Evaluation of Ramp Meter Retiming Procedure

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Ramp Meter Retiming Procedure

by

Chanyoung Lee Ph.D.
University of Wisconsin at Madison
Department of Civil and Environmental Engineering
Phone: 608-265-8582 Fax: 608-262-5199
Email: chanyounglee@wisc.edu

Bin Ran Ph.D.
University of Wisconsin at Madison
Department of Civil and Environmental Engineering
Phone: 608-262-0052 Fax: 608-262-5199
Email: bran@wisc.edu

Shan Di
University of Wisconsin at Madison
Department of Civil and Environmental Engineering
University of Wisconsin at Madison
Department of Civil and Environmental Engineering
Phone: 608-262-2524 Fax: 608-262-5199
Email: sdi@wisc.edu

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TRAFFIC OPERATIONS AND SAFETY LABORATORY
University of Wisconsin-Madison
Department of Civil and Environmental Engineering
1415 Engineering Drive
Madison, WI 53706
www.topslab.wisc.edu

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1 BACKGROUND

Ramp meters (RM) were installed along the I-94 East-West Corridor in the Milwaukee area as early as late 1960's. RMs were expanded system-wide along the Southeast (SE) Wisconsin freeways in the mid-1990's and have helped minimize travel times and crash rates as traffic continues to grow significantly with minimal capacity expansion.

Currently, each ramp meter has a programmed algorithm which constantly collects, analyzes, and reacts (releases vehicles) to local freeway traffic conditions, i.e., volume, speed, and percent occupancy (percent of time vehicles are occupying the loop in a 20 second period). High volumes, low speeds, or high occupancy in the vicinity of the ramp meter will generate a restrictive rate based on pre-coded intervals and thresholds under a localized "Traffic Responsive" operation.

According to the 2002 Regional Mobility and Reliability study performed by Texas Transportation Institute and Cambridge Systematics, Inc., traffic congestion and travel unreliability in the Milwaukee area has increased, equally in both morning and evening peak travel periods. In addition, sixty percent of total daily freeway delay occurs during the peak periods.

To effectively handle the increased traffic congestion and unreliability, at a minimum, ramp meters should be operated using locally optimized conditions. This can be achieved by re-evaluating "intervals" and "thresholds" on a routine basis as well as making adjustments due to major special events or construction. The process can be defined as "Ramp Meter Retiming."

In 2003, all ramp meters in Southeast Wisconsin were retimed based on traffic data and different thresholds established during the prior 6 months, including volume, speed, and V/C ratio. In 2004, all ramps were retimed based on feedback from operators using a season-based approach, which considers school months (June-August) and non-school months (September-May). However, no major changes in traffic congestion were observed.

2 OBJECTIVES

The objective of this study is to review the ramp meter retiming process developed in Southeast Wisconsin and evaluate if the process is adequate to minimize delay and crashes in the SE Wisconsin Freeway System.

3 METHODOLOGY

Initially, the document "Ramp Meter Retiming Procedure in Wisconsin" was reviewed, including a detail investigation of the ramp meter retiming workbook. However, there is very little literature available regarding RM retiming and no major studies have been found as basis for comparison. Therefore, the evaluation team decided to recruit experts in other states to participate in the evaluation process. A web-based survey was used. This is a modified Delphi method, which serves as a reliable and creative exploration of ideas from a group of experts by using of a series of questionnaires interspersed with controlled opinion feedback.

To evaluate the RM retiming procedure in SE Wisconsin, a questionnaire was developed and a survey of State DOTs was conducted through a website. Prior to the survey, contact information for each state agency was collected and a person from each agency who was involved in ramp metering operations was invited to participate the web-based survey. Respondents were asked to review the Wisconsin ramp metering procedure prior to participating in the survey. Both a summary and a full explanation of the Wisconsin ramp metering procedure were provided.

4 RECENT STUDIES ON RAMP METERING SYSTEMS

The research on freeway ramp metering extends back nearly 50 years. The most common RM timing strategies are categorized as fixed-time, reactive and proactive ramp control. Most research focuses on the improvement of reactive ramp metering and proactive-control. Reactive strategies aim to maintain freeway traffic conditions (such as occupancy, volume) close to pre-specified, desired values by the use of real-time measurements. Proactive strategies aim to achieve optimal traffic conditions for a freeway corridor or an entire network based on traffic demand predictions over a reasonably long time horizon. The most common research areas in ramp metering are summarized as below.

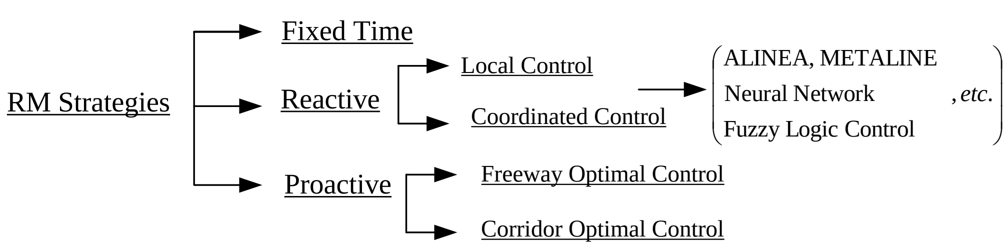

Figure 1 Research Areas in Freeway Ramp Metering

The research of proactive ramp control comes from the idea of system optimal control in the presence of freeway bottlenecks. There are mainly two approaches for proactive ramp control. One approach is to optimize the total travel time of a sufficiently long time by adjusting the ramp metering rate. The other approach considers the possible impact of ramp inflow control on surface streets and develops corridor control strategies by combining ramp metering with intersection signal control and route guidance. A basic assumption for this kind of control requires predictive information about freeway demand. However in practice, a reliable time-dependent origin-destination (OD) table is seldom available. Therefore this approach is seldom applied. Recently researchers have developed new approaches which try to avoid using the OD information. These methods are still in research level and no practical application is available.

Reactive ramp metering strategies may be local or coordinated. Local strategies measures traffic conditions in the vicinity of each ramp, to calculate the corresponding individual ramp metering values; while coordinated strategies use available traffic measurements from greater portions of a freeway to make decisions for ramp metering values. Local strategies are much easier to design and implement; nevertheless, researches (Papageorgiou et al. 1997) have proved non-inferior to more sophisticated coordinated approaches under recurrent traffic congestion conditions.

Traffic-responsive metering determines metering rates based on current traffic conditions. Because traffic-responsive metering responds to real time traffic variations, it is more effective in preventing or reducing traffic congestion than fixed time metering. Theoretical studies on reactive control focus on the effectiveness of various types of controllers, e.g., linear controller, artificial Neural Network controller (H.M. Zhang 1997) and fuzzy-logic controller (Taylor et al. 1998). The controllers are adaptive to both local control and coordinated control. A popular strategy using a linear controller is the well known ALINEA local ramp metering. Figure 2 shows the working strategies of demand-capacity method and ALINEA model (Papageorgiou et al. 2002). The demand-capacity or occupancy strategies, which are popular in North America, attempt to add to the measured upstream flow as much ramp flow as necessary to reach the downstream freeway capacity, which is generally known to be quite sensitive to various nonmeasurable disturbances. In Figure 2 on the left, q_{cap} is the freeway capacity downstream of the ramp, q_{in} is the freeway flow measurement upstream of the ramp, o_{out} is the freeway occupancy measurement downstream of the ramp, o_{cr} is the critical occupancy (at which the freeway flow becomes maximum), and r_{min} is a prespecified minimum ramp flow value. The strategy sets the ramp inflow determined by the following equation:

$$r(k) = \begin{cases} q_{cap} - q_{in}(k-1), & o_{out}(k) < o_{cr} \\ r_{\min}, & otherwise \end{cases}$$

In ALINEA model regulator parameter is applied to adjust downstream occupancy which is set to a desired value. The ALINEA strategy reads:

$$r(k) = r(k-1) + K_R[\hat{o} - o_{out}(k)]$$

Where K_R is a regulator parameter and $\hat{o}$ is a desired value for the downstream occupancy. The difference between desired and actual downstream occupancy is smoothed and thus it may prevent congestion by stabilizing the traffic flow.

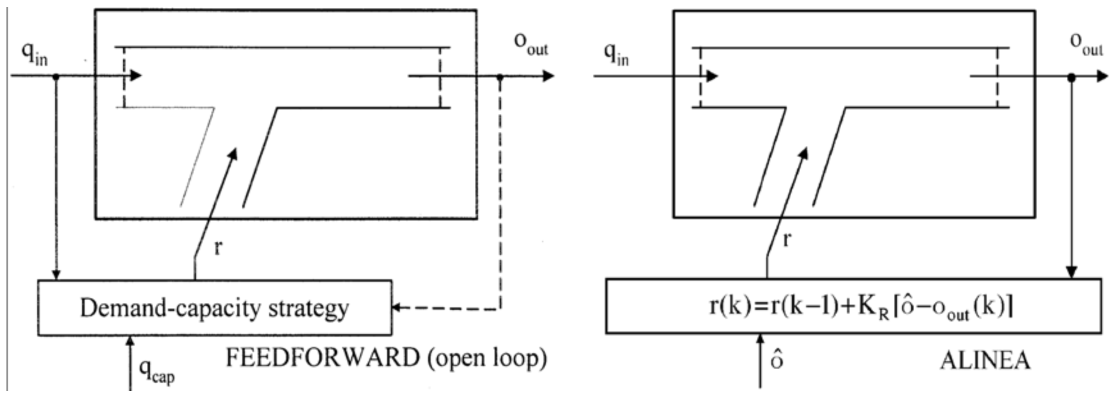

Figure 2 Local Demand-Capacity RM strategies vs. ALINEA RM strategies

The neural network introduces feedback into control design considering the disturbances and modeling errors in the systems. Algorithms are developed to train the neural network controllers from the real time data. A usual ramp control objective is to maintain traffic density around a desired target value. As have been studied, compared with the conventional automatic control techniques, artificial neural networks offer a number of advantages: first, neural network control can directly handle nonlinear systems without resorting to linearization; second, neural network control algorithms can be tuned on-line, which makes them adaptive to a changing environment. Zhang (1997) had presented a detailed study of freeway ramp metering using artificial neural networks.

