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				Study
Corridor/Between	**Type A**	**Type B**	**Type C**	**Type D**	**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)

Corridor/Between	% Attributable to Category Type A	Type B	Type C	Type D	Study 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

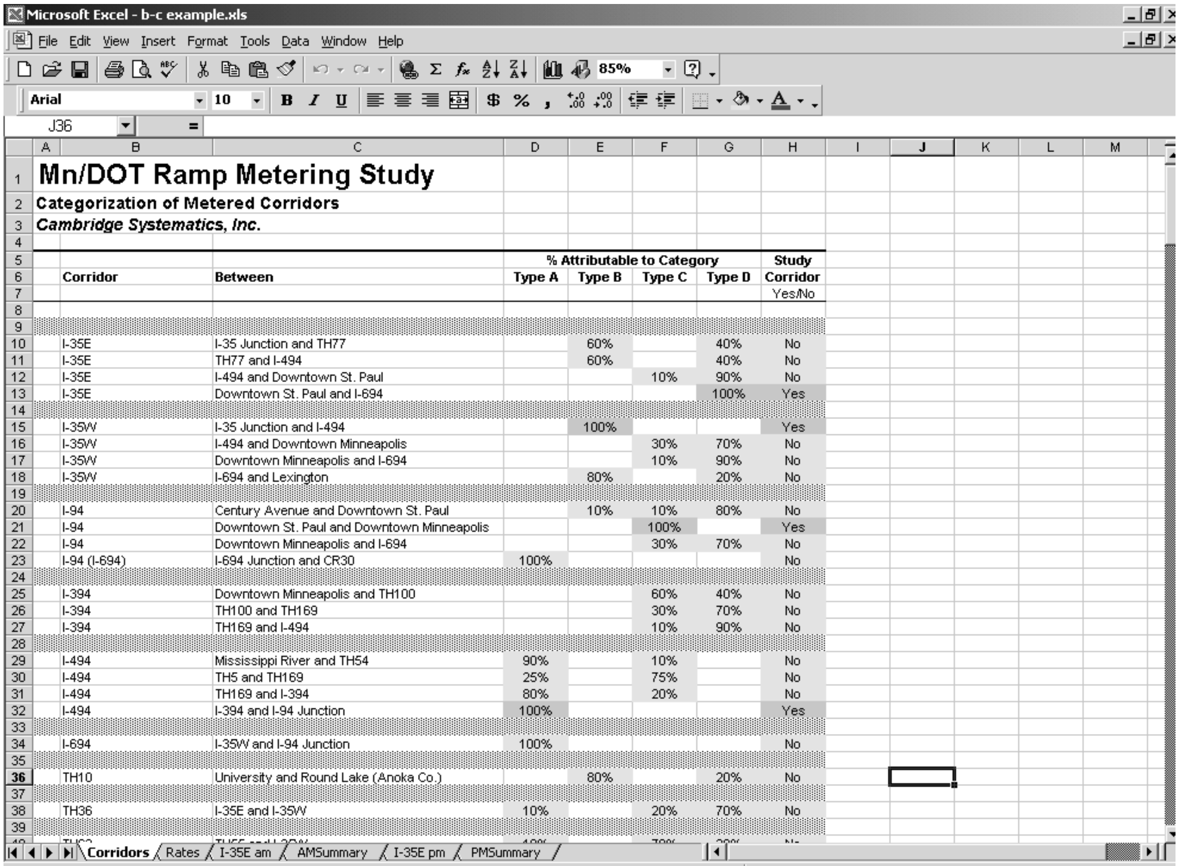
