EVALUATION OF COORDINATED AND LOCAL RAMP METERING ALGORITHMS USING MICROSCOPIC TRAFFIC SIMULATION

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Abstract

This paper evaluates four ramp metering algorithms at varying levels of complexity and sophistication. ALINEA is a local ramp metering algorithm. ALINEA/Q is an extension of ALINEA, which handles ramp queues in a more efficient manner. FLOW is a coordinated algorithm that keeps traffic at a predefined bottleneck below capacity. The Linked Algorithm is a coordinated algorithm that optimizes a linear-quadratic objective function.

A generic network was created in MITSIMLab, and the effect of four variables was studied: total demand, ramp spacing, proportion of traffic using ramps, and traffic distribution among ramps. A regression analysis was performed on each algorithm to determine the sensitivity to each variable. The most significant result was that ramp metering, especially the coordinated algorithms, was only effective when the ramps are spaced closely together. It was also observed that ramp metering was only effective at relatively high demand, and that ALINEA/Q and the coordinated algorithms were more effective than ALINEA when the volume was extremely high.

Keywords: Ramp metering; Traffic simulation; Evaluation
Topic area: C3 Traffic Control

1. Introduction

Ramp meters are special traffic signals at the end of freeway on-ramps that regulate the flow of traffic onto the mainline. The main purpose of ramp meters is to guarantee the efficient use of freeway capacity by keeping mainline traffic from becoming overly congested. Ramp metering controllers can be either pre-timed or traffic responsive. Pre-timed controllers utilize different programs depending on the time of day and based on historical traffic conditions (Blosseville, 1985). However, because these controllers are based solely on historic traffic patterns, they are unable to adapt to real-time traffic conditions. Traffic responsive controllers determine control settings according to real time traffic measurements.

Ramp metering controllers can also be classified as either local or coordinated. Local or isolated ramp meters only consider a single ramp, whereas coordinated ramp meters are designed to take into account area-wide traffic conditions. Local ramp metering controllers can be further classified as either open loop or closed loop. Open loop strategies do not use the system output as input for the next iteration. In contrast, with closed loop, or feedback control, the control input is based on the system output. Generally, closed loop systems are more robust than open loop systems. The most widely used closed-loop local ramp metering algorithm ALINEA (Papageorgiou et al., 1991).

The current trend is toward coordinated or area-wide algorithms. These algorithms are designed to set the control at several on-ramps jointly rather than at each ramp separately in order to achieve greater efficiency. Area-wide algorithms can be further divided into three classes: incremental or cooperative algorithms; bottleneck or competitive algorithms; and integral algorithms (Kwon et al., 2001; Zhang et al., 2001).

Cooperative, or incremental algorithms work similarly to local algorithms. However, when a ramp is metered very restrictively, the upstream ramps are also metered more restrictively, in order to spread congestion from a single ramp. A cooperative algorithm is used in Denver, Colorado (Lipp et al., 1991). Bottleneck, or competitive algorithms calculate both a local metering rate and a bottleneck metering rate. The bottleneck metering rate is calculated to keep the flow of traffic at a defined bottleneck below capacity. For each ramp, the more restrictive of the two rates is chosen. An example of a bottleneck algorithm is FLOW (Jacobson et al., 1989). The third class of coordinated ramp metering algorithms is integral algorithms. Integral algorithms optimize signal settings using a well-defined objective function. Zhang et al. (2001), note that these algorithms are the most theoretically sound and potentially the most robust, however, they are also the most complex to calibrate and operate. The linked algorithm (Taylor et al., 1998) is an example of an integral algorithm.

Many ramp metering algorithms are used in conjunction with either queue adjustment and/or queue override. Queue adjustment modifies the metering rate to be less restrictive when a ramp queue becomes excessively long. Queue override completely disables ramp metering when the ramp queue exceeds a certain point. Both queue adjustment and queue override are often operated separately and independently from the main control algorithm, and compete with it. This can lead to oscillation, where the freeway will become congested, causing ramps to be metered very restrictively, leading to long queues, which in turn activate queue adjustment or override. This will then allow vehicles to over-saturate the freeway, leading to increased congestion, which causes an even more restrictive metering rate, and so on.