The fuzzy logic algorithm incorporates a hybrid learning procedure into the control system. It utilizes incomplete or inaccurate data and does not require extensive system modeling. The traffic responsive metering rate is determined for every short time interval by the algorithm. In general, fuzzy logic control involves three main steps: 1) fuzzification to convert the quantitative inputs into natural language variables, 2) rule evaluation to implement the control heuristics, and 3) defuzzification to map the qualitative rule outcomes to a numerical output. Taylor and Meldrum presented a more detailed application of fuzzy logic control to ramp metering. Also quite a few tests and simulations have been done to evaluate the performance fuzzy logic control. (e.g. Chen and May, 1990: A CALTRANS research group tested entry control to the San Francisco-Oakland Bay Bridge; Cynthia Taylor and Deirdre Meldrum : Three ramp metering algorithms used in the greater Seattle area.)

Neutral network or fuzzy control is especially suitable when an accurate system model is unavailable. Traffic's complexity, nonlinear nature, and non-stationary behavior make obtaining a control model extremely difficult. These two models are more useful in practice. These algorithms are of good reference value for this project inasmuch they do the RM retiming procedures based on on-line data input.

5 SUMMARY OF CURRENT RAMP METER RETIMING PROCEDURE

5.1 Introduction

The developed procedure for RM retiming in SE Wisconsin is intended to guide an engineer and/or operator through developing timings for a new ramp meter or retiming existing ramp meters. The entire procedure is considered a "living" process that requires modifications as the ramp and mainline traffic characteristics evolve. The following list summarizes the procedure:

Step 1 Collect Background Information
Step 2 Ramp Meter Field Inspection
Step 3 Data Collection and Data Validation
Step 4 Ramp Meter Retiming Spreadsheet
Step 5 Ramp Meter Timings Review and Acceptance
Step 6 New Timings Entry Into 170 User Interface
Step 7 Ramp Meter Observation
Step 8 Documentation and Filing Documents

5.2 Collect Background Information

The first step in retiming a ramp meter is to collect background information on the ramp and ramp meter. The following historical information is needed to properly retime a ramp meter:

- Current design or as-built Freeway Traffic Management System (FTMS) plan view sheets
- Current design or as-built pavement marking plan
- Current design or as-built signage plan
- Current timing plan (printout of 170 timings) if not a new ramp meter

5.3 Ramp Meter Field Inspection

A ramp meter field visit should be conducted prior to retiming a ramp meter. The inspection is done in order to ensure proper ramp meter operations, detect and report any maintenance needs, and validate signing and pavement marking. The inspection must take place during the AM or PM ramp metering period and requires a minimum of 15 minutes of observation. The user should take a blank Ramp Meter Field Inspection Report to the field. There are three major steps for field inspection:

Step 1. Completion of Ramp Meter Field Inspection Report

The inspection report covers information of ramp meter area including signing, pavement markings and conditions, hardware, action taken, etc. The detailed items are listed in Table 1.

Table 1 Field Inspection Entries and Contents

Field Inspection Entries	Content
General Information	Configuration Discharge Type Ramp and Freeway Conditions
Signing	Ramp Metered When Flashing Signs Stop Here On Red Signs Lane Designation Signs HOV Signs Signs on Side Streets
Pavement Marking	Stop Bar Edge Lines Lane Skips Median Paint HOV Lane Designation Symbols
Pavement Condition	Pavement Type and Condition Pavement Condition In Area of Loop Detectors
Hardware	Signal Heads Advanced Flashers
Cabinet	Cabinet Exterior Cabinet Interior

Step 2. Documenting Pavement Repair and Pavement Marking Maintenance Needs

The inspector must document any pavement repair or pavement marking maintenance needs in the database. The database will be used to develop contracts for refurbishment and placement of faded or missing items.

Step 3. Follow Up

The inspector is also responsible for follow-up on the maintenance requests to ensure maintenance personnel address the issues.

5.4 Data Collection and Data Validation

Once the field visit has been completed, data must be collected. Ramp meters are retimed based on current freeway traffic conditions. In order to get an account of current traffic conditions, archived data must be queried. A program called the Data Extractor was developed to enhance the collection of data for ramp meter retiming. The Data Extractor software is available to all WisDOT staff and can be installed on any computer by talking with the TOC's IT Specialist.

5.5 Ramp Meter Retiming Workbook

After the data has been saved in the Data Extractor, it is transferred into an Excel workbook formatted for ramp meter retiming. The Ramp Meter Retiming Workbook is comprised of 9 worksheets used for data formatting and calculations. The Ramp meter retiming spreadsheet requires geometric and traffic flow information to the RM retiming workbook to generate a retiming strategy. Based on thresholds and interval retiming strategies, control plans are created in the 170 Controller User worksheet.

Thresholds Table setting:

Average of collected traffic data (24 hours, for volume, occupancy, speeds) is taken for up to 18 discrete days throughout a year. Five percentile values of all the values are used for plan 1 and the ninety five percentile value is used for plan 6. Other plan thresholds are decided by interpolating plan 1 and plan 6 values. Some adjustment may be applied to the values.

Interval Table setting:

Green: The green time is typically set to 2.0 sec for plan 1 and 2.5 sec for plans 2 through 6. If the average maximum ramp volume of observed days are greater than 850 veh/lane/hr, plan 1 is set to 1.6 sec green time, plans 2-6 are set to 2.5 sec green time.

Red: Plan 1 takes minimum critical red phase length, which depends on the ramp discharge type. Plan 6 takes the maximum red phase multiplied by a fraction, which depends on the average mainline volume of observed days. Plans 2-5 take interpositions of plan 1 and 6.

The numbers appeared above, such as 2.0 sec, 2.5 sec and 850 veh/hr, are experiential values which are decided by field engineers. After threshold and intervals has been set up, a table similar to Figure 1 is created for a local traffic responsive plan.

Ramp Interval Timings

AM Interval Timing

Plan	1	2	3	4	5	6
Green	2.0	2.5	2.5	2.5	2.5	2.5
Yellow						
Red	1.8	2.5	3.5	5.0	7.0	9.0
Red Ext.						

PM Interval Timing

Plan	1	2	3	4	5	6
Green	2.0	2.5	2.5	2.5	2.5	2.5
Yellow						
Red	1.8	2.5	3.5	5.0	7.0	9.0
Red Ext.						

Ramp Thresholds

AM Thresholds

Plan	1	2	3	4	5	6
Volume	1200	1400	1600	1800	2000	2200
Occupancy	8	10	12	14	16	18
Veh. Speed	60	55	50	45	40	35
Queue Occ.	60	55	50	40	30	20

PM Thresholds

Plan	1	2	3	4	5	6
Volume	1000	1200	1400	1600	1800	2000
Occupancy	6	8	10	12	16	18
Veh. Speed	60	55	50	45	40	35
Queue Occ.	60	55	50	40	30	20

Figure 3 (170 User Worksheet) RM Interval Timings and Ramp Threshold

5.6 New Timings Entry Into 170 User Interface

After the new ramp meter timings have been reviewed and approved by RM retiming operators, they are entered into WisDOT's 170 User Interface program and downloaded to the controller. In this step, schedule sheets are set up for different plans using a variety of strategies. Basically WisDOT uses 16 plans for RM retiming. Table 2 summarizes the 16 plans with setting strategies.

Table 2 Plan Setting Strategies

Plan Number	Description	Notes
Plans 1-6	Fixed metering times	Plan 1 has the shortest cycle length; plan 6 has the longest cycle length
Plan 7	Non-metering	—
Plan 8	TOD (Time Of Day) schedule	—
Plan 9	Must/May Plan 1	If one of the thresholds is met (metering in need), the RM will start metering in traffic responsive Interval Timing Plan 1(see table1) prior to user defined time and shut off earlier. Ramp meter will not switch between traffic responsive Interval Timing plans 1-6 due to change of volumes, speed etc., but stay with Plan 1. The thresholds values in Plan 1 (table 1) are lower bounds to perform RM.
Plan 10	Traffic Responsive (TR) Must/May	If one of the thresholds is met (metering in need), the RM will start metering in traffic responsive Interval Timing Plan 1(see table1) prior to user defined time and shut off earlier. Ramp meter will switch between traffic responsive Interval Timing plans 1-6 due to change of volumes, speed etc. The thresholds values in Plans 1-6 (table 1) are upper bounds to perform RM of that Plan number.
Plan 11	TR Minimum Plan 1	Ramp meter will meter traffic responsive and switch control plans between Interval Timing Plan1-6 due to change of volumes, speeds etc. The thresholds values in Plans 1-6 (table 1) are upper bounds to perform RM of that Plan number.
Plan 12	TR Minimum Plan 2	Similar to Plan 11 except control plans switch between 2-6;
Plan 13	TR Minimum Plan 3	Similar to Plan 11 except control plans switch between 3-6;
Plan 14	TR Minimum Plan 4	Similar to Plan 11 except control plans switch between 4-6;
Plan 15	TR Minimum Plan 5	Similar to Plan 11 except control plans switch between 5-6;
Plan 16	TR Minimum Plan 6	Similar to Plan 11 except control plans do not switch but stay with TR Plan 6.

5.7 Ramp Meter Observation

The user observes the ramp meter for a minimum of 30 minutes, after the new timings are downloaded, to ensure proper metering. The user must complete the Ramp Meter Retiming Field Review form. The Form is comprised of 3 main sections – Ramp Conditions, Freeway Conditions, and Recommendations for Improvement.

If the ramp meter requires timings or threshold adjustments, or if the ramp requires maintenance, the user must observe the ramp meter again after all adjustments and repairs are made. A second observation form must also be completed to verify the meter is operating effectively.

5.8 Documentation and Filing Documents

It is necessary to record all changes made to ramp meter timings in the MONITOR maintenance log and to file documentation for ramp meter retiming properly. The documents are saved in WisDOT database for future reference.

5.9 Summary

Overall, the current eight steps for the RM retiming is a very comprehensive procedure. Compared with other states, the data collection with the Data Extractor is very reasonably designed to ensure proper data retrieval. Some states such as GA have similar procedures but many other states do not have a document.

The entire retiming procedure examines traffic conditions for comprehensive local RM operations, combines engineering experiences with reasonable calculations, and follows with necessary observation and documentation. It performs as an integrated system combining the eight steps. Possible traffic variations are considered in the setting of the 16 plans. It promises a ramp metering system that excels in accommodating traffic variations. As it is discussed in a later chapter, the survey results show the average rating for current eight steps is 7.5 points based on a 10 points rating system, with the lowest rating 5 points and the highest rating 10 points.

6 ANALYSIS OF CURRENT RAMP METER RETIMING WORKBOOK

The ramp meter retiming workbook is an essential part of the retiming procedures because it involves the calculation of signal intervals. This chapter will analyze the RM Retiming Workbook in detail.

To clarify the setting of thresholds and interval timing, we use AM peak period data from the detector “RM-40-006”(I-94 EB @ 35th St.) as an example to demonstrate the procedures.

