RAMP METERING IN THE NETHERLANDS: AN OVERVIEW

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Abstract: Dynamic traffic management is an important part of the Dutch transport policy. All kinds of measures have been implemented and assessed on the motorway network, such as the motorway traffic management system with speed limits and queue tail warning, ramp metering, variable message signs, dedicated lanes, peak lanes, incident management, etc. In this paper the focus is on ramp metering, which is the management of traffic on an on-ramp, depending on the traffic conditions on the motorway and the on-ramp. The main purpose is the improvement of traffic conditions on the motorway, taking into account the conditions on the on-ramp and surface roads. History, principles, assessment studies and future plans are discussed.

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1. INTRODUCTION

Since 1990, dynamic traffic management is an important part of the Dutch transport policy to drive back the negative impacts of ever increasing traffic demand. All kinds of measures have been tested and implemented on the motorway network, such as the motorway traffic management system with speed limits and AID function to warn for queues on the motorway, ramp metering, variable message signs with information about queue lengths, dedicated lanes for certain road users (e.g. trucks), peak lanes, overtaking prohibition for trucks, incident management, etc. An extensive overview over all types of measures is given by Middelham (2003).

In this paper the focus is on ramp metering. Ramp metering is the management of traffic on an on-ramp, depending on the traffic conditions on the motorway and the on-ramp. The main purpose is the improvement of traffic conditions on the motorway, taking into account the conditions on the on-ramp and surface roads.

Ramp metering is widely applied in the United States. Quite recently, the U.S. Federal Highway Administration’s Office of Operations has released a handbook that provides guidance and recommended practices on managing and controlling traffic on ramps with freeway facilities (Jacobson et al., 2006).

In 1989, the first ramp metering system in The Netherlands became operational on the S101 on-ramp to the A10-West near the Coentunnel. This on-ramp was used by a large number of rat-runners who tried to avoid the congestion before the Coentunnel, but in the same time caused the increase of congestion on the A10-West. The system was a great success and was followed by a second pilot on the Delft-Zuid on-ramp to the A13 in the direction of Rotterdam. This also turned out to be a success.

Based on these results more on-ramps were equipped to a total number of 54 at the end of 2005. On 10 of these locations a successful assessment study was done. Through 17 years, also different metering algorithms have been investigated. In this paper we will briefly describe the different algorithms and their impact. The research on algorithms is still an important issue.

2. RAMP METERING

Ramp metering is the control of a traffic stream from an on-ramp to the motorway. This is done using special traffic lights that allow vehicles to enter the motorway one by one; the so-called "one car per
green" strategy. In the Rijkswaterstaat Region of Utrecht on some locations also a "two cars per green" strategy is in operation. The objective of ramp metering is to improve traffic conditions on the motorway, but of course, conditions on the on-ramp and connecting roads in urban areas should be taken into account.

Ramp metering can be applied in the following situations:
- On-ramps close to a bottleneck;
- On-ramps which cause disruptions in the traffic stream on the motorway due to the merging process, for example caused by platoons of vehicles coming from a signalised intersection.

The last on-ramp before the Coentunnel to the A10-West motorway (part of the ring road around Amsterdam), the S101, is an example of the first situation. The demand on the motorway and on-ramp together is too high for the capacity of the Coentunnel, with daily congestion as a result.

One of the consequences was that traffic from the city chose the last on-ramp to avoid this congestion (rat-running). After the implementation of the metering system in March 1989, many drivers had to choose another on-ramp or route. This had the effect that the average speed on the motorway increased, the number of rat-runners decreased and the number of vehicle kilometres on the A10 increased.

The on-ramp Delft-Zuid to the A13 in the direction of Rotterdam is an example of the second situation. On a daily basis, during short periods, the capacity was exceeded, leading to shock waves and slow-moving traffic. The disruptions in the traffic stream were caused by platoons of vehicles coming from the on-ramp, which had to merge into the traffic stream on the motorway.

