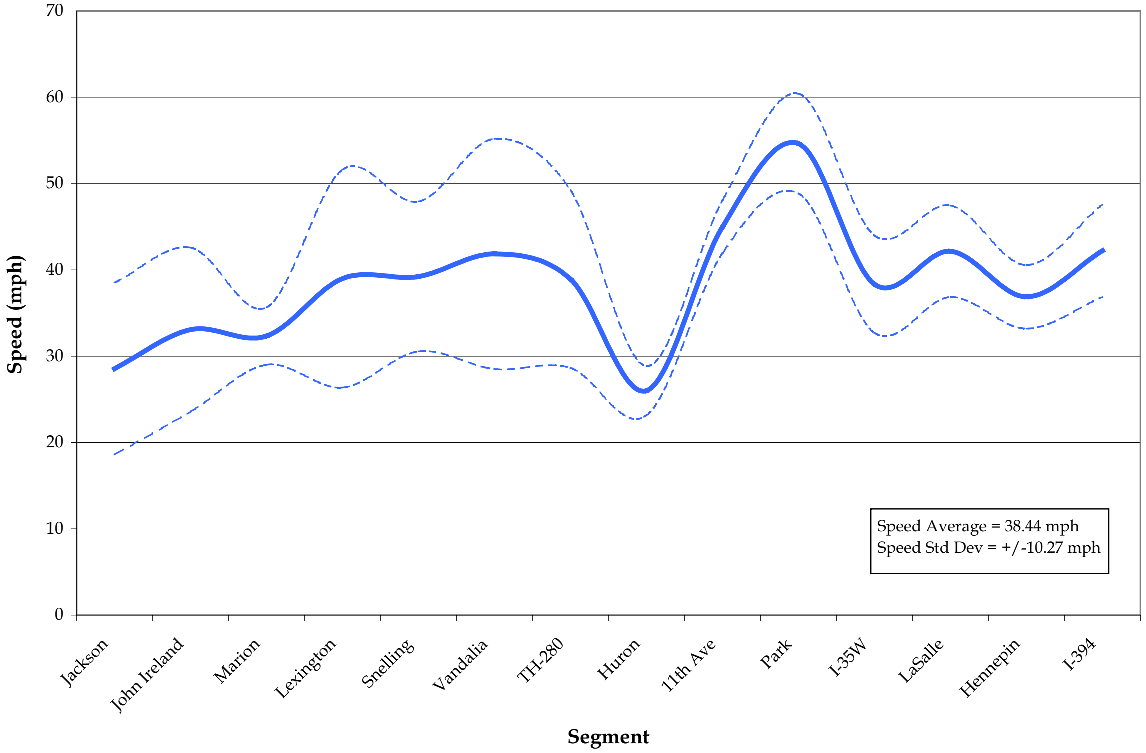


Figure 5.6 I-94 WB P.M. Peak Period Speed and Speed Variability

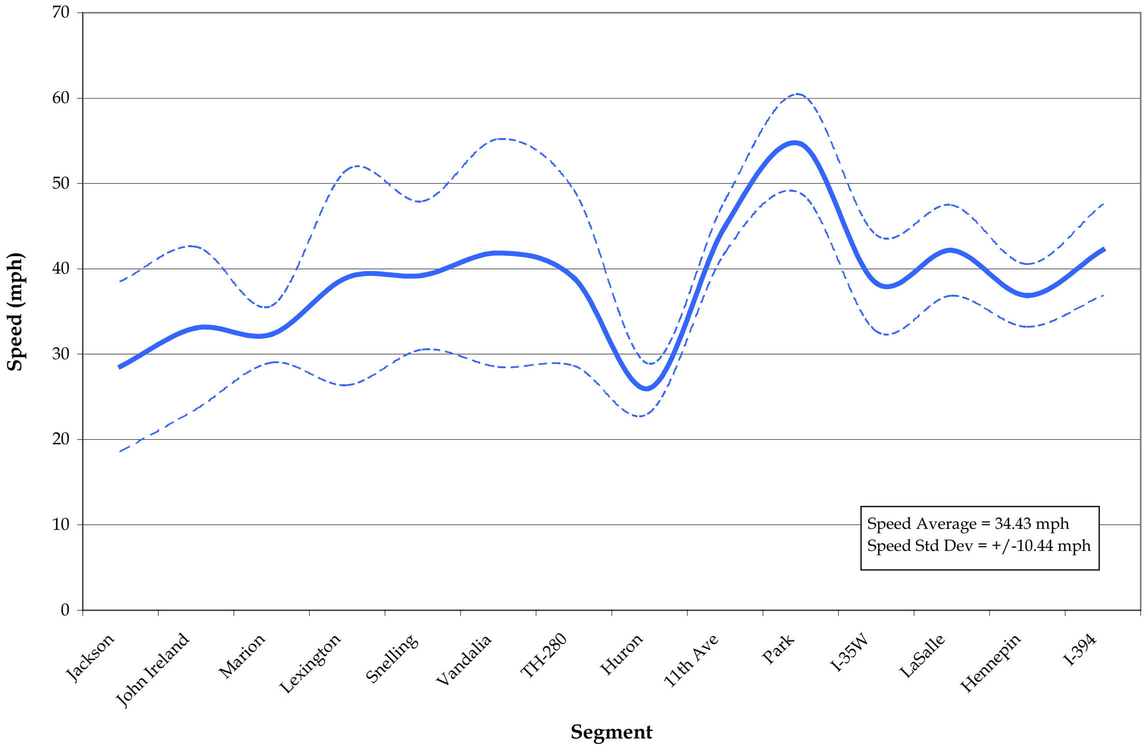


Figure 5.7 I-35E SB A.M. Peak Period Speed and Speed Variability

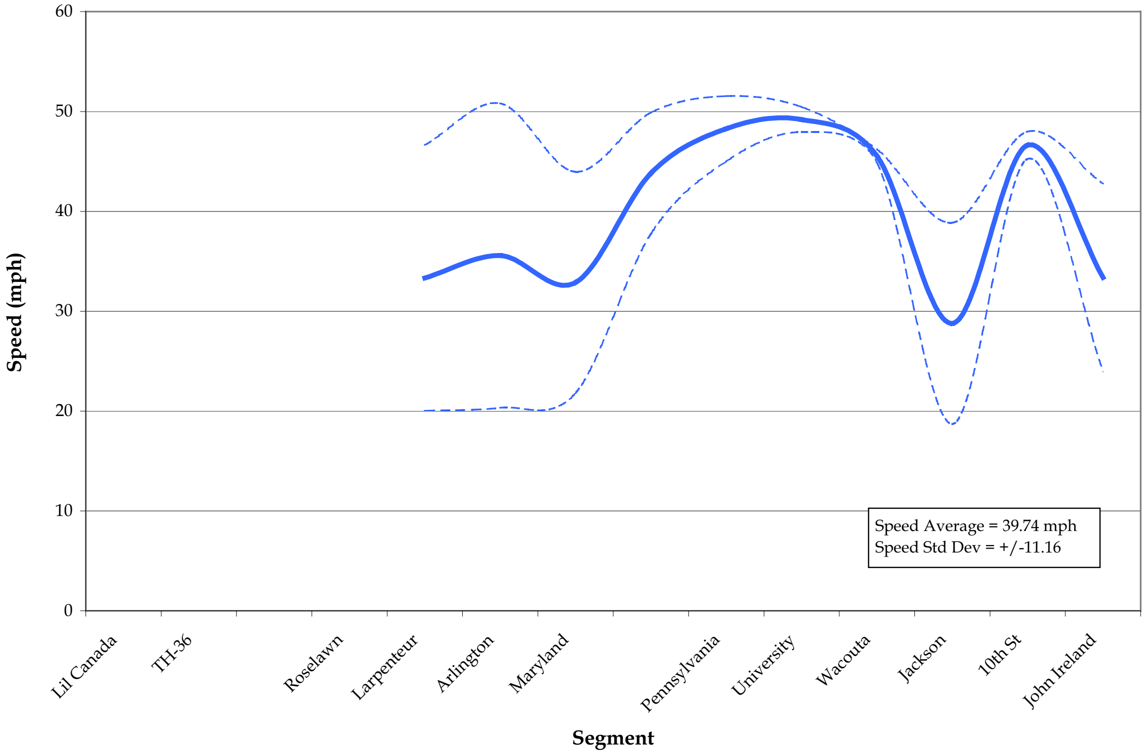
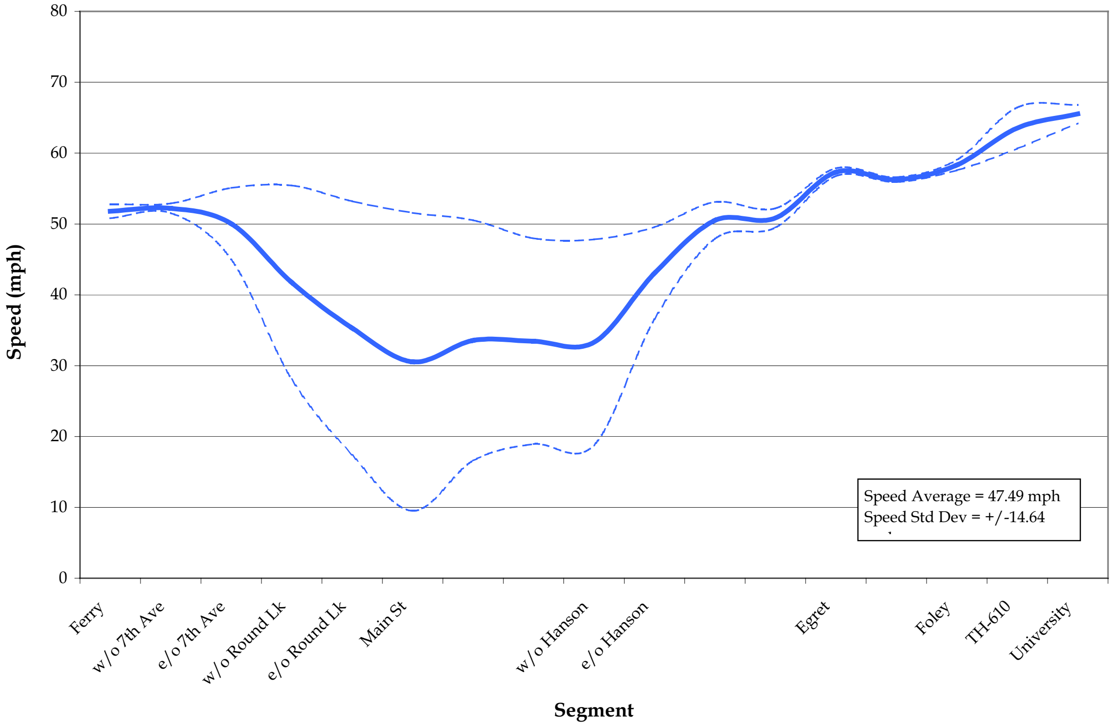


Figure 5.8 TH-10 EB A.M. Peak Period Speed and Speed Variability



■ 5.2 Freeway Traffic Volume and Throughput

During the Fall 2001 study period, peak period vehicle volume averaged 12,640 vehicles across the corridors observed. Corridor TH-10 EB during the morning peak carried the least number of vehicles, averaging less than 9,000 vehicles, while corridor I-94 WB during each of the a.m. and p.m. peak periods carried over 15,000 vehicles. Figures 5.9 through 5.16 show the traffic volumes at various locations at the freeway corridors.

