Evaluation of Ramp Meter Effectiveness for Wisconsin Freeways, A Milwaukee Case Study: Part 2, Ramp Metering Effect on Traffic Operations and Crashes

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Final Report

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16. Abstract

The purpose of the research is to determine the benefits of ramp meters in the Milwaukee area freeway system, to determine underlying relationships that permit evaluation of new ramp meters or ramp meter systems elsewhere, and to develop a coherent framework for performing evaluation of ramp meter effectiveness on a whole system. Part 2 concentrates on the traffic operations effect six new ramp meters had on the 14-mile long corridor where six ramp meters were already operational. A crash rate comparison was performed between the periods the corridor operated without and with the six new ramp meters. Metered on-ramp queue length and delay information is presented in Appendix A; details of the operation of a metered on-ramp as well as mainline speed occupancy and volume information in the vicinity of the ramp are presented in Appendix B.

Average corridor speeds improved when the new ramp meters were operational. Vehicle-hours of travel were lower during the more congested afternoon peak period. It is suggested that fine-tuning of ramp metering parameters is very likely to result in additional benefits for the corridor.

Crash rates during ramp metering hours were lower by 13% with the new ramp meters operational.

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Chapter 5
Ramp Metering Effect on Traffic Operations and Crashes

Introduction

The objective of the present chapter is to evaluate the incremental traffic operations impact of newly introduced ramp metering on six ramps in the southbound direction of USH 45. The evaluated corridor extended from the Waukesha – Washington County line on the North to just South of the Greenfield Avenue (a length of 14 miles). Ramp metering was already present on six ramps; four of these ramps were located at the south end of the corridor, which carried the heaviest traffic volumes.

The chapter addresses ramp and mainline freeway traffic operations Measures of Effectiveness (MOE) separately; overall MOE are also provided.

Analysis Corridor

The analysis corridor consisted of the southbound U.S. 45 direction, starting at the Washington/Waukesha County line on the North, crossing into Milwaukee County and extending through the interchange with I-94 (Zoo interchange) and continuing on to I-894 (the extension of U.S. 45) to a point just South of the Greenfield Avenue on-ramp (**Figure 5-1**).

Ramp metering was operational on six on-ramps along the analysis corridor when the study was initiated. Six additional on-ramps began to be metered as part of the WisDOT ramp metering program (see **Figure 5-1**). It was desired to evaluate the impact that these additional ramp meters would have on traffic operations in the analysis corridor.

Analysis Methodology

A "Without" and "With" new ramp meters comparison evaluation was chosen as an appropriate way to measure the impact of the newly installed ramp meters on freeway operations. The "Without" period represented freeway conditions when only the six existing ramp meters were operational. The "With" period represented freeway conditions when the additional six ramp meters were also operational.[1]

Detailed information on ramp delay and queue length patterns during the evaluation period is provided in **Appendix A**. Ramp metering settings and details of the ramp meter operation during the afternoon peak period of February 9 of 2000 are presented in **Appendix B** for Wisconsin Avenue, one of the most congested parts of the analyzed corridor. This information allows a detailed insight into metered ramp queue patterns and the effect of the chosen ramp metering

[1] The Main Street ramp meter was installed but not turned on during the evaluation period, thus only six new ramp meters were operating during the "With" period.