After the implementation of the metering system at the end of 1989, the capacity of the A13 slightly increased and the congestion decreased dramatically.

3. DESIGN ASPECTS

On two cross-sections of the motorway (upstream and downstream the on-ramp), traffic data is measured with induction loops. The flow and average speed measured is compared with certain threshold values. If these thresholds are exceeded, the metering system is activated. During the green time, only one (or two) vehicle per lane is allowed to enter the motorway. The length of the red time varies, dependent on the actual situation on the motorway and taking the queuing on the on-ramp into account.

The metering system is switched off based on the measured flows and speeds, again which are compared with certain thresholds.

3.1. Detection

On the slip road, there is a queue detector close to the surface streets. Near the stop line there is a demand detector, a start amber detector and a start red detector. See fig. 1 for a typical detector layout for a one-lane ramp meter. Indicated are loop detectors, information panels stating: “one car per green”, advance warning signs and traffic signals.

Fig. 1. Typical detector layout for one lane ramp meter

If public transport is using the slip road, a bus lane is introduced, adjacent to the lanes for normal traffic. In one occasion in The Netherlands a truck lane exists, adjacent to the lanes for normal traffic. Busses and trucks have priority over an existing queue on the slip road, i.e. as soon as they are detected; they get green in the next cycle.

3.2. Signal heads

The lights of the metering system differ from normal traffic lights at several points:
- A yellow background shield in stead of black;
- Beneath the lights, a sign is put with the text “one car per green”.
- Signals are located as close as possible near the

Fig. 2. A2-Maarsen Oost: two-lane ramp meter
car driver (lower and closer to the stop line then normal)

− They operate lane dependent. This is a legal requirement and formalised by law. As a 'full lens signal' is applied, in the case of a two-lane ramp meter, there is additional information in the form of ‘linkerrijstrook’ (i.e. ‘left lane only’) and ‘falling arrows’ on the background shield of the overhead signals

Every signalhead is mounted on a standard pole and/or gantry. In case of a one-lane ramp meter, the gantry can be replaced by a pole on the left side of the lane. The situation for a two-lane ramp meter is clearly depicted in Fig. 2, which is a situation along the A2 near Maarssen-Oost.

3.3. Pre-signing

A normal ‘you are approaching a traffic signal’ sign is used to warn for the on-coming signals. An additional text panel states: ‘doseerlichten’ (i.e. 'metering signal'). When the signals are in operation, an amber flashing signal has to draw extra attention.

3.4. Enforcement

Standard equipment includes red-light cameras. Red violation is minor when congestion can be observed on the motorway. The fine is 50 euro per violation. Not in all situations a red-light camera is applied.

3.5. Implementation Costs

The implementation costs are € 150.000,- for a one-lane controller and € 175.000,- for a two-lane controller including outside equipment. Red-light camera's add another € 45.000,-. The maintenance costs are € 10.000,- per annum. All these figures are exclusive central equipment and the costs for infrastructural additions like extra queueing capacity.

4. ALGORITHMS

In The Netherlands, some research was done to compare different algorithms for ramp metering. The algorithms are: the RWS strategy, the ALINEA strategy and an algorithm based on FUZZY logic.

4.1. RWS strategy

The RWS strategy is based on the flows on the motorway and on-ramp and the speed of the traffic on the motorway. The measurements are smoothed to reduce variations. The strategy aims at a good use of the capacity available. The heart of the algorithm consists of the following calculations. The number of vehicles allowed to enter the motorway is calculated with:

\[ r_k = C - I_{k-1} \]  \hspace{1cm} (1)

Where \( r_k \) is the number of vehicles allowed to enter the motorway in time interval \( k \), \( C \) is the pre-specified capacity of the motorway downstream the on-ramp and the variable \( I_{k-1} \) is the measured and smoothed flow upstream the on-ramp in the previous time interval. The cycle time of the metering system is then calculated with:

\[ t = \frac{n \times 3600}{r_k} \]  \hspace{1cm} (2)

where \( t \) is the cycle time in seconds and \( n \) is the number of lanes on the on-ramp. This calculated cycle time is compared with a minimum and maximum value and if necessary, these values are used instead of the calculated one. When speed drops on the motorway either upstream or downstream, the access from the slip road is limited to a minimum. When a queue develops on the slip road, the access from the slip road may be set to a maximum. The choice between minimum and maximum is a political decision and can be activated by toggling a software switch.