Several recent field evaluations of ramp metering centered around the Minneapolis-St. Paul metro area, Minnesota. Cambridge Systematics (2000) estimated that ramp metering saves the motoring public $40 Million annually, increases mean freeway speeds from 46 mph to 53 mph, and significantly reduces accidents. A recent study (Hourdakis and Michaelopoulos, 2002) in which ramp meters where switched on and off for comparison, ramp meters reduced total travel time between 6% and 16%, and increased speeds between 13% and 26%. It was also estimated that ramp metering reduced both fuel consumption and pollutant emissions by between 2% and 47%.

Although field testing can be a useful method to evaluate ramp metering algorithms, they have many limitations. Field testing can be expensive, difficult to implements and time consuming. The flexibility of these studies is limited by data collection constraints, such as availability and locations of traffic sensors. Moreover, field experiments involve many uncontrollable factors, such as weather, incidents, construction, or changes in traffic patterns, which make it difficult to isolate the effect of the ramp metering itself. For these reasons, traffic simulation models have become valuable alternative evaluation tools.

Kwon et al (2001) used a macroscopic traffic simulation model to compare three different coordinated algorithms that are in use in Colorado, Minnesota and Seattle, Washington. They found that the Minnesota algorithm, which does not use queue control, yielded the most restrictive metering rates, the lowest amount of mainline congestion and the longest ramp queues. The two other algorithms both showed that queue control can reduce the mainline efficiency.

Hasan (1999) used MITSIMLab, a microscopic traffic simulation model, to study ramp metering in Boston. He compared the local strategy ALINEA with the coordinated strategy FLOW. The results showed that ramp metering deteriorated system performance at low demands, and that coordination was only effective at very high demand levels. However, ramp metering almost always improved the mainline traffic flow. He also showed that queue control always improved system performance, and that coordination significantly improved performance when a bottleneck existed downstream of the on-ramp.

Zhang et al. (2001) used another microscopic traffic simulation model, Paramics, to compare four algorithms with varying levels of complexity: ALINEA, Bottleneck, Zone, and SWARM. The tests showed that all of the algorithms tested improve traffic flow with very little difference between the performance of each algorithm. This may be explained by the difficulty to calibrate the more complex coordinated algorithms.

The literature review shows that a large number of ramp metering algorithms have been proposed. However, only limited field and simulation evaluations of these algorithms have been performed, mostly focusing on testing existing implantations. Very little research has been done to identify conditions under which ramp metering is effective and the conditions under which coordination is useful. This paper aims to address this issue by performing simulation evaluations of various ramp metering algorithms under varying geometric and demand settings.

2. Ramp metering algorithms

Four ramp metering algorithms were studied in this project: ALINEA, ALINEA/Q, FLOW, and the Linked Algorithm. These algorithms are representative of the various classes of ramp metering algorithms that are in use today.

ALINEA

ALINEA (Papageorgiou et al., 1991) is a local, closed loop ramp metering algorithm. ALINEA works by measuring the occupancy at a loop detector downstream of the ramp, and measuring the difference between the measured occupancy, and the optimal set point occupancy. The set point occupancy is generally set slightly lower than the critical occupancy, in order to ensure that the freeway operates below capacity. The metering rate for time interval k is calculated by:

$$r(k) = r(k-1) + K_R\left[O - O_{out}(k-1)\right] \qquad (1)$$

$r(k)$ ε and $r(k-1)$ are the metering rates for the time intervals and , respectively. is the regulator parameter. *O* and $k k-1 K_R O_{out}(k-1)$ are the set point occupancy and the measured occupancy at time interval $1k$.

