DETERMINING THE EFFECTS OF A LOCAL
RAMP METERING STRATEGY BASED ON
FLOW STABILITY USING
MICROSIMULATION

Martijn Ruijgers · Eric van Berkum

* University of Twente, PO Box 217, 7500 AE, Enschede,
the Netherlands

** Goudappel Coffeng, PO Box 161, 7400 AD, Deventer,
the Netherlands

Abstract: In this contribution a modification of the ALINEA local on-ramp control
strategy is presented. In this modification, as in ALINEA, the metering rate is
determined by a feedback mechanism where the occupancy rate downstream of
the merge area is used, yet a correction procedure is added, where the stability of
the flow upstream of the merge area is used in order to fine-tune the metering rate.
Microscopic simulation shows that this improved strategy may yield a significant
higher throughput of on-ramp without deteriorating freeway operations.

Keywords: Ramp metering, ALINEA, AIMSUN, Flow Stability

1. INTRODUCTION

In the past fifty years ramp metering has proven
to be an effective method to improve freeway
operations. Since the first implementation, many
different strategies have been developed, that can
be categorized as:

**pre-timed control** where the metering is not
directly influenced by mainline traffic

**local-actuated control** where metering is influ-
enced by real-time local conditions

**system control** where real-time information on
total freeway conditions is used to determine
the metering rate

In this contribution we will deal with local-
actuated ramp control. This type of ramp control
is either based on the feed-forward or feedback
philosophy. Well-known example of a feed-forward
strategy is the demand-capacity strategy (Koble
et al., 1980), where upstream volume (demand)
is compared with capacity downstream the merge
area. Example of a feed-back strategy is ALINEA
(Papageorgiou et al., 1989) which is based on the
occupancy rate downstream the merge area.

Most strategies use macroscopic data to determine
the metering rates. Commonly used quantities
are: average freeway speed, occupancy, capacity
and flow. They are based on the assumption that
traffic conditions change from non-congested state
to a congested state at capacity or at critical
density (or occupancy). Various studies however
show that this is not necessarily the case. E.g.
capacity can vary not only between roads but also
during time at the same location. In fact, even
when variables like time of day, traffic composition
or weather are identical, there appears to be a
range of flow or occupancy values where the traffic
flow changes to the congested regime. Elefteriadou
and Lerworawanich (2002) concluded that the
maximum sustained flow at a certain freeway
section varies and does not necessarily occur in
conjunction with breakdown. Hence, for equal
flows breakdown may or may not occur. Flows
at the moment of breakdown may vary and can
indeed be lower than maximum observed flows or capacity flow.

These phenomena may be considered as completely random, yet also a traffic flow may contain qualities that are not captured using the macroscopic variables as average speed, flow or occupancy (Elbers, 2005).

In fact this is the avenue that will be followed in the remainder of this contribution. The question that is addressed is whether a local ramp metering strategy can be improved by taking into account not only macroscopic but other, also more microscopic qualities of the main-line flow.

The basic goal in ramp metering is to release as many vehicles as possible from the on-ramp to the main-line traffic, yet to maintain the uncongested regime in the bottleneck downstream the merge area. Considering the findings above however, using only predefined macroscopic qualities as fixed capacity or optimal density may yield suboptimal results. In some instances breakdown will occur while demand has not reached predefined capacity or desired occupancy. In other occasions, for instance when circumstances are very stable (though busy), the metering rate could have been increased such that flow or occupancy exceed predefined values.

One possibility to overcome these problems may be to include some form of microscopic strategy. An example is the so-called release-to-gap strategy. Here it is tried to synchronize the merge of on-ramp vehicles into gaps that were measured upstream the merge area. This is done by determining the moment of release at the ramp meter. However, because of the large variety in accelerating characteristics of on-ramp vehicles, and the heavily changing on-ramp gaps, this strategy has proven not be very successful (Ran et al., 1999).

In an alternative approach it is tried to modify a traditional ramp metering strategy where other flow characteristics are included in order to determine the optimal metering rate.

2. ALTERNATIVE APPROACH

2.1 Combining macroscopic and mesoscopic flow characteristics

As was demonstrated above, ramp metering strategies that are based on macroscopic assumptions insufficiently reflect the stochastic character of capacity and breakdown, while those that are based on microscopic assumptions depend on too many uncertainties. Therefore it was decided to combine a macroscopic feed back strategy with a mesoscopic feed forward strategy. The base-metering rate is determined by a macroscopic strategy, and this rate is than adjusted based on mesoscopic flow characteristics.

Elbers (2005) studied the probability of breakdown and concluded that indicators for flow stability may be used to better predict breakdown. In this contribution one of these indicators will be used as a mesoscopic flow characteristic.

2.2 Components of the new strategy

Currently coordinated and pro-active metering strategies are not able to outperform respectively local and reactive strategies due to hard parameter calibration and data gathering (Zhang et al., 2001). Therefore it was decided to use a local actuated strategy. In this way, only local processes will affect the performance of the new strategy and differences in output will be due to differences in control strategy. Here the ALINEA strategy (2.3) was chosen as the basis for the alternative strategy. This means that the base-metering rate is determined using ALINEA, and this rate is adjusted using information on local stability upstream of the merge area. This is done, using the stability indicator (see 2.4) as developed by Elbers (2005). This is shown in figure 1.