Figure 5.9 I-494 NB P.M. Traffic Volume

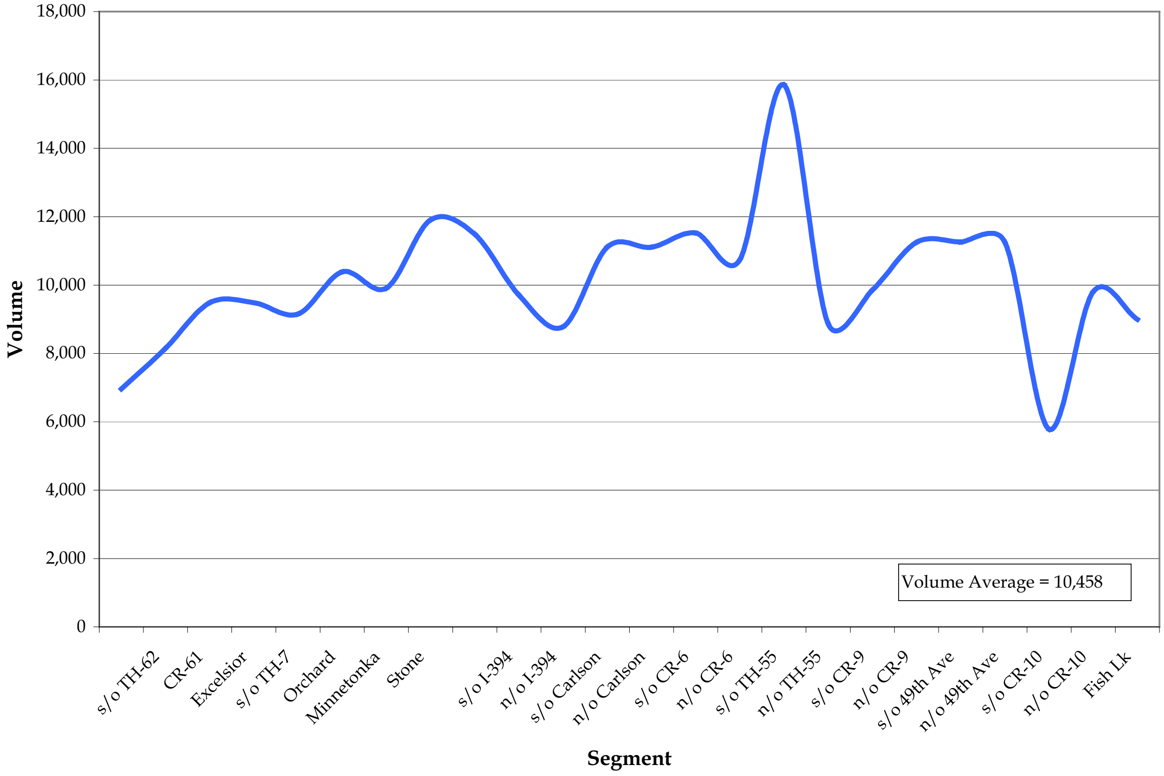


Figure 5.10 I-494 SB A.M. Traffic Volume

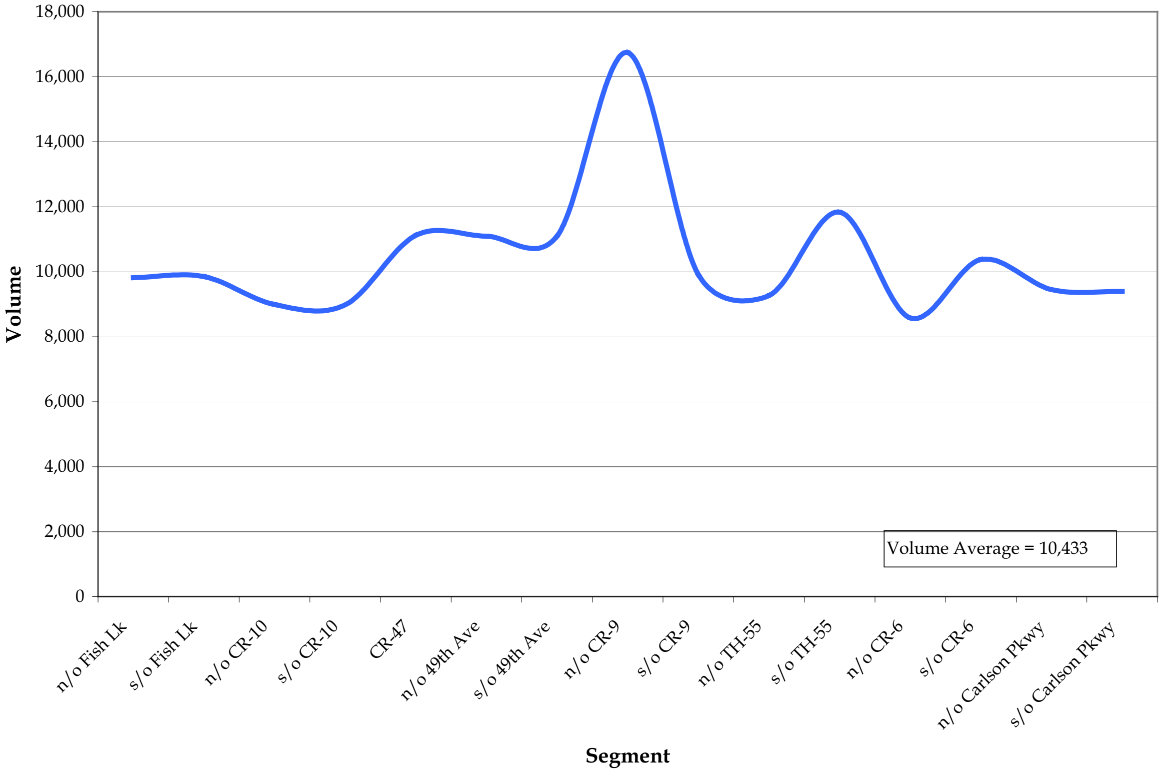


Figure 5.11 I-35W NB A.M. Traffic Volume

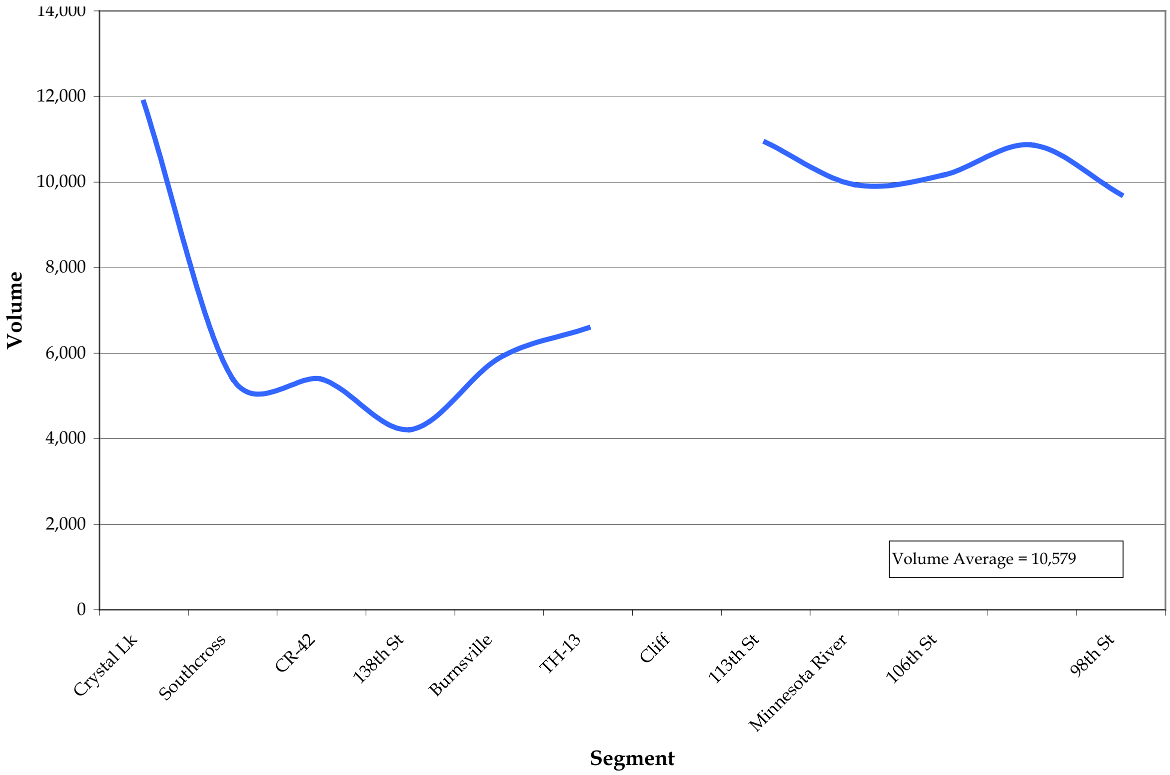


Figure 5.12 I-94 EB P.M. Traffic Volume

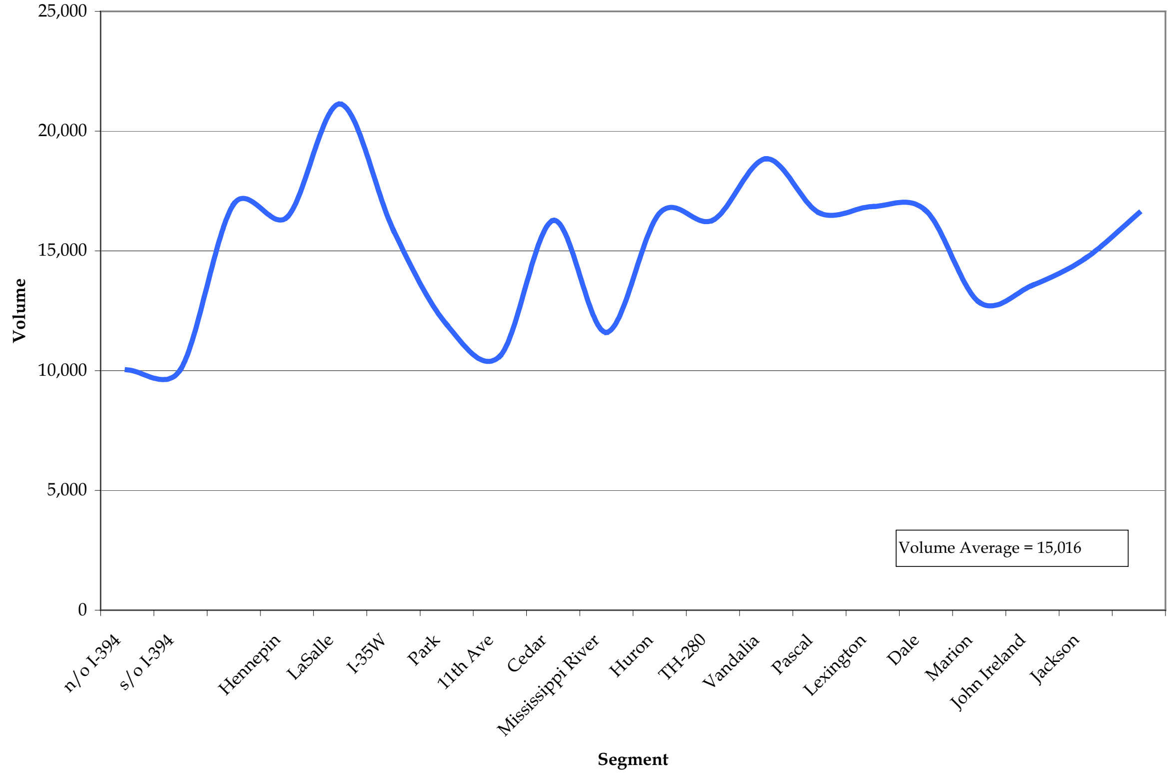


Figure 5.13 I-94 WB A.M. Traffic Volume

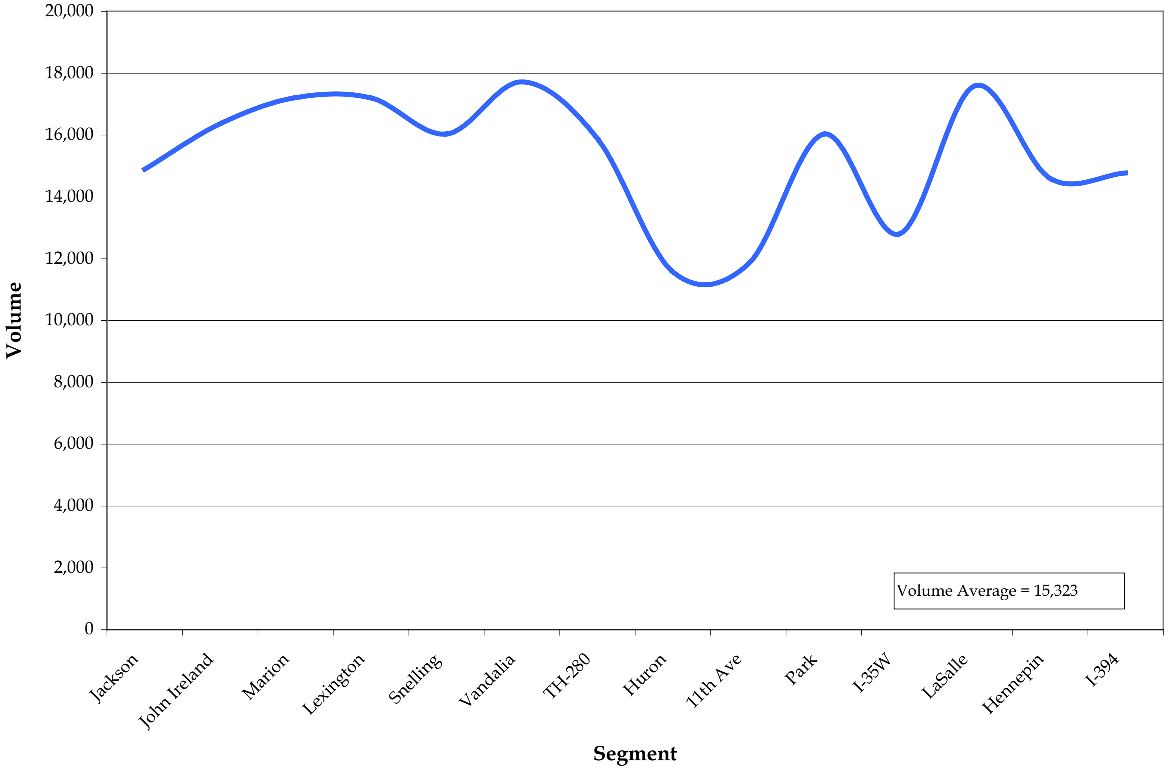


Figure 5.14 I-94 WB P.M. Traffic Volume

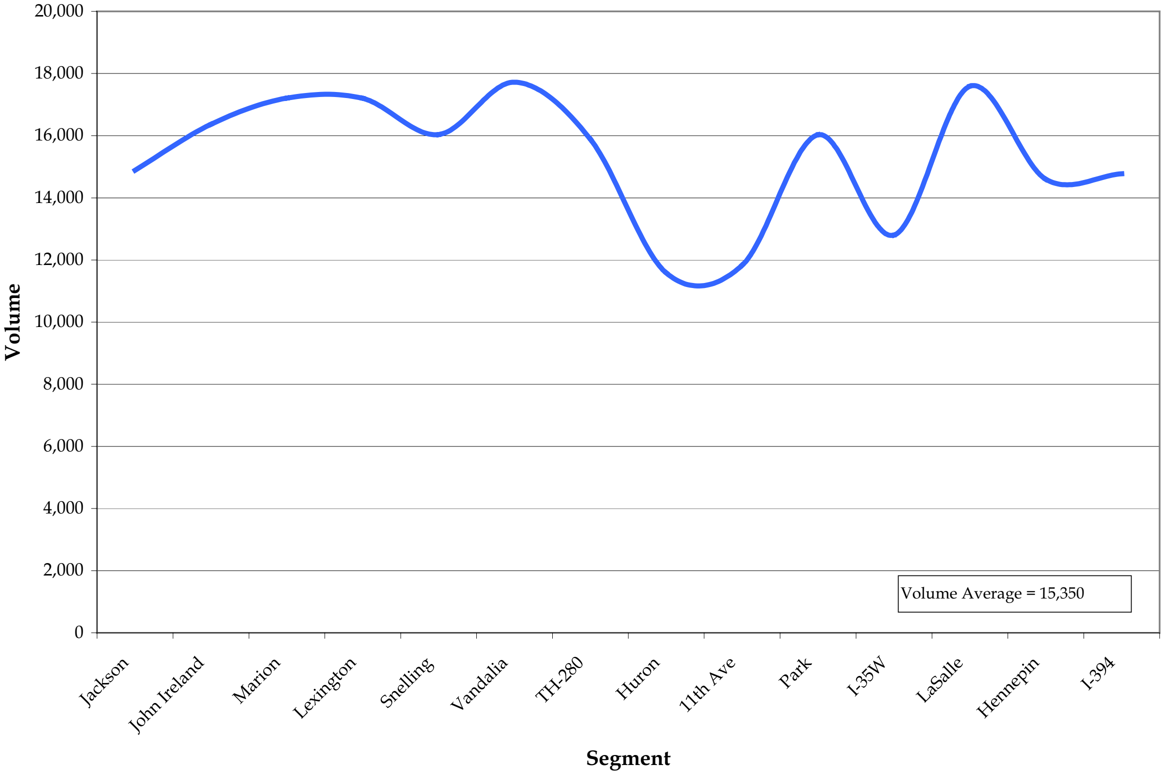


Figure 5.15 I-35E SB A.M. Traffic Volume

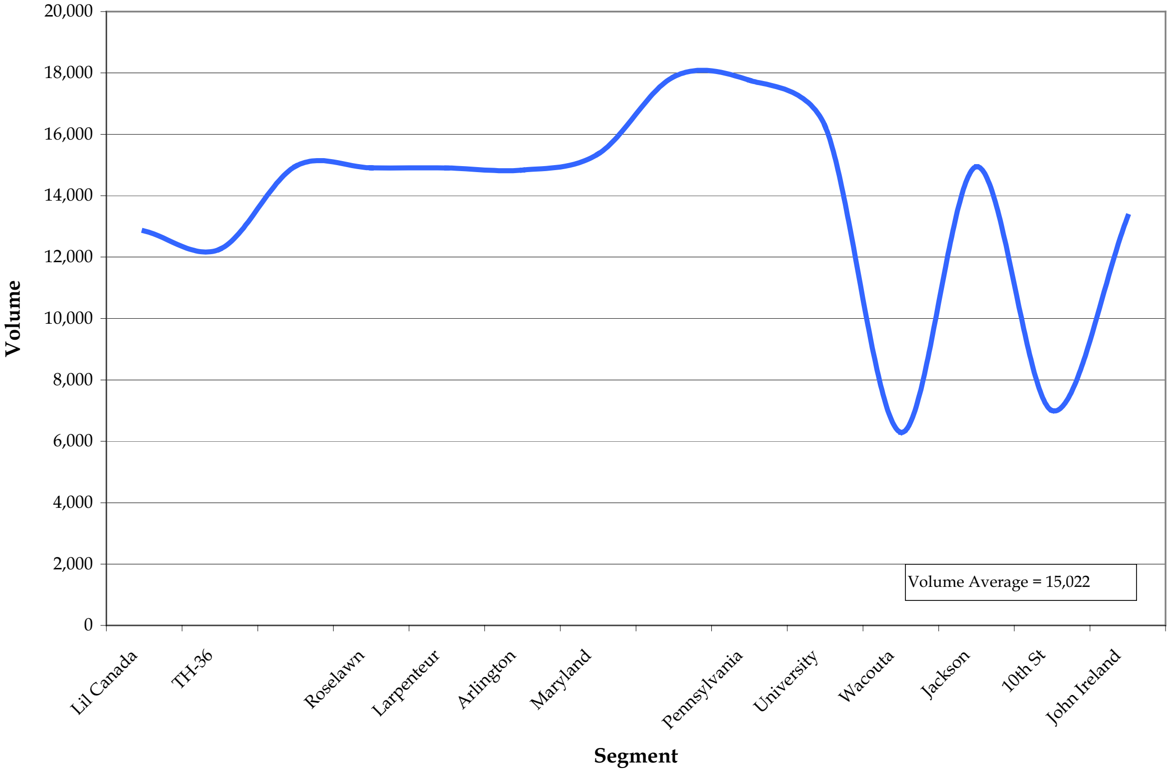
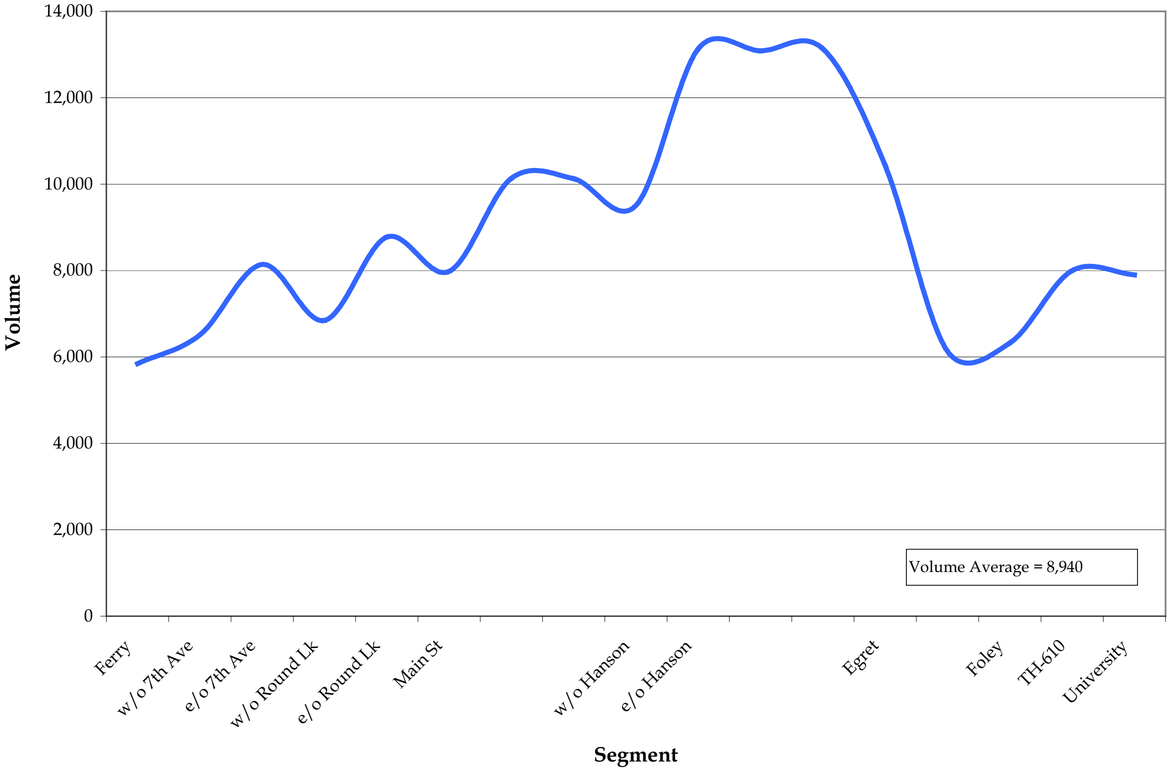


Figure 5.16 TH-10 EB A.M. Traffic Volume



5.3 Arterial Speed, Travel Time, and Volume

Arterial travel time data were collected at a five-mile stretch on University Avenue between Snelling Avenue and downtown St. Paul. Traffic counts along University Avenue were conducted at three locations. The data collection efforts were conducted during times when ramp meters on the main corridor were activated.