ALINEA/Q

ALINEA/Q (Smaragdis and Papageorgiou, 2003) is an enhancement to the traditional ALINEA algorithm, which incorporates a queue control strategy. This algorithm relies on installation of video detectors to measure the length of the ramp queue. The algorithm calculates two metering rates. The first rate is calculated similarly to the metering in ALINEA. The second rate is the metering rate needed to keep the ramp queue below the maximum allowable queue length. This rate is calculated by:

$$r'(k) = -\frac{1}{T}\left[w - w(k-1)\right] + d(k-1) \qquad (2)$$

$r'(k)$ i is the queue metering rate for interval . and $kww(k-1)$ are the maximum allowable queue length and the number of vehicles in the ramp queue at interval , respectively. T is the time period over which measurements are taken. is the number of vehicles entering the ramp at time interval $k-1d(k-1k-1$.

The final calculated rate is the greater of the two control rates:

$$R(k) = max\{r(k), r'(k)\} \qquad (3)$$

This algorithm provides a smoother adjustment of the metering rates to account for ramp queue formation. The additional queue measurements can potentially keep queues from forming by progressively metering the queue length rather than waiting until a long queue to develop before taking any action.

FLOW

FLOW (Jacobson et al., 1989) is a competitive, bottleneck-based, area-wide ramp metering algorithm. For each ramp, FLOW calculates both a local metering rate and a bottleneck metering rate and selects the more restrictive of the two rates.

The local metering rate is calculated with a percent occupancy algorithm, which uses a lookup table t determine metering rates based on upstream occupancy measurements. The lookup table is constructed based on historical volume occupancy relationships.

The bottleneck metering rate is based on identification of freeway bottleneck locations. Each bottleneck is associated with an influence zone, which includes one or more on-ramps. The bottleneck metering is invoked if two conditions are met. The first is that downstream occupancy must exceed a pre-defined threshold, which indicates that the demand in the section is above capacity. The second condition is that the freeway section must be storing vehicles, i.e., the number of vehicles entering the section and via the mainline and the on-ramps is greater than the number of vehicles exiting the section at the downstream end and via off-ramps. The excess flow at section *i* is calculated by:

$$U_i(k) = q_{IN_i}(k-1) + q_{ON_i}(k-1) - q_{OUT_i}(k-1) - q_{OFF_i}(k-1) \qquad (4)$$

$U_i(k)$ i is the excess flow for which the metering rate needs to be adjusted. and $q_{IN_i}(k-1q_{ON_i}(k-1)$ are the flows entering the section from the mainline and from on-ramps, respectively. and $q_{OUT_i}(k-1)\, q_{OFF_i}(k-1)$ are the flows existing the section at the downstream mainline end and to off-ramp, respectively.

The metering rate of each on-ramp within the influencing zone of the bottleneck is adjusted using a weighing function, which captures the effect of flow from this ramp on the bottleneck. These factors depend on the distance between the ramp and the bottleneck and on historical demand on the ramp. The bottleneck metering rate reduction (BMRR) for each ramp *j* within is given by:

$$BMRR_{ji}(k) = U_i(k)\frac{WF_j}{\sum_{k \in i}(WF_k)} \qquad (5)$$

WF_j is the weighing factor for ramp *j*.

The bottleneck metering rate for each ramp is calculated by subtracting the BMRR from the measured on-ramp flow during the previous interval. If influence zones overlap, the most restrictive rate is chosen:

$$BMR_{ji}(k) = q_{ON_j}(k-1) - BMRR_{ji}(k) \quad (6)$$

$$BMR_j(k) = \min_i BMR_{ji}(k) \quad (7)$$

Linked Algorithm

The Linked algorithm (Taylor et al., 1998) is a coordinated ramp metering algorithm based on Proportional-Intergral-Plus (PIP) control theory. The basis of the control design is the non-minimal state space (NMSS) description of the system to be controlled. The NMSS is formulated using the states, past values of inputs and outputs, and additional integral-of-error states. The NMSS is formulated as a set of linear models, one for each point in the network, for which measurements are available. The linear describes the state of the system at time interval *k*, in terms of sensor occupancies, depending on the previous measurements at the current location, as well as the upstream and downstream locations, a vector of set point occupancies for each measurement location and boundary conditions at the upstream and downstream ends of the section. On-ramp flows are used as additional variables for on-ramp linear models. The control flows are determined using the state-space model using linear quadratic control.

This algorithm is a theoretical design, which does not explicitly incorporate queue control. The implementation of this algorithm that was tested also included a queue adjustment algorithm.