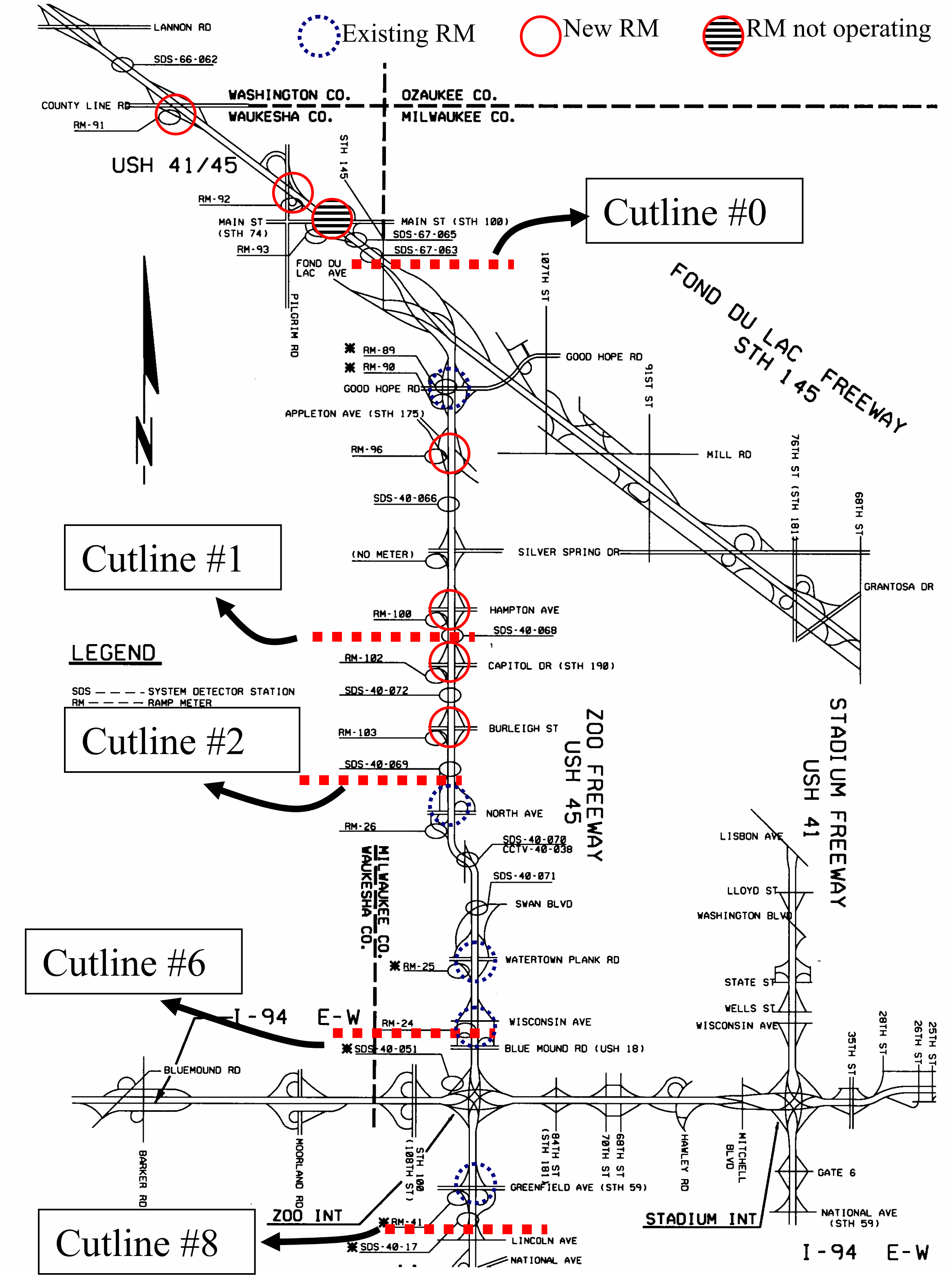

Figure 5-1. Cutlines Used for Traffic Operations MOE Evaluation & Ramp Meter Locations

parameters on metered ramp operation. Information on mainline traffic operations parameters at the same location is also presented in detail.

Database

Traffic data was gathered on Tuesdays, Wednesdays and Thursdays during consecutive weeks, in order to capture travel patterns that were most representative of weekday commuter traffic. "Without" period data were gathered on February 1, 2, and 3 (week 1), February 8, 9, and 10 (week 2) of 2000. "With" period data were gathered on March 14, 15, and 16 (week 3), March 21, 22, and 23 (week 4), starting on the 33rd day after the end of the "Without" period. The time period separating the Without and With periods was intended to allow drivers to become accustomed to the presence of the new ramp meters. Data was collected during the morning and the afternoon peak periods (7:00 am to 8:30 am and 4:00 pm to 5:30 pm, respectively).

Gathered data consisted of:

1. **Travel time runs** performed every 15 minutes during the peak periods.
2. **Traffic volume and speed**, collected through mainline and ramp pavement-embedded detectors, **every 20 seconds**.
3. **Fifteen-minute traffic volume counts** were collected through specially-installed on-ramp counters (on-ramps not equipped with pavement-embedded detectors).
4. **On-ramp queue lengths** recorded every 20 seconds (videotaped or observer-recorded in the field).