Table 5.2 summarizes the average speeds and travel times on University Avenue. Based on the results, University Avenue carried between 1,965 and 3,654 vehicles during the peaks, which ran at 18.4 to 22.3 mph.

Table 5.2 Summary of University Avenue Evaluation Results – Fall 2001

	University EB p.m.	University WB a.m.	University WB p.m.
Speed Average (mph)	18.4	22.3	21.3
Speed Standard Deviation[1] (mph)	2.47	3.38	1.64
Travel Time Average (min)	15.5	12.8	13.4
Travel Time Standard Deviation[1] (min)	2.40	2.28	1.12
Average Volume	3,654	1,965	2,436
Volume Standard Deviation[1]	212	118	263

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

5.4 Ramp Travel Time and Delay

During the Fall 2001 study period, the ramp meters were operated at a reduced capacity, with the main objective of breaking up platoons of vehicles as they entered the freeway. Under this condition, metering delays were minimal. Based on visual observations conducted by Traffic Management Center (TMC) staff, no queues were formed at the ramp meters within the study area.

Since no queues were found under this reduced metering capacity, vehicles traveled on the ramps at free-flow speed, which was assumed to equal the speed on the right-most lane of the freeway mainline. Table 5.3 summarizes the ramp meter travel times during the Fall 2001 study period.

Table 5.3 Ramp Travel Time and Delay – Fall 2001

	I-494		I-35W	I-94			I-35E	TH-10
	NB p.m.	SB a.m.	NB a.m.	EB p.m.	WB a.m.	WB p.m.	SB a.m.	EB a.m.
Average Free-Flow Travel Time (sec)	15	19	15	21	29	29	16	24
Average Ramp Delay (sec)	0	0	0	0	0	0	0	0
Total Ramp Travel Time (sec)	**15**	**19**	**15**	**21**	**29**	**29**	**16**	**24**

■ 5.5 Safety Impacts

The evaluation team analyzed the average crash data for the first seven months of years 1998 through 2001. These historical data were used to identify any changes in crash rates resulting from the implementation of less restrictive ramp metering strategies starting in December 2000. The analysis found that the metering strategy adopted prior to Fall 2000 resulted in 15 percent fewer crashes of all types. Figures 5.17 and 5.18 show the comparisons between historical crash rates (original metering strategy) and the post-shutdown 2001 crash rates (reduced metering capacity).

Figure 5.17 Comparison of Crash Occurrence by Crash Type (for Peak Period Metered Freeways)

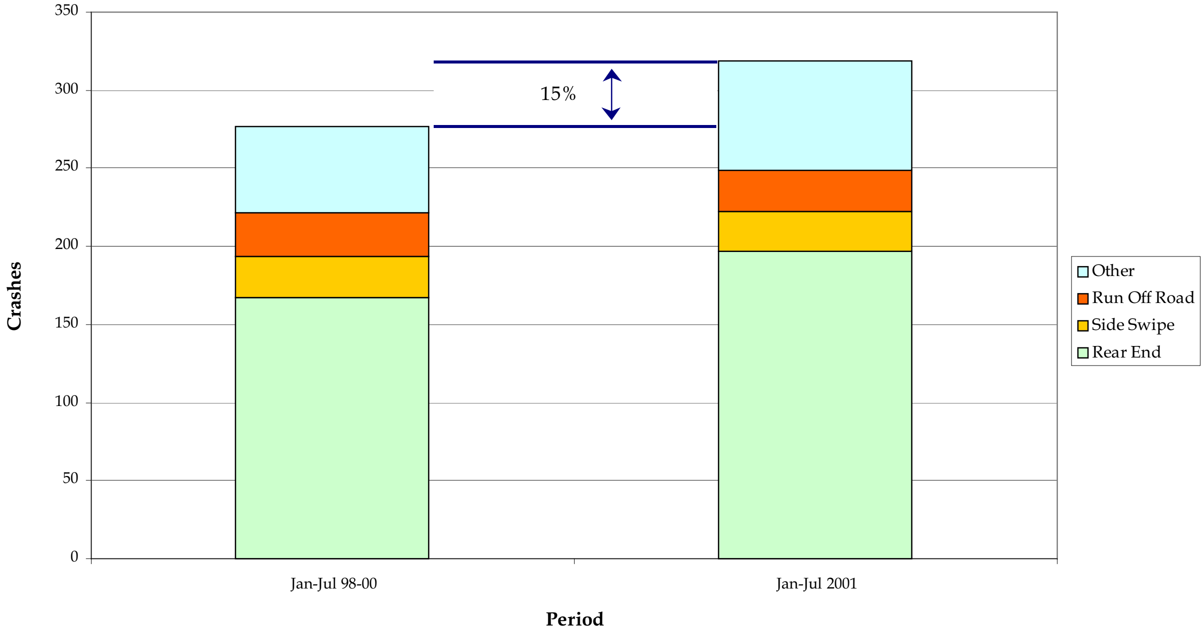
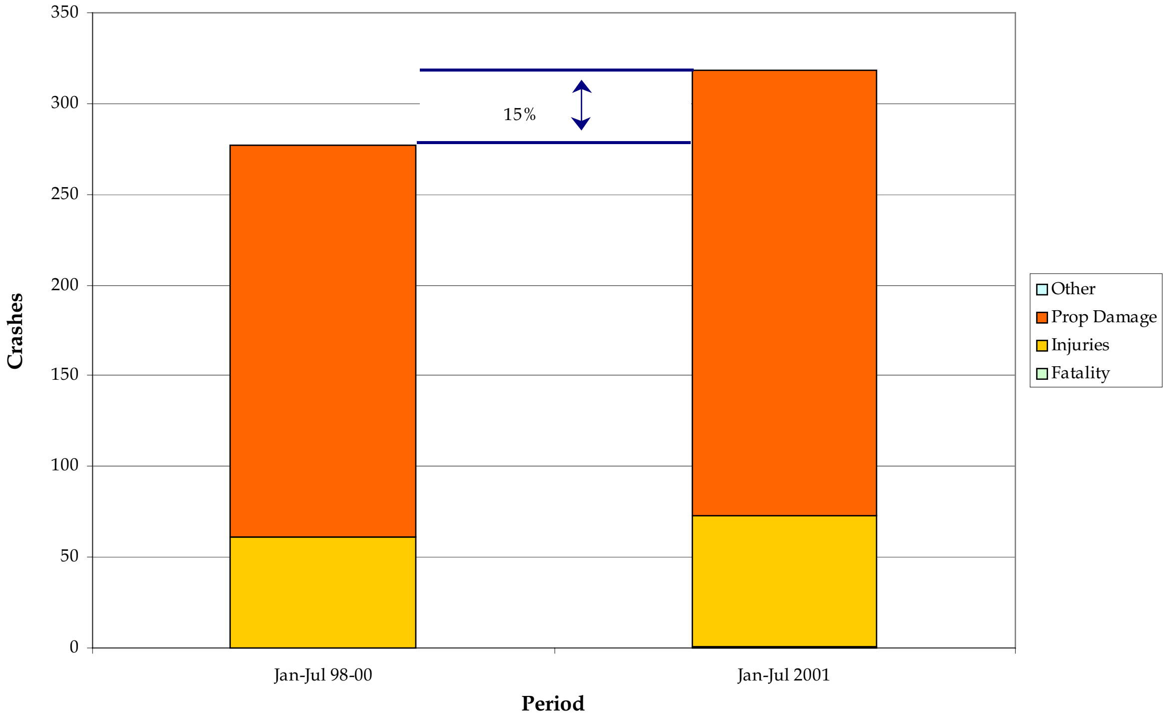


Figure 5.18 Comparison of Crash Occurrence by Crash Type (for Peak Period Metered Freeways)



6.0 Phase II Traveler Surveys

6.0 Phase II Traveler Surveys

Travelers' perceptions of the ramp meter strategies implemented were quantified through a set of Phase II telephone surveys among travelers in the Minneapolis/St. Paul metropolitan area. An important element in the evaluation of the ramp meter strategy evaluation was the measurement of travelers' attitudes toward different ramp metering strategies. The Fall 2001 surveys consisted of a random survey of Twin Cities residents. The following sections highlight the survey efforts.

■ 6.1 Fall 2001 Traveler Survey Methodology

The objective of the fall 2001 wave of surveys was to assess travelers' views of the ramp meter operations during the first nine months in 2001. Respondents were asked about their opinions on a range of different ramp metering strategies that are under consideration for implementation. The random sampling was developed by means of random digit dialing, and included all travelers (potentially including transit riders) who traveled during the peak periods. This sample allowed comparisons at an area-wide level, but it did not allow for comparisons at a corridor level with a high degree of statistical confidence.

The survey was similar to the sample surveys fielded during Phase I of the evaluation, and included the following groups of questions:

1. A set of screener questions to identify respondents traveling in the peak direction between 6:00 and 9:00 a.m. and/or between 3:00 and 6:00 p.m. Interviews with respondents working for Mn/DOT, planning agencies, media outlets, and city/county public works departments were discontinued.

2. Characteristics of their last peak-period trip that included:
   - Trip purpose, place of trip origin, and date and time of trip;
   - Origin and destination (at town/suburb level and in detail);
   - Total travel time and percentage of time traveled on freeway;
   - Rating of freeway congestion; and
   - Wait time at entrance meter and at other freeway-freeway meter(s).

3. Experience with a "typical" freeway trip, including the frequency of using the freeway, the percentage of time the respondents experienced longer wait times at ramps, and the corresponding longer total travel time.

4. A battery of attitudinal statements regarding the respondent's travel experiences in general and ramp meters in particular. Ramp-related questions consisted of travelers' attitudes toward ramp wait times, safety considerations, predictability of travel, and the usefulness of ramp by-pass lanes.

5. Travelers' preferences for a set of ramp metering strategies, including a queue management policy to cap wait times at ramps, the re-definition of time windows when ramp meters are in operation, the testing of a freeway-freeway ramp metering policy, and a policy of ad-hoc ramp metering to respond to incident congestion.

6. Demographic information to control for differences among respondents.

The statistical analysis aimed to identify important differences by focusing on differences that are statistically significant at a 95 percent confidence level.

Tasks and deliverables in this effort included:

1. Design of the survey instrument for a random sample traveler survey. Mn/DOT participated in giving input and approval.

2. Programming of the random sample survey into a computer-aided telephone interview program to accommodate any changes to the original survey design.

3. Administration of the telephone survey for the random sample.

4. Data processing of the survey with two books of cross-tabulations (32 banner points).

5. A comparative statistical analysis of traveler perceptions and travel behavior with the previous two surveys and across traveler market segments.

6. Presentations to Mn/DOT of the survey analysis findings.

■ 6.2 Fall 2001 Market Research Results

During the Fall 2001 study period, the traveler survey was conducted by telephone and was based on a random sample of 500 travelers in the seven-county metropolitan study area. This section details the results of the market research analysis. The analysis focused on a comparative statistical analysis of traveler perceptions and travel behavior with the previous two waves of "With metering" and "Without metering" surveys conducted in the Fall of 2000, as well as across different segments of the traveler market. The statistical analysis identified important differences by focusing on those differences that were statistically significant at least at the 95 percent confidence level.

6.2.1 Socioeconomic Profile

There are great similarities in the socioeconomic characteristics of respondents who participated in each of the three random sample surveys. The respondents' profile was constructed based on their gender, age, automobile ownership, income, education, and household size. As can be seen in Table 6.1 through Table 6.6, the distributions of gender, age, automobile ownership, income, education, or household size are very similar across surveys ensuring that the randomly drawn samples are effectively the same and representative of the seven-county area population.

Table 6.1 Gender Distribution for Random Samples

	"With Metering" – Fall 2000		"Without Metering" – Fall 2000		Fall 2001	
	Frequency	**Percentage**	**Frequency**	**Percentage**	**Frequency**	**Percentage**
Male	126	49.8%	126	50.0%	253	50.0%
Female	127	50.2%	126	50.0%	253	50.0%
Total	**253**	**100.0%**	**252**	**100.0%**	**506**	**100.0%**

Table 6.2 Age Distribution for Random Samples

	"With Metering" – Fall 2000		"Without Metering" – Fall 2000		Fall 2001	
	Frequency	**Percentage**	**Frequency**	**Percentage**	**Frequency**	**Percentage**
18 to 29 years	42	16.7%	45	18.0%	80	16.0%
30 to 39 years	61	24.2%	57	22.8%	117	23.4%
40 to 49 years	70	27.8%	73	29.2%	137	27.3%
50 to 59 years	42	16.7%	39	15.6%	89	17.8%
60 to 69 years	25	9.9%	22	8.8%	40	8.0%
70 or more years	12	4.8%	14	5.6%	38	7.6%
Total	**252**	**100.0%**	**250**	**100.0%**	**501**	**100.0%**

Table 6.3 Car Ownership for Random Samples

	"With Metering" – Fall 2000		"Without Metering" – Fall 2000		Fall 2001	
	Frequency	**Percentage**	**Frequency**	**Percentage**	**Frequency**	**Percentage**
None	0	0.0%	0	0.0%	6	1.2%
1 vehicle	52	20.7%	38	15.1%	99	19.8%
2 vehicles	120	47.8%	145	57.5%	266	53.3%
3 vehicles	47	18.7%	44	17.5%	80	16.0%
4 or more vehicles	32	12.7%	25	9.9%	54	10.8%
Total	**251**	**100.0%**	**252**	**100.0%**	**499**	**100.0%**

Table 6.4 Income Distribution for Random Samples

	"With Metering" – Fall 2000		"Without Metering" – Fall 2000		Fall 2001	
	Frequency	**Percentage**	**Frequency**	**Percentage**	**Frequency**	**Percentage**
Under $20,000	6	2.6%	8	3.9%	26	5.8%
$20,000 to $34,000	39	17.2%	19	9.3%	41	9.1%
$35,000 to $49,000	36	15.9%	25	12.2%	83	18.4%
$50,000 to $64,000	42	18.5%	47	22.9%	79	17.5%
$65,000 to $79,000	37	16.3%	45	22.0%	81	18.0%
$80,000 to $99,000	22	9.7%	27	13.2%	67	14.9%
$100,000 to $149,000	34	15.0%	24	11.7%	52	11.5%
$150,000 or more	11	4.8%	10	4.9%	22	4.9%
Total	**227**	**100.0%**	**205**	**100.0%**	**451**	**100.0%**

Table 6.5 Education Levels for Random Samples

	"With Metering" – Fall 2000		"Without Metering" – Fall 2000		Fall 2001	
	Frequency	**Percentage**	**Frequency**	**Percentage**	**Frequency**	**Percentage**
High School or less	43	17.0%	44	17.5%	97	19.2%
Technical/vocational school	29	11.5%	23	9.1%	71	14.1%
Some college	59	23.3%	59	23.4%	107	21.2%
College graduate	75	29.6%	75	29.8%	132	26.2%
Post-graduate studies	47	18.6%	51	20.2%	97	19.2%
Total	**253**	**100.0%**	**252**	**100.0%**	**504**	**100.0%**

Table 6.6 Household Size for Random Samples

	"With Metering" – Fall 2000		"Without Metering" – Fall 2000		Fall 2001	
	Frequency	**Percentage**	**Frequency**	**Percentage**	**Frequency**	**Percentage**
One-person household	44	17.4%	31	12.3%	76	15.0%
Two-person household	91	36.0%	100	39.7%	183	36.2%
Three-person household	49	19.4%	47	18.7%	95	18.8%
Four-person household	51	20.2%	49	19.4%	100	19.8%
Five + person household	18	7.1%	25	9.9%	51	10.1%
Total	**253**	**100.0%**	**252**	**100.0%**	**505**	**100.0%**

The hypothesis of identical survey samples was tested using the statistical analysis technique known as "analysis of variance" (ANOVA). This technique was used to test whether any differences in the distribution of socioeconomic characteristics were statistically significant. In every case, there were no statistically significant differences at the 95 percent confidence level. As a result, the similarities in the respondent profile over the three survey waves strongly suggest that the three independently drawn samples are indistinguishable in terms of their socioeconomic composition.