3. Calibration and validation of MITSIMLab

This study used the microscopic traffic simulation model MITSIMLab (Yang and Koutsopoulos, 1996). Data from loop detectors in the M27 Motorway near Southampton, UK was used to calibrate MITSIMLab for this project. The detector data was aggregated into 15-minute intervals during the peak traffic period, 6 AM – 9 AM, Monday through Friday. Simulation parameters that affect traffic flow were calibrated using an iterative procedure. First, a sensitivity analysis was performed, showing that the three parameters that have the most effect on traffic flow are the sensitivity factors for acceleration and deceleration car-following behaviors (see Ahmed, 1999 for details) and the mean of the desired speed distribution. An example of the calibration results is shown in Figure 1.

A second set of detector measurements was used for validation. The validation results for the same sensor location are shown in Figure 2.

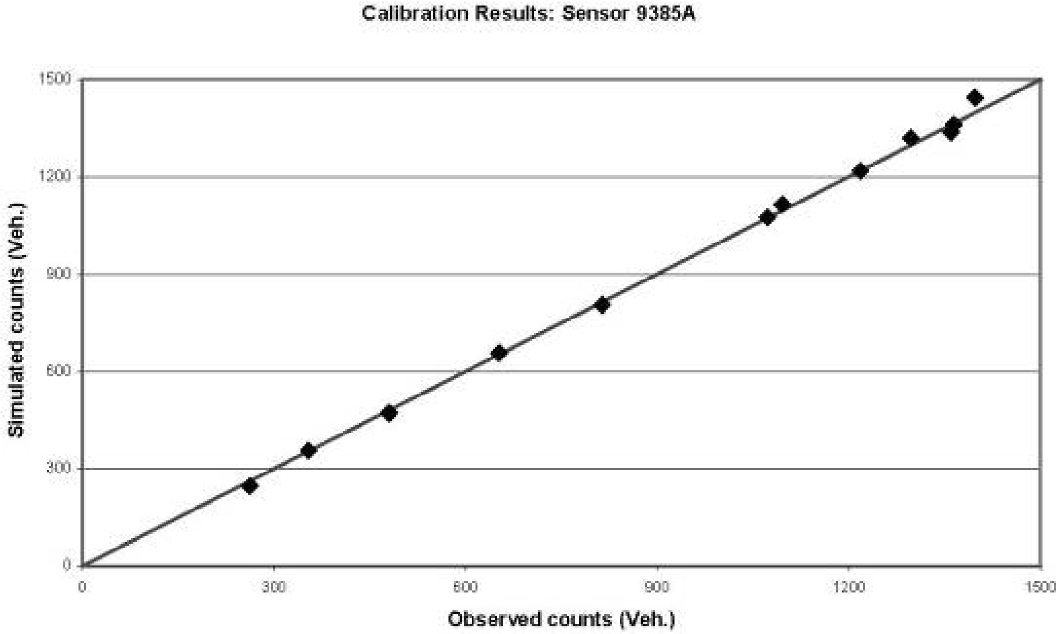

Figure 1: Sample calibration results

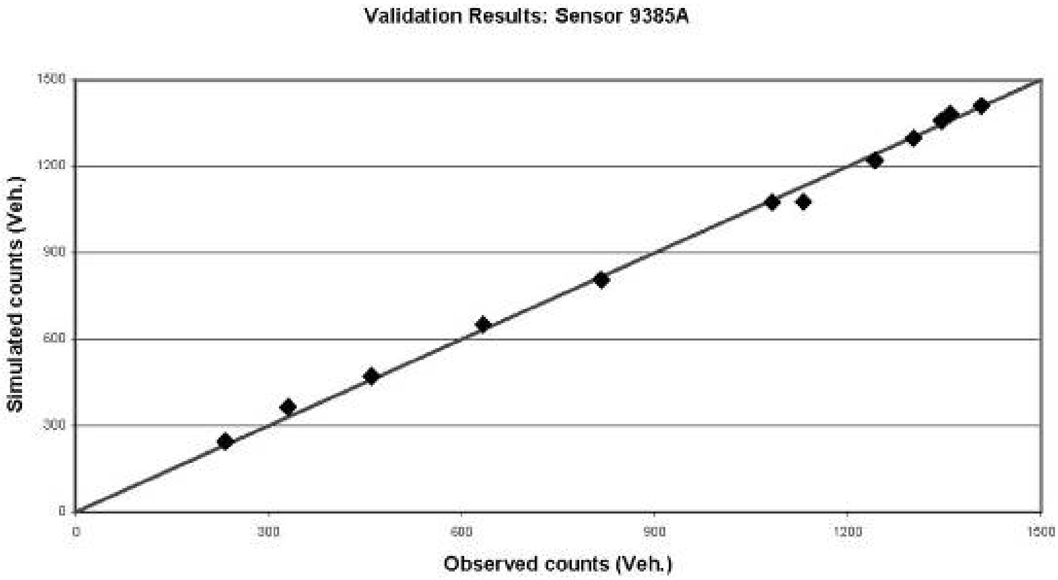

Figure 2: Sample validation results

4. Experimental design

For the evaluation study, a generic network, containing four on-ramps and four off-ramps, was created. This network is shown in Figure 3. The impact of four variables on the performance of ramp metering algorithms was tested: demand level, spacing between ramps, distribution of traffic among ramps, and percentage of the total demand that originates from the ramps. For each one of these factors, several levels were defined: four levels of demand, four levels of ramp spacings, three distribution patterns and three ramp traffic percentages.