So, the cycle time is calculated from the difference of upstream (motorway) demand and downstream (motorway) capacity and number of lanes on the slip road. Capacity itself is not calculated on-line (like in the earlier Birmingham trials). The cycle time is limited to a maximum value (normally 12 - 15 seconds).

An important point is that the green time is dynamic. It depends upon the reaction time of the driver and its acceleration and is in a range of tenths of seconds. Typically, the green time is 2.0 seconds. The amber time is dynamic and depends upon the speed behind the stop line. Typically, the amber time is 0.5 seconds. The red time is the rest of the cycle time minus the green time minus the amber time. The minimum red time is 2.0 seconds. Given these figures the minimum cycle time is typically 2.0 + 0.5 + 2.0 = 4.5 seconds.

The controller is always in operation, with the signals being dead. The signals are put in effect, if the demand on the motorway exceeds a certain threshold.
or the speed on the motorway (either upstream or downstream) lowers a certain threshold. The signals are switched off again if the demand on the motorway lowers a certain threshold and the speed on the motorway (both upstream and downstream) exceeds a certain threshold. All thresholds have some hysteresis. The initiation procedure is 15 seconds amber flashing, 5 seconds fixed amber and 5 seconds fixed red.

In case of a two-lane ramp meter, start of green is synchronized; this is the so-called non-staggered start. End of green per lane depends upon reaction time and acceleration speed of the first vehicle.

When a long truck slowly accelerates, the start of green in a new cycle is postponed as long as the truck occupies the 'start amber' and/or the 'start red' detector.

4.2. ALINEA strategy

The ALINEA strategy was developed by the Technical University of Munich and tested by INRETS on the Boulevard Périphérique (Paris) (Papageorgiou et al., 1991) and by Rijkswaterstaat on the A10-West motorway (ringroad of Amsterdam) in the framework of the DRIVE I project CHRISTIANE (Papageorgiou et al., 1998).

This strategy tries to keep the occupancy downstream the on-ramp on a certain pre-specified value: the occupancy set point. The rules for switching the system on and off are the same as for the RWS strategy. Only the calculation of the number of vehicles allowed to enter the motorway is different. It is based on the occupancy downstream the on-ramp. The formula is:

\[ r_k = r_{k-1} + K \cdot (O_s - O_{k-1}) \]  

Where \( r_k \) is the number of vehicles allowed to enter the motorway in time interval \( k \), \( r_{k-1} \) the (smoothed) number of vehicles having entered the motorway in the previous time interval, \( K \) a constant, \( O_s \) the occupancy set point and \( O_{k-1} \) the occupancy measured downstream the on-ramp in the previous time interval. The cycle time calculation and the other metering conditions are the same as for the RWS strategy.

4.3. FUZZY strategy

The FUZZY strategy is based on three input variables: speed upstream the on-ramp, speed downstream the on-ramp and the time a queue is present on the on-ramp. The cycle time is the output variable. The input variables are divided into a number of classes, e.g. very low, low, medium, high and very high. The measured value of an input variable is transferred to degrees of membership for those classes (fuzzification). Rules are triggered (fired) depending on the classes a measured value is a member. These rules have the form:

IF speed upstream = medium
AND speed downstream = low
THEN cycle time = long

These rules lead to the activation of the classes and the corresponding membership functions in which the output variable is divided. The degrees of membership are then transferred to a value of the cycle time (defuzzification). The on and off switching of the fuzzy strategy is very different from the other strategies. The system switches on when the calculated cycle time exceeds a certain threshold and switches off when it drops below another threshold. The conditions for the minimum and maximum cycle time are the same.