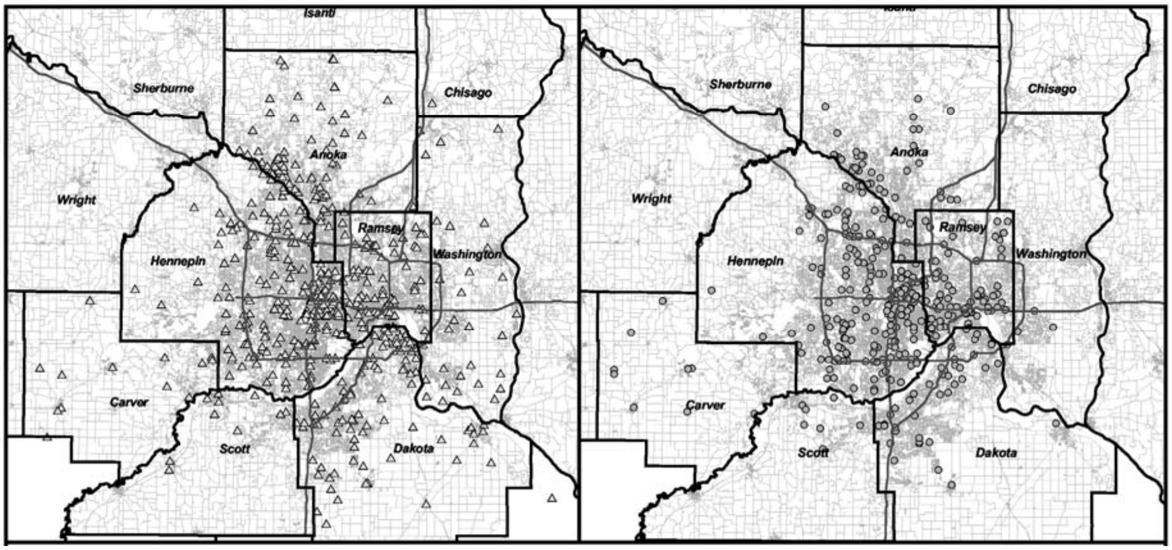
6.2.2 Geographic Representativeness

Subsequently, the survey data were examined and described geographically through maps that show respondents' origins and destinations. The objective of developing these maps was to ensure that respondents were spread out within the study area and were, therefore, not concentrated in specific sections potentially biasing the survey results.

Each of the 506 surveys contained geographic data describing the detailed origins and destinations of the respondents' trips and their home zip code. These data were geocoded using a Geographic Information System (GIS). These maps were developed in ArcView using the *Lawrence Group (TLG) Street Centerline Data* to match respondents' origin and destination addresses. Where matching was not feasible due to missing information, the respondent's home zip code was used to randomly assign each individual within the zip code boundaries.

The results of this geocoding effort are illustrated in Figure 6.1. The two maps showing respondents' origins and destinations clearly reflect a widespread distribution of respondents within the study area. These findings provide further support to the representativeness of the randomly drawn survey sample.

Figure 6.1 Fall 2001 Survey Geocoding Results



6.2.3 Travel Patterns

A key piece of information used to summarize potential differences in travel patterns within the Twin Cities metropolitan area was the average origin-destination travel time reported for peak-period trips. Tables 6.7 and 6.8 show the distribution of reported total travel times and the reported freeway travel times in each of the three survey waves.

Table 6.7 Total Travel Time for Random Samples

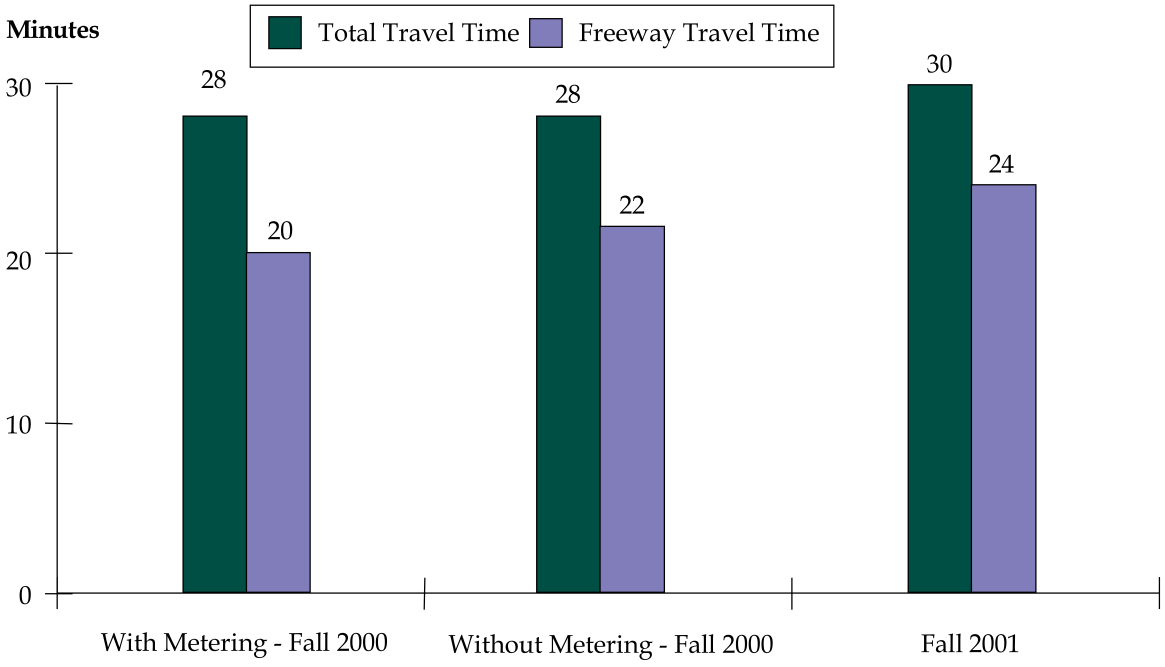
	"With Metering" – Fall 2000		"Without Metering" – Fall 2000		Fall 2001	
	Frequency	Percentage	Frequency	Percentage	Frequency	Percentage
Less than 15 minutes	38	15.0%	38	15.1%	88	17.4%
15 to 19 minutes	43	17.0%	26	10.3%	66	13.0%
20 to 24 minutes	44	17.4%	46	18.3%	76	15.0%
25 to 29 minutes	24	9.5%	43	17.1%	54	10.7%
30 to 34 minutes	36	14.2%	30	11.9%	67	13.2%
35 to 44 minutes	27	10.7%	27	10.7%	53	10.5%
45 to 59 minutes	25	9.9%	24	9.5%	59	11.7%
1 to 1.5 hours	12	4.7%	17	6.7%	36	7.1%
More than 1.5 hours	4	1.6%	1	0.4%	7	1.4%
Total	**253**	**100.0%**	**252**	**100.0%**	**506**	**100.0%**

Table 6.8 Freeway Travel Time for Random Samples

	"With Metering" – Fall 2000		"Without Metering" – Fall 2000		Fall 2001	
	Frequency	**Percentage**	**Frequency**	**Percentage**	**Frequency**	**Percentage**
Less than 15 minutes	64	25.3%	75	29.8%	107	21.1%
15 to 19 minutes	26	10.3%	45	17.9%	53	10.5%
20 to 24 minutes	27	10.7%	31	12.3%	52	10.3%
25 to 29 minutes	11	4.3%	19	7.5%	33	6.5%
30 to 34 minutes	23	9.1%	16	6.3%	41	8.1%
35 to 44 minutes	14	5.5%	16	6.3%	28	5.5%
45 to 59 minutes	4	1.6%	13	5.2%	20	4.0%
More than 1 hour	5	2.0%	7	2.8%	15	3.0%
Total	**174**	**68.8%**	**222**	**88.1%**	**349**	**69.0%**

There was a modest increase in the average value for total origin-destination travel times with a 30-minute time travel time reported under the Fall 2001 study period (Figure 6.2). This estimate is comparable to the almost identical "With metering" and "Without metering" total travel time estimates of 28 minutes in 2000. The comparisons between these three values suggest that there were no statistically significant differences in total travel times across the three survey waves.

Figure 6.2 Average Travel Times



Q3I – How much time did this trip take from the time you started until you reached your destination?

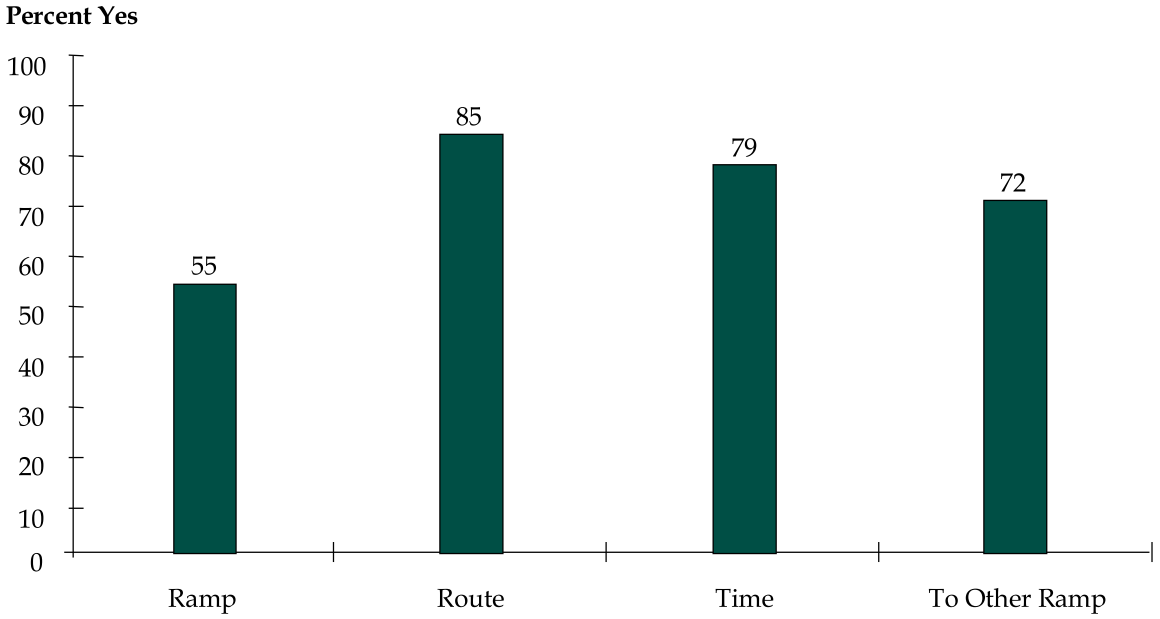
Q3K2 – How many minutes of this travel time did you spend on any freeways?

On the other hand, the average peak period travel times spent on a freeway showed a gradual modest increase in travel time from each wave of data collection to the next. This results in a Fall 2001 freeway travel time of almost 24 minutes compared to a low of a 20-minute freeway travel time under the "With Metering – Fall 2000" conditions.

This difference corresponds to ***a statistically significant increase in the average travel time spent on freeways*** by survey respondents in the random sample. This finding suggests that, despite an overall similar total travel time, respondents believe that the time they spent on the freeways during the peak periods increased following the implementation of the reduced ramp metering strategy. This finding is consistent with the findings of an increase in actual travel times and decrease in speed measurements along the freeway corridors of interest to the study.

Finally, the stated diversion patterns in response to congestion are illustrated in Figure 6.3. It should be noted that respondents gave a higher-stated probability of changing their departure times (85 percent) and diverting to an alternate route (79 percent), rather than using another ramp. This pattern again confirms the underlying changes in ramp meter operations that have changed the focus of travelers' attention from the ramp meter delays to traffic conditions on the freeways.

Figure 6.3 Diversion Pattern Under Current Conditions



Q11B – Do you sometimes use alternate routes to
B-1 Avoid waiting at ramp meters?
B-2 Avoid traveling on congested freeways?

Q11C – Do you sometimes leave earlier or later to avoid traffic congestion?

Q11D – Do you sometimes avoid a ramp that is backed up and use a different ramp?

6.2.4 Attitudes Toward Aspects of Travel

The battery of attitudinal questions examined travelers' attitudes toward their overall travel in the area, as well as specific attributes of their travel experience that were affected by ramp meter operations. Respondents rated the statements on a scale of zero 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.

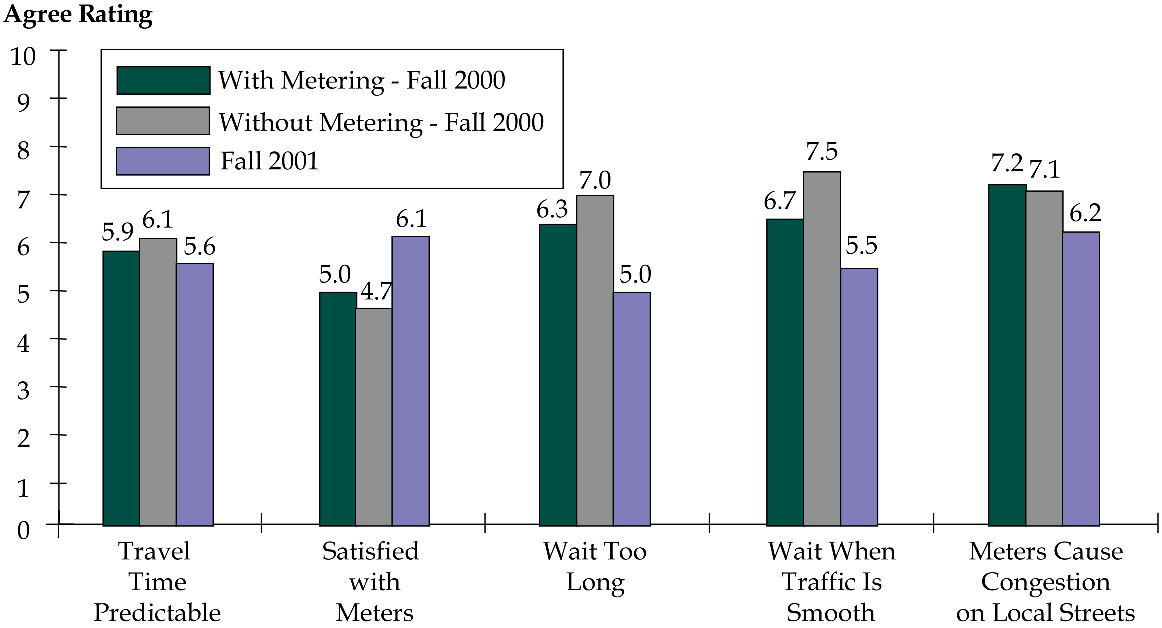
Respondents were asked to rate the same battery of attitudinal statements in each of the three survey waves with consistent wording of each question. Table 6.9 illustrates respondents' ratings for all of the original (Fall 2000) statements, plus the two new statements that were added in the Fall 2001 survey. The most important patterns and interesting findings have been summarized in Figure 6.4 and include the following:

Table 6.9 Comparison in Respondents' Ratings Across Waves of Random Samples

	Average Rating		
	"With Metering" – Fall 2000	**"Without Metering" – Fall 2000**	**Fall 2001**
Feel safe from crashes on freeways	5.64	6.10	5.61
Special lane for buses/carpools	4.64	5.23	5.00
Good freeway network	5.43	5.16	5.03
Travel time predictable during peak	***5.86***	***6.09***	***5.59***
Overall satisfied with ramp meters	***4.99***	***4.72***	***6.13***
Wait time at meters is too long	***6.28***	***6.98***	***5.04***
Never know how long wait time will be	***6.89***	***6.91***	***5.94***
Safe when leaving ramp meter to merge	5.81	6.15	6.18
Ramp meters improve overall traffic	5.41	5.32	5.63
Cost of ramp meters is good value	4.63	4.14	4.74
Ramp meters shorten travel time	4.37	4.37	4.54
Ramp meters reduce car crashes	5.38	5.27	5.38
Ramp by-pass lanes benefit to me	4.33	4.26	4.24
Some meters may not be necessary	6.38	7.88	6.89
Buses/carpools should have ramp by-pass lanes	7.52	7.39	7.33
Sometimes need to wait even with smooth traffic	***6.72***	***7.52***	***5.50***
More alternative routes to avoid ramp meters	6.49	6.22	5.89
Ramp meters cause congestion on local streets	***7.16***	***7.13***	***6.20***
Electronic sign stating wait time	5.85	5.13	
Do not feel safe when going through a meter			4.17
Length of time drivers wait at meters is too short			3.62
Tolerance for congestion	5.27	4.54	5.29
Amount of traffic congestion	5.82	5.45	5.67

Italics = Statistically significant differences.