6.1 Current Interval Timing

Figure 3 illustrate the interval setting of AM peak period (PM interval setting is very similar). In the retiming process, historical ramp data are used to determine the green intervals, while mainline data combined with ramp discharge type are used to determine the red intervals.

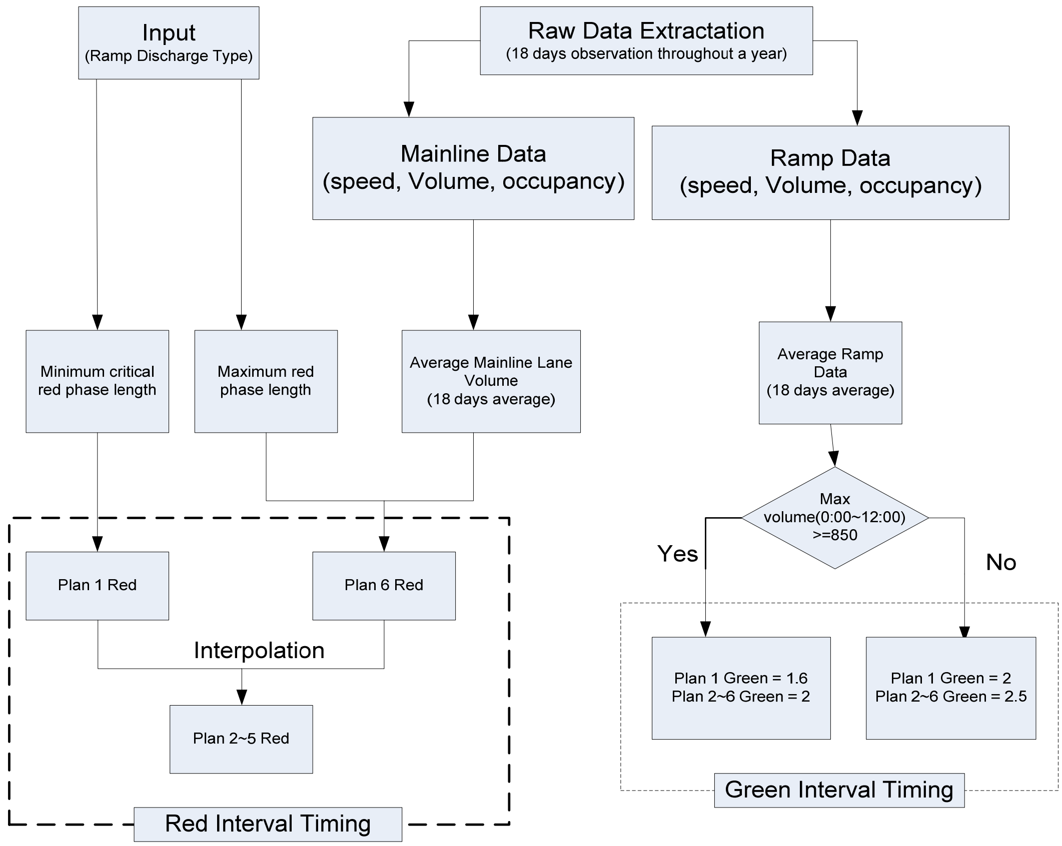

Figure 4 Interval Timing Flow Chart for AM Peak Period

Green

The setting of green time depends on collected historical ramp volumes. Ramp volume data is collected for 18 observation days throughout a year and averaged every 5 minutes. For the AM case,

- Plan 1: If the maximum ramp volume during AM hours 0:00~12:00 is greater than 850 vph, set green time as 1.6sec; otherwise set green time as 2sec;
- Plan 2-6: If the maximum of the ramp volume of 0:00~12:00 is no smaller than 850 vph, set green time as 2sec; otherwise set green time as 2.5sec;

Red

The setting of red time depends on collected historical mainline volume data. The 5 minute mainline volume is averaged by lanes and observation days. Average mainline volume takes the average of 5 min volume for the time period of 6:00AM~9:00PM.

Discharge types are also taken into account for establishing red times. Three discharge types are defined as a single lane, two lanes together and staggered (dual).

- Plan 1 uses a minimum critical red phase length, as shown in Table 3.

Table 3 Length of Minimum Critical Red Phase

Discharge type	Length of minimum critical red phase
Single lane	2.5 sec
Two lanes together	2.5 sec
Staggered (dual)	1.8 sec

- The red interval setting of Plan 6 is determined by the average mainline volume and maximum red phase length as shown in Table 4. The length of maximum red phase with regard to discharge type is listed in Table5.

Table 4 Traffic Volume Threshold for Red Phase in Plan 6

Plan 6 Red	Average mainline lane volume (vph)
Maximum red phase length*0.58	< 1100vph
Maximum red phase length*0.75	< 1300vph
Maximum red phase length*0.92	< 1700vph

Table 5 Length of Maximum Critical Red Phase in Plan 6

Discharge type	Length of minimum critical red phase
Single lane	10 sec
Two lanes together	10 sec
Staggered (dual)	8 sec

- Once the red time interval of Plan 1 and Plan 6 is determined, the red interval settings of Plan 2 to Plan 5 are interpolated, as shown in Table 6. Figure 2 illustrates the interval setting procedures.

Table 6 Length of Maximum Critical Red Phase

Plan No.	Length of Red Phase
Plan 2	(Plan1+ Plan3)*0.45
Plan 3	Plan6 *0.5
Plan 4	(Plan6-Plan3) *0.334+ Plan3
Plan 5	(Plan6-Plan3) *0.667+ Plan3

6.2 Current Ramp Thresholds

The current timing procedure has three kinds of thresholds: volume, occupancy and speed. Thresholds of volume, speed and occupancy for the six plans are based on the average of mainline data of all lanes. Ramp meter will be activated if any one of the three thresholds is satisfied.

Volume

The threshold of volume based on the average of mainline lane traffic volume. The settings of thresholds of 6 plans are listed in Table 7.

Table 7 Volume Thresholds Setting

Plan No.	Thresholds
Plan 1	(5th percentile of the highest of 18 days of average mainline lane

	volume) +50
Plan 2	(Minimum of 18 days of average mainline lane volume)*1.12+150
Plan 3	Median of 18 days of average mainline lane volume
Plan 4	Average of Plan 3 and Plan 5
Plan 5	(Maximum of 18 days of average mainline lane volume) +50
Plan 6	(95th percentile of the highest of 18 days of average mainline lane volume) +100

Occupancy

The threshold of occupancy based on the average of mainline lane traffic occupancy. The settings of thresholds of 6 plans are listed in Table 8.

Table 8 Occupancy Thresholds Setting

Plan No.	Thresholds
Plan 1	5^{th} percentile of the highest of 18 days of average mainline lane occupancy
Plan 2	(Minimum of 18 days of average mainline lane occupancy)+1%
Plan 3	Median of 18 days of average mainline lane occupancy
Plan 4	Average of Plan 3 and Plan 5
Plan 5	Maximum of 18 days of average mainline lane occupancy
Plan 6	95^{th} percentile of the highest of 18 days of average mainline lane occupancy +1%

Speed

The threshold of volume based on the average of mainline lane traffic speed. The settings of thresholds of 6 plans are listed in Table 9.

Table 9 Speed Thresholds Setting

Plan No.	Thresholds
Plan 1	Minimum of 65 mph and 95^{th} percentile of the highest of 18 days of average mainline lane speed
Plan 2	Minimum of 64 mph and max(18 days of average mainline lane speed)
Plan 3	Median of 18 days of average mainline lane speed
Plan 4	Average of Plan 3 and Plan 5
Plan 5	Minimum of 18 days of average mainline lane speed
Plan 6	5^{th} percentile of the highest of 18 days of average mainline lane speed

6.3 Summary

The workbook uses historical traffic volume data to generate interval and threshold tables for ramp meter operation. Based on the local traffic characteristics, it provides comprehensive plan settings to accommodate various traffic demands. Overall, the result of the workbook seems to be very reasonable and easy to use. However, some refinements are recommended for consideration.

First, it seems that the result of retiming through the workbook heavily depends on the customized values usually derived from individual experience of field engineers. In other words, manual adjustments to the generated tables are required by field engineers who have experience in operating ramp meters.

Second, the activation of meters is solely determined by traffic conditions at a local ramp, without consideration of adjacent ramps. It would be reasonable to consider corridor control, which takes the advantage of ATIS technologies to navigate drivers.

Third, the setting of interval timing and thresholds based on the past 18 days data (average, median, 95 percentile and 5 percentile are used) may not reflect the future temporal variation of traffic conditions and neglect the increase and the decrease of traffic flow. For example, Figure 3 shows a slight decrease of average mainline traffic volume (at 16:30) as it goes from August to November and the ramp volume shows a more obvious decrease in Figure 4. In this case, it is more appropriate to use traffic parameters that can reflect the trend.

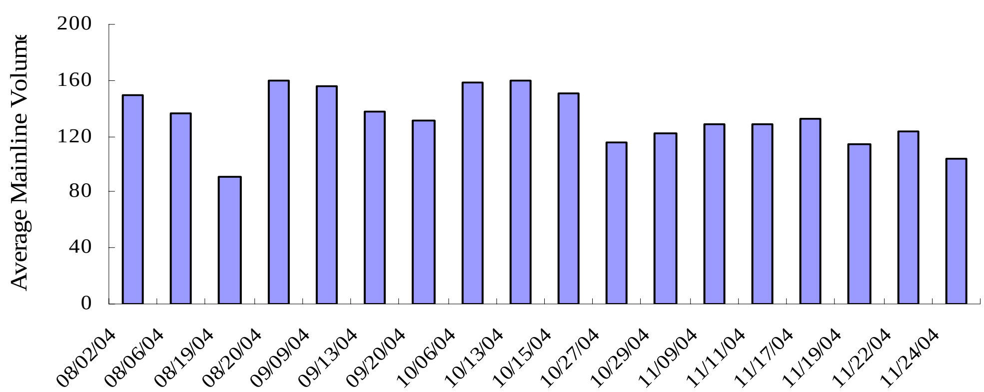

Figure 5 Mainline Traffic Volumes (RM-40-006)

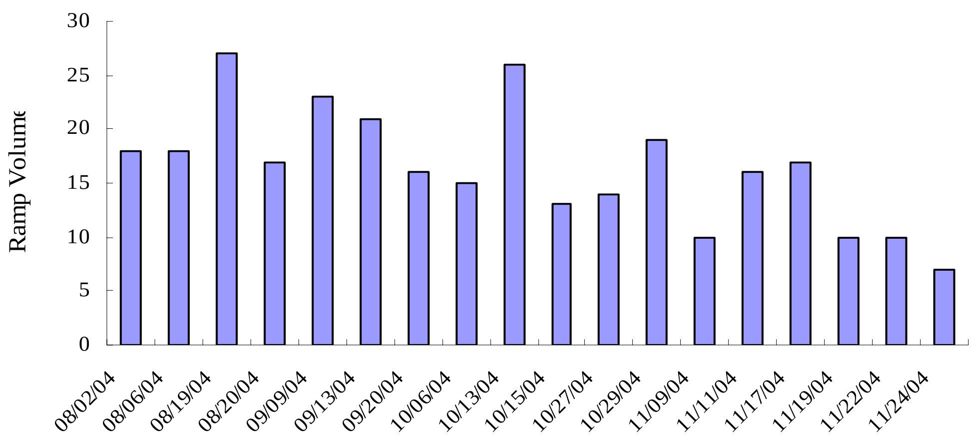

Figure 6 Ramp Traffic Volumes (RM-40-006)

A possible reference for this issue is the “Fuzzy Logic algorithm”, which is currently used by Washington DOT. It automatically calculates a new meter rate every 20 sec and adjusts the meter rate according to current traffic conditions, without engineers to manually conduct the meter operation.

