WISCONSIN TRAFFIC OPERATIONS
& SAFETY LABORATORY
UNIVERSITY OF WISCONSIN-MADISON
Department of Civil and Environmental Engineering

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Subject: Ramp Metering Evaluation – Technical Memo #4
Metering Algorithms

The Bureau of Highway Operations Traffic Operations Unit, the Statewide Traffic Operations Center, and the Wisconsin Traffic Operations and Safety (TOPS) Lab have explored Wisconsin's ramp metering algorithm operations. WisDOT currently utilizes a time of day local ramp metering algorithm, and there has never been any evaluation of the effectiveness of this ramp metering algorithm in Wisconsin, and whether or not the algorithm could be improved.

An survey was completed of 33 different ramp metering algorithms used throughout the country. Each algorithm was evaluated against its benefits, relative costs, and concerns related to implementation and operation. Discussions were held with selected states, including Oregon, Colorado, and New York, to aid in understanding other states' experiences with ramp metering algorithms. This effort has resulted in valuable insight into the widely varied practice of ramp metering nationwide.

Given the possibility that the time and expense needed to implement an entirely new algorithm in Wisconsin was beyond the resources available, it was decided that the next best steps are to perform a detailed evaluation of current metering operations and whether improvements are possible given the current constraints of the equipment and software. This is to be accomplished by utilizing existing microsimulation models developed using Paramics and available at numerous metering locations in the Milwaukee and Madison areas.

The existing ramp meter algorithm may be modeled at each of five on-ramps, along with different ramp metering timing schemes to determine whether more optimal plans are achievable for low cost. Simple examples of possible improvements include gradual quickening of the metering rate at the end of the metering time period so that the residual queue does not flood the freeway all at once and also modifying the volume to capacity thresholds currently in use.

It is expected that the results of this evaluation could lead to more efficient operations of meters utilizing the existing algorithm.

Nationwide Ramp Meter Algorithms

In late 2006, WisDOT reviewed many ramp metering algorithms used throughout the country. Each algorithm was evaluated against its benefits, relative costs, and concerns related to implementation and operation. Furthermore, discussions were held with selected states, including Oregon, Colorado, and New York, to aid in understanding other states' experiences with ramp metering algorithms. This effort has resulted in valuable insight into the widely varied practice of ramp metering nationwide.

Below is a list of many diverse ramp meter algorithms (Scariza 2003; Zhang et al 2001). Traffic responsive ramp meters use local and/or coordinated ramp meter algorithms. This is an abbreviated and descriptive list that includes neither interview material nor the initial assessment of feasibility and benefits.

Local Ramp Meter Algorithms

Local control is a process of selecting ramp meter rates based solely on conditions present at an individual ramp. In some cases, congestion problems at the ramp may appear to be fixed, when in reality problems are transferred to or uncovered at upstream or downstream locations.

<u>ALINEA</u>
The control input is based on the system output. The goal of ALINEA is to sustain near maximum flow downstream of the on-ramp by regulating the downstream occupancy to a target value, which is set a little below the critical occupancy at which congestion first appears.

<u>ALINEA/Q</u>
This algorithm calculates two metering rates. The first rate is calculated exactly the same as ALINEA. The second rate that is calculated is the minimum rate needed to keep the ramp queue at or below the maximum allowable queue length.

<u>FL-ALINEA</u>
FL-ALINEA uses flow measurements from downstream detectors, rather than occupancy measurements.

<u>MALINEA</u>
MALINEA addresses a shortcoming of ALINEA by measuring the upstream occupancy.

<u>UF-ALINEA</u>
It simply uses the sum of the upstream flow and the ramp flow to estimate the downstream flow.

<u>UP-ALINEA</u>
Uses occupancy measurements, but from upstream detectors, and estimates the downstream occupancy.

<u>X-ALINEA/Q</u>
This is where any of the modified ALINEA algorithms are used with queue control. All of these algorithms, except for X-ALINEA/Q are less efficient than the traditional ALINEA algorithm, but are useful when various occupancy measurements are not available.