Travel Time Runs

Vehicles were dispatched every fifteen minutes during the analyzed peak periods and a crew recorded travel times between fixed landmarks along the analysis corridor. Thus, no more than six travel time runs were performed during any given one and one-half hour peak period. Travel time data were scheduled to be collected on the dates indicated above. However, no data were collected during certain dates as shown in **Table 5-1** below, due to certain circumstances (e.g., predicted adverse weather, traffic incidents, etc.)

Table 5-1. Number of Travel Time Runs Performed on US 45.

Day/Date	Without		Day/Date	With	
	AM Peak Period	PM Peak Period		AM Peak Period	PM Peak Period
Tue 2/1/00	0	6	Tue 3/14/00	0	0
Wed 2/2/00	6	0	Wed 3/15/00	6	0
Thu 2/3/00	0	0	Thu 3/16/00	6	0
Tue 2/8/00	6	6	Tue 3/21/00	4	4
Wed 2/9/00	4	6	Wed 3/22/00	4	6
Thu 2/10/00	4	0	Thu 3/23/00	6	4
Total	20	18		26	14

Volume and speed data from pavement-embedded detectors.

Volume and speed data were collected through 13 controllers (see "RM" listings in column "Controller ID," **Table 2-1**). However, due to various equipment problems, uninterrupted information for the Without and the With periods was available only for the five controllers that collected information corresponding to cutlines#1 (Congress Str.), #2 (Center Str.), #6 (S. of Wisconsin Ave.) and #8 (Lapham Str.) [2] An additional cutline (cutline #0) was established for Part 2 of the report at the Waukesha/Milwaukee County line (**Figure 5-1**). Each controller provided 20-second summary information for an on-ramp and each of the three mainline lanes.

On-Ramp Queue Length

Table 5-2 summarizes available on-ramp data availability for each peak period (morning and afternoon) and each analysis period (Without and With ramp metering). A detailed inventory of ramp queue length and delay information is presented in **Appendix A**.

Table 5-2. Ramp Delay-Available Data.

		On-Ramp Delay Data Inventory			
Location	Ramp meter	AM Peak Without	AM Peak With	PM Peak Without	PM Peak With
County Line Rd.[1]	New		√		
Pilgrim Rd.[1]	New		√		
Main Str.[2]	New				
Good Hope Rd. Loop Ramp	Existing	√	√	√	√
Good Hope Rd. Slip Ramp	Existing	√	√	√	√
Appleton Ave.	New		√		√
Hampton Ave.	New		√		√
Capitol Dr.	New		√		√
Burleigh St.	New		√		√
North Ave.	Existing	√	√	√	√
Watertown Plank Rd.	Existing	√	√	√	√
Wisconsin Ave.	Existing	√	√	√	√
Greenfield Ave.	Existing		√	√	√

Check marks indicate that data was available.

[1] The County Line Rd. and Pilgrim Rd. ramp meters did not operate during the PM peak in the With period.

[2]The Main Str. Ramp meter was installed but did not operate during the evaluation period.

[2] These cutline numbers are shown in **Figure 5-1**, and **Table 2-5** page 32 and **Figure 2-4** page 33 in Part 1 of the present report.

Freeway Operation Measures of Effectiveness

Loop detector data, collected in 20-second intervals were converted to equivalent hourly volumes and cumulative statistics were compiled for the morning and afternoon one and one-half hour peak periods. Thus, 270 values were used as inputs for volumes and an identical number for speeds for each lane at each cut line during each analyzed peak period of any given day.

Travel times compiled based on travel time runs were compared to travel times based on loop detector data in order to verify the validity of loop detector information. The two data sources were found to be in close agreement. It was decided to use loop detector data in lieu of travel time run data, because they provided travel time information compiled every 20 seconds (270 values per peak period) compared to six travel time runs—at most—during any given peak period (see **Table 5-1** for available number of travel time runs).

Data collected at the cut lines were aggregated into one and one-half hour average values for each peak period and each analysis day. The tables presented below show overall averages for all "Without" days and all "With" days at each cut line. The freeway lengths on which cut line statistics are applied is provided in **Table 5-3**. Cumulative statistics for the entire analyzed corridor are provided in each table.

Mainline Traffic Volumes: **Table 5-3** indicates small traffic volume increases along the corridor. A two-to-three percent increase was experienced at the south, most congested, end of the analyzed corridor during the morning peak; the same area experienced a zero-to-two percent increase during the afternoon peak, when the largest increase, percentage-wise (4%) was evidenced at the north end of the corridor, which had lighter traffic volumes.