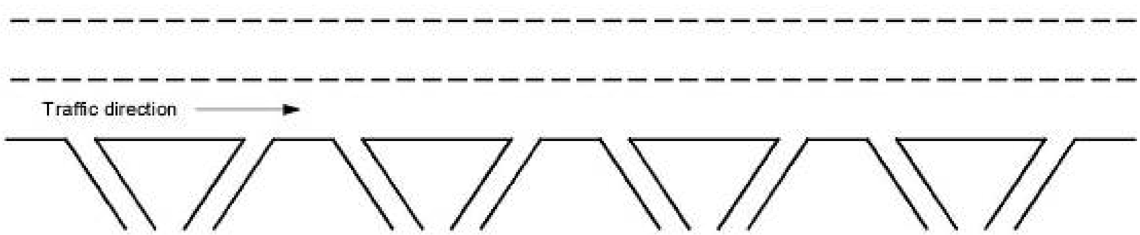

Figure 3: Diagram of network

This experiment considers four OD levels, four ramp spacings, three demand distribution patterns, and three ramp traffic demand percentages, with a total of 4x4x3x3, or 144 combinations. A fractional factorial design was used in order to reduce the number of experiments. We used an orthogonal design with 16 scenarios (Addleman, 1962). The 16 combinations that were used are shown in Table 1. In order to ensure statistical significance 10 simulation replications were run for each scenario and the results were averaged.

For the ramp distributions, #1 denotes the case that the upstream ramps have the heaviest demands, #2 denotes that all ramps have equal demands, and #3 denotes that the downstream ramps have the heaviest demand.

Table 1: Experimental design

Scenario	Demand Level (veh/hr)	Ramp Spacing (ft)	Ramp Distribution	Ramp demand (%)
1	6600	2000	1	25
2	6600	4000	2	35
3	6600	8000	3	30
4	6600	16,000	2	30
5	6900	2000	2	30
6	6900	4000	1	30
7	6900	8000	2	35
8	6900	16,000	3	25
9	7200	2000	3	35
10	7200	4000	2	25
11	7200	8000	1	30
12	7200	16,000	2	30
13	7500	2000	2	30
14	7500	4000	3	30
15	7500	8000	2	25
16	7500	16,000	1	35

5. Results

Table 2, Table 3 and Table 4 show the percent travel time savings for the mainline traffic, ramp vehicles, and the entire corridor, respectively.