Figure 6.4 Ramp Metering Attributes



Q10 – Use a scale of 1 to 10 to tell me how much you agree with the statement
D – Travel time is predictable
E – Overall satisfied with ramp meters
F – Length of time waiting at meters is too long
P – Wait at meters when traffic is moving well
Q – Meters cause congestion on local streets

- The ***predictability of travel times*** during the peak period in the Fall 2001 survey was given the lowest rating among the three survey waves. This finding is consistent with the observed traffic patterns along the freeways of interest to the study as illustrated by the increased variability in travel times during the most recent wave of data collection.

- Respondents' ***overall satisfaction with ramp meters*** was considerably higher under the Fall 2001 survey. This finding is consistent with the change in ramp metering operations that has reduced the waiting times at the meters.

- The same pattern was reflected in respondents' ratings of ***wait time at the meters***. Their higher level of agreement reflected the lower wait times under the Fall 2001 conditions. Similarly, respondents in the Fall 2001 survey disagreed more strongly that they ***had to wait too long at the meters even when traffic was proceeding smoothly,*** again reflecting the perceived improvement in ramp metering operations.

- Furthermore, respondents in the Fall 2000 survey disagreed more strongly about the statement that ramp meter operations cause a spillover of ***congestion on local streets***.

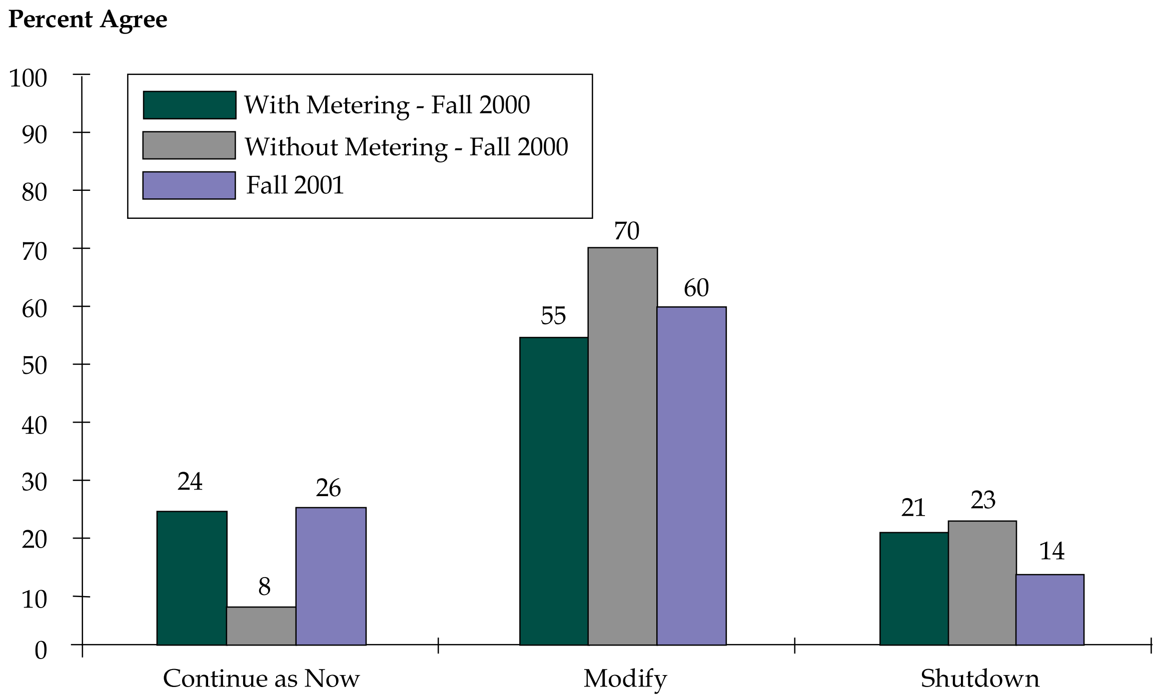
The lack of such localized congestion was again confirmed by the lack of any ramp queues as observed during the traffic data collection effort.

- Finally, there did not seem to be any particular safety concerns reflected either in the original safety-related statements or in the new statements that were added for the Fall 2001 wave of data collection.

6.2.5 Traveler Opinions About the Future of Ramp Metering

The future of ramp metering was assessed with the same "polling" question across the three waves of data collection. Figure 6.5 illustrates the continuing very strong support for experimenting with ramp metering efforts trying to fine-tune the metering operations. Although the support for further ramp metering modifications has dropped a little compared to the "Without metering" survey, the support for completely shutting off the ramp meters was at its lowest level among the three survey waves.

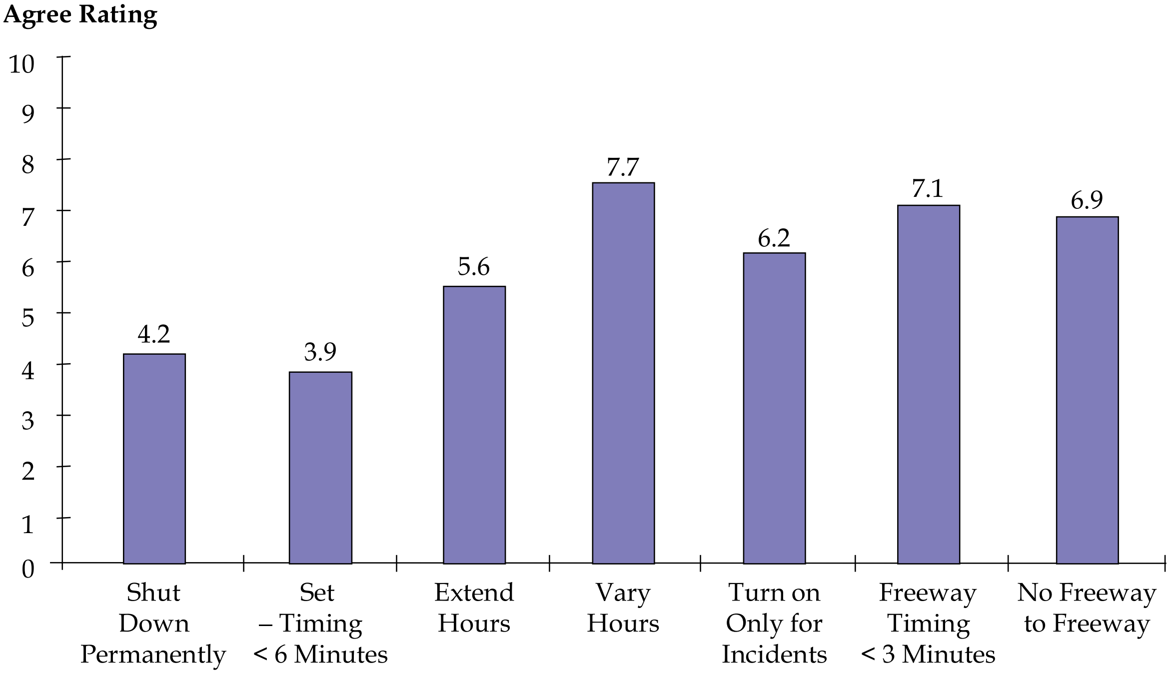
Figure 6.5 Results of the Polling Questions



Q13-A Do you think the ramp meter system should be continued as now, modified, or shutdown?

In the Fall 2001 survey, respondents were also asked a follow-up question to examine the appeal of different proposed modifications in ramp metering operations. Figure 6.6 summarizes respondents' level of agreement with the different ramp metering strategies. The option that received the greatest support among respondents was that *"The hours that ramp meters operate would vary in different locations depending on the traffic congestion"* (average rating of 7.7). Strong agreement was also provided *for "When using a ramp that takes you from one freeway to another, set the timing on the ramp meter so that vehicles would never wait more than two or three minutes"* and *"When using a ramp that takes you from one freeway to another, you should not have to wait at a ramp meter to enter the next freeway"* with average ratings of 7.1 and 6.9, respectively.

Figure 6.6 Policy Options for Metering Modification



Q11-J There are a number of ways meters could be operated.
Tell me how much you agree with each option

- Shut down
- Set timing so you might have to wait longer than you do now but never more than 6 minutes
- Extend hours if traffic is heavy
- Vary hours depending on congestion
- Turn on only in response to incidents
- When using a freeway-to-freeway ramp, set timing so wait is never more than 2-3 minutes
- When using freeway-to-freeway ramp, you should not have to wait at a meter

The option that received the lowest level of support was stated, *"Set the timing so you might have to wait longer than you do now, but never more than six minutes"* (average rating of 3.9) and was also followed at a very low level of support by *"Shut down all ramp meters permanently"* (average rating of 4.2). It should be noted that lack of support for a maximum wait time of six minutes does not necessarily mean lack of support for lesser wait times, which would still represent an increase from Fall 2001 negligible wait times if this resulted in an overall improvement in traffic operations and travel times.

Finally, Table 6.10 provides yet another way of examining these statements in addition to focusing on the average ratings. An examination of the distribution of "Agree" versus "Disagree" responses is provided by grouping ratings of 1-3 (strongly disagree), 4-7 (neither agree nor disagree), and 8-10 (strongly agree).

Table 6.10 Grouping of Responses for Metering Policy Options

		Strongly Disagree	**Neither Agree Nor Disagree**	**Strongly Agree**
	Average Rating	**Rating Between 1 and 3**	**Rating Between 4 and 7**	**Rating Between 8 and 10**
Shut down all ramp meters permanently	4.2	51%	27%	22%
Set the timing so you might have to wait longer than you do now, but never more than 6 minutes	3.9	56%	27%	17%
Extend the hours that ramp meters are operating if traffic continues to be heavy	5.6	29%	39%	32%
Turn the ramp meters on only when there are specific incidents that cause traffic congestion such as road construction or car crashes	6.2	24%	33%	43%
When using a ramp that takes you from one freeway to another, set the timing on the ramp meter so that vehicles would never wait more than 2 or 3 minutes	7.1	14%	32%	55%
The hours that ramp meters operate would vary in different locations depending on the traffic congestion	7.7	7%	28%	65%
When using a ramp that takes you from one freeway to another you should not have to wait at a ramp meter to enter the next freeway	6.9	19%	29%	52%

The distribution of ratings suggests that two out of three respondents strongly agreed with the ramp metering strategy that states: *"The hours that ramp meters operate would vary in different locations depending on the traffic congestion."* At the opposite end of the spectrum, more than half of the respondents strongly disagreed with the ramp metering strategy proposing to *"Set the timing so you might have to wait longer than you do now, but never more than six minutes."*

6.2.6 Summary and Conclusions

The results of this market research supported the findings of the traffic analysis which indicate that freeway operations continued to be degraded under the Fall 2001 (representing the reduced metering capacity) study period relative to the "With metering" scenario in the fall of 2000. Support for continued modification of the system remained high, while support for a permanent shutdown was at its lowest level during the course of these evaluations.

7.0 Benefit/Cost Analysis

7.0 Benefit/Cost Analysis

This section presents detailed instructions on how to conduct benefit-cost analysis using a spreadsheet tool developed for the Phase I evaluation; this tool can readily be used in future evaluations of ramp metering or other traffic management strategies. The objective of the benefit/cost analysis is to extrapolate the findings from the analysis of selected corridors to provide estimates of the system-wide benefits and costs of the ramp metering system. Impacts of ramp metering are quantified using the collected field data. The ramp metering system's capital, operating, and maintenance costs are also quantified, and compared against the system's benefits.

7.1 Extrapolating Field Data

This section describes the steps necessary to apply the study area impacts to the entire Twin Cities ramp metering system; impacts of ramp metering include system travel time, travel time reliability, and safety.

7.1.1 Segment Categorization

The key to the benefit/cost analysis process is to determine how similar each freeway segment in the region is to the selected study corridors. This "categorization" of freeway sections allows for the extrapolation of the measured impacts of the study corridors to the rest of the Twin Cities metropolitan area freeway system to provide systemwide evaluation results. In Phase I of the evaluation, 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 suburb-to-suburb commuters.

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.

Each corridor is generally divided into three to four segments, which may or may not share the same characteristics of the neighboring segments. In coordination with Mn/DOT and the advisory committee, the evaluation team has categorized all freeway segments within the Twin Cities region. Table 7.1 lists the results of this task.

Table 7.1 Twin Cities Corridor Categorization

	% Attributable to Category				
Corridor/Between	**Type A**	**Type B**	**Type C**	**Type D**	**Study Corridor**
I-35E					
I-35 Junction and TH77		60%		40%	No
TH77 and I-494		60%		40%	No
I-494 and Downtown St. Paul			10%	90%	No
Downtown St. Paul and I-694				100%	Yes
I-35W					
I-35 Junction and I-494		100%			Yes
I-494 and Downtown Minneapolis			30%	70%	No
Downtown Minneapolis and I-694			10%	90%	No
I-694 and Lexington		80%		20%	No
I-94					
Century Avenue and Downtown St. Paul		10%	10%	80%	No
Downtown St. Paul and Downtown Minneapolis			100%		Yes
Downtown Minneapolis and I-694			30%	70%	No
I-94 (I-694)					
I-694 Junction and CR30	100%				No
I-394					
Downtown Minneapolis and TH100			60%	40%	No
TH100 and TH169			30%	70%	No
TH169 and I-494			10%	90%	No
I-494					
Mississippi River and TH54	90%		10%		No
TH5 and TH169	25%		75%		No
TH169 and I-394	80%		20%		No
I-394 and I-94 Junction	100%				Yes
I-694					
I-35W and I-94 Junction	100%				No
TH10					
University and Round Lake (Anoka Co.)		80%		20%	Yes
TH36					
I-35E and I-35W	10%		20%	70%	No

Table 7.1 Twin Cities Corridor Categorization (continued)

	% Attributable to Category				Study
Corridor/Between	**Type A**	**Type B**	**Type C**	**Type D**	**Corridor**
TH62					
TH55 and I-35W	10%		70%	20%	No
I-35W and TH100	10%		70%	20%	No
TH100 and I-494	20%		70%	10%	No
TH77					
I-35E and I-494		100%			No
I-494 and TH62			10%	90%	No
TH100					
I-494 and TH62			70%	30%	No
TH62 and I-394			70%	30%	No
TH169					
I-494 and TH62			40%	60%	No
TH62 and I-394	5%		40%	55%	No
I-394 and I-94/I-694	15%		20%	65%	No