Freeway Vehicle-Miles of Travel: **Table 5-3** presents the changes in Vehicle-Miles of Travel (VMT) that occurred between the Without and With periods for each of the daily peak traffic periods. There was an overall VMT increase of one percent during the morning peak; the increase was two percent for the afternoon peak.

Freeway-Vehicle Hours of Travel: <u>Mainline</u> freeway hours of travel decreased by 2% during the morning peak and by 5% during the afternoon peak period (see **Table 5-4**). However, <u>total</u> freeway vehicle hours *increased* by 4% (69.32 veh-hr) during the morning peak and decreased by 2% (36.32 veh-hr) during the afternoon peak.

Ramp Delay: This discrepancy between mainline and total vehicle hours of travel is explained by ramp delay statistics (see **Table 5-5**): ramp delay increased 64% (106.17 veh-hr) during the morning peak and 34% (54.14 veh-hr) during the afternoon peak. Minor overall delay increases were evident on existing ramps (15.14 veh-hr during the am peak, 6.24 veh-hr during the pm peak). The operation of new ramp meters introduced 91.03 veh-hr of delay during the morning peak and 47.91 veh-hr of delay during the afternoon peak. Thus the new ramp meters played a pivotal role in overall veh-hr statistics.

Ramp delay was 3.2% of total freeway veh-hr without the new ramp meters and 8.6% with the new ramp meters during the morning peak period. For the afternoon peak period, the corresponding percentages were 4.9% without and 7.6% with the new ramp meters in operation.

Freeway Speeds: Corridor speeds increased during both peaks when the new ramp meters were operational (**Table 5-6**). The increase was 1.83 mph (3%) during the morning peak, and 2.35 mph (4%) during the afternoon peak.

On-Ramp Queue Lengths: **Appendix A** presents all collected queue length and delay information. The longest queues occurred on the existing Good Hope loop ramp where maximum queue lengths averaged 60 vehicles during the morning and 50 vehicles during the afternoon peak period (pp. 8-15, **Appendix A**). Although queue lengths did not change substantially when the new ramp meters were operational, ramp delays increased.

Table 5-3. Freeway Vehicle-Miles of Travel: Without-and-With New Ramp Meters.
AM peak period (7:00 am to 8:30 am) PM peak period (4:00 pm to 5:30 pm)

	Mainline Volume Per Peak Period (vehicles)						
Cut Line	Miles	AM Peak Without	AM Peak With	% Change	PM Peak Without	PM Peak With	% Change
	3.2						
#0 Waukesha Co. Line		6476	6491	0	4044	4209	4
	4.5						
#1 Congress Str.		8485	8411	-1	7881	8009	2
	2.0						
#2 Center Str.		8418	8677	3	8006	8112	1
	2.4						
#6 Wisconsin Ave.		8380	8550	2	9829	9827	0
	1.9						
#8 Belton RR		7027	7243	3	10174	10434	2
Total Freeway VMT		109208	110254	1	107338	109144	2

Table 5-4. Freeway Vehicle-Hours of Travel: Without-and-With New Ramp Meters.
AM peak period (7:00 am to 8:30 am) PM peak period (4:00 pm to 5:30 pm)

Cut Line	Mainline Vehicle-Hours of Travel Per Peak Period					
	AM Peak Without	AM Peak With	% Change	PM Peak Without	PM Peak With	% Change
#0 Waukesha Co. Line	297.64	300.96	1	188.11	196.49	4
#1 Congress Str.	618.42	570.11	-8	524.29	532.87	2
#2 Center Str.	294.96	294.64	0	331.92	298.24	-11
#6 Wisconsin Ave.	353.43	357.68	1	547.23	489.94	-12
#8 Belton RR	223.69	227.92	2	416.95	400.51	-4
Freeway VHT	1788.15	1751.30	-2	2008.51	1918.05	-5
Ramp VH Delay	58.88	165.05	64	103.63	157.77	34
Total Freeway VH	1847.03	1916.35	4	2112.14	2075.82	-2

Table 5-5. Ramp Delay: Without-and-With New Ramp Meters.
AM peak period (7:00 am to 8:30 am) PM peak period (4:00 pm to 5:30 pm)