4.4. Comparison of strategies

In the comparison of the RWS and ALINEA strategy it was concluded that the ALINEA algorithm produced comparable or better results than the RWS algorithm. ALINEA increased the total service of the motorway and the on-ramp (Middelham and Smulders, 1991).

In the comparison of the FUZZY strategy with the RWS- and ALINEA strategy, it was concluded that the FUZZY strategy gave better results than the other two as capacity increased with about 5% (however not significant), leading to higher speeds and lower travel times. The RWS and ALINEA strategies gave comparable results compared with each other (Taale et al., 1996).

4.5. Test with V-ALINEA

Occupancy as a set parameter is not understood very easily. So, due to operational reasons like comprehensibility by traffic operators and traffic managers, it was decided to stay with the RWS strategy. This was also because tuning and validating ramp controllers from time to time is inevitable and a difficult and time-consuming task.

This is the reason for a pilot with the V-ALINEA strategy, which is currently running near Barneveld.
along the A1 in the Rijkswaterstaat region East-Netherlands.

In traffic flow theory, there exists a relation between flow (veh/hr), speed (km/hr) and density (veh/km) as depicted in Fig. 4. Normally these variables are averaged over a period of time, (1 minute, expressed in hours) and length of a road section (set in kilometers). It is however very difficult to measure density in practice, as this requires very long loops or complex calculations in which two big numbers, obtained at two cross sections of the road, 500 meters apart, have to be subtracted. The sum of the errors in both measurements has to be taken into account in the difference, which normally is zero (no congestion case), hence the error is infinite large.

It is assumed that the same relations exist for cross sections measurements in terms of flow, speed, and occupancy. This being the case, it can be seen in the figure that the RWS strategy operates in the 1st quadrant with flow as control variable. From the figure it can be concluded that the same value of flow is related to no-congestion (the green square and dots) and with congestion (the red square and dots). This is not the case for occupancy and speed. Hence the equation for V-ALINEA strategy reads:

\[ r_k = r_{k-1} + K[V_s - V_{k-1}] \]  

(4)

Where \( r_k \) is the number of vehicles allowed to enter the motorway in time interval \( k \), \( r_{k-1} \) the (smoothed) number of vehicles having entered the motorway in the previous time interval, \( K \) a constant in veh/hr for a difference in speed of 1 km/hr, \( V_s \) the speed set point and \( V_{k-1} \) the speed measured at an arbitrary location in the bottleneck, close to the on-ramp. Please note that choosing a good location is necessary but less sensitive for a mistake then for occupancy that has to be measured downstream the merging area. The cycle time calculation and the other metering conditions are the same as for the RWS strategy.

**4. EFFECTS OF RAMP METERING**

For 10 on-ramps with ramp metering a successful assessment study was done. For two on-ramps, even two studies were conducted. That makes ramp metering one of the most studied dynamic traffic management measures in The Netherlands. Nevertheless, it turns out to be difficult to make a judgement about the effects of ramp metering.

In Table 1 the effects found are summarised. The table is derived from various reports on the assessment studies: BGC (1990), Gronmij (1990, 1994 and 1995), Heidemij (1996), Goudappel Coffeng (1998), Witteveen+Bos (1999) and AGV (2000). In the table the most common indicators are used and the numbers shown are made consistent as much as possible.

From the table it can be concluded that the effect on capacity can vary between no effect and an increase of about 5%. The speed on the motorway increased in all cases, but the order varies substantially. Dependent on the situation and the objective of ramp metering the use of the on-ramp decreases strongly. Because the speed on the motorway increases, travel time decreases, at least in those cases were this indicator was analysed. The calculation of total delay in vehicle hours does not happen often (only in 3 studies). On the other hand red light violation is studied in almost all assessments. If there is a clear bottleneck, about 6% of the car drivers ignore the red light. If there is no clear bottleneck, this percentage increases to about 15%. If a red light camera is installed, only about 2% to 3% risks a fine.