The results show that ramp metering has the potential to greatly improve mainline travel times, although the conditions under which it is beneficial are relatively narrow. The most important factors affecting the usefulness of ramp metering are the ramp spacing and the demand level. Ramp metering is only useful when the ramps are spaced relatively close together. This is because when the ramps are close together, the bottleneck caused by the traffic merging has a significant impact on the mainline traffic. However, when the ramps are spaced further apart, the ramp traffic has less of an effect on the mainline, and thus the potential usefulness of ramp metering is reduced. Also, ramp metering was shown to be useful only at the higher OD levels, where congestion occurred. At the lower OD levels, ramp metering causes vehicles to unnecessarily stop before entering the freeway, and this reduces the efficiency of the traffic flow.

In all cases, ramp metering increased the travel time for ramp vehicles, as well as the total travel time. However, the numbers are misleading for several reasons. First of all, particularly in the networks with the short ramp spacing, vehicles spend a disproportionate amount of time on the ramps, and not much time on the network. Once they finally enter the network, their travel time would be faster than it was with no ramp metering, and so, the travel time savings to traffic on the mainline are under-represented.

Ramp metering may have additional beneficial impacts that are not captured in the simulation model. Decreasing the travel time for mainline vehicles while increasing travel time for ramp vehicles discourages usage of the freeway for short sections. This encourages use of the freeway for distance travel, where it is intended to be, while encouraging local traffic to use local roads. Similarly, when one ramp experiences long queues, drivers are encouraged to use other nearby ramps. This will result in a more efficient usage of ramp capacities. Another effect is that ramp meters decrease accidents on the freeway, which further improves travel time.

Table 2: Mainline travel time savings (%)

Scenario	ALINEA	ALINEA/Q	Flow	Linked
1	-0.6	-0.3	0.0	-0.4
2	0.8	0.2	0.5	0.3
3	-0.7	-1.2	-1.1	-1.0
4	0.1	0.0	-0.4	0.2
5	2.3	2.5	2.4	0.9
6	-0.5	1.1	0.8	-0.1
7	-0.8	0.0	-0.3	-0.7
8	0.5	0.4	0.5	0.7
9	7.6	8.6	8.1	5.2
10	3.0	2.0	2.7	1.1
11	-0.4	0.2	0.0	-1.0
12	-0.2	-0.1	-0.2	-0.3
13	3.4	5.6	8.0	2.9
14	1.9	3.2	3.3	2.5
15	1.1	0.9	0.5	0.2
16	-0.3	-0.2	0.0	-0.1

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Table 3: Ramp travel time savings (%)

Scenario	ALINEA	ALINEA / Q	Flow	Linked
1	-16.5	-17.6	-10.9	-14.0
2	-6.2	-9.1	-14.0	-6.0
3	-3.2	-4.2	-4.1	-3.2
4	-2.1	-1.9	-2.1	-1.4
5	-92.9	-108.0	-55.2	-75.9
6	-15.5	-17.0	-26.3	-10.4
7	-5.6	-8.1	-5.1	-2.9
8	-1.6	-1.8	-1.9	-0.9
9	-106.3	-114.4	-108.6	-101.7
10	-28.7	-34.1	-40.3	-24.2
11	-8.5	-13.7	-12.0	-4.2
12	-3.3	-3.9	-4.8	-2.0
13	-113.3	-121.3	-115.9	-107.2
14	-51.5	-59.4	-68.5	-35.8
15	-9.0	-13.7	-12.1	-3.3
16	-8.6	-10.5	-8.1	-3.7

Table 4: Overall travel time savings (%)

Scenario	ALINEA	ALINEA / Q	Flow	Linked
1	-2.6	-2.4	-1.4	-2.0
2	-0.4	-1.3	-1.9	-7.2
3	-1.1	-1.6	-1.5	-1.3
4	-0.5	-0.5	-0.8	-0.3
5	-11.2	-13.2	-5.8	-10.0
6	-2.6	-1.4	-3.0	-1.5
7	-1.7	-1.4	-1.1	-1.1
8	0.0	-0.1	0.1	0.4
9	-7.9	-8.0	-7.7	-9.4
10	-0.5	-2.0	-2.1	-1.7
11	-1.6	-1.9	-1.8	-1.4
12	-0.8	-1.0	-0.8	-0.6
13	-8.8	-7.5	-4.6	-8.4
14	-4.7	-4.5	-5.5	-2.3
15	-0.1	-0.8	-1.0	-0.3
16	-2.5	-3.4	-2.1	-1.2