Location	Ramp meter	Ramp Metering Delay (veh-hr)			
		AM Peak Without	AM Peak With	PM Peak Without	PM Peak With
County Line Rd.	New		15.49		
Pilgrim Rd.	New		11.96		
Main Str.	New				
Good Hope Rd. Loop Ramp	Existing	26.48	38.55	13.74	21.80
Good Hope Rd. Slip Ramp	Existing	0.28	0.80	0.43	0.30
Appleton Ave.	New		15.91		2.22
Hampton Ave.	New		11.75		7.21
Capitol Dr.	New		20.56		7.84
Burleigh St.	New		15.36		30.64
North Ave.	Existing	16.10	13.82	28.81	28.37
Watertown Plank Rd.	Existing	14.29	18.60	41.98	40.40
Wisconsin Ave.	Existing	1.72	1.53	4.78	9.34
Greenfield Ave.	Existing		0.73	13.88	9.65
New ramp meters		not installed	91.03	not installed	47.91
Existing ramp meters		58.88	74.02	103.63	109.87
Total		58.88	165.05	103.63	157.77

Notes:
Main Str. ramp metering was installed, but not turned on during the evaluation period.
Greenfield Ave. existing ramp metering was not turned on during the AM peak in the Without period.
County Line Rd. and Pilgrim Rd. ramp metering was not turned on during the afternoon peak in the With period.

Table 5-6. Freeway Speeds: Without-and-With New Ramp Meters.
AM peak period (7:00 am to 8:30 am) PM peak period (4:00 pm to 5:30 pm)

Cut Line	Freeway Speeds (MPH)					
	AM Peak Without	AM Peak With	% Change	PM Peak Without	PM Peak With	% Change
#0 Waukesha Co. Line	69.62	69.01	-1	68.81	68.55	0
#1 Congress Str.	61.94	66.39	7	67.64	67.63	0
#2 Center Str.	57.09	58.90	3	48.29	54.42	13
#6 Wisconsin Ave.	56.91	57.39	1	44.09	48.28	10
#8 Belton RR	59.69	60.38	1	46.78	49.53	6
Corridor Average Speed	61.45	63.28	3	55.96	58.31	4

Table 5-5 indicates that the highest ramp delays (42 and 40 veh-hr during the afternoon per peak period without and with the new meters, respectively) occurred on the existing Watertown Plank Road on-ramp. These delays corresponded to queues with average maximum lengths of 47 and 40 vehicles Without and With the new ramp meters operational, respectively (pp. 83-100, **Appendix A**). Maximum queue length for the HOV lane was one vehicle.

Maximum queue length on the new Burleigh Street ramp meter was about 30 vehicles during the morning peak and 45 vehicles during the afternoon peak, when ramp delay averaged 30.6 veh-hr. The High Occupancy Vehicle ramp was seldom utilized; queue length did not exceed 2-3 vehicles.

Maximum queue lengths on the existing North Avenue ramp meter averaged 32 vehicles during the afternoon peak, with ramp delays of approximately 28 veh-hr throughout the evaluation period.

High Occupancy Vehicle ramps were seldom utilized; queue lengths rarely exceeded one or two vehicles at a time.

Traffic Flow Characteristics-Discussion

Ramp meters were already installed in the southern, most congested part of the analyzed corridor, where ramp metering would be anticipated to have the greatest impact in terms of facilitating merging into the mainline and potentially diverting traffic to alternate routes during peak periods. Smoother merging into the mainline was expected to lead to increased capacity and decreased mainline travel times by minimizing the potential of shock wave formation at merge areas. The six new ramp meters were installed north of the most congested part of the corridor, thus they were expected to smooth traffic feeding into this most congested part of the corridor. The strongest smoothing effects were expected to be from the new ramp meters installed immediately upstream of the existing ramp metering installations, at Burleigh Street, Capitol Drive, and Hampton Avenue.

Because two of the remaining three new ramp meters were installed in the northern-most, less traveled part of the corridor (County Line Road and Pilgrim Road), their incremental impact on freeway operations MOE would not be expected to result in a net benefit for the north end of the corridor in terms of speeds and travel times:

- Speeds at cutline #0 were at- or near-free-flow levels before the new meters became operational and could not be expected to increase significantly. (Speeds were somewhat lower at cutline #1, allowing some room for a moderate speed increase.)
- Ramp delays (not present in this part of the corridor before the new ramp meters were operational) would thus mainly increase travel times, because drivers would not be able to make up for ramp delay by traveling much faster on the mainline.