<u>Demand-Capacity</u>

This traffic responsive algorithm measures the downstream occupancy. If it is above the critical occupancy, congestion is assumed to exist. The metering rate is then set to the min rate. Otherwise, the volume is measured upstream of the merge and the metering rate is set to the difference between the downstream capacity and the upstream volume.

<u>Fixed-Rate or Time-of-Day</u>
Ramp meter timings are adjusted automatically by specified time-of-day parameters. This algorithm does not afford flexibility for changing traffic conditions.

<u>Percent-Occupancy</u>
This strategy uses only upstream sensor occupancy measurements to identify and measure congestion. The critical occupancy is measured using historical data.

<u>RPMS (Ramp Metering Pilot Scheme)</u>
The heart of the algorithm is the function that cycles through each of the following conditions: determines if ramp metering needs to be switched on or off using mainline smoothed flows and speeds downstream of the ramp; determine if a new cycle length needs to be calculated; determine if queue adjustment is necessary; and determine the technical issues related to the ramp meter signals.

System-wide Coordinated Ramp Meter Algorithms

This is a process of selecting metering rates based on conditions throughout the entire length of the metered corridor. This makes system-wide control more flexible in handling reductions in capacity that occur as a result of congestion or non-recurring incidents.

<u>ARMS (Advanced Real-time Metering System)</u>
ARMS works on two levels. In the first level, a system-wide control policy is to maintain free flow conditions. A prediction and pattern recognition algorithm is also developed to predict in real time the potential occurrence of recurrent congestion. In the second level, the algorithm works to resolve congestion once it develops. It does this by minimizing the congestion clearance time and queues on the controlled ramps.

<u>BEEX (Balanced Efficiency & Equity)</u>
BEEX seeks to minimize the total weighted travel time, which involves weighting both the freeway mainline travel time and the ramp delays.

<u>Fuzzy Logic</u>
It can balance several performance objectives simultaneously, such as occupancy, flow rate, speed, and ramp queue. The performance objectives are divided into finite categories and then rules are developed with different weighting factors to relate traffic conditions with metering levels. Fuzzy logic can anticipate a problem and take temperate, corrective action before congestion occurs. With congestion indicators as inputs, the Fuzzy Logic can handle poor data, incidents, special events, and adverse weather without modifying the control parameters.

<u>Linear</u>

The linear algorithm maximizes the weighted sum of ramp flows. It also computes a real-time capacity for each road segment. The drawbacks of this algorithm are 1) its performance is heavily dependent on accurate O-D data, and 2) it is static, i.e., it neglects the variation of travel time in its computation of ramp metering rates.

METALINE
The metering rate of each ramp is computed based on the change in measured occupancy of each freeway segment under METALINE control, and the deviation of occupancy from critical occupancy for each segment that has a controlled on-ramp.

Metering model for non-recurrent congestion
It has a dynamic traffic flow model to describe the traffic flow process, explicitly links control with a clear set of objectives, takes into account system-wide physical and environmental constraints and projected traffic conditions, and uses a rigorous yet straightforward solution procedure to obtain real-time metering rates.

MILOS (Multi-Objective, Integrated, Large-Scale, & Optimized System)
The area wide coordinator assigns target ramp metering rates to maximize freeway throughput, balance ramp queue growth rates, and minimize queue spill-back into the adjacent surface street interchanges.

SZM (Stratified Zone Metering)
Effective in reducing ramp delays and queues, reducing freeway travel time and delay, increasing freeway speed, smoothing freeway flow, as well as reducing the number of stops.

Local & Systemwide Coordinated Ramp Meter Algorithms

The following algorithms have both local and coordinated capabilities.

Bottleneck
For each ramp, the more restrictive of the two rates is chosen. Local: A control strategy compares the upstream demand with the downstream supply, then takes the difference of them as the locally determined metering rate. Systemwide: A coordinated control strategy first identifies bottlenecks, decides the volume reduction for the bottleneck based on flow conservation, and then distributes the volume reduction to upstream ramps according to predetermined weights.