7 EVALUATION OF RAMP METER RETIMING PROCEDURE IN SE WISCONSIN

A web-based survey was used to evaluate the current retiming procedure in Wisconsin. Respondents were asked to answer questions after reviewing the ramp meter retiming procedure in Wisconsin. As seen in Question 1, most states with local traffic responsive ramp metering system, do not have a firm retiming procedure.

Q1. Does your state have similar procedures to retime RM operations? If yes, please explain. If not, any reason?

State	Response
AZ	Plans 1-7 are the same. No plan 8, however we can set the mode 0 or 1 for Traffic Responsive. The green interval is fixed while the red interval varies. Our volume threshold is 1200 to 2400. Our occupancy is 55-75%. When queue occupancy is met the meter goes to level 1 (plan 1) which is the fastest metering rate.
CO	Not currently, but looking for some guidelines to follow.
GA	Yes, we perform similar retiming procedures.
MN	Our Stratified Zone Metering is not based on "timing" but we do time a simple time of day rate for each meter as a backup in case of loop detector malfunction. These are timed annually and set to 130% of the peak hourly demand rate. This is meant to simply break platoons and smooth merging but not manage bottlenecks. When is the data from? We like to use October data since it has higher volumes and less construction impact than summer months and less weather problems than winter and spring.
NY	No
UT	No, the WI procedures are far more advanced than ours currently.
WA	No. Our Fuzzy Logic Algorithm automatically calculates a new meter rate every 20 secs and adjusts the meter rate accordingly without engineers needing to manually tend to the meter operation. It basically allows us to do what you do once a year, every 20 secs. To optimize or "tune" a ramp meter for various objectives (i.e. high ramp volume, downstream mainline congestion, freeway incidents) we can change parameter weightings associated with the algorithm to get the meter to detect and respond accordingly.

The state of Arizona uses re-timing methods similar to Wisconsin. A respondent wondered that if plans 5 and 6 in Wisconsin, which have a longer red time, cause backups into intersections from the ramp meters. In New York, longer metering rates contribute to lower stopping compliance. In Utah, it was found that vehicles did not pass the stop bar uniformly with shorter cycles, with some unnecessary stopping and confusion.

Q2. Have you noticed any potential problems with the 16 plans that have been used in SE Wisconsin?

State	Response
AZ	No
CO	No
GA	No
MN	Do plan 5 and 6 cause backups into intersections from the ramp meters?? We use queue detectors (loops at the upstream end of the ramp) to override when this is likely to happen and prevent it.
NY	Long metering rates may promote non-compliance (It would in NY). Depending on ramp volume, queues may back-up onto crossroad. Will definitely cause diversion and may overload surface street system (traffic signals). Sometimes it is better to keep things simple.
UT	We use minimum of 4.5 second cycle - 2G, 2.5 R. Our experience with shorter cycles found that vehicles did not pass the stop bar uniformly, with some unnecessary stopping and confusion. We use a 2 second green with the rest of the cycle red
WA	No

Q3. Have you noticed any potential problems with the eight steps for retiming?

Most respondents strongly agreed with the Wisconsin RM retiming procedure. But they raised some questions regarding the use of optimization process. Also they indicated that the measure of effectiveness after the completion of retiming is not clear.

As illustrated in questions 4 and 5, the average evaluation score of the Wisconsin ramp meter retiming procedure is 7.5 on a scale of ten. In general, they also showed positive expectation on the improvement of ramp metering operation with the retiming procedure. Some respondents agreed the procedure itself seems reasonable but showed less expectation for the improvement of ramp metering operation.

Q4. Please give a score for the current eight steps for retiming in SE Wisconsin? (1-Very Poor 10-Very Good)

State	Response
Respondent 1	5
Respondent 2	10
Respondent 3	8
Respondent 4	6
Respondent 5	8
Respondent 6	8
Respondent 7	7
Respondent 8	8
Average	7.5

Q5. Do you believe this kind of retiming process will improve RM operation? (1-Not at all, 10-Very Helpful)

State	Response
Respondent 1	5
Respondent 2	10
Respondent 3	9
Respondent 4	5
Respondent 5	5
Respondent 6	5
Respondent 7	7
Respondent 8	9
Average	6.88

The one major component for ramp metering operation is determining proper “Green” and “Red” intervals. According to the survey, no major difference has been found between states and average for minimum and maximum green is 1.6 second and 2.1 seconds, respectively.

Q6.What is the minimum/maximum green time for RM operation in your state?

State	Minimum Green	Maximum Green
AZ	1.5	1.5
CO	2.0	2.5
GA	1.5	3.0
MN	1.3	1.3
NY	1.5	1.5
UT	2	2
WA	1.5	3.0
Average	1.6	2.1

The value for maximum red time varies by state. Also it depends on operational algorithm. The state of Arizona does have dual ramp meters in the sense that an on-ramp has two signal heads--one on the left and one on the right. The dual meters are set up to show only one green at a time. Only one car per green is permitted.

The state of New York discharges one vehicle per green. If it is a two lane ramp, it offsets the stop bars and discharge one vehicle per green per lane

Q7.What is the minimum/maximum red time for RM operation in your state?

State	Single discharge		Simultaneous Discharge		Duel Discharge	
	Min Red	Max Red	Min Red	Max Red	Min Red	Max Red
AZ	1.5	Balance of cycle length	N/A	N/A	N/A	N/A
CO	2	13	2	13	2	6
GA	1.5	6.0	N/A	N/A	N/A	N/A
MN	1	13	N/A	N/A	2.2	15.1
NY	2.5	until next veh actuation	2.5	until next veh actuation	N/A	N/A
UT	2.5	10	N/A	N/A	N/A	N/A
WA	1.5	6.0	N/A	N/A	N/A	N/A

8 REVIEW OF RAMP METER OPERATIONS IN OTHER STATES

A total of 11 states in the U.S. participated in the survey. The survey aimed to collect detailed information regarding operational features of ramp metering in various states. Table 10 and 11 summarize the general characters of ramp metering systems. The state of California is the most active state to deploy ramp meters and it is interesting the state of New York has a relatively low number of ramp meters considering it has a high level of traffic congestion.

In SE Wisconsin, Ramp meters were first installed in 1969 and have continued to grow to the current number of 125 ramp meters covering approximately 60 miles of freeway. Each RM has its own plan - depending on freeway volumes, ramp storage, and other ramp-specific instances.

Table 12 shows the ramp meter operational strategies being used in 11 states. Fixed time is the simplest form of metering which breaks up platoons of entering vehicles into single-vehicle entries. Usually, detectors are installed on the ramp to actuate and terminate the metering cycle, the metering rate is fixed, based on historically averaged traffic conditions. For local traffic responsive operation, the metering rate is based on prevailing traffic conditions in the vicinity of the ramp. Controller electronics and software algorithms select an appropriate metering rate by analyzing occupancy or flow data from ramp and mainline detectors.

System wide traffic responsive ramp metering operation seeks to optimize a multiple-ramp section of highway. Typically a centralized computer supervises numerous ramps and implements control features which override local metering instructions. It requires significant effort to develop proper control technique and algorithms. It seems most states are using more than one strategy depending on the characteristics of specific highway corridors. Preemption functions for emergency vehicle have not developed in any states yet.

Table 10 Summary of Ramp Metering Systems in the U.S.

State	Location/Corridor of RM	Time of implementation	Number of Meters	Corridor length	ADT	Heavy vehicle%
AZ	I-10, SR 51, SR 143, I-17, US 60, L101, L202	1980s	119	approximately 140 miles	approximately 130,000	8-12%
CA	Most freeways in major metropolitan areas. (total 12 districts in CA, among them, 7 districts have meters)	Fresno: 1993 San Diego: 1968	Fresno:18 Los Angeles: 1043 Orange County: 350 Sacramento: 52 San Bernardino: 116 San Diego: 238 San Francisco: 206 (2000)			
CO	I-25, I-225, I-70, I-270, US-36, SH470, US-6	Began with a demonstration project in 1981	54 currently with more planned	varies	varies	varies
GA	I-75 NB, north of downtown ATL, and 75/85 SB in downtown ATL	I-75 – 1996; I-75/85 – April 2005	9 total	I-75 – 6 miles; I-75/85SB–5 miles	I-75: 96,000 (NB alone); 75/85: 180,000 (SB alone)	10%
IL	Chicago Metro	started in 1962	113	175 center line miles	N/A	unknown
MN	Ramps meters exist on all colored corridors- http://www.dot.state.mn.us/rampmeterstudy/images/map011127.gif	built up over the last 30 years or so	approximately 400	varies	varies	varies
NY	Nassau, Suffolk and Queens Counties (Long Island)	1987	80	50 miles	186,000 & 165,000 (Two freeways within corridor)	10 % peak, 20% off Peak
OH	I-71, I-70, SR315	1993 and later	17 plus municipalities	6 miles	140,000	12%
OR	I-5, I-405, I-205, I-84, US 26, Ore217	In the 80's until present	> 140	ranges from 4 mi. to 24 mi.	80,000	appx. 10%