Given the traffic flow conditions at the north end of the analysis corridor before the new ramp meters became operational, it is mainly traffic volumes that could experience an increase among the reported MOE: the highest per lane volume was 1,885 vehicles per hour (at cutline #1), allowing room for a substantial increase. These two ramps were more than four miles away from cutline #2 where the first significant speed reductions were present, thus their impact on mainline operations south of cutline #2 would be minimal.

Moderate congestion existed between cutlines #1 and #2, where the new Capitol Drive and Burleigh Street ramp meters were installed, with maximum per lane volumes of 1,870 vehicles per hour at cutline #2.

On-ramps at the south end of the corridor, represented by statistics at cutlines #6 and #8, were metered during both analysis periods (Without and With the new ramp meters). This was the most congested part of the corridor (with maximum per lane volumes of 2,260 vehicles during the afternoon peak period) operating at speeds significantly lower than the north end of the corridor. Thus there was substantially more room for speed improvement in this part of the corridor than at the north end, where speeds were near free-flow levels.

Speed increases were evident for the corridor (**Table 5-6**) with the most encouraging findings being speed increases observed at the south end of the corridor at cutlines #2, #6 and #8, during the most heavily-traveled afternoon peak period. Speeds increased by

13%, 10% and 6% at these cutlines, respectively, resulting in an overall corridor five percent reduction in mainline vehicle-hours of travel. Vehicle-hours of travel were two percent lower during the morning peak period.

An added benefit was that the above-mentioned speed increases occurred in the presence of small mainline traffic volume increases (0 - 2% during the afternoon peak and 2 - 3% during the morning peak) at the south end of the corridor. Corridor vehicle-miles of travel increased by two percent during the afternoon peak and by one percent during the morning peak.

The following discussion is based on information presented in **Table 5-7**, which is compiled from **Tables 5-4** and **5-5**.

Table 5-7. Corridor Vehicle-Hours of Travel.

	Vehicle-Hours of Travel (veh-hr)					
	AM Peak Without	AM Peak With	Change (veh-hr)	PM Peak Without	PM Peak With	Change (veh-hr)
Freeway VHT	1788.15	1751.30	-36.85	2008.51	1918.05	-90.46
New ramp meters	*not installed*	*91.03*	*91.03*	*not installed*	*47.91*	*47.91*
Existing ramp meters	*58.88*	*74.02*	*15.14*	*103.63*	*109.87*	*6.24*
Total Ramp VH Delay	58.88	165.05	106.17	103.63	157.77	54.14
Total Freeway VH	1847.03	1916.35	69.32	2112.14	2075.82	-36.32

Ramp delay was a higher percentage of total freeway vehicle hours of travel when the new meters were operational. Ramp delay at 3.2% of total freeway vehicle hours of travel in the morning peak, increased to 8.6%; for the afternoon peak the increase was from 4.9% to 7.6%.

Ramp delay increases were mostly due to the new ramp meters. New ramp meters added 91.03 vehicle-hours of delay to the morning peak (the total increase was 106.17 veh-hr of delay) and 47.91 veh-hr of delay to the afternoon peak (total increase was 54.14 veh-hr of delay).

Ramp delays were a small percentage of total veh-hr of travel, however, increases in ramp delays when the new ramp meters were operational, had a drastic impact on overall vehicle-hours of travel. Despite a decrease of 36.85 veh-hr of travel on the mainline during the ***morning peak***, an increase of 106.17 veh-hr of ramp delay resulted in an overall increase of 69.32 corridor veh-hr of travel (a 4% increase).

The impact of increased ramp meter delays was of a smaller magnitude during the ***afternoon peak***. Due to the smaller magnitude of the ramp delay, and the larger magnitude of the mainline veh-hr of travel during this peak, ramp delay had a much smaller impact on overall freeway veh-hr of travel. Despite the increased ramp delay, overall veh-hr of travel decreased by two percent when the new ramp meters were operational.