Compass
The most restrictive of the following two rates is selected. Local: Determines the metering rates from an ad-hoc look-up table, which has multiple levels for each ramp, determined by the local mainline occupancy, the downstream mainline occupancy, and the upstream mainline volume. Systemwide: Coordinated control use of off-line optimization to generate metering rates based on system-wide information. Compass addresses spillback through overriding restrictive rates. If the occupancy at a ramp queue detector exceeds its threshold value, the metering rate is increased by one rate level until the detected occupancy is back below the threshold level.

Dynamic metering control
Local control attempts to maintain traffic conditions close to the target traffic conditions that are provided by area-wide control. It obtains metering rates through minimizing the total system travel time that includes travel time on freeway and delay on ramps, subject to demand and queue capacity constraints.

FLOW
FLOW tries to keep traffic at a predefined bottleneck below capacity and works best at very high traffic volumes. The most restrictive of the following two rates is chosen. Local: The metering rate associated with each upstream occupancy is the difference between the capacity and volume associated with the occupancy on the fundamental diagram. Systemwide: For the bottleneck metering rate, bottleneck locations on the freeway must be determined. The bottleneck metering rate for each ramp is then calculated by subtracting the bottleneck metering rate reduction from the measured on-ramp flow during the previous interval.

Helper (or incremental)
A freeway corridor is divided into six groups consisting of one to seven ramps per group. Local: In the local traffic responsive metering component, each meter selects one of six available metering rates based on localized upstream mainline occupancy. Systemwide: If a ramp grows a long queue and is classified as critical, its metering burden will be sequentially distributed to its upstream ramps.

Linked
Local: It is separated into a number of local traffic responsive controllers. This algorithm is based on the demand-capacity concept, and the local metering rate is determined based on upstream flow measurement at each location where the metering rate is equal to the target flow rate minus the upstream flow rate. Systemwide: Whenever a ramp's metering rate is in one of its lowest three metering rates, then the upstream ramp is required to meter in the same rate or less, and, if necessary, the further upstream ramps are also required to do so.

Neural Control
Local: This algorithm uses feedback regulation to maintain a desired level of occupancy, or the target occupancy, which is usually chosen to be the critical occupancy. Moreover, the neural control algorithm is limited in adaptive control if on-line tuning is not implemented. Systemwide: This uses artificial neural networks to learn and memorize the metering plans generated by a traffic simulation model and a ramp control expert system.

RAMBO (Ramp Adaptive Metering Bottleneck Optimization)
Local: RAMBO I evaluates plans generated based on ramp metering specifications. Systemwide: RAMBO II evaluates ramp metering rates based on forecasted traffic conditions along an extended section of freeway containing up to 12 metered on-ramps and 12 exit ramps. RAMBO II develops ramp metering rates using capacity and merge constraints for the entire freeway segment specified by the user.

SWARM (System Wide Adaptive Ramp Metering)
SWARM has to stay within a TOD max and min range. The most restrictive rate is selected for each ramp. Local: The local control decides ramp metering rates based on

local density. Systemwide: When a bottleneck is detected, a new set of ramp metering rates are determined. Downstream ramp meters will be shut off and upstream ramp meters will have a more restrictive timing. SWARM has the potential to be proactive, rather than reactive. It has a built-in failure management module to clean faulty input data from detectors. It also allows further adjustment to accommodate queue spill-back handling. It automatically adjusts timing for incidents and holidays.

ZONE
Local: Zone provides for local control by using the occupancy control philosophy. Systemwide: ZONE divides a freeway into several zones of 3 to 6 miles in length. The upstream end of a zone is a free-flow area, whereas downstream end of a zone is a critical bottleneck. ZONE calculates metering rates based on volume control in each zone. To accomplish this, ZONE relies on proper division of zones, accurate estimates of bottleneck capacity, and accurate measurements of all in-and out-flows from a zone.