Use of the Spreadsheet Tool

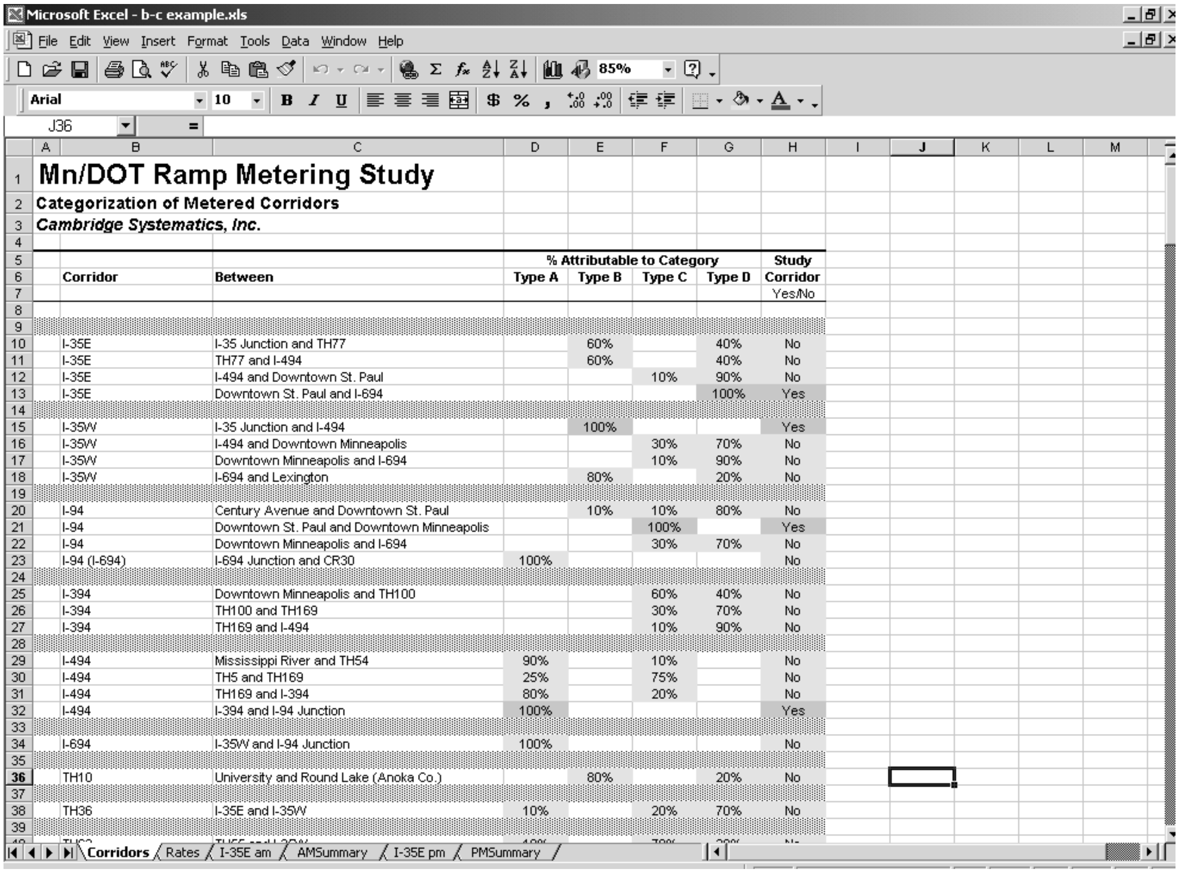
Using a Microsoft Excel™ spreadsheet, the analyst may enter the resulting categorization into the appropriate cells, segment-by-segment. This worksheet is automatically linked to the other worksheets to obtain the estimated impacts of ramp metering at each corridor. Figure 7.1 illustrates a sample view of the categorization worksheet.

7.1.2 Extrapolation Factors

The expansion factors serve as the underlying assumptions for the systemwide extrapolation. These factors include:

- Crash rates (by severity) per 100 million vehicle miles of travel (VMT) from the 1998 Minnesota Motor Vehicles Crash Facts;
- Change in number of crashes during the study periods;
- Peak-hour-to-peak-period freeway volume expansion factor;
- Ramp-to-freeway volume factor; and
- Average vehicle occupancy (AVO).

Figure 7.1 Sample View of the Corridor Categorization Worksheet



Mn/DOT Ramp Metering Study

Categorization of Metered Corridors

Cambridge Systematics, Inc.

		% Attributable to Category				Study
Corridor	**Between**	**Type A**	**Type B**	**Type C**	**Type D**	**Corridor**
						Yes/No
I-35E	I-35 Junction and TH77		60%		40%	No
I-35E	TH77 and I-494		60%		40%	No
I-35E	I-494 and Downtown St. Paul			10%	90%	No
I-35E	Downtown St. Paul and I-694				100%	Yes
I-35W	I-35 Junction and I-494		100%			Yes
I-35W	I-494 and Downtown Minneapolis			30%	70%	No
I-35W	Downtown Minneapolis and I-694			10%	90%	No
I-35W	I-694 and Lexington		80%		20%	No
I-94	Century Avenue and Downtown St. Paul		10%	10%	80%	No
I-94	Downtown St. Paul and Downtown Minneapolis			100%		Yes
I-94	Downtown Minneapolis and I-694			30%	70%	No
I-94 (I-694)	I-694 Junction and CR30	100%				No
I-394	Downtown Minneapolis and TH100			60%	40%	No
I-394	TH100 and TH169			30%	70%	No
I-394	TH169 and I-494			10%	90%	No
I-494	Mississippi River and TH54	90%		10%		No
I-494	TH5 and TH169	25%		75%		No
I-494	TH169 and I-394	80%		20%		No
I-494	I-394 and I-94 Junction	100%				Yes
I-694	I-35W and I-94 Junction	100%				No
TH10	University and Round Lake (Anoka Co.)		80%		20%	No
TH36	I-35E and I-35W	10%		20%	70%	No

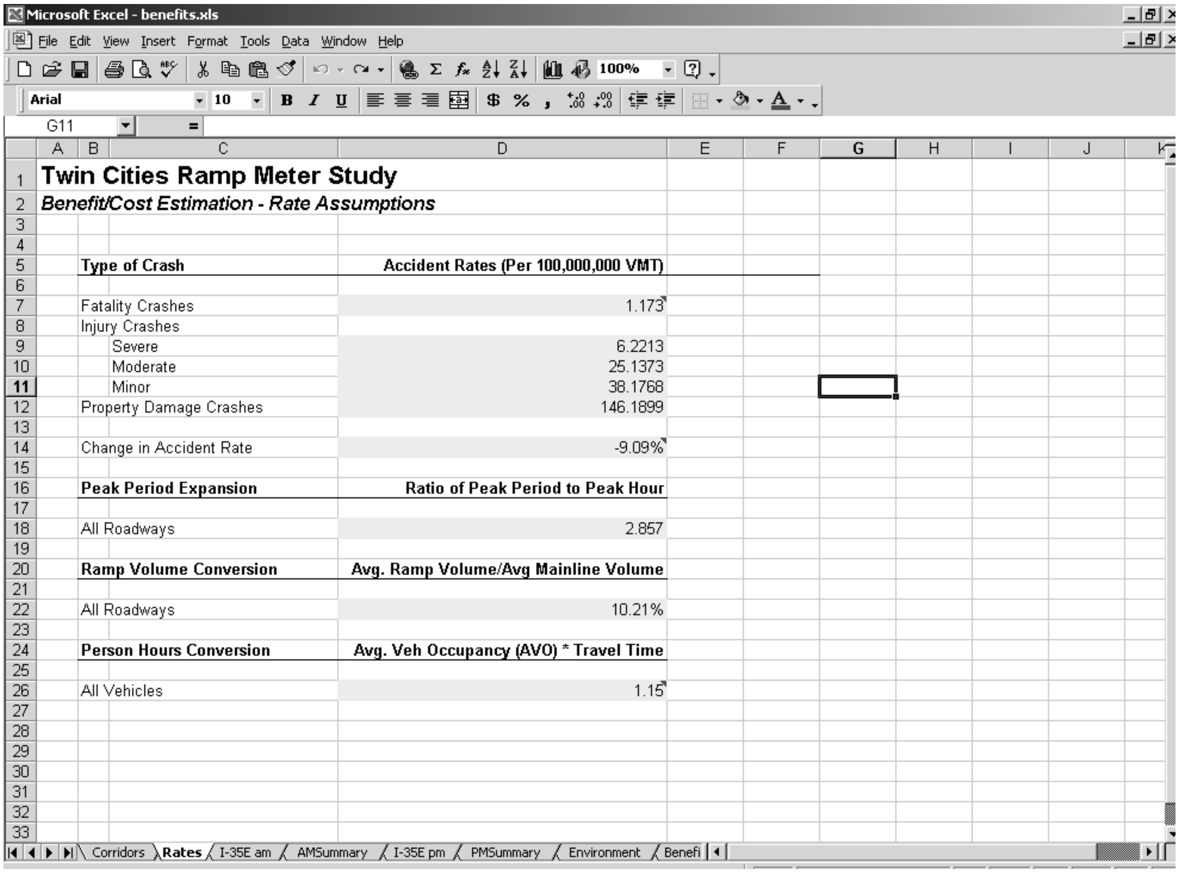
Use of the Spreadsheet Tool

In a Microsoft Excel™ spreadsheet, the user enters the desired extrapolation factors for crash rates, reduction in crashes during the study periods, peak-period mainline volume, and peak-period ramp volume conversion factors. This worksheet is automatically linked to the extrapolation worksheets to obtain the estimated impacts of ramp metering at each corridor. Figure 7.2 illustrates a sample view of the extrapolation factor worksheet.

7.1.3 Extrapolation Worksheets

With the corridor categories and the extrapolation factors in place, now the extrapolation process may begin. The extrapolation can be applied for each segment of a corridor, so as to obtain more discrete impacts of the ramp metering system. For each segment, the following inputs are needed:

Figure 7.2 Sample View of the Extrapolation Factor Worksheet



Twin Cities Ramp Meter Study

Benefit/Cost Estimation - Rate Assumptions

Type of Crash	Accident Rates (Per 100,000,000 VMT)
Fatality Crashes	1.173
Injury Crashes	
Severe	6.2213
Moderate	25.1373
Minor	38.1768
Property Damage Crashes	146.1899
Change in Accident Rate	-9.09%

Peak Period Expansion	Ratio of Peak Period to Peak Hour
All Roadways	2.857

Ramp Volume Conversion	Avg. Ramp Volume/Avg Mainline Volume
All Roadways	10.21%

Person Hours Conversion	Avg. Veh Occupancy (AVO) * Travel Time
All Vehicles	1.15

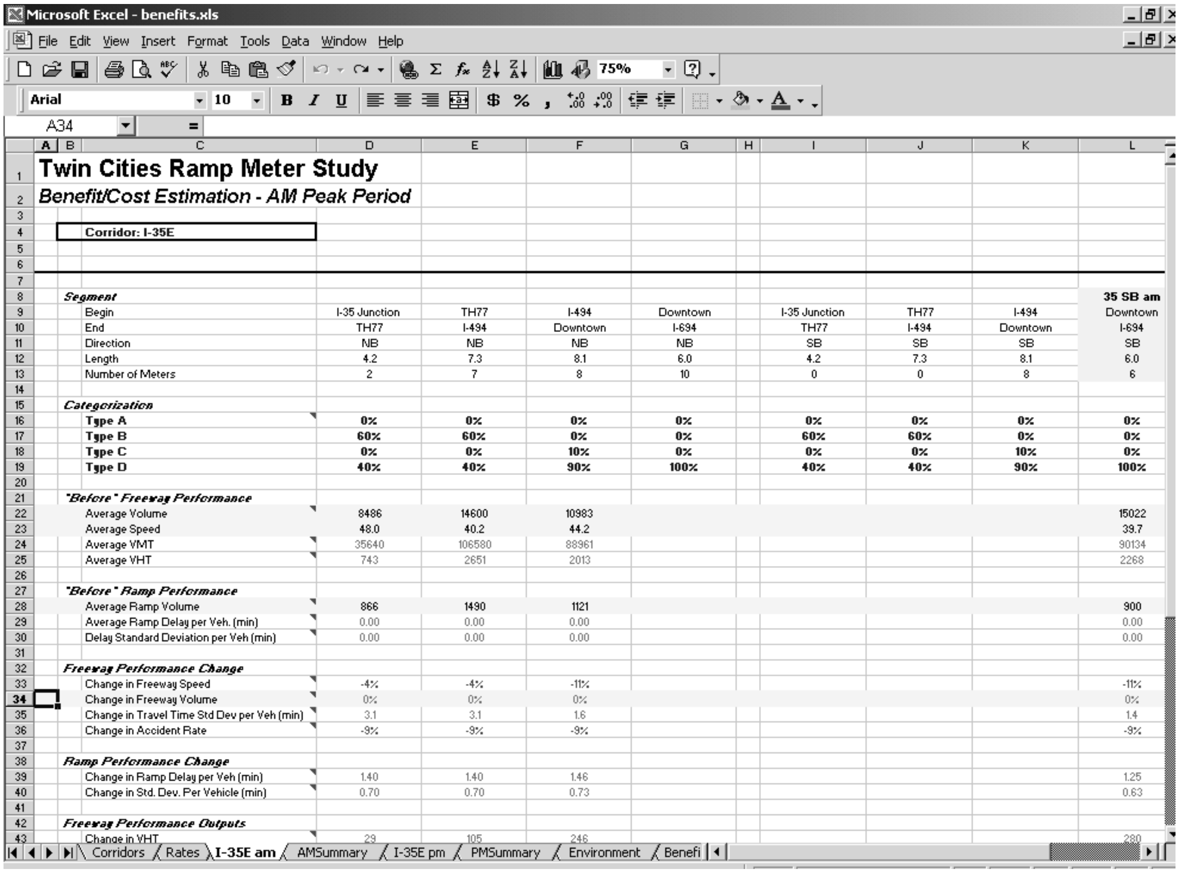
- Segment length;
- Number of ramp meters;
- Average peak-period freeway volume;
- Average peak-period freeway speed;
- Average peak-period ramp volume; and
- Estimated change in freeway volume (assumed to be zero).

The resulting output from this process includes changes in peak-period freeway speed, travel time, travel time reliability, volume, ramp delay, and segment-wide VMT and vehicle-hours of travel (VHT).

Use of the Spreadsheet Tool

A Microsoft Excel™ worksheet is needed for each corridor analyzed. Figure 7.3 shows a sample view of the extrapolation worksheet for corridor I-35E during the morning peak period. Within this worksheet, each segment is listed, along with its corridor categorization based on the categorization worksheet described in Section 7.1.1. *The analyst should enter the input only for segments with active metering in this particular time period.* For example, since the ramp meters on I-35E northbound between I-695 and downtown St. Paul are not active during the morning peak, no impacts estimation is needed for this segment.

Figure 7.3 Sample View of the Extrapolation Worksheet



Twin Cities Ramp Meter Study

Benefit/Cost Estimation - AM Peak Period

Corridor: I-35E

		D	E	F	G	H	I	J	K	L
8	***Segment***									**35 SB am**
9	Begin	I-35 Junction	TH77	I-494	Downtown		I-35 Junction	TH77	I-494	Downtown
10	End	TH77	I-494	Downtown	I-694		TH77	I-494	Downtown	I-694
11	Direction	NB	NB	NB	NB		SB	SB	SB	SB
12	Length	4.2	7.3	8.1	6.0		4.2	7.3	8.1	6.0
13	Number of Meters	2	7	8	10		0	0	8	6
15	***Categorization***									
16	**Type A**	**0%**	**0%**	**0%**	**0%**		**0%**	**0%**	**0%**	**0%**
17	**Type B**	**60%**	**60%**	**0%**	**0%**		**60%**	**60%**	**0%**	**0%**
18	**Type C**	**0%**	**0%**	**10%**	**0%**		**0%**	**0%**	**10%**	**0%**
19	**Type D**	**40%**	**40%**	**90%**	**100%**		**40%**	**40%**	**90%**	**100%**
21	***"Before" Freeway Performance***									
22	Average Volume	8486	14600	10983						15022
23	Average Speed	48.0	40.2	44.2						39.7
24	Average VMT	35640	106580	88961						90134
25	Average VHT	743	2651	2013						2268
27	***"Before" Ramp Performance***									
28	Average Ramp Volume	866	1490	1121						900
29	Average Ramp Delay per Veh. (min)	0.00	0.00	0.00						0.00
30	Delay Standard Deviation per Veh (min)	0.00	0.00	0.00						0.00
32	***Freeway Performance Change***									
33	Change in Freeway Speed	-4%	-4%	-11%						-11%
34	Change in Freeway Volume	0%	0%	0%						0%
35	Change in Travel Time Std Dev per Veh (min)	3.1	3.1	1.6						1.4
36	Change in Accident Rate	-9%	-9%	-9%						-9%
38	***Ramp Performance Change***									
39	Change in Ramp Delay per Veh (min)	1.40	1.40	1.46						1.25
40	Change in Std. Dev. Per Vehicle (min)	0.70	0.70	0.73						0.63
42	***Freeway Performance Outputs***									
43	Change in VHT	29	105	246						280

The user may enter the average peak-period freeway volumes into the appropriate cells; if the peak-period volumes are not known, peak-hour volumes may be used multiplied by the peak-hour-to-peak-period expansion factor contained in the extrapolation expansion factor worksheet (Section 7.1.2). Likewise, when the average peak-period ramp volumes are not known, users may utilize the peak-period freeway volumes multiplied by the ramp-to-freeway volume factor.