Crashes

New ramp metering equipment was installed in 1999 and was activated on February 15, 2000. Crash statistics presented herein are based on a six-month period that the corridor operated without the new ramp meters (from August 10, 1999 to February 10, 2000) and a six-month period that the corridor operated with the new ramp meters (from August 10, 2000, to February 10, 2001). The analysis included all I-94 Southbound crashes between the Waukesha County/Washington County line, and the Zoo interchange, as well as all I-894 southbound crashes between the Zoo interchange and Lincoln Avenue.

Crash statistics changes along the corridor were due to the ramp meters installed in addition to those already in operation at Good Hope Rd., North Ave., Watertown Plank Rd., Wisconsin Ave. and Greenfield Ave., as well as geometric improvements to ramps and pavement resurfacing that took place during the new ramp meter installation project.

During ramp metering hours of operation[3] a total of 152 crashes occurred along the analysis corridor in the period when the freeway operated without the new ramp meters, and 128 crashes occurred in the period that the freeway operated with the new ramp meters in place. The crash rate was 298 crashes per 100 MVM of travel "Without," and 260 crashes per 100 MVM of travel "With" the new ramp meters.

Operation of the new ramp meters in conjunction with improved ramp merging geometrics and mainline pavement resurfacing resulted in an overall 16% reduction in the number of crashes (a 13% crash rate reduction) during ramp metering hours.

Conclusions

During the period with new ramp meters in operation the most congested south part of the analysis corridor experienced an improvement in traffic operations measures of effectiveness, during the most critical (most congested) afternoon peak period.

During the afternoon peak period, a substantial reduction in vehicle-hours of travel due to increases in travel speeds, under minimal volume changes (a zero to two percent increase) was documented between Capitol Drive and Greenfield Avenue. Speeds increased by 13% in the segment between Capitol Drive and Burleigh Street, by 10% between North Avenue and Wisconsin Avenue, and by 6% between Bluemound Road and Greenfield Avenue.

However, corridor average speed increased by only four percent during the afternoon peak, because no speed changes were effected on the north part of the corridor where near-free-flow speeds existed at all times. Although mainline vehicle hours of travel

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[3] Assumed to be 6:00 am to 9:00 am (morning peak period) and 2:00 pm to 7:00 pm (afternoon peak period), Monday through Friday for the crash analysis.

decreased by five percent, when ramp delay was also taken into account, total vehicle hours of travel decreased by two percent. There was an overall increase of two percent in corridor vehicle miles of travel.

It is interesting to note that morning peak period ramp delays without the new ramp meters were approximately half the ramp delays of the afternoon peak period ramp delays. Ramp delays with the new ramp meters were approximately equal during both peak periods. Given that traffic volumes were lighter during the morning peak period, it is quite likely that ramp metering rates were more restrictive than their optimal values during this period.

The operation of new ramp meters, in conjunction with geometric improvements in ramp merging areas and mainline resurfacing resulted in a 13% crash rate reduction for the analyzed corridor during ramp metering hours.

Appendix B information indicates that ramp metering rate override due to high ramp occupancy occurs rather frequently and over a large portion of peak periods. When queue override occurs, ramp queues are very likely to be discharged at the highest metering rate when heavier mainline volumes demand more restrictive metering rates. This situation moderates potential ramp metering benefits.

Recommendations

Ramp delay played a critical role in the balance of overall corridor veh-hr of delay: although mainline veh-hr of travel decreased when the new ramp meters were operational, overall veh-hr of travel increased during the morning peak due to ramp delays. Travel time reduction benefits in the most congested part of the corridor during the afternoon peak were tempered due to additional ramp delays. Fine-tuning of ramp metering parameters during the morning peak period in order to reduce ramp delays is very likely to produce a reduction in total freeway veh-hr of travel.

Further reductions in total freeway veh-hr of travel during the afternoon peak may also be possible by reducing ramp delay on the existing Good Hope Road loop ramp where the mainline is not very congested; the current high level of ramp delay on the new Burleigh Street ramp could probably also be reduced. County Line Road and Pilgrim Road ramp metering probably contributes rather small mainline benefits at the present time, given the lower traffic volumes and substantial distance from the currently congested part of the corridor. Minimizing delays on these ramps would, in all likelihood decrease corridor delays.

Any changes in ramp metering parameters aiming to reduce ramp delays, should be carefully balanced against possible increases in mainline travel times.

Appendices A and **B** provide detailed information that can serve as the decision-making foundation for desired ramp metering parameter changes.