8.0 Secondary Research

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

■ 8.1 Basics of Ramp Metering

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

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

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

Disadvantages of ramp metering may include:

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

8.2 Use of Ramp Metering Across the Country

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

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

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

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

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

Ramp Metering Goals and Strategies

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

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

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

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

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

8.3 Keys to a Successful Ramp Metering Program

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

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

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

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

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

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

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

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

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

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

8.4 Peer City Interviews

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

8.4.1 Seattle, Washington

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

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

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

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

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

8.4.2 Phoenix (AZ)

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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