2.3 ALINEA

Of all local actuated strategies, ALINEA is probably the most widely studied and implemented strategy. Simulation studies (Hasan et al., 2002) as well as field experiments (Papageorgiou et al., 1997) prove that it is an effective strategy for multiple measures of effectiveness (MOE) like: increasing throughput, reducing congestion and increasing speeds.

ALINEA is a simple feed back control mechanism, based on (1).

\[ r(k) = r(k-1) + K_R [\bar{o} - o_{out}(k)] \] (1)
where \( r(k) \) is the metering rate for time interval \( k \), \( K_R \) is a regulator parameter, \( \dot{o} \) is the desired (usually critical) occupancy and \( o_{\text{out}}(k) \) is the measured occupancy at time interval \( k \).

The parameter values are based on a combination of literature review (Chu and Yang, 2003) and calibration results. Detectors are located at all lanes, 260 meters downstream of the 'nose' of the on-ramp, the parameter \( K_R \) is set (as usual) to 70 and \( \dot{o} \) is 22 %. The length of interval \( k \) is 60 seconds.

In reality often several override tactics are applied, since the queue on the on-ramp may become excessive. Also the metering rates are bounded by both a minimum and maximum rate, i.e. the minimum cycle time is usually about 4 seconds, to avoid driver confusion due to rapidly changing lights and the maximum cycle time is about 15 seconds, to avoid red light ignorance by impatient drivers. These override tactics may limit the performance of the control strategy significantly. Since in this contribution we are mostly interested in the performance of the metering strategy as such, in the remainder override tactics are ignored.

This means for instance that when congestion is about to occur, the metering strategy will increase the cycle time, possibly such that metering rate becomes zero.

### 2.4 String stability indicator

Elbers (2005) has developed an indicator for the stability of a traffic stream. This indicator has a value between 0 and 1, where 1 indicates a very stable stream and 0 indicates an extremely unstable stream. The value is based on the outcome of experiments with a platoon of 10 vehicles. For such a platoon average speed and the variance are recorded. The indicator then follows from a series of experiments where for each follower in the platoon a certain car-following behavior is assumed (specifically the 3rd GM model, see 2) as a result of a certain deceleration of one leading vehicle.

\[
\ddot{x}_n(t + \Delta t) = \alpha \frac{x_n(t) - \ddot{x}_{n+1}(t)}{x_n(t) - x_{n+1}(t)} \tag{2}
\]

\( x_n \) represents the position of vehicle \( n \), which is following vehicle \( n + 1 \) at time \( t \). Dots denote time derivatives, \( \Delta t \) is a time delay (i.e. drivers reaction time) and \( \alpha \) is a sensitivity parameter. All vehicles have the same parameters (\( \alpha = 9 \text{ m/s}, \Delta t = 0.6 \text{ seconds} \) and acceleration is restricted from -8 m/s² up to 3 m/s²), the only difference between the vehicles is the initial distance to their predecessors, which is drawn randomly from a headway distribution function.

![Fig. 2. String stability indicator](image)

In some occasions vehicles will not be able to react adequate to the deceleration of their predecessor, with a collision as result. For multiple combinations of average and standard deviation of time gaps the frequency of collisions is determined. Now if for instance for 100 different platoon compositions with an average time gap of 1.3 seconds and a standard deviation of 0.6 seconds 30 collisions are measured, the collision probability is 0.3 and stability is set to 0.7. All these experiments result in a chart as shown in 2.

The vertical axis shows the standard deviation, while the horizontal axis shows the average of the time gaps in a string of ten vehicles.

The charts are not completely covered with observations. For the white squared area not enough data points have been calculated. Due to the stochastic character of the stability indicator, not for every combination of average and standard deviation enough observations were found. Simulation results show that only very few combinations are found in the undefined regions, and therefore this has hardly an effect on the strategy. Combinations in the triangle at the bottom of the chart can not be found because negative time gaps are impossible and a fixed number of vehicles is considered.

How is this stability indicator used in the alternative strategy? On the right lane of the freeway about 600 meters upstream of the 'nose' of the on-ramp a detector determines the gaps between successive vehicles. After an initialization period (necessary to fill register ten vehicles) the stability of a string of ten vehicles is determined, i.e. the average and standard deviation of the gaps are calculated, and the corresponding stability is determined by interpolating in the look-up table underlying 2. Every time a new vehicle crosses the detector, the crossing time of the oldest vehicle is removed from and the crossing time of the new vehicle is added to an array. Consecutively, stability is recalculated.
2.5 Combination of both elements into one strategy

Main idea of the stability component is that if local upstream conditions are stable the metering rate as determined by ALINEA can be increased, and vice versa, if conditions are unstable the ALINEA metering rate is decreased. The stability indicator is updated every time a vehicle crosses an upstream loop detector.