Using a Microsoft Excel™ spreadsheet, the analyst may enter the resulting categorization into the appropriate cells, segment-by-segment. This worksheet is automatically linked to the other worksheets to obtain the estimated impacts of ramp metering at each corridor. Figure 7.1 illustrates a sample view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

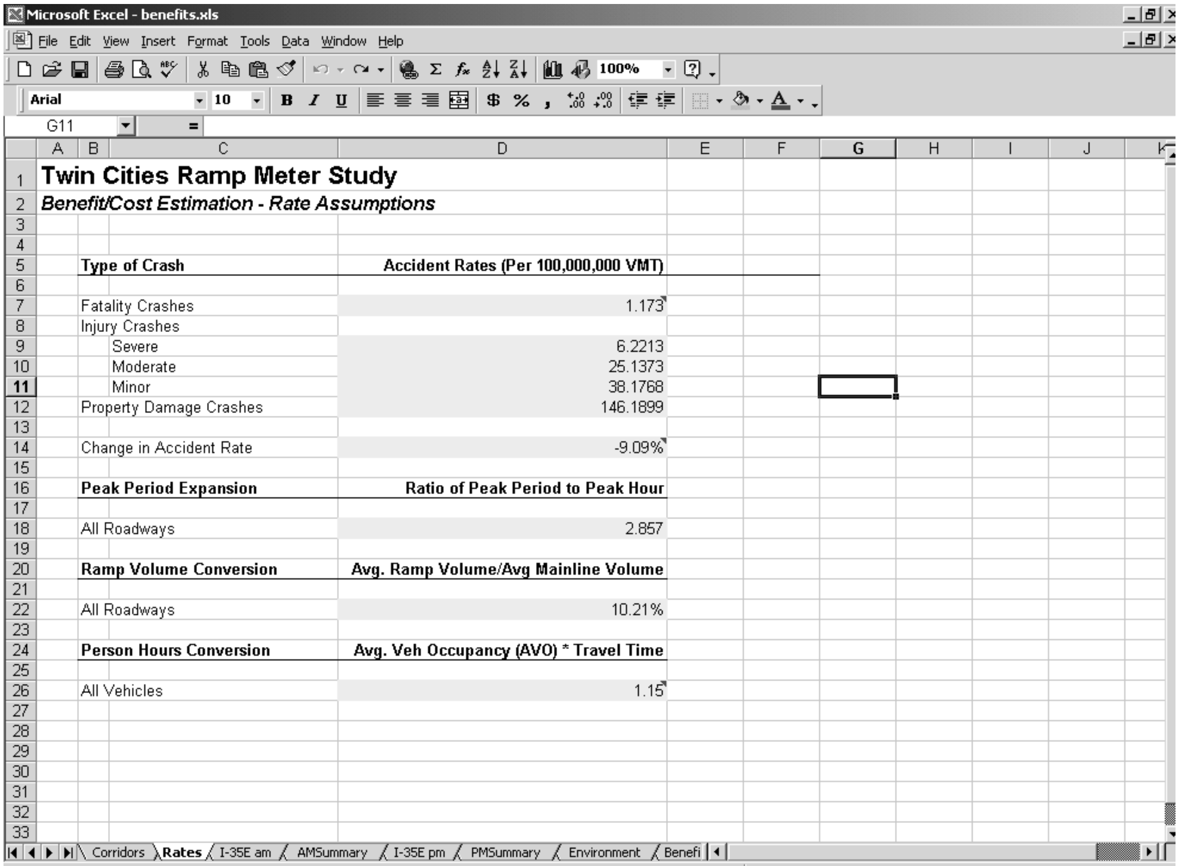
Use of the Spreadsheet Tool

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

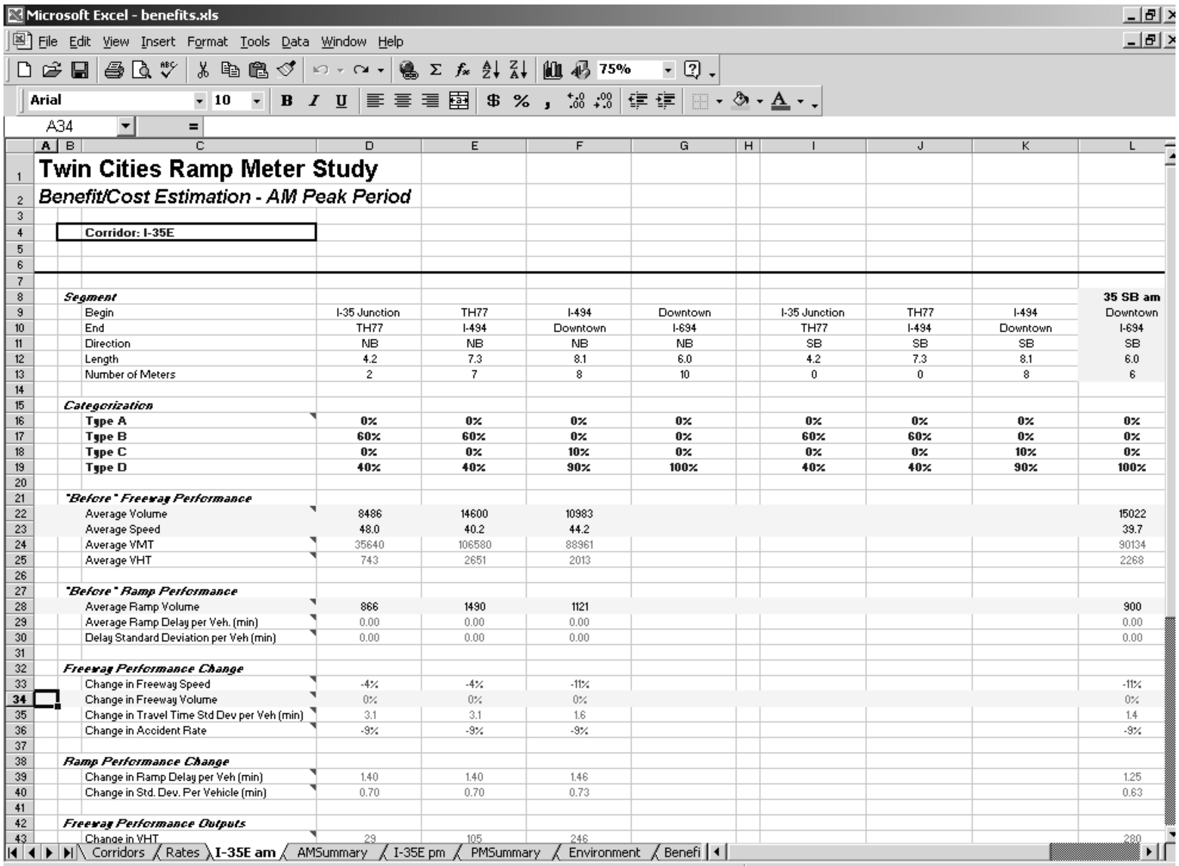
- Segment length;
- Number of ramp meters;
- Average peak-period freeway volume;
- Average peak-period freeway speed;
- Average peak-period ramp volume; and
- Estimated change in freeway volume (assumed to be zero).

