Analysis of the Local Effects of Ramp-Metering on Two Junctions with the Motorway A10-West Using FLEXSYT

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Publication date
1993

Document Version
Final published version

Citation (APA)
Taale, H. (1993). *Analysis of the Local Effects of Ramp-Metering on Two Junctions with the Motorway A10-West Using FLEXSYT*. Rijkswaterstaat Adviesdienst Verkeer en Vervoer.

EVALUATION STUDIES OF ON-RAMP METERING

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ABSTRACT

This paper discusses the experience with ramp metering in the Netherlands. Different types of control strategies are applied in different situations. For instance, ramp metering can be used to force the drivers to use a different on-ramp, or it can be used to smoothen the merging process.

The most recent completed study concerns the effects of the ramp metering system located on the on-ramp near Zoetermeer along the A12 motorway, just upstream of a point causing recurrent congestion during evening rush-hour.

We investigated the effects of ramp metering on a variety of measurable quantities. Examples are: travel times, volume distribution, queue formation and red-light running on the on-ramp; rat-running on the surrounding network; travel times, congestion and capacity on the main roadway.

Results due to ramp metering are, for instance, a 3% gain in capacity of the downstream bottle-neck and a significant reduction of severe congestion.

Apart from this study, we will report on ramp metering evaluations near a tunnel in the Amsterdam ring road, on the A13 near Delft and on the still on-going evaluation study of ramp metering along the ring-road A10 around Amsterdam. Upstream from the Coentunnel four ramp metering systems have recently been realised on four adjacent on-ramps. The evaluation study aims at investigating the differences between a number of control strategies, of which some are local strategies, some others are coordinated control strategies.

1 RAMP METERING IN THE NETHERLANDS

1.1 Introduction

Traffic metering on on-ramps is a growing 'industry' in the Netherlands. Some installations have already been operating for some years. At present, six on-ramps are equipped with ramp metering installations; another is in the pipeline and plans are being made for a score of installations.

For every realisation, extensive evaluation studies have been carried out. Each involving the measurement and analysis of a considerable number of quantities. This paper describes the Dutch ramp metering systems and the evaluation methods used so far. Descriptions of the sites equipped with ramp metering will be given in the next section. Although we review the several studies, pictures are only presented for the Zoetermeer study, the most recent one.

1.2 General objectives and site description

Ramp metering is generally used to improve the level-of-service on the *main roadway*, by forcing the in-flow of traffic to attain a more favourable pattern. Condition for installing ramp metering is, of course, that congestion is caused by traffic mounting on the main roadway at the on-ramp concerned.

In the Netherlands, ramp metering operates roughly along one of two approaches:

- **Limiting the traffic flow on the on-ramp to some value**

  This is the solution in cases where traffic, trying to circumvent the major part of the queue on the main roadway, mounts on as far ahead as possible, i.e. closest to the bottle-neck.

  Ramp metering on this ramp leads to a reduction of (unwanted) traffic on the urban network. The effect can be characterised as spreading the traffic over the different adjacent on-ramps: 'space-spreading'.

  Sites

  The on-ramp on the A10 ring road around Amsterdam, just before the Coentunnel. Very recently, three other on-ramps, adjacent to the one just mentioned, have been equipped with ramp meters. The project is part of the DRIVE II project V2017: EUROCOR (European Urban Corridor Control).

  In the near future, the on-ramp near Vianen on the A2, south of Utrecht, north-bound, will be equipped.

- **Smoothing the on-ramp flow**

  This is a more friendly way of metering. Condition is that ramp metering should not cause severe congestion on the surrounding network. The on-ramp flow on a time-scale of several minutes is not affected/reduced, but the peaks in the minute-flows are cut off. 'Time-spreading' is a short-hand way to characterise the control strategy.

  Sites

  The on-ramp near Delft on the A13 from The Hague in the direction of Rotterdam. The on-ramp near Zoