INTRODUCTION

Since 1990 dynamic traffic management is an important part of the Dutch policy to drive back the negative impacts of 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, 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. See for example Remeijn (1), Van den Hoogen and Smulders (2), Buijn et al (3), Taale et al (4), Van Eeden et al (5), Taale and Van Velzen (6), De Haes and Bokma (7), Smulders and Helleman (8) and Helleman et al (9) for more details and Middelham (10) for an overview.

Table 1 gives an overview of the implemented dynamic traffic management measures until the end of 1998. The implementation of all these measures is the consequence of the policy to build less infrastructure and to focus on a better use of the existing infrastructure. The table was derived from a report from the Construction Department of Rijkswaterstaat (11).

Table 1: Overview traffic management measures

<table>
<thead>
<tr>
<th>Measure</th>
<th>Number</th>
<th>Kilometers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motorway Traffic Management</td>
<td>807</td>
<td></td>
</tr>
<tr>
<td>Dynamic Route Information</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Ramp-Metering Systems</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Peak Lanes</td>
<td>3</td>
<td>15</td>
</tr>
<tr>
<td>Truck Lanes</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>Bus Services</td>
<td>23</td>
<td>65</td>
</tr>
<tr>
<td>Overtaking prohibition trucks</td>
<td>36</td>
<td>399</td>
</tr>
</tbody>
</table>

In this paper the focus will be on ramp-metering. Ramp-metering is the management of traffic on an on-ramp, dependent of 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.

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 this results more on-ramps were equipped to a total number of 20 at the end of 1998. On eight of these locations an assessment study was done. In the paper these assessment studies and the effects of ramp-metering on capacity, flow, speed, travel time, etc. will be discussed.

In this ten years also different metering algorithms have been investigated. The paper will describe the different algorithms and their impact. The research on algorithms is still an important issue. The paper will conclude with some remarks about assessments and will draw some conclusions.

RAMP-METERING

Application of 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 which allow vehicles to enter the motorway one by one. 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-ramps 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 a part of the traffic had to choose another on-ramp or route. This had the effects that the average
speed on the motorway increased, the number of ratrunners 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 ex-
ceeded, 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.

The Principles of Ramp-Metering

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 acti-
vated. During the greentime only one vehicle per lane is
allowed to enter the motorway. The length of the red
time is varied, depending on the actual situation on the
motorway and also taking the queuing on the on-ramp
into account.
The metering system is switched off again based on the
measured flows and speeds, which are compared with
certain thresholds.

Design Issues

The light of the metering system differ from normal
traffic lights on two points:
− a yellow background shield in stead of black;
− beneath the lights a sign is put with the text “one car
per green”. The signals are located as close as possi-
ble near the car driver (lower and closer to the
stopline as normal) and can operate lane dependent.

In figure 1 an example of a metering signal is given.

Locations

At the end of 1998 in The Netherlands 20 on-ramps had
a ramp-metering system. In figure 2 these locations are
given. As can be seen from this picture most of the
system are located near the cities Amsterdam, Rotter-
dam and Utrecht.

Effects of Ramp-Metering

For eight on-ramps with ramp-metering an 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.
Nevertheless it turns out to be difficult to make a
judgement about the effects of ramp-metering.
In table 2 the effects found are summarised. The table is
derived from BGC (12), Grontmij (13), (14), (15), (16)
and (19), Heidemij (17), Goudappel Coffeng (18) and
Witteveen+Bos (20). 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 seen 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
ignoring the red light is studied in almost all assess-
ments. If there is a clear bottleneck, about 6% of the car drivers ignores 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. This shows the control dilemma.

A recent simulation study by Middelham (21) showed that there is strong dependence between ramp-metering and the use of on-ramps. Ramp-metering is an effective way to reroute rat-runners. It is also important that ramp-metering has an positive effect on the capacity of the motorway. If this is the case, than there will also be positive effects for the surface network.

**Algorithms**

In The Netherlands some research was done to compare different algorithms for ramp-metering. Three algorithms were studied: the RWS strategy, the ALINEA strategy and an algorithm based on fuzzy logic.

**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 measurement 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

\[
r_k = C - I_{k-1}
\]  

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 cycletime of the metering system is then calculated with

\[
t = \frac{n \times 3600}{r_k} 
\]  

where \( t \) is the cycletime in seconds and \( n \) the number of lanes on the on-ramp. This calculated cycletime is compared with a minimum and maximum value and if necessary these values are used in stead of the calculated one. If there is a queue on the on-ramp the calculated cycletime can be overruled with the minimum cycletime. Other calculations determine whether or not the system should be turned ‘on’ or ‘off’.

**ALINEA strategy.** The ALINEA strategy was developed by the Technical University of Munich and tested by INRETS on the Boulevard Périphérique (Paris) and by Rijkswaterstaat on the A10-West motorway (ringroad of Amsterdam) in the framework of the DRIVE I project CHRISTIANE. This strategy tries to keep the occupancy downstream the on-ramp on a certain pre-specified value: the occupancy setpoint. 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:

\[
r_k = r_{k-1} + K \times [O_s - O_{k-1}] 
\]  

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

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**Table 2: Effects of ramp-metering**

<table>
<thead>
<tr>
<th>Capacity bottleneck</th>
<th>Speed motorway</th>
<th>Use of on-ramp</th>
<th>Total delay (veh.hours)</th>
<th>Travel time motorway</th>
<th>Ignoring red light</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coentunnel (1 on-ramp)</td>
<td>=</td>
<td>+30 km/u</td>
<td>-50%</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Coentunnel (4 on-ramps)</td>
<td>+1-2%</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>-6%</td>
<td>=</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>
</tbody>
</table>

‘=’ means equal, ‘<’ means decrease, ‘>’ means increase, ‘=’ means variable and ‘-’ means not studied.
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 cycletime 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). Depending on the classes a measured value is a member of, rules are triggered (fired). These rules have the form: IF speed upstream = medium AND speed downstream = low THEN cycletime = long. These rules lead to the activation of the classes and the corresponding membership functions the output variable is divided into. The degrees of membership are then transferred to a value of the cycletime (defuzzification). The on and off switching of the fuzzy strategy is very different from the other strategies. The system switches on when the calculated cycletime exceeds a certain threshold and switches off when it drops below another threshold. The conditions for the minimum and maximum cycletime are the same.

Comparison. In two studies the control strategies described were compared with each other. Smulders and Middelham (22) compared the RWS and ALINEA strategy and concluded that the ALINEA algorithm produced results comparable or better than the RWS algorithm. ALINEA increased the total service of the motorway and the on-ramp. Taale et al (23) compared the fuzzy strategy with the other two and found that this strategy gave better results than the other two: capacity increased with about 5% (not significant), leading to higher speeds and lower travel times. The RWS and ALINEA strategies gave comparable results.

Further research. At this moment a project is done to simplify the algorithm currently used. The traffic engineer has to deal with too much parameters which makes tuning a difficult task. Also an algorithm based only on speed is considered.

ASSESSMENT FRAMEWORK

The assessment studies described, show a large variation in indicators, measurement and analysis methods. This makes it difficult to compare results. With a common framework hopefully the comparison of results will become easier, not only for ramp-metering, but for all dynamic traffic management measures.

Assessment Study

An assessment starts with the writing of an assessment plan (see next paragraph). After the assessment plan is approved, normally a tender takes place. After the contract negotiations final decisions can be made about parts of the assessment, for example data collection. Then the data is collected, selected and analysed. An assessment is ready when the report is completed. After that communication of the results is an important aspect. Decisions about continuation of the measure, implementation on other locations or adjust the measure can depend on a good communication plan.

Assessment plan

A good and complete assessment plan is the basis for every assessment. It makes clear who is responsible for every part of the assessment and must prevent misunderstandings (e.g. about the data collection) and wrong interpretations (e.g. about the definition of indicators). Ideally an assessment plan consists of the following parts:

- a description of the measure studied;
- the goal of the assessment;
- research questions;
- expected effects;
- research design (before and after measurements or other design);
- indicators (which data should be collected and during which period);
- size of the area under study (local effects or also network effects);
- data collection (period, sources, level of aggregation, etc.)
- data selection (taking into account weather conditions, traffic demand, incidents, etc.)
- analysis (the analysis answers the research questions with the use of statistics);
- writing the report (which requirements are necessary);
- organisation (name and role of interested parties);
- planning.

An assessment plan has three purposes:

- clarity about the things which should be done and by whom;
- part of the tender and basis to judge the proposals;
- guarantee that every interested party has the same expectations about the assessment;

By using this structured approach assessment studies become much more comparable with each other, which is necessary to measure the effects of a certain policy and to maintain it.

CONCLUSION

Ramp-metering is an accepted traffic management measure in The Netherlands. About 20 on-ramps are equipped with a metering system and, 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, etc. An assessment framework should make it
more easy to compare results, not only for ramp-metering, but for all traffic management measures.

REFERENCES