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	I	J	K	L
Segment								**35 SB am**
Begin	I-35 Junction	TH77	I-494	Downtown	I-35 Junction	TH77	I-494	Downtown
End	TH77	I-494	Downtown	I-694	TH77	I-494	Downtown	I-694
Direction	NB	NB	NB	NB	SB	SB	SB	SB
Length	4.2	7.3	8.1	6.0	4.2	7.3	8.1	6.0
Number of Meters	2	7	8	10	0	0	8	6
Categorization								
Type A	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**
Type B	**60%**	**60%**	**0%**	**0%**	**60%**	**60%**	**0%**	**0%**
Type C	**0%**	**0%**	**10%**	**0%**	**0%**	**0%**	**10%**	**0%**
Type D	**40%**	**40%**	**90%**	**100%**	**40%**	**40%**	**90%**	**100%**
"Before" Freeway Performance								
Average Volume	8486	14600	10983					15022
Average Speed	48.0	40.2	44.2					39.7
Average VMT	35640	106580	88961					90134
Average VHT	743	2651	2013					2268
"Before" Ramp Performance								
Average Ramp Volume	866	1490	1121					900
Average Ramp Delay per Veh. (min)	0.00	0.00	0.00					0.00
Delay Standard Deviation per Veh (min)	0.00	0.00	0.00					0.00
Freeway Performance Change								
Change in Freeway Speed	-4%	-4%	-11%					-11%
Change in Freeway Volume	0%	0%	0%					0%
Change in Travel Time Std Dev per Veh (min)	3.1	3.1	1.6					1.4
Change in Accident Rate	-9%	-9%	-9%					-9%
Ramp Performance Change								
Change in Ramp Delay per Veh (min)	1.40	1.40	1.46					1.25
Change in Std. Dev. Per Vehicle (min)	0.70	0.70	0.73					0.63
Freeway Performance Outputs								
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

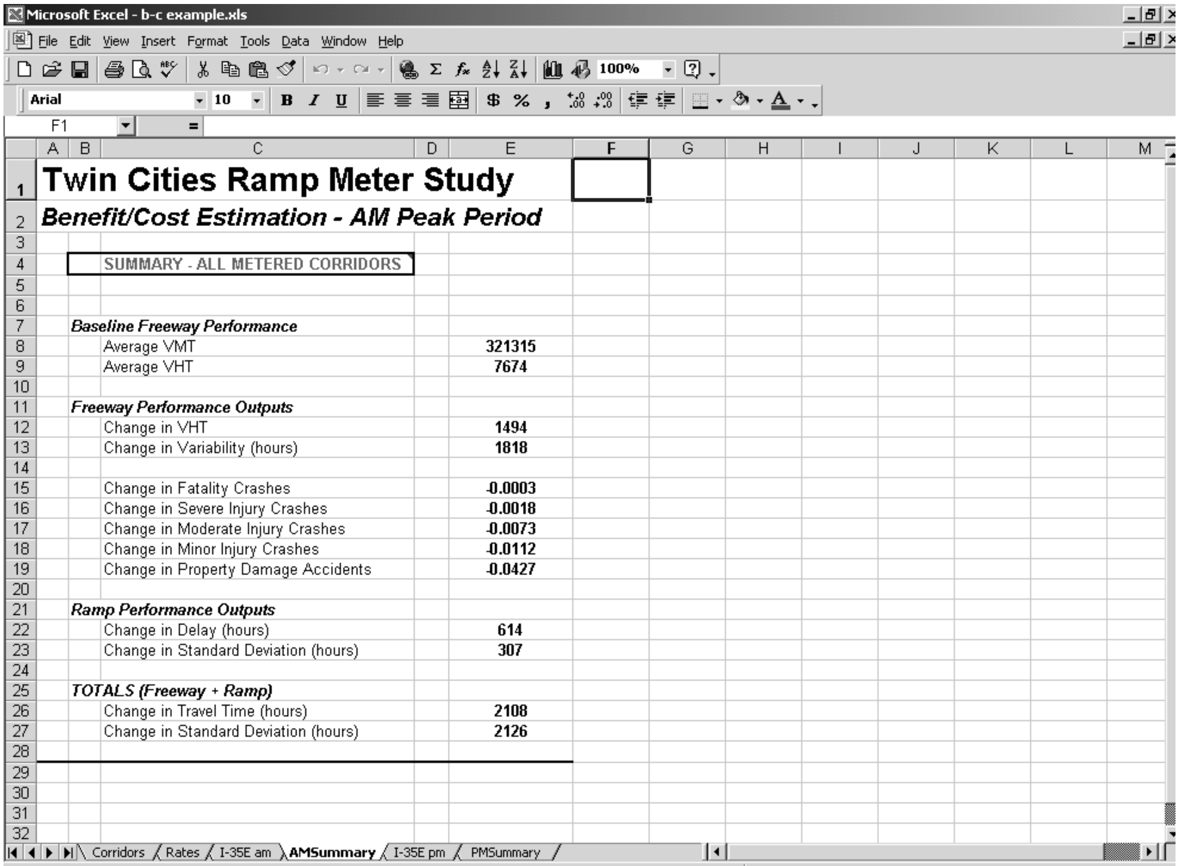
Using Microsoft Excel™, one summary worksheet for the a.m. peak and one worksheet for the p.m. peak are used to estimate the systemwide changes. No inputs are necessary for this worksheet, since all entries are automatically linked and calculated from previous worksheets. Figure 7.4 shows a view of the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