For each of the four algorithms, a regression analysis was performed on the mainline travel times in order to evaluate the impact of the various factors on the ramp metering usefulness. The following functional form was used:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + ... + \beta_{10} X_{10} + \varepsilon$$

The regression factors are:

Y = Corridor Travel Time Savings (%)
X1 = 1 if OD Demand at 6900 vph, 0 otherwise
X2 = 1 if OD Demand at 7200 vph, 0 otherwise
X3 = 1 if OD Demand at 7500 vph, 0 otherwise
X4 = 1 if Ramp Spacing at 4000 ft, 0 otherwise
X5 = 1 if Ramp Spacing at 8000 ft, 0 otherwise
X6 = 1 if Ramp Spacing at 16000 ft, 0 otherwise
X7 = 1 if Upstream Ramps have most traffic, 0 otherwise
X8 = 1 if Downstream Ramps have most traffic, 0 otherwise
X9 = 1 if 30% of total traffic enters from on-ramps
X10 = 1 if 35% of total traffic enters from on-ramps

Table 5 shows the results of the regression analysis for each algorithm.

Table 5: Regression analysis results

	ALINEA		ALINEA/Q		FLOW		Linked	
	Coef	t-statistic	Coef	t-statistic	Coef	t-statistic	Coef	t-statistic
B 0	1.945	1.616	1.138	0.889	1.900	1.309	0.657	0.868
B 1	0.475	0.501	1.325	1.313	1.100	0.961	0.425	0.712
B 2	2.600	2.740	3.000	2.973	2.900	2.533	1.475	2.471
B 3	1.861	1.873	3.225	3.054	3.633	3.033	1.902	3.046
B 4	-1.875	-1.976	-2.475	-2.453	-2.800	-2.446	-1.200	-2.011
B 5	-3.375	-3.556	-4.125	-4.088	-4.850	-4.236	-2.775	-4.649
B 6	-2.914	-2.934	-3.550	-3.362	-4.217	-3.519	-1.723	-2.758
B 7	-1.427	-1.635	-0.663	-0.714	-1.017	-0.966	-0.673	-1.226
B 8	1.113	1.354	1.363	1.559	1.050	1.059	1.275	2.467
B 9	-0.321	-0.401	0.750	0.879	0.750	0.775	0.179	0.354
B 10	0.943	0.805	2.100	1.686	1.733	1.227	1.210	1.642
Adj. R2	0.629		0.685		0.667		0.735	

ALINEA

The intercept shows that in the case of a total demand of 6600 vph, ramp spacing of 2000 ft, even distribution among on-ramps, and 25% ramp traffic, the corridor travel time improves by nearly 2% when ALINEA is used. The performance substantially improves when the total demand reaches 7200 vph, by 2.6%, and less so when the demand is at the 7500 vph level, by only 1.9%. This may be because at a demand level of 7200 vph ramp metering has a chance to improve travel time, while at the greater congestion of 7500 vph, ramp metering is less effective, since traffic will always be congested. The results also show that larger ramp spacings significantly reduce the effectiveness of ramp metering, while ramp traffic distribution and percentage of ramp traffic do not have any significant effect on performance. When the ramp spacing reaches 8000 ft, the ramp metering performance decreases by 3.4%, making ramp spacing the most sensitive parameter.

ALINEA / Q

This analysis, as expected, shows that ALINEA / Q behaves similarly to ALINEA. With a total demand of 6600 vph, ramp spacing of 2000ft, 25% ramp traffic, and even distribution among ramps, ramp metering improves corridor travel time by 1.1%. As with ALINEA, the ramp spacing and OD level have the strongest impact on performance. The major difference between ALINEA and ALINEA / Q is that ALINEA / Q performs best at, the highest OD level, 7500 vph, where it improves travel time by an additional 3.2%. This is because at the highest OD level, the queue control algorithm is invoked more frequently, and thus the more efficient queue control algorithm in ALINEA / Q's has more of an effect on performance.