UT	I-15 Salt Lake and Davis Counties	1996 and 2001	23	25 miles	130,000 to 210,000	2-5%
WA	NB/SB I-5 between MP 154.14 – MP 186.34; NB/SB I-405 between MP 0.94 – MP 28.86; EB/WB I-90 between MP 3.52 – MP 17.87; EB/WB SR 520 between MP 1.05 – MP 12.0; NB/SB SR 167 between MP 15.82 – MP 26.81	For sections within the corridor: I-5: 1981; I-405: 1996; I-90: 1993; SR 520: 1986; SR 167: 1998	I-5: 47 meters; I-405: 36 meters; I-90: 16 meters; SR 520: 14meters; SR 167: 9 meters	I-5: 35 miles; I-405: 28 miles; I-90: 15 miles; SR 520: 11 miles; SR 167: 10 miles	I-5: 242,000 vehicles; I-405: 191,000 vehicles; I-90: 147,000vehicles; SR 520: 103,000 vehicles; SR 167: 124,000 vehicles	I-5: 11%; I-405: 7%; I-90: 19%; SR 520: 3%; SR 167: 8%

Table 11 Summary of Ramp Metering Operational Features

State	Controller type	Field Firmware /Software type	Preemption function for emergency vehicle
AZ	179, 2070	BiTran, i2 (Siemens ITS)	No
CA	C170 / C170E	TOS: V2.1.1 (in District 4) Semi-Automatic Traffic Management Software (SATMS) (in District 12 and 7) San Diego Ramp Metering Software (SDRMS): 7.0 (in District 3, 6, 8, 11)	No
CO	170 and 170E but moving to 170E solely	TransCore firmware, and ITT Industries Ramp Metering Control System software	No
GA	I-75: 170; 75/85: 2070	I-75: BiTran; 75/85 : Siemens	No
IL	ATMS - Central control using Local Traffic Response	FSK tone telemetry, central control - Custom by NET (National Engineering Technology)	No pre-emption
MN	170	in house custom firmware	No hardware/software, occasionally they call in to the operations center and the meters are overridden
NY	170E migrating to 2070 Lite	BiTran	No
OH	I70E	BiTran	No
OR	170E	W4LRM (Wapiti)	No
UT	Eagle 2070	Modified Gardner Siemens Nextphase	No
WA	Model 170	N/A	No. Preemption is manually switched remotely through the software by engineers at the TSMC.

Table 12 Types of Ramp Metering Systems

State	Fixed Time	Local Traffic Responsive	System-Wide Traffic Responsive	Other
AZ		√		
CA	√	√	√	
CO		√	√	Upstream coordination
GA	√			
IL	√	√		
MN	meters rates are set by zones up to 3 miles in length			
NY	√			
OH	√		√	
OR	√		√	
UT	√			
WI		√		
WA			√	

Table 13 summarizes different signal operations plans for ramp metering systems being used in 11 states plus Wiscosnin and Table 14 summarizes characteristics of RM "intervals" and "thresholds" in each sate and how the values are established.

Table 13 Summary of Signal Operations Plans

State	Signal operations plans
AZ	All are fixed time meaning turn on time is fixed and turn off time is fixed. Some are local traffic responsive meaning the rates (intervals) vary based on detection in the vicinity. Others are fixed rate meaning the meter has constant intervals that do not change unless a queue override is necessary.
CA	TOS, used in District 4 of Caltrans (Bay Area): can be set up as a fixed-time control or traffic responsive control. The traffic responsive control is usually set up as occupancy control, which is based on the occupancy data collected by freeway mainline detectors. One metering controller can meter up to four metered lanes with demand, passage and queue detectors per lane. It has six tables, each with 16 entries, and sixteen time-of-day tables, each with separate metering command action code for each metered lane and support for mainline HOV lanes. It also allows up to sixteen holiday / special event tables, each with independent action in time-of-day table. SATMS, used in District 7 (Los Angeles) and 12 (Orange County) of Caltrans: can be setup as a fixed-time control or traffic responsive control. The traffic responsive control is usually setup as demand-capacity control, which is based on the volume data collected by freeway mainline detectors. Queue override control is applied to avoid queue on on-ramp to spillback to surface streets. SDRMS, used in District 11 (San Diego), 3 (Sacramento), 6 (Fresno), 8 (San Bernardino) of Caltrans: can be setup as a fixed-time control or traffic responsive control. The traffic responsive control is either occupancy control or volume control, which is based on the occupancy data collected by freeway mainline detectors. Queue override control is applied to avoid queue on on-ramp to spillback to surface streets.
CO	Each signal has an a.m. and/or p.m. plan consisting of 6 metering rates per plan.
GA	Use a different plan for each day of the week, so 5 (per meter). Because the

	volumes on the freeway climb to excessive levels at different times each day of the week, with Monday being latest and Friday being earliest. Meter in PM rush hours only at this point. On Monday meters are activated at 2:00 pm, by Fridays meters are activated as early as 1:00 pm. The meter plan is based on volumes on the ramp. In order to prevent excessively long queues, the meters cycle the slowest when volumes are low (540 veh/hr), and the fastest when volumes are higher (900 veh/hr). Although this may seem counterintuitive to metering goals, the volumes are so high this is the only method can be used. Traffic responsive metering is not implemented yet, however, does have the infrastructure/detection to do this. There are mainline detectors, queue detectors and presence and passage detectors. Meters on I-75 are single lane ramps, and on 75/85 they are all dual lane meters with staggered release.
IL	Both fixed time and LTR
MN	Use a simple time of day plan only when detector data is not available, much less than 5% of meters, otherwise Stratified Zone Metering
NY	Meter at 900vph and use time of day clock to coincide with weekday commuter peak
OH	Developed on a case by case basis
OR	Loops are installed at the on-ramp and mainlines to calculate the density.
UT	2 fixed time (regular rate and queue override) Regular fixed time rates are determined by modeling, and currently applied to the entire peak hour
WI	Each RM has its own plan - depending on freeway volumes, ramp storage, and other ramp-specific instances.
WA	Ramp meters are operated using the Fuzzy Logic Algorithm.

Table 14 "Intervals" and "Thresholds" in Ramp Metering Systems

State	Signal operations plans
AZ	It is called intervals rates. The rates vary from 12 to 22 cars per minute. There are speed thresholds and volume thresholds. The speed thresholds vary from 55 to 15 miles per hour. The volume thresholds vary from 1200 to 2200 vehicles per hour per lane.
CA	For one metered lane, rate varies from 3 to 15 vehicles per minute (corresponding to 180 and 900 vehicles per hour). Metering rate changes every 30 second, which is a standard loop data collection interval used in California. Metering time period is usually from 6 to 9. Some locations may have longer period. Some meters are metered during the daytime.
CO	Generally try to limit the waiting period for vehicles queued on ramps to a maximum of 4-5 minutes.
GA	-
IL	Range from 10 to 18 vehicles per minute, permissive during peak traffic periods weekdays. At this time the ramps are disabled overnight, weekends and legal holidays.
MN	-
NY	-
OH	20 second poll of aggregated data (in server at TMC) provides loop status, volume, occupancy demand, queue and exit status RM activated based on this criteria, which occasionally occurs during off peak due to incidents
OR	Intervals and thresholds are historically based with modifications as necessary. These will be used in conjunction with a dynamically responsive system that is currently being phased in.
UT	Intervals determined by modeling. Thresholds not applicable at this time. Turn meters on and off by time of day. Metered with the specified rate for entire peak hour, unless queue override is called for by queue detectors
WI	Each ramp has intervals (red and green times) that are more restrictive as higher thresholds (volume, speed, occupancy) on the freeway are reached.
WA	-

Table 15 summarizes how often each state update "intervals" and "thresholds" for each RM plan, and what kinds of efforts are being made to validate/optimize the operation of RM.

Table 15 Validation/Optimization of Ramp Metering Systems

State	How often for RM updates	Validate/optimize efforts
AZ	No. Updates are made for new or malfunctioning meters on an as needed basis. An adaptive ramp metering study is underway.	N/A
CA	Regularly check our metering plans for various locations.	Based on our field observation, traffic data and on-ramp storage, adjust our metering rate accordingly.
CO	Rapid growth in the Denver Metro area means increased mainline and ramp volumes. Periodic adjustments have to be made to accommodate changing conditions.	Also, where a ramp may have been metered during the am or pm rush hour, may benefit from metering during both periods.
GA	Approx 1 time per year the plans are updated.	Use traffic volumes on the ramps primarily to validate the timing patters. Also, observation of the queues on the ramps.
IL	LTR is dynamic, time of day visited annually.	N/A
MN	Research at the University of Minnesota is currently in progress for improving thresholds and an in house analyst is responsible for day to day issues.	N/A
NY	No updates	N/A
OH	No updates	N/A
OR	Yes, at least once a year.	By reviewing traffic data and by observations.
UT	Recently updated interval timing after 3 years of operation. Probably undertake another corridor retiming in 2 years	Monitor ramp operation daily using computerized control with once per second status displays and also observe on CCTV.
WI	Retime each ramp 2 times a year. Some ramps are retimed more often due to construction/maintenance activities and/or complaints.	N/A
WA	Ramp meter optimization is performed continuously by engineers and interns working in the TSMC.	N/A

Table 16 shows information regarding preventive maintenance programs for ramp metering. Most states have a PM program but it is mainly for ramp meter physical features (e.g., lamps, cleaning cabinets, testing connectors, etc.).

Table 16 Preventive Maintenance Programs for Ramp Metering Systems

State	Signal operations plans
AZ	Filters are changed and controller cabinets are cleaned.
CA	N/A
CO	There is an ongoing consultant contract to provide technical support and rewrite code as needed to provide solutions to problems. Currently rewriting the controller firmware to enhance and/or expand capabilities of our system. Frequent modifications made to client

	interface software as well. Bi-annual preventative maintenance inspections on field equipment. Regular daily maintenance as needed.
GA	With a small number of meters so far, No comprehensive PM plan has been developed yet. The maintenance consists mainly of trimming trees/shrubs from around the signal heads, and replacing burned out lamps as needed. However, it has planned to increase the number of ramp meters in Atlanta to 119, so definitely develop a PM plan soon.
IL	Maintenance contract for hardware, failures and damage. 1 hour response to failure, next day for knock-downs. Maintenance involves testing, replacement of load relays, lamp replacement.
MN	During each metered peak two operators are, among other things, responsible for watching the meter operation and reporting anything questionable. It is later looked at in more detail. Since we use time of day as a backup for when not enough loop detector data is available to run our normal algorithm the metering requires little maintenance. Loop detectors are continuously tested with software and other tests are performed annually. The hardware of ramp meters is visually inspected quarterly; this includes watching the meter through a cycle.
NY	RM's are inspected monthly and any deficiencies are repaired. Also respond to complaints if any are received
OH	Software - none, respond to problems identified Hardware - visual inspection for various components, such as input and output card, CPU, modem, wiring, grounding, filters
OR	Annual inspections of Hardware and Software
UT	Technicians visit cabinets twice per year for HW PM. Check cleanliness of cabinet, fan, filter.
WI	Replacement of lights, loops, and other equipment.
WA	Each region within the state operates and maintains their ITS devices independently. We have an in-house software group that continuously updates software with new features. We have a budgeted ITS maintenance crew.