The alternative strategy may only be successful if the indicator does not change within a few seconds from very stable to unstable or vice versa.

In figure 3 it can be seen that stabilities between 0.9 and 1.0 are seldom followed by a large drop into unstable regions. Between 0.8 and 0.9 a transition zone can be seen in which stabilities can both increase and decrease very fast. Finally, stabilities below 0.8 only exist for a short time (NB. stabilities greater than 1 represent combinations of outside the known area of figure 2). Of course, this is no evidence that a pattern indeed exists, especially since also time periods can be found which show more disordered observations. To obtain a better substantiated relationship statistical analysis methods should be used, based on results with less error values. It was assumed that these findings were accurate enough to determine a correction function within this project. The following adjustment scheme (3) has been defined.

\[
\tau_{corr}(k) = \begin{cases} 
+2: & S < 0.7 \\
+1: & 0.7 < S \leq 0.8 \\
0: & 0.8 < S \leq 0.9 \\
-1: & 0.9 < S \leq 1.0 
\end{cases}
\]  

(3)

This scheme has not been optimized yet. Therfore it is very well possible that other adjustment-schemes may lead to better results.

The chosen strategy is very simple. Depending on the stability \( S \) the cycle time is corrected. If for example \( S = 0.95 \), circumstances are very stable, and the cycle time is decreased by 1 second.

3. EFFECTS OF THE ALTERNATIVE STRATEGY

3.1 Network

The effects of the alternative strategy compared to ALINEA were determined using microscopic simulations with the program AIMSUN (Barcelo and Ferrer, 1997). A thorough comparison of simulation results with field data show that lane changing and merging behavior in AIMSUN is acceptable to model merging behavior on on-ramps (Ruijgers, 2005). The network that was used for this purpose consists of an on-ramp, which merges into a three lane freeway. The freeway is about ten kilometers long, and the on-ramp is located halfway, to enable spill back of congestion.

3.2 Demand

Simulations are run for a period of one hour. During this hour freeway and on-ramp demands are constant. Three levels of freeway demand have been used:

- light (about 5430 vehicles per hour);
- medium (about 6057 vehicles per hour);
- high (about 6675 vehicles per hour).

On-ramp flow is very high (1400 vehicles per hour), to make sure that every time the metering light turns green a vehicle is waiting to enter the freeway. There are three vehicle types defined, cars (90% of total demand), trucks (7.5%) and long trucks (2.5%).

3.3 Measures of effectiveness

In general ramp meters are implemented to improve the traffic situation in terms of

- decrease travel time on the freeway;
- increase throughput at the bottleneck downstream the merge area;
- increase traffic safety;
- decrease rat-run traffic;
- etc.

Here the effects of the two strategies on throughput (upstream and downstream the merge area and on the on-ramp) are studied.

4. RESULTS

The performance of the combined strategy is compared to the traditional ALINEA, for the three levels of freeway demand. For all six combinations of strategy and demand, 250 simulation runs with
Table 1. Throughput

<table>
<thead>
<tr>
<th>Demand</th>
<th>ALINEA Flow (veh/h)</th>
<th>Alternative Flow (veh/h)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>low</td>
<td>5436</td>
<td>687</td>
<td>6123</td>
</tr>
<tr>
<td>medium</td>
<td>6047</td>
<td>617</td>
<td>6664</td>
</tr>
<tr>
<td>high</td>
<td>6673</td>
<td>453</td>
<td>7126</td>
</tr>
</tbody>
</table>

Table 2. Speeds

<table>
<thead>
<tr>
<th>Demand</th>
<th>speed (km/h)</th>
<th>ALINEA</th>
<th>Alternative</th>
</tr>
</thead>
<tbody>
<tr>
<td>low</td>
<td>103.0</td>
<td>102.8</td>
<td></td>
</tr>
<tr>
<td>medium</td>
<td>101.1</td>
<td>100.9</td>
<td></td>
</tr>
<tr>
<td>high</td>
<td>98.1</td>
<td>98.4</td>
<td></td>
</tr>
</tbody>
</table>

different ransom seeds were performed. The results are shown in Table 1 and 2.

As can be seen the alternative strategy does not influence the total throughput on the freeway. Total on-ramp flow however is increased by the alternative strategy, especially when demand is low. Increases on the metering rates are respectively 11%, 3% and 2% when main-line demand is low, medium and high. Further it can be seen that the new strategy leads only to a tiny decrease in speed (travel time on the freeway increases by less than 1 second). Thus, the alternative metering approach may increase throughput at the on-ramp significantly, especially when demand is low, i.e. an V/C ratio of about 0.8. When demand increases towards an V/C ratio of 1 still an improvement of a few percent on the on-ramp can be obtained.

Although the results of this first test are positive, there are some elements which need further study. The values and constraints of the adjustment scheme were now taken intuitively. A more systematic approach may lead to better results.

5. ACKNOWLEDGEMENTS

This research was part of the Transumo Programme.

REFERENCES