FLOW

This analysis shows that FLOW performs similarly to the other algorithms. With a total demand level of 6600 vph, ramp spacing of 2000 ft, 25% ramp traffic, and even distribution among ramps, FLOW improves mainline travel time by 1.9%. These results are consistent with Hasan (1999) showing that FLOW is most effective at very high OD levels, with a total demand of 7500 vph improving the performance of ramp metering by an additional 3.6%. As with the other algorithms, of all the parameters, ramp spacing had the most effect on the travel time savings. When the ramp spacing reaches 8000 ft, the effectiveness of the ramp metering is reduced by 4.9%, which is a greater decrease than in the local algorithms. This is because when the ramps are spread far apart, the traffic at one ramp has little impact on the traffic at another ramp, which makes coordination less useful.

Linked Algorithm

This regression shows that the Linked algorithm performs similarly to the other algorithms. A total demand of 6600 vph, a ramp spacing of 2000 ft, 25% ramp traffic, and even ramp traffic distribution shows that the linked algorithm improves mainline travel time by 0.7%. Similar to FLOW this algorithm is shown to perform best under highest demand levels, where at a demand level of 7500 vph, the linked algorithm improves travel time by an additional 1.9%. One result unique to this algorithm is that it performs significantly better when the downstream on-ramps have the most volume, improving performance by an additional 1.3%. This may be because the algorithm uses the upstream conditions to predict congestion at the downstream end of the network.

6. Conclusions

The analysis showed that under the right conditions, with closely spaced ramps and heavy traffic, ramp metering can be very beneficial to the mainline traffic. However, the conditions under which ramp metering is beneficial are fairly narrow. Although ramp metering may increase delays to the ramp traffic, this can actually promote more efficient use of the network. The following summarizes our findings:

1. Ramp metering has the most significant impact on mainline traffic flow when the ramps are closely spaced. Ramp metering can significantly improve traffic when the ramps are spaced at 2000 ft. However, once the ramp spacing reaches around 8000 ft, ramp metering ceases to have any significant benefits. This is because closely spaced ramps can significantly impact the flow of traffic on the mainline, whereas if the ramps are spread

farther apart, they have less of an impact

2. Ramp metering is only useful at high demand levels, where flow breaks down. In order for ramp metering to be effective, the traffic volumes upstream of the ramp must be below capacity, while the traffic volumes downstream of the ramp must be above capacity
3. The traditional ALINEA algorithm performs best when the total demand is slightly above capacity, 7200 vph in this case. When the volume reaches 7500 vph, the controller spends much of its time in queue override, which causes ramp metering to shut off, and defeats any benefits.
4. ALINEA / Q performs significantly better than ALINEA at very high traffic volumes, 7500 vph. This is because rather than using a binary on / off queue algorithm, this algorithm takes into account both mainline traffic conditions as well as queue length in calculating the metering rate. The queue override algorithm raises the metering rate just enough to maintain the queue at its maximum allowable length, making maximum use of the ramp queue storage space.
5. The coordinated algorithms: FLOW and the Linked Algorithm, also perform better at very high traffic volumes, 7500 vph. This is because the coordination used in these algorithms makes them more suitable to handle highly congested traffic at locations away from the ramp, and allows ramps upstream of a bottleneck to be metered more restrictively, rather than placing all the burden on a single ramp.
6. For coordinated algorithms, the performance degrades at higher ramp spacings, starting around 8000 ft, even more than the local algorithms. This is because when the ramps are spaced further apart, traffic at one ramp has very little impact on the traffic at another ramp, thus defeating the purpose of coordination.
7. When the downstream ramps have the most traffic, the Linked algorithm performs significantly better, while the other algorithms are not sensitive to traffic distribution. This is due to the predictive nature of the linked algorithm, which allows it to use upstream measurements to predict the downstream conditions, and meter each ramp accordingly
8. Ramp metering, by itself, significantly increases delay to ramp traffic and to the total traffic. However, this encourages more efficient use of the network. It encourages long distance traffic to use the freeway, while local traffic would be encouraged to use local streets.

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