**5. CONCLUSIONS**

At the end of 2005 in The Netherlands 54 on-ramps had a ramp metering system. In Fig. 5 the locations are shown. As can be seen from this picture most of the system are located near the cities Utrecht, Rotterdam and Amsterdam.

<table>
<thead>
<tr>
<th>Capacity of bottleneck</th>
<th>Speed on motorway</th>
<th>Use of on-ramp</th>
<th>Total delay (veh.hrs)</th>
<th>Travel time motorway</th>
<th>Redlight violations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coentunnel S101 (1 on-ramp)</td>
<td>=</td>
<td>+30 km/u</td>
<td>-50%</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>A10-West (4 on-ramps)</td>
<td>2%</td>
<td>+20 km/u</td>
<td>±</td>
<td>-20%</td>
<td>-</td>
</tr>
<tr>
<td>Delft-Zuid (1st assessment)</td>
<td>5%</td>
<td>-</td>
<td>=</td>
<td>&lt;</td>
<td>-</td>
</tr>
<tr>
<td>Delft-Zuid (2nd assessment)</td>
<td>4%</td>
<td>-</td>
<td>=</td>
<td>&lt;</td>
<td>-</td>
</tr>
<tr>
<td>Zoetermeer</td>
<td>3%</td>
<td>-</td>
<td>=</td>
<td>-</td>
<td>-6%</td>
</tr>
<tr>
<td>Schiedam-Noord</td>
<td>&gt;</td>
<td>+20 km/u</td>
<td>-8%</td>
<td>-</td>
<td>-6%</td>
</tr>
<tr>
<td>Barendrecht</td>
<td>5%</td>
<td>+20 km/u</td>
<td>-35%</td>
<td>-</td>
<td>-10%</td>
</tr>
<tr>
<td>Kolkweg</td>
<td>=</td>
<td>+4 km/u</td>
<td>-10%</td>
<td>-</td>
<td>-3%</td>
</tr>
<tr>
<td>Vianen</td>
<td>5%</td>
<td>+5 km/u</td>
<td>-36%</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Muiden/Muiderslot</td>
<td>-</td>
<td>-</td>
<td>±</td>
<td>-</td>
<td>=</td>
</tr>
<tr>
<td>Vinkeveen</td>
<td>1-3%</td>
<td>+10km/u</td>
<td>=/-</td>
<td>-</td>
<td>-5 min</td>
</tr>
</tbody>
</table>
Ramp metering is an accepted traffic management measure in The Netherlands. According to the assessment studies, good results are obtained. Reviewing the assessment studies made clear that they vary much in research approach, measuring methods and indicators.

6. FURTHER RESEARCH

An important reason for installing ramp meters is the better merging of slip road traffic onto the mainline and the occurrence of lesser shockwaves on the motorway. Fewer accidents have been reported mainly from United States experience. Because any investigation in traffic safety requires a lot of data and a long before and after period, the question now is, given the installation of several ramp meters during the years 1999-2003 in the Region of Utrecht, whether or not accident data is able to show any change in traffic safety during recent years. In the context of the 6th Framework consortium EURAMP, traffic safety data will be collected and analysed from the A28 running from Amersfoort to Utrecht, with three metered on-ramps.

A good basis for ramp metering may be found in the fact that fewer kilometres are travelled in the urban area (for a better traffic safety) in favour of more kilometres on the motorway (a better use of the motorway). It may be noticed here that in a generic global network optimum approach, ramp metering also at non-congested on ramps is appropriate in a coordinated approach. This has recently been discussed in a paper by Kotsialos et al. (2005), in which the Amsterdam ring road is taken as an example. This probably will be the basis for a decision by the Dutch authorities to test and study a coordinated approach in real life.

REFERENCES