Table 17 summarizes the benefit and drawbacks that have been found in ramp metering systems. Most states observed a reduction of traffic congestion and an increase in speeds on the main line due to ramp metering implementation. However, it seems negative public reaction and queuing spillback onto local streets are still on-going issues for many states.

Table 17 Summary of Benefits and Drawbacks of Ramp Metering Systems

State	Benefits	Drawbacks
AZ	▪ Safer merging	▪ Traffic has few if any alternate route to divert to once ramp meter capacity has been met.
CA		▪ Local level control
CO	▪ Reduction in certain types of accidents (rear-end, side swipes) ▪ Increased average mainline speeds during am/pm rush hours.	▪ Initial negative phone calls from citizens using the on ramps when a new meter is installed because of what they perceive as an additional delay. These calls diminish and eventually cease after they get used to it and realize its benefits. Then get calls notifying us when a meter isn't on as scheduled. Also get requests for expanding our system to currently unmetered ramps. ▪ Some ramps cannot be metered due to its geometrics that would otherwise benefit from metering.
GA	▪ Reduction in mainline congestion. Specifically, it is observed that the congested conditions (less than 35 mph) start later in the rush hour, and conclude earlier in the rush hour. ▪ Additionally, the lowest speed reached in the rush hour is not as low with meters.	▪ None
IL	▪ Decreased travel times, decreased accidents. ▪ Study has not been conducted for 10 years.	▪ None - Some mainline back-ups onto ramps have been blamed of RM, but it mainline is not accepting vehicles, the RM has no effect.
MN	▪ Increased throughput, reduced crashes, reduced travel time, reduced travel time reliability, etc. ▪ See ramp meter study of 2001, ▪ http://www.dot.state.mn.us/rampmeterstudy/reports.html	▪ It is difficult for the public to understand the benefits that are more complicated than what they see.
NY	▪ Extends free flow operation of limited access facility during peak periods. ▪ Has increased operating speed during peak. ▪ Decreased area where freeway operated below 30 mph by 50%	▪ None
OH	▪ Congestion reduction, mainline crash rate reduction	▪ Ramp crash rate increases motorist complaints, generally resulting from equipment malfunction
OR	▪ Improved the mainline speed and volumes.	▪ Short ramps from designs dating previous to ramp meters. Maintaining data and communications.
UT	▪ Smoother traffic flow and reduced delays on mainline	▪ Occasionally queuing spillback onto local streets

WI	▪ Freeway Mainline speeds increase ▪ Accident rates decrease ▪ Travel time/delay time decreases, reduces platoons of vehicles which helps merging movements	▪ Delays entering freeway, queues extending to the arterials, some public dislike.
WA	▪ Ramp meters are a proven and cost-effective method of relieving traffic congestion. By increasing the efficiency of freeway use, ramp meters save taxpayers costs associated with building new lanes. ▪ Past ramp meter activations have reduced rear-end and side-swipe collisions by over 30%. ▪ On average, drivers wait less than 2 minutes at ramp meters during peak hours.	▪ None

Table 18 shows various activities in 11 states plus Wisconsin to improve ramp metering operations. System-wide operation and precise calibration for thresholds are commonly investigated items for future improvement. Several states are considering additional ramp meter implementation.

Table 18 Summary of the anticipated improvements for Ramp Metering

State	Improvements
AZ	An adaptive ramp metering study is underway.
CA	TOS 2.11 has been developed recently and is a highly enhanced program. The program is at its optimal condition and is being updated regularly based on our needs. The best way to optimize the metering operation is to use a program like Freq 11 and perform a traffic responsive (mainline occupancy) ramp metering plan. California initiated the Universal Ramp Metering System (URMS) Program in 1998. URMS can be configured to handle a wide range of ramp metering configurations and simulating both SDRMS and SATMS. A system wide ramp metering algorithm (called SWARM) has been tested in Los Angeles.
CO	The possible addition of a mid-day (lunch hour) rush plan. Feasibility studies to determine benefits of additional sites in Region VI (Denver Metro) and expansion into other Regions of CDOT.
GA	Implementing a System Wide Area Ramp Metering algorithm into our central software (SWARM). This will allow adjacent meters to "coordinate" their operation and do more balancing of volumes through the corridor. Currently, each meter runs independently with no regard to other meters in the area.
IL	Possible system wide control, HOV ramp meter, tuning the rates.
MN	Improve some threshold values, capacity, critical density, etc.
NY	Considering using the traffic responsive capabilities of the system for operations during non-peak weekday hours. Such as weekends during summer beach season
OH	Ohio State University is investigating (as part of a research contract) and will recommend plan of action replace central FMS software in future
OR	System Wide traffic responsive
UT	Presently working on plans to make ramp meters operate in local traffic responsive mode with corridor-wide algorithms
WI	Better optimization
WA	Possibly installing an additional set of loop detectors on the ramp, after the stop bar, to assist in secondary queue detection.

9 CONCLUSION AND RECOMMENDATION

To evaluate the ramp meter retiming procedure in Wisconsin, the retiming document was reviewed and studied. Eight steps of the retiming procedure seem to be very comprehensive and reasonable. The data collection process with the Data Extractor is well documented and visual inspection is in place to detect any abnormality in the data set.

The Ramp Meter Retiming Workbook uses historical traffic volume data to generate interval and threshold tables for ramp meter operation. In general, the workbook seems to be very reasonable, however, there is a varying degree of subjectivity that can heavily depend on the customized values which are usually modified based on individual experience of field engineers. The next logical step in advancing retiming of meters is to consider characteristics of adjacent ramps with the ultimate goal of establishing a system wide ramp metering algorithm that enhances mobility and safety throughout the region.

A survey was conducted to collect information regarding ramp meter retiming practices in other states. The survey also served as a peer review of current Wisconsin procedures. Most respondents strongly agreed with the Wisconsin RM retiming procedure. However, some respondents raised questions if the current procedure includes appropriate optimization process. The respondents also indicated the measure of effectiveness after the completion of retiming is not clear. The average evaluation score of the Wisconsin ramp meter retiming procedure is 7.5 on a scale of ten. However, some respondents indicated the procedure seems to be reasonable but does not clearly indicate the expected improvement of ramp metering operations.

Most states observed a reduction of traffic congestion and an increase in speeds on the main line due to ramp metering implementation. However, it seems negative public reaction and queuing spillback onto local streets are still on-going issues for many states.

Overall, the proposed retiming procedure is reasonable. But some improvements can be made though further study as follows:

1. The observation and analysis of SE Wisconsin highway traffic is needed. The justification of retiming for ramp meter comes from the variation of traffic volume. Thus, it is very essential to understand temporal variation of traffic volume.

2. Simulation analysis was not conducted in this study to evaluate the benefit of ramp meter retiming due to the limited scope of study. It is expected that simulation analysis can enhance the procedure itself as well as ensure the benefit of the ramp metering operation.

3. For local traffic responsive systems, the WI process seems to be quite sophisticated in comparison with other states.

4. To enhance the ramp metering operation in SE Wisconsin, corridor based timing with a longer term plan for a system wide RM algorithm should be studied and developed. As an initial step, system-wide ramp meter evaluation can be considered to measure mobility and safety impacts of ramp metering in SE Wisconsin.

APPENDIX: SUMMARY OF AGENCY SURVEY RESPONSES

Utah Department of Transportation

Q1. Please provide brief information about Ramp Metering (RM) in your State?
(If you state has several corridors that have Ramp Metering, please give us information for each corridor)
-Location/Corridor of RM in your State? I-15 Salt Lake and Davis Counties
-When it was implemented? 1996 and 2001
-How many ramp meters? 23
-What is the length of corridor? 25 miles
-What is the ADT on the corridor? 130,000 to 210,000
-Controller type? Eagle 2070
-Field Firmware/Software type? Modified Gardner Siemens Nextphase
-Does RM in your state have preemption function for emergency vehicle? No
-Percentage of heavy vehicle? 2-5%

Q2. RM operations in your State are:
Fixed Time

Q3. How many different signal operations plans are being used for RM in your State? Please explain details for each plan. Any particular algorithm has been applied? If you have any document on this, please email us.
2 fixed time (regular rate and queue override) Regular fixed time rates are determined by modeling, and currently applied to the entire peak hour 。

Q4.Please explain RM "intervals" and "thresholds" characteristics in your State and how your State decided/developed "intervals" and "thresholds"?
Intervals determined by modeling. Thresholds are not applicable at this time. We turn meters on and off by time of day. Unless queue override is called for by queue detectors, they run specified rate for entire peak hour.

Q5. Describe your preventive maintenance program for RM in your State? (Software/Hardware)
Technicians visit cabinets twice per year for HW PM. Check cleanliness of cabinet, fan, and filter.

Q6. Does your State often/regularly update "intervals" and "thresholds" for each RM plan? If yes, how often? What kinds of efforts are being made to validate/optimize the operation of RM?
We recently updated interval timing after 3 years of operation. We monitor ramp operation daily using computerized control with once per second status displays and also observe on CCTV. We will probably undertake another corridor retiming in 2 years.

Q7. What are major benefits that have been observed from RM implementation in your State?
Smoother traffic flow and reduced delays on mainline.

Q8. What are major drawbacks that have been observed from RM implementation in your State?
Occasional queuing spillback onto local streets

Q9. What improvements are you investigating that will improve RM in your State?
We are presently working on plans to make ramp meters operate in local traffic responsive mode with corridor-wide algorithms.

Oregon Department of Transportation

Q1. Please provide brief information about Ramp Metering (RM) in your State?
(If you state has several corridors that have Ramp Metering, please give us information for each corridor)
-Location/Corridor of RM in your State? I-5, I-405, I-205, I-84, US 26, Ore217
-When it was implemented? In the 80's until present
-How many ramp meters? 140
-What is the length of corridor? Ranges from 4 mi. to 24 mi.
-What is the ADT on the corridor? 80,000
-Controller type? 170 E
-Field Firmware/Software type? W4LRM (Wapiti)
-Does RM in your state have preemption function for emergency vehicle? No
-Percentage of heavy vehicle? Appx. 10%

Q2. RM operations in your State are:
Local Traffic Responsive, System-Wide Traffic Responsive

Q3. How many different signal operations plans are being used for RM in your State? Please explain details for each plan. Any particular algorithm has been applied? If you have any document on this, please email us.
Loops are installed at the on-ramp and mainlines to calculate the density.