Based on these user inputs, as well as links to the field data summary, corridor categorization, and extrapolation factors worksheets, the impacts of ramp metering for this corridor will be automatically calculated. At the far right column, the sum of the changes in VHT, ramp delay, corridor travel time, and travel time reliability for this corridor will be displayed.

7.1.4 Extrapolation Summary Worksheet

The extrapolated systemwide changes in facility speed, vehicle travel time, travel time variability, and number of accidents are summed across all metered corridors, all segments, and all directions. The summaries are separated by periods of operation (a.m. and p.m. peak periods), and are used as a basis to estimate the monetary value of the benefits. Output measures from this worksheet include:

- Average VMT;
- Average VHT;
- Change in VHT;
- Change in variability (hours);
- Change in crashes (by severity);
- Change in ramp delay average (hours);
- Change in ramp delay standard deviation (hours);
- Change in total travel time average (hours); and
- Change in total travel time standard deviation (hours).

Use of the Spreadsheet Tool

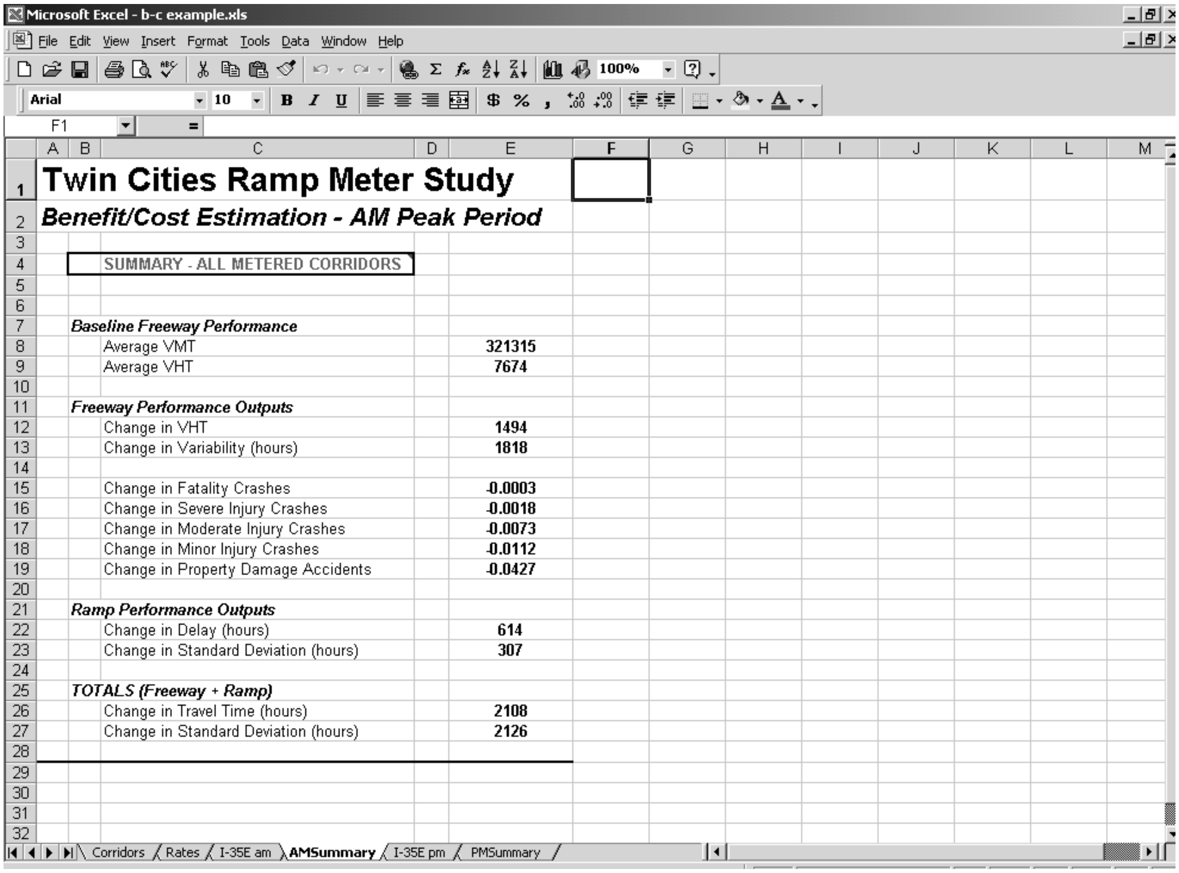
Using Microsoft Excel™, one summary worksheet for the a.m. peak and one worksheet for the p.m. peak are used to estimate the systemwide changes. No inputs are necessary for this worksheet, since all entries are automatically linked and calculated from previous worksheets. Figure 7.4 shows a view of the summary of ramp metering impacts during the a.m. peak.

■ 7.2 Environmental Impacts

The environmental impacts can be estimated using the average speed and total VMT for the entire Twin Cities region. In this analysis, the emission rates and fuel consumption rates were obtained from the U.S. Environmental Protection Agency's Mobile 5A model, taking into account the freeway average speeds.

The environmental impacts are calculated by simply multiplying the corridor segment VMT with the individual emissions and fuel consumption rates. This model predicts the amount of emissions/fuel based on different vehicle types, the amount of travel, and the speed of travel. It is assumed that the mix of vehicle types remains constant across study periods, therefore, only the amount and speed of travel varies. The appropriate rates for emissions (expressed in grams per vehicle mile traveled (VMT)) are obtained based on

Figure 7.4 Sample View of the Extrapolation Summary Worksheet



Twin Cities Ramp Meter Study

Benefit/Cost Estimation - AM Peak Period

SUMMARY - ALL METERED CORRIDORS

Baseline Freeway Performance	
Average VMT	**321315**
Average VHT	**7674**
Freeway Performance Outputs	
Change in VHT	**1494**
Change in Variability (hours)	**1818**
Change in Fatality Crashes	**-0.0003**
Change in Severe Injury Crashes	**-0.0018**
Change in Moderate Injury Crashes	**-0.0073**
Change in Minor Injury Crashes	**-0.0112**
Change in Property Damage Accidents	**-0.0427**
Ramp Performance Outputs	
Change in Delay (hours)	**614**
Change in Standard Deviation (hours)	**307**
TOTALS (Freeway + Ramp)	
Change in Travel Time (hours)	**2108**
Change in Standard Deviation (hours)	**2126**

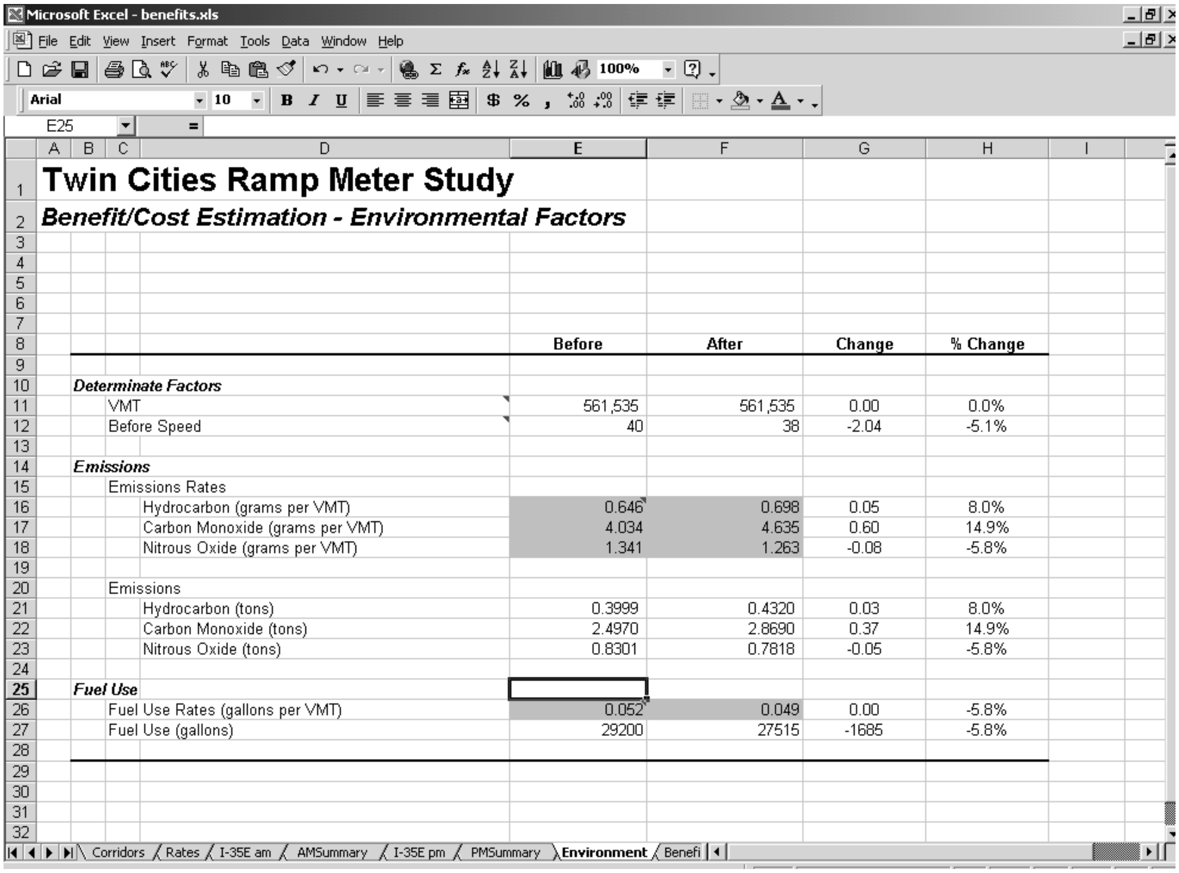
observed speeds from the Mobile 5A model. The emissions analyzed include Hydrocarbons (HC), Carbon Monoxide (CO), and Nitrous Oxides (NOx). The emissions rates are applied to the observed VMT for the appropriate analysis scenario, totals are converted into tons of emissions, and emissions monetary cost values are applied (as recommended by the Federal Highway Administration (FHWA)) to the incremental difference between the analysis scenario.

Fuel use was calculated similarly with FHWA fuel use rates being obtained for the observed speeds for the analysis scenarios. A monetary value of fuel cost per gallon is then applied to the incremental difference of estimated fuel consumption in the two analysis scenarios.

Use of the Spreadsheet Tool

In this Microsoft Excel™ spreadsheet, the default emission and fuel consumption rates have been entered. To change these, the user may enter any desired new rates, and the resulting environmental impacts will be automatically updated. Figure 7.5 illustrates a sample view of the environmental impacts worksheet.

Figure 7.5 Sample View of the Environmental Impacts Worksheet



Twin Cities Ramp Meter Study

Benefit/Cost Estimation - Environmental Factors

	Before	After	Change	% Change
Determinate Factors				
VMT	561,535	561,535	0.00	0.0%
Before Speed	40	38	-2.04	-5.1%
Emissions				
Emissions Rates				
Hydrocarbon (grams per VMT)	0.646	0.698	0.05	8.0%
Carbon Monoxide (grams per VMT)	4.034	4.635	0.60	14.9%
Nitrous Oxide (grams per VMT)	1.341	1.263	-0.08	-5.8%
Emissions				
Hydrocarbon (tons)	0.3999	0.4320	0.03	8.0%
Carbon Monoxide (tons)	2.4970	2.8690	0.37	14.9%
Nitrous Oxide (tons)	0.8301	0.7818	-0.05	-5.8%
Fuel Use				
Fuel Use Rates (gallons per VMT)	0.052	0.049	0.00	-5.8%
Fuel Use (gallons)	29200	27515	-1685	-5.8%

7.3 Estimation of Benefits and Costs

Once the impacts of ramp metering are extrapolated to the entire region, systemwide monetary benefits can be calculated.

7.3.1 Estimation of Benefits

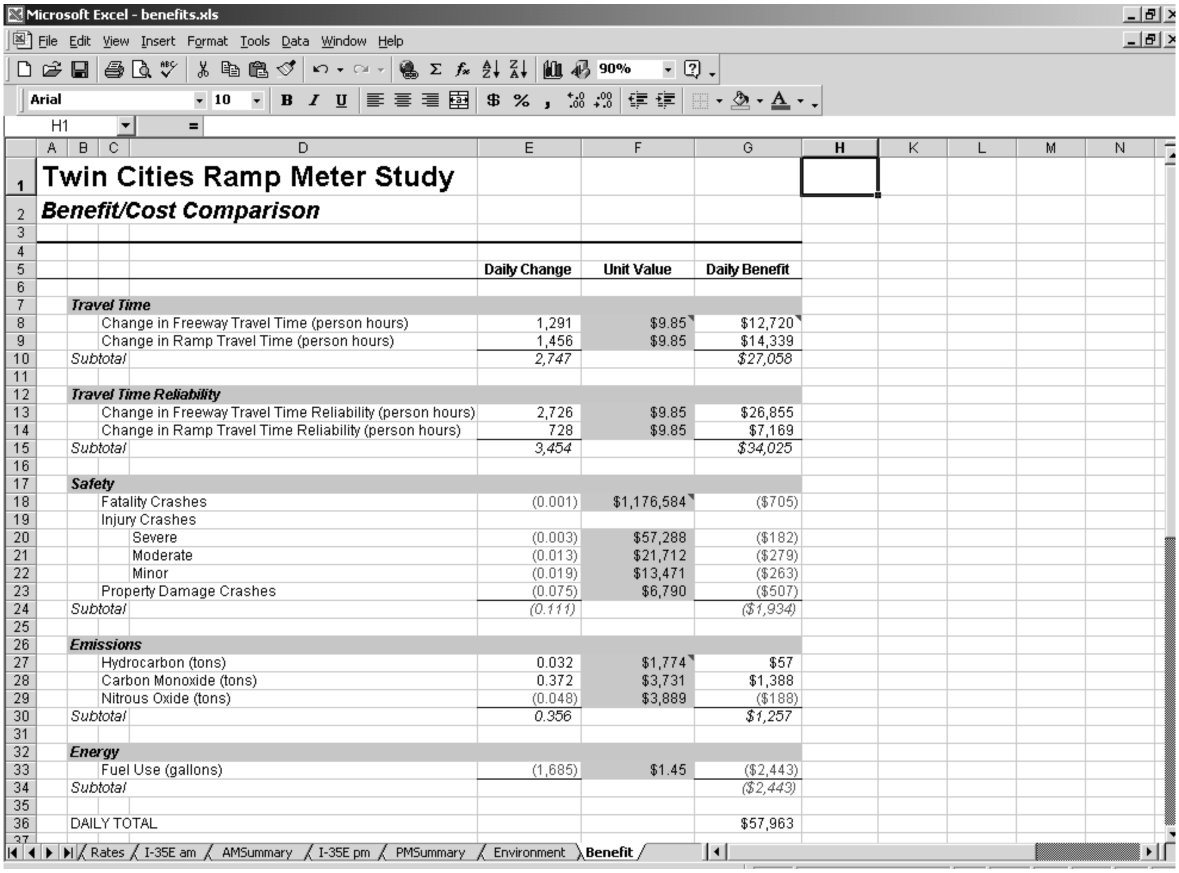
Established per unit dollar values are applied to the sum of the changes in performance measures. For example, the estimated change in Vehicle Hours Traveled (VHT) is multiplied with the Average Vehicle Occupancy (AVO) rate to estimate the change in person hours of travel. A value of travel time (assumed at $9.85 per hour) is applied to the change in person hours of travel to determine the incremental dollar value of the impact, regardless of the positive or negative nature of the impact.

The dollar values for each impact category are summed to estimate the average daily impact value for the entire ramp metering system. This figure is then multiplied by 247 days or the number of workdays 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. Crash and emission unit values were obtained from ITS Deployment Analysis System (IDAS) and the *1998 Minnesota Motor Vehicles Crash Facts.*

Use of the Spreadsheet Tool

In this Microsoft Excel™ spreadsheet, the default monetary values of time, crashes, and environmental impacts have been entered. To change these values, the user should simply enter any new desired values and the resulting benefits will be automatically updated. Figure 7.6 shows a sample view of the benefit estimation worksheet.