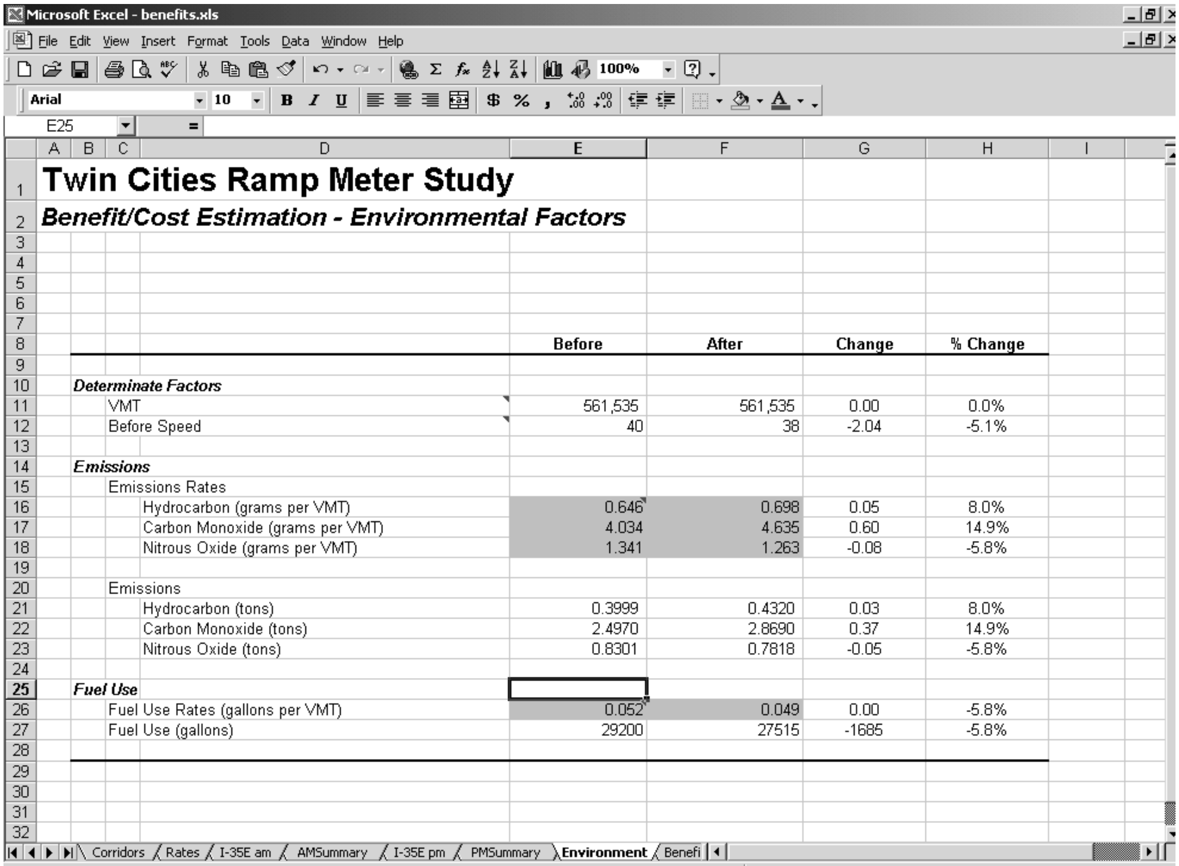
observed speeds from the Mobile 5A model. The emissions analyzed include Hydrocarbons (HC), Carbon Monoxide (CO), and Nitrous Oxides (NOx). The emissions rates are applied to the observed VMT for the appropriate analysis scenario, totals are converted into tons of emissions, and emissions monetary cost 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

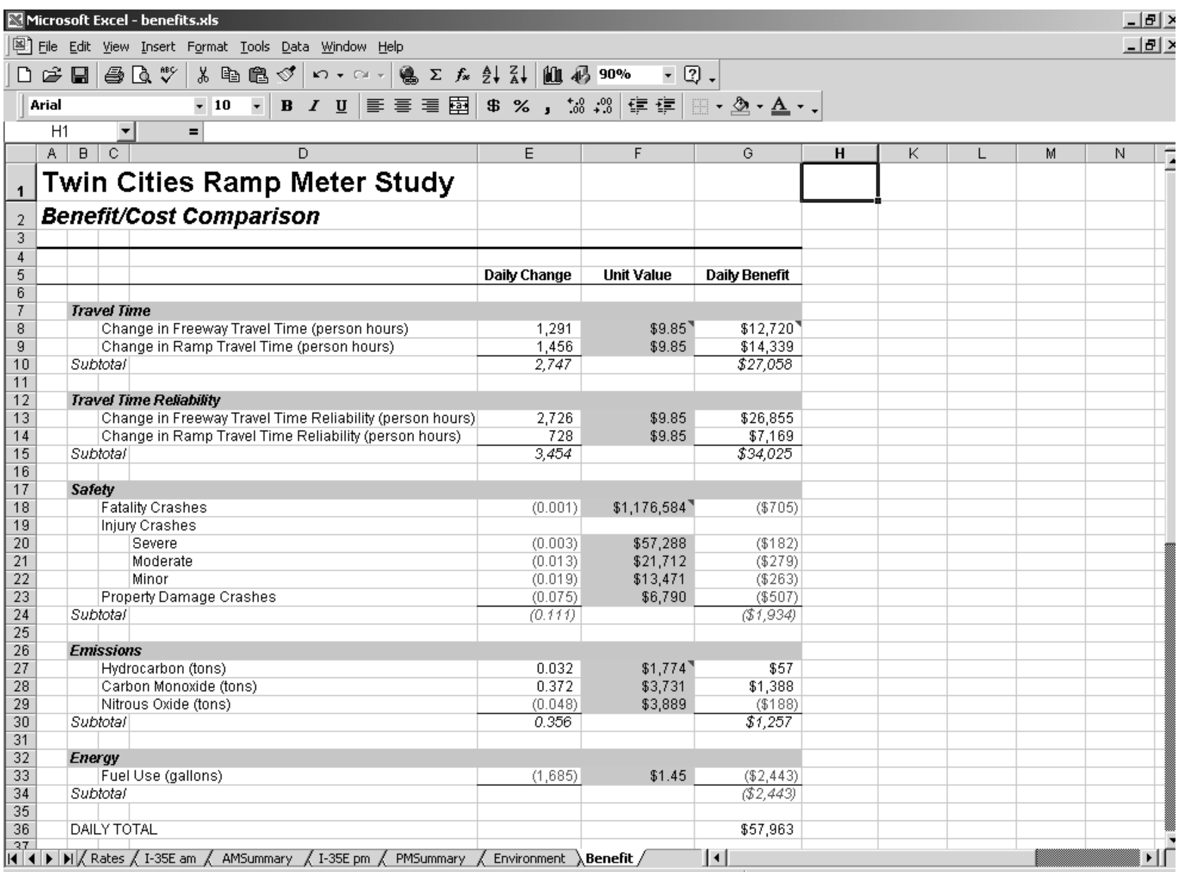
Established per unit dollar values are applied to the sum of the changes in performance measures. For example, the estimated change in Vehicle Hours Traveled (VHT) is multiplied with the Average Vehicle Occupancy (AVO) rate to estimate the change in person hours of travel. A value of travel time (assumed 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.