Q4.Please explain RM "intervals" and "thresholds" characteristics in your State and how your State decided/developed "intervals" and "thresholds"?
Intervals and thresholds are historically based with modifications as necessary. These will be used in conjunction with a dynamically responsive system that is currently being phased in.

Q5. Describe your preventive maintenance program for RM in your State? (Software/Hardware)
Annual inspections of Hardware and Software

Q6. Does your State often/regularly update "intervals" and "thresholds" for each RM plan? If yes, how often? What kinds of efforts are being made to validate/optimize the operation of RM?
Yes, at least once a year. By reviewing traffic data and by observations.

Q7. What are major benefits that have been observed from RM implementation in your State?
The mainline speed and volumes.

Q8. What are major drawbacks that have been observed from RM implementation in your State?
Short ramps from designs dating previous to ramp meters. Maintaining data and communications.

Q9. What improvements are you investigating that will improve RM in your State?
System Wide traffic responsive

Ohio Department of Transportation

Q1. Please provide brief information about Ramp Metering (RM) in your State?
(If you state has several corridors that have Ramp Metering, please give us information for each corridor)
-Location/Corridor of RM in your State? I-71, I-70, SR315
-When it was implemented? 1993 and later
-How many ramp meters? 17 plus municipalities
-What is the length of corridor? 6 miles
-What is the ADT on the corridor? 140,000
-Controller type? I70E
-Field Firmware/Software type? Bitran
-Does RM in your state have preemption function for emergency vehicle? no
-Percentage of heavy vehicle? 12

Q2. RM operations in your State are:
Local Traffic Responsive, System-Wide Traffic Responsive

Q3. How many different signal operations plans are being used for RM in your State? Please explain details for each plan. Any particular algorithm has been applied? If you have any document on this, please email us.
Developed on a case by case basis

Q4.Please explain RM "intervals" and "thresholds" characteristics in your State and how your State decided/developed "intervals" and "thresholds"?
20 second poll of aggregated data (in server at TMC) provides loop status, volume, occupancy demand, queue and exit status RM activated based on this criteria, which occasionally occurs during off peak due to incidents

Q5. Describe your preventive maintenance program for RM in your State? (Software/Hardware)
Software - none, respond to problems identified Hardware - visual inspection for various components, such as input and output card, CPU, modem, wiring, grounding, filters

Q6. Does your State often/regularly update "intervals" and "thresholds" for each RM plan? If yes, how often? What kinds of efforts are being made to validate/optimize the operation of RM?
no

Q7. What are major benefits that have been observed from RM implementation in your State?
Congestion reduction, mainline crash rate reduction

Q8. What are major drawbacks that have been observed from RM implementation in your State?
Ramp crash rate increases motorist complaints, generally resulting from equipment malfunction.

Q9. What improvements are you investigating that will improve RM in your State?
Ohio State University is investigating (as part of a research contract) and will recommend plan of action Replace central FMS software in future.

New York Department of Transportation

Q1. Please provide brief information about Ramp Metering (RM) in your State?
(If you state has several corridors that have Ramp Metering, please give us information for each corridor)
-Location/Corridor of RM in your State?
Nassau, Suffolk and Queens Counties (Long Island)
-When it was implemented? 1987
-How many ramp meters? 80
-What is the length of corridor? 50 miles
-What is the ADT on the corridor? 186,000 & 165,000 (Two freeways within corridor)
-Controller type? Currently 170e migrating to 2070 lites
-Field Firmware/Software type? BiTran
-Does RM in your state have preemption function for emergency vehicle? No
-Percentage of heavy vehicle? Varies 10 % peak, 20% off Peak

Q2. RM operations in your State are:
Fixed Time

Q3. How many different signal operations plans are being used for RM in your State? Please explain details for each plan. Any particular algorithm has been applied? if you have any document on this, please email us.
We meter at 900vph and use time of day clock to coincide with weekday commuter peak

Q4.Please explain RM "intervals" and "thresholds" characteristics in your State and how your State decided/developed "intervals" and "thresholds"?
N/A

Q5. Describe your preventive maintenance program for RM in your State? (Software/Hardware)
RM's are inspected monthly and any deficiencies are repaired. We also respond to complaints if any are received

Q6. Does your State often/regularly update "intervals" and "thresholds" for each RM plan? If yes, how often? What kinds of efforts are being made to validate/optimize the operation of RM?
No

Q7. What are major benefits that have been observed from RM implementation in your State?
Extends freeflow operation of limited access facility during peak periods. Has increased operating speed during peak. Decreased area where freeeway operated below 30 mph by 50%

Q8. What are major drawbacks that have been observed from RM implementation in your State?
Can't think of any

Q9. What improvements are you investigating that will improve RM in your State?
We are considering using the traffic responsive capabilities of the system for operations during non-peak weekday hours. Such as weekends during summer beach season

Minnesota Department of Transportation

Q1. Please provide brief information about Ramp Metering (RM) in your State?
(If you state has several corridors that have Ramp Metering, please give us information for each corridor)
-Location/Corridor of RM in your State? Ramps meters exist on all colored corridors
-When it was implemented? Built up over the last 30 years or so
-How many ramp meters? Approximately 400.
-What is the length of corridor? Varies
-What is the ADT on the corridor? Varies
-Controller type? 170
-Field Firmware/Software type? In house custom firmware
-Does RM in your state have preemption function for emergency vehicle?
No hardware/software, occasionally they call in to the operations center and the meters are overridden
-Percentage of heavy vehicle? varies

Q2. RM operations in your State are:
Meters rates are set by zones up to 3 miles in length

Q3. How many different signal operations plans are being used for RM in your State? Please explain details for each plan. Any particular algorithm has been applied? if you have any document on this, please email us.
We use a simple time of day plan only when detector data is not available, much less than 5% of meters, otherwise Stratified Zone Metering (document emailed)

Q4.Please explain RM "intervals" and "thresholds" characteristics in your State and how your State decided/developed "intervals" and "thresholds"?
See emailed document.

Q5. Describe your preventive maintenance program for RM in your State? (Software/Hardware)
During each metered peak two operators are, among other things, responsible for watching the meter operation and reporting anything questionable. It is later looked at in more detail. Since we use time of day as a backup for when not enough loop detector data is available to run our normal algorithm the metering requires little maintenance. Loop detectors are continuously tested with software and other tests are performed annually. The hardware of ramp meters is visually inspected quarterly, this includes watching the meter through a cycle.

Q6. Does your State often/regularly update "intervals" and "thresholds" for each RM plan? If yes, how often? What kinds of efforts are being made to validate/optimize the operation of RM?
Yes, research at the University of Minnesota is currently in progress for improving thresholds and an in house analyst is responsible for day to day issues.

Q7. What are major benefits that have been observed from RM implementation in your State?
Increased throughput, reduced crashes, reduced travel time, reduced travel time reliability, etc. See ramp meter study of 2001,
http://www.dot.state.mn.us/rampmeterstudy/reports.html

Q8. What are major drawbacks that have been observed from RM implementation in your State?
It is difficult for the public to understand the benefits that are more complicated than what they see.

Q9. What improvements are you investigating that will improve RM in your State?
We would like to improve some threshold values, capacity, critical density, etc.

Illinois Department of Transportation

Q1. Please provide brief information about Ramp Metering (RM) in your State?
(If you state has several corridors that have Ramp Metering, please give us information for each corridor)
-Location/Corridor of RM in your State?
-When it was implemented? Started in 1962
-How many ramp meters? 113
-What is the length of corridor? 175 center line miles
-What is the ADT on the corridor?
-Controller type? ATMS - Central control using Local Traffic Response
-Field Firmware/Software type?
FSK tone telemetry, central control - Custom by NET (National Engineering Technology
-Does RM in your state have preemption function for emergency vehicle? No pre-emption
-Percentage of heavy vehicle? unknown

Q2. RM operations in your State are:
Fixed Time and Local Traffic Responsive

Q3. How many different signal operations plans are being used for RM in your State? Please explain details for each plan. Any particular algorithm has been applied? if you have any document on this, please email us.
Both fixed time and LTR

Q4.Please explain RM "intervals" and "thresholds" characteristics in your State and how your State decided/developed "intervals" and "thresholds"?
Range from 10 to 18 vehicles per minute, permissive during peak traffic periods weekdays. At this time the ramps are disabled overnight, weekends and legal holidays.

Q5. Describe your preventive maintenance program for RM in your State? (Software/Hardware)
Maintenance contract for hardware, failures and damage. 1 hour response to failure, next day for knock-downs. Maintenance involves testing, replacement of load relays, lamp replacement.

Q6. Does your State often/regularly update "intervals" and "thresholds" for each RM plan? If yes, how often? What kinds of efforts are being made to validate/optimize the operation of RM?
LTR is dynamic, time of day visited annually.

Q7. What are major benefits that have been observed from RM implementation in your State?
Decreased travel times, decreased accidents. Study has not been conducted for 10 years.

Q8. What are major drawbacks that have been observed from RM implementation in your State?
None - Some mainline back-ups onto ramps have been blamed of RM, but it mainline is not accepting vehicles, the RM has no effect.

Q9. What improvements are you investigating that will improve RM in your State?
Possible system wide control, HOV ramp meter, tuning the rates.

Georgia Department of Transportation

Q1. Please provide brief information about Ramp Metering (RM) in your State?
(If you state has several corridors that have Ramp Metering, please give us information for each corridor)
-Location/Corridor of RM in your State?
I-75 NB, north of downtown ATL, and 75/85 SB in downtown ATL
-When it was implemented? I-75 - 1996; I-75/85 - April 2005
-How many ramp meters? 9 total
-What is the length of corridor? I-75 - 6 miles.... I-75/85 SB - 5 miles
-What is the ADT on the corridor?
I-75: 96,000 (NB alone); 75/85: 180,000 (SB alone)
-Controller type? I-75: 170; 75/85: 2070
-Field Firmware/Software type? I-75: BiTrans; 75/85 : Siemens
-Does RM in your state have preemption function for emergency vehicle? No
-Percentage of heavy vehicle? 0%

Q2. RM operations in your State are:
Fixed Time

Q3. How many different signal operations plans are being used for RM in your State? Please explain details for each plan. Any particular algorithm has been applied? if you have any document on this, please email us.
We use a different plan for each day of the week, so 5 (per meter). The reason we do this is because the volumes on the freeway climb to excessive levels at different times each day of the week, with Monday being latest and Friday being earliest. We meter in PM rush hours only at this point. On Monday they activate at 2:00 pm, by Fridays they activate as early as 1:00 pm.
The meter plan is based on volumes on the ramp. In order to prevent excessively long queues, the meters cycle the slowest when volumes are low (540 veh/hr), and the fastest when volumes are higher (900 veh/hr). Although this may seem counterintuitive to metering goals, the volumes are so high this is the only method we can use.
We have not tried traffic responsive metering as of yet. However, we do have the infrastructure/detection to do this. We have mainline detectors, queue detectors and presence and passage detectors.
Our meters on I-75 are single lane ramps, and on 75/85 they are all dual lane meters with staggered release.