Figure 7.6 Sample View of the Benefit Estimation Worksheet



Twin Cities Ramp Meter Study

Benefit/Cost Comparison

	Daily Change	Unit Value	Daily Benefit
Travel Time			
Change in Freeway Travel Time (person hours)	1,291	$9.85	$12,720
Change in Ramp Travel Time (person hours)	1,456	$9.85	$14,339
Subtotal	*2,747*		*$27,058*
Travel Time Reliability			
Change in Freeway Travel Time Reliability (person hours)	2,726	$9.85	$26,855
Change in Ramp Travel Time Reliability (person hours)	728	$9.85	$7,169
Subtotal	*3,454*		*$34,025*
Safety			
Fatality Crashes	(0.001)	$1,176,584	($705)
Injury Crashes			
Severe	(0.003)	$57,288	($182)
Moderate	(0.013)	$21,712	($279)
Minor	(0.019)	$13,471	($263)
Property Damage Crashes	(0.075)	$6,790	($507)
Subtotal	*(0.111)*		*($1,934)*
Emissions			
Hydrocarbon (tons)	0.032	$1,774	$57
Carbon Monoxide (tons)	0.372	$3,731	$1,388
Nitrous Oxide (tons)	(0.048)	$3,889	($188)
Subtotal	*0.356*		*$1,257*
Energy			
Fuel Use (gallons)	(1,685)	$1.45	($2,443)
Subtotal			*($2,443)*
DAILY TOTAL			$57,963

7.3.2 Estimation of Costs

In order to provide a meaningful comparison of ramp metering costs and benefits, an annual estimate of system-related costs is required. This snapshot estimate of current system costs was calculated by analyzing deployment cost information for Mn/DOT's various subsystems related to congestion management. Historical expenditures, as well as recent "per unit" contract bid costs, are used to construct the capital equipment cost of the system. The annual capital costs are estimated by dividing the total equipment deployment costs by the useful life of the equipment.

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, and administrative and managerial personnel are based on 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, are also included in the cost estimate. These ongoing operation and maintenance costs are added with the annual capital costs to estimate the denominator for the benefit/cost comparison.

8.0 Planning for Future Ramp Meter Deployments

8.0 Planning for Future Ramp Meter Deployments

Potential ramp metering strategies can be tested and screened using various analysis and traffic simulation packages. This section presents planning and micro-simulation tools that can be used in the context of a ramp metering deployment plan.

8.1 ITS Deployment Analysis System (IDAS)

IDAS is a sketch-planning analysis tool that can be used to estimate the impacts, benefits, and costs resulting from the deployment of ITS components and strategies, including ramp metering. IDAS operates as a post-processor to travel demand models and is used by metropolitan planning organizations (MPOs) and other agencies for transportation planning purposes.

The set of impacts evaluated by IDAS include changes in user mobility, travel time/speed, travel time reliability, fuel costs, operating costs, accident costs, emissions, and noise associated with the full spectrum of ITS components and strategies from ramp metering to traveler information systems. IDAS also provides benefit/cost comparisons of various ITS improvements individually or in combination.

Table 8.1 lists the different ITS components that can be analyzed in IDAS. Ramp metering analysis may be conducted in IDAS, requiring identification of metered ramps and affected freeway links, as well as input of ramp metering parameters. Then IDAS can be used to answer the following metering deployment questions:

- What types of impacts/benefits result from the deployment of different types of ramp metering?
- Which ramp metering deployment provides the greatest benefits for the region?
- On which facilities does the deployment of metering provide the greatest level of benefits?
- At which geographic locations does the deployment of metering provide the greatest level of benefits?
- What is the impact of combining different types of ITS components?

Table 8.1 ITS Components in IDAS

Arterial Traffic Management Systems

- Isolated Traffic Actuated Signals
- Preset Corridor Signal Coordination
- Actuated Corridor Signal Coordination
- Central Control Signal Coordination
- Emergency Vehicle Signal Priority
- Transit Vehicle Signal Priority

Freeway Management Systems

- Pre-set Ramp Metering
- Traffic Actuated Ramp Metering
- Centrally Controlled Ramp Metering

Advanced Public Transit Systems

- Fixed Route Transit – Automated Scheduling System
- Fixed Route Transit – Automatic Vehicle Location
- Fixed Route Transit – Combination Automated Scheduling System and Automatic Vehicle Location
- Fixed Route Transit – Security Systems
- Paratransit – Automated Scheduling System
- Paratransit – Automatic Vehicle Location
- Paratransit – Automated Scheduling System and Automatic Vehicle Location

Incident Management Systems

- Incident Detection/Verification
- Incident Response/Management
- Incident Detection/Verification/Response/ Management combined

Electronic Payment Systems

- Electronic Transit Fare Payment
- Basic Electronic Toll Collection

Railroad Grade Crossing Monitors

Emergency Management Services

- Emergency Vehicle Control Service
- Emergency Vehicle AVL
- In-Vehicle Mayday System

Regional Multimodal Traveler Information Systems

- Highway Advisory Radio
- Freeway Dynamic Message Sign
- Transit Dynamic Message Sign

Regional Multimodal Traveler Information Systems (continued)

- Telephone-Based Traveler Information System
- Web/Internet-Based Traveler Information System
- Kiosk with Multimodal Traveler Information
- Kiosk with Transit-only Traveler Information
- Handheld Personal Device – Traveler Information Only
- Handheld Personal Device – Traveler Information with Route Guidance
- In-Vehicle – Traveler Information Only
- In-Vehicle – Traveler Information with Route Guidance

Commercial Vehicle Operations

- Electronic Screening
- Weigh-in-Motion
- Electronic Clearance – Credentials
- Electronic Clearance – Safety Inspection
- Electronic Screening/Clearance combined
- Safety Information Exchange
- On-board Safety Monitoring
- Electronic Roadside Safety Inspection
- Hazardous Materials Incident Response

Advanced Vehicle Control and Safety Systems

- Motorist Warning – Ramp Rollover
- Motorist Warning – Downhill Speed
- Longitudinal Collision Avoidance
- Lateral Collision Avoidance
- Intersection Collision Avoidance
- Vision Enhancement for Crashes
- Safety Readiness

Supporting Deployments

- Traffic Management Center
- Transit Management Center
- Emergency Management Center
- Traffic Surveillance – CCTV
- Traffic Surveillance – Loop Detector System
- Traffic Surveillance – Probe System
- Basic Vehicle Communication
- Roadway Loop Detector
- Information Service Provider Center

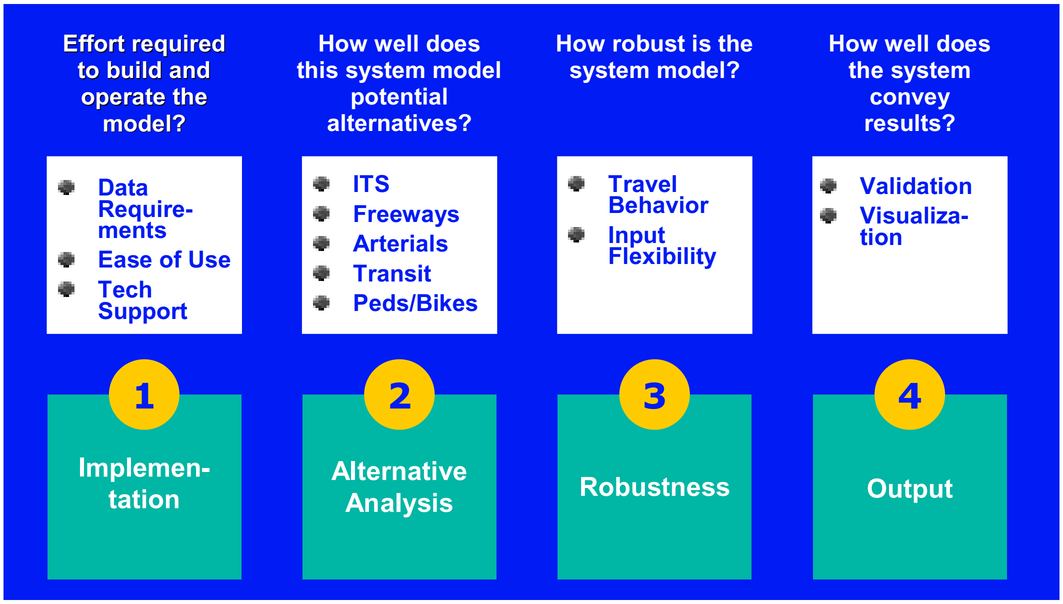
Generic Deployments

- Link-based
- Zone-based

8.2 Traffic Simulation Tools

IDAS is not intended to be used as a design tool to evaluate infrastructure modifications or to optimize ramp meter operations. A traffic simulation model is more appropriate for obtaining more detailed analysis of the planned metering deployment. In this section, three traffic simulation tools are being evaluated for ramp metering analysis, including Paramics, VISSIM, and CORSIM. Figure 8.1 presents the criteria used in evaluating these tools. The following sections present brief overviews of each traffic simulation tool, which are also summarized in Table 8.2.

Figure 8.1 Simulation Tool Evaluation Criteria



8.2.1 Paramics

Paramics is a suite of simulation tools designed to model the movement and behavior of individual vehicles on urban and highway road networks. It consists of Paramics Modeler, Paramics Processor, and Paramics Analyzer; each designed to build, run, and view the networks, respectively. Figure 8.2 illustrates a sample view of Paramics.

Paramics has a smaller program size, is easier to use, and provides for an advanced ability to model driver behavior and individual vehicles. To work properly, networks must be built in detail, which requires more input data and manpower effort than the other simulation tools. However, Paramics has an established customer support group and a well-maintained official web site to attend to customer inquiries.

Table 8.2 Simulation Tool Comparison

Category	Task	Paramics	VISSIM	CORSIM
Data requirements	Import capabilities	Poor	Poor	Average
	Network geometry	Extensive	Average	Minimal
	Trip distribution	Good	Average	Good
	Transit	Poor	Average	Poor
	Parking	Poor	Average	Good
	Driver behavior	Good	Average	Poor
Ease of use	User interface	Good	Average	Good
	Stability	Average	Average	Average
	Customer support	Average	Average	Average
	Cost	High	High	Low
ITS modeling capabilities	Transit signal priority	Good	Good	Poor
	Ramp metering	Good	Average	Average
	Variable message signs	Good	Average	Poor
	Traffic signal coordination	Average	Good	Good
	Interchanges	Good	Average	Average
	Loop detectors	Good	Good	Average
	Incident management	Good	Poor	Poor
	Electronic toll collection	Average	Poor	Poor
	In-vehicle messaging	Good	Good	Poor
Transit modeling capabilities	Bus transit	Average	Good	Poor
	Bus lanes	Average	Good	Poor
Traveler response modeling capabilities	Route diversion and traffic assignment	Good	Average	N/A
	Mode shift	Poor	Average	N/A
	Temporal diversion	Poor	Poor	N/A
	Induced demand	Poor	Poor	N/A
	Queues	Good	Good	Good
	Travel times	Good	Good	Good
Input flexibility	Vehicle types	Good	Good	Good
	Driver type settings	Good	Average	Poor
	Pedestrian/cyclist	Poor	Good	Poor
	Travel lanes modeled	Good	Good	Average
Validation	VMT, VHT	Good	Good	N/A
	Link volumes	Good	Good	Good
	Turn volumes	Good	Good	Good
	Link speeds	Good	Good	Good
	Trip tracking	Good	Average	N/A
Visualization	Scale	Good	Average	Poor
	Realism of animation	Good	Good	Good
	Image quality	Good	Good	Good
	Perspective	Good	Good	Average
	Travel modes	Poor	Good	Poor
	Simultaneous simulation	Good	Poor	N/A

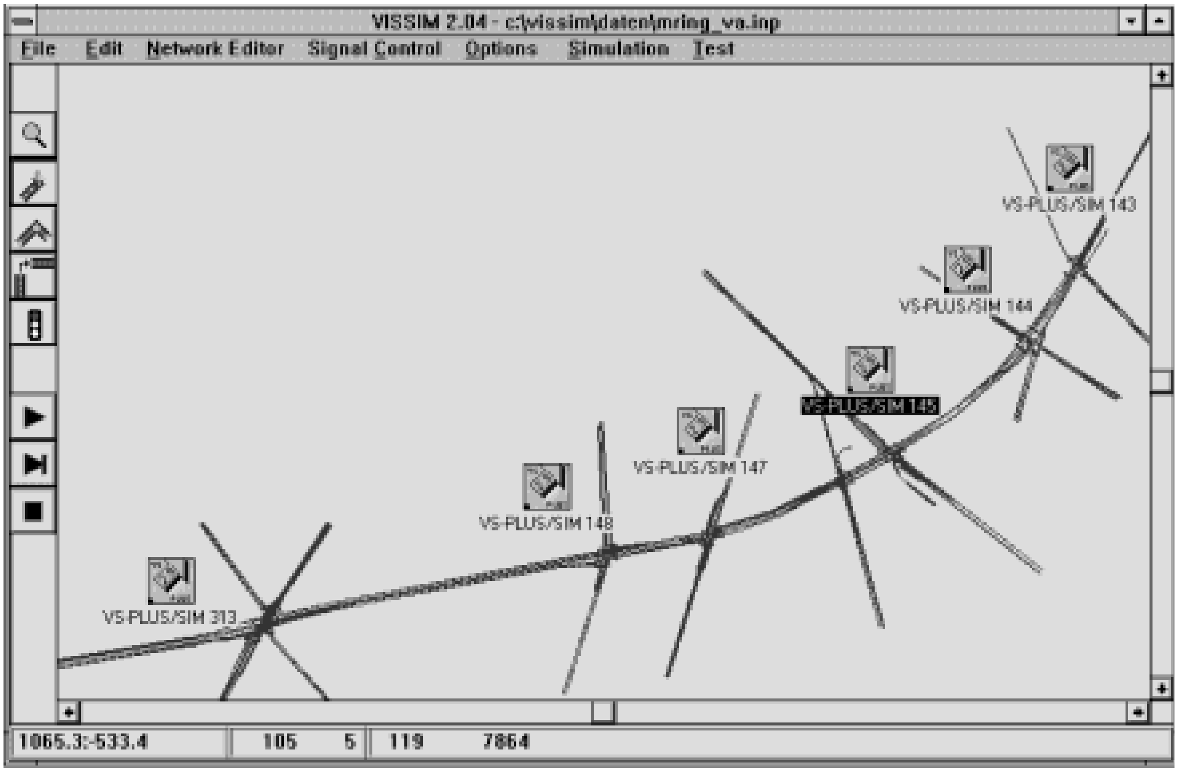
Figure 8.2 Sample View of Paramics

Paramics can simulate route diversion between freeways and arterials with relative ease – an important component in ramp metering evaluations to estimate traffic diversion on parallel arterials due to ramp delays. It can also effectively simulate fixed-time ramp metering operations, but a separate "programmer's license" and a custom plug-in software must be developed to be able to simulate more advanced ramp metering strategies. It also features 3-D views and car tracking modes for presentation purposes.

8.2.2 VISSIM

VISSIM is another established simulation tool that may be used to evaluate ramp metering operations. Originally built to evaluate alternative transportation operations, such as transit, bicycles, and pedestrians, VISSIM may not be as robust in modeling freeway operations. Trip distributions are done through turn tables as opposed to zone-to-zone volumes, and network construction is simpler than Paramics. Figure 8.3 shows a sample view of VISSIM.

Figure 8.3 Sample View of VISSIM



VISSIM is a simpler tool, which makes it easier to learn, and requires less input. It is relatively easy to use with many project examples to draw upon for guidance. Unfortunately, few ITS components can be directly modeled in VISSIM. VISSIM also does a good job handling the input and producing a variety of simulation output in multiple formats, and its visualization tools are good.

8.2.3 CORSIM

CORSIM was developed by the FHWA to simulate freeway and highway networks. This tool is very robust when used to evaluate intersections and general freeway operations, but it does not simulate ITS components well. In its recent assessment, the FHWA has decided to depart the role of model developer in the commercial market, and instead pursue a greater role in facilitating the private markets, making the future status of CORSIM's technical support questionable. In sum, CORSIM may not be the best tool available for simulating ramp meter operations. While clearly more widely used as a simulation tool, the unique nature of the ramp metering planning process requires a more robust tool than CORSIM.