Q4.Please explain RM "intervals" and "thresholds" characteristics in your State and how your State decided/developed "intervals" and "thresholds"?
see above

Q5. Describe your preventive maintenance program for RM in your State? (Software/Hardware)
With a small number of meters so far, we have not developed a comprehensive PM plan. Our maintenance consists mainly of trimming trees/shrubs from around the signal heads, and replacing burned out lamps as needed. However, we have plans to increase the number of ramp meters in ATL to 119, so we'll definitely develop a PM plan soon.

Q6. Does your State often/regularly update "intervals" and "thresholds" for each RM plan? If yes, how often? What kinds of efforts are being made to validate/optimize the operation of RM?
Approx 1 time per year the plans are updated. We use traffic volumes on the ramps primarily to validate the timing patters. Also, observation of the queues on the ramps.

Q7. What are major benefits that have been observed from RM implementation in your State?
Reduction in mainline congestion. Specifically, we see the congested conditions (less than 35 mph) start later in the rush hour, and conclude earlier in the rush hour.

Additionally, the lowest speed reached in the rush hour is not as low with meters.

Q8. What are major drawbacks that have been observed from RM implementation in your State?
None.

Q9. What improvements are you investigating that will improve RM in your State?
We are implementing a System Wide Area Ramp Metering algorithm into our central software (SWARM). This will allow adjacent meters to "coordinate" their operation and do more balancing of volumes through the corridor. Currently, each meter runs independently with no regard to other meters in the area.

Colorado Department of Transportation

Q1. Please provide brief information about Ramp Metering (RM) in your State?
(If you state has several corridors that have Ramp Metering, please give us information for each corridor)
-Location/Corridor of RM in your State? I-25, I-225, I-70, I-270, US-36, SH470, US-6
-When it was implemented? Began with a demonstration project in 1981.
-How many ramp meters? 54 currently with more planned
-What is the length of corridor? Varies
-What is the ADT on the corridor? Varies
-Controller type? 170 and 170E but moving to 170E solely
-Field Firmware/Software type?
JHK firmware, and ITT Industries Ramp Metering Control System software.
-Does RM in your state have preemption function for emergency vehicle? No
-Percentage of heavy vehicle? varies by corridor

Q2. RM operations in your State are:
Local Traffic Responsive, System-Wide Traffic Responsive and upstream coordination

Q3. How many different signal operations plans are being used for RM in your State? Please explain details for each plan. Any particular algorithm has been applied? if you have any document on this, please email us.
Each signal has an a.m. and/or p.m. plan consisting of 7 metering rates per plan with 7 being off.

Q4.Please explain RM "intervals" and "thresholds" characteristics in your State and how your State decided/developed "intervals" and "thresholds"?
We generally try to limit the waiting period for vehicles queued on ramps to a maximum of 4-5 minutes.

Q5. Describe your preventive maintenance program for RM in your State? (Software/Hardware)
We have an ongoing consultant contract to provide technical support and rewrite code as needed to provide solutions to problems. Currently rewriting the controller firmware to enhance and/or expand capabilities of our system. Frequent modifications made to client interface software as well. Bi-annual preventative maintenance inspections on field equipment. Regular daily maintenance as needed.

Q6. Does your State often/regularly update "intervals" and "thresholds" for each RM plan? If yes, how often? What kinds of efforts are being made to validate/optimize the operation of RM?
Yes. Rapid growth in the Denver Metro area means increased mainline and ramp volumes. Periodic adjustments have to be made to accommodate changing conditions. Also, where a ramp may have been metered during the a.m or p.m. rush hour, may benefit from metering during both periods.

Q7. What are major benefits that have been observed from RM implementation in your State?
Reduction in certain types of accidents (rear-end, side swipes)and increased average mainline speeds during am/pm rush hours.

Q8. What are major drawbacks that have been observed from RM implementation in your State?
Initial negative phone calls from citizens using the on ramps when a new meter is installed because of what they perceive as an additional delay. These calls diminish and eventually cease after they get used to it and realize it's benefits. Then we get calls notifying us when a meter isn't on as scheduled. Also get requests for expanding our system to currently unmetered ramps. Some ramps cannot be metered due to it's geometrics, that would otherwise benefit from metering.

Q9. What improvements are you investigating that will improve RM in your State?

The possible addition of a mid-day (lunch hour) rush plan. Feasibility studies to determine benefits of additional sites in Region VI (Denver Metro) and expansion into other Regions of CDOT.

Arizona Department of Transportation

Q1. Please provide brief information about Ramp Metering (RM) in your State?
(If you state has several corridors that have Ramp Metering, please give us information for each corridor)
-Location/Corridor of RM in your State? I-10, SR 51, SR 143, I-17, US 60, L101, L202
-When it was implemented? 1980s
-How many ramp meters? 119
-What is the length of corridor? Approximately 140 miles
-What is the ADT on the corridor? Approximately 130,000
-Controller type? 179, 2070
-Field Firmware/Software type? BiTrans, i2 (Siemens ITS).
-Does RM in your state have preemption function for emergency vehicle? No
-Percentage of heavy vehicle? 8-12%

Q2. RM operations in your State are:
Local Traffic Responsive

Q3. How many different signal operations plans are being used for RM in your State? Please explain details for each plan. Any particular algorithm has been applied? if you have any document on this, please email us.
All are fixed time, meaning turn on time is fixed and turn off time is fixed. Some are local traffic responsive, meaning the rates (intervals) vary based on detection in the vicinity. Others are fixed rate, meaning the meter has constant intervals that do not change unless a queue override is necessary.

Q4.Please explain RM "intervals" and "thresholds" characteristics in your State and how your State decided/developed "intervals" and "thresholds"?
We call intervals rates. Our rates vary from 12 to 22 cars per minute. We have speed thresholds and volume thresholds. The speed thresholds vary from 55 to 15 miles per hour. The volume thresholds vary from 1200 to 2200 vehicles per hour per lane.

Q5. Describe your preventive maintenance program for RM in your State? (Software/Hardware)
Filters are changed and controller cabinets are cleaned.

Q6. Does your State often/regularly update "intervals" and "thresholds" for each RM plan? If yes, how often? What kinds of efforts are being made to validate/optimize the operation of RM?
No. Updates are made for new or malfunctioning meters on an as needed basis. An adaptive ramp metering study is underway.

Q7. What are major benefits that have been observed from RM implementation in your State?
Safer merging.

Q8. What are major drawbacks that have been observed from RM implementation in your State?
Traffic has few if any alternate routes to divert to once ramp meter capacity has been met.

Q9. What improvements are you investigating that will improve RM in your State?
An adaptive ramp metering study is underway.

Washington Department of Transportation

Q1. Please provide brief information about Ramp Metering (RM) in your State?
(If you state has several corridors that have Ramp Metering, please give us information for each corridor)
-Location/Corridor of RM in your State?
NB/SB I-5 between MP 154.14 - MP 186.34; NB/SB I-405 between MP 0.94 - MP 28.86; EB/WB I-90 between MP 3.52 - MP 17.87; EB/WB SR 520 between MP 1.05 - MP 12.0; NB/SB SR 167 between MP 15.82 - MP 26.81
-When it was implemented?
For sections within the corridor: I-5: 1981; I-405: 1996; I-90: 1993; SR 520: 1986; SR 167: 1998
-How many ramp meters?
I-5: 47 meters; I-405: 36 meters; I-90: 16 meters; SR 520: 14 meters; SR 167: 9 meters
-What is the length of corridor?
I-5: 35 miles; I-405: 28 miles; I-90: 15 miles; SR 520: 11 miles; SR 167: 10 miles
-What is the ADT on the corridor?
I-5: 242,000 vehicles; I-405: 191,000 vehicles; I-90: 147,000 vehicles; SR 520: 103,000 vehicles; SR 167: 124,000 vehicles
-Controller type? Model 170
-Field Firmware/Software type?
-Does RM in your state have preemption function for emergency vehicle?
No. Preemption is manually switched remotely through the software by engineers at the TSMC.
-Percentage of heavy vehicle?
I-5: 11%; I-405: 7%; I-90: 19%; SR 520: 3%; SR 167: 8%

Q2. RM operations in your State are:
System-Wide Traffic Responsive Other

Q3. How many different signal operations plans are being used for RM in your State? Please explain details for each plan. Any particular algorithm has been applied? if you have any document on this, please email us.
Ramp meters are operated using the Fuzzy Logic Algorithm. I've emailed a document (Fuzzy Logic Manual) explaining how this algorithm is implemented on our ramp meters.

Q4.Please explain RM "intervals" and "thresholds" characteristics in your State and how your State decided/developed "intervals" and "thresholds"?
N/A

Q5. Describe your preventive maintenance program for RM in your State? (Software/Hardware)
Each region within the state operates and maintains their ITS devices independently. We have an in-house software group that continuously updates software with new features. We have a budgeted ITS maintenance crew.

Q6. Does your State often/regularly update "intervals" and "thresholds" for each RM plan? If yes, how often? What kinds of efforts are being made to validate/optimize the operation of RM?
Ramp meter optimization is performed continuously by engineers and interns working in the TSMC.

Q7. What are major benefits that have been observed from RM implementation in your State?
Ramp meters are a proven and cost-effective method of relieving traffic congestion. By increasing the efficiency of freeway use, ramp meters save taxpayers costs associated with building new lanes. Past ramp meter activations have reduced rear-end and side-swipe collisions by over 30%. On average, drivers wait less than 2 minutes at ramp meters during peak hours.

Q8. What are major drawbacks that have been observed from RM implementation in your State?
N/A

Q9. What improvements are you investigating that will improve RM in your State?
Possibly installing an additional set of loop detectors on the ramp, after the stop bar, to assist in secondary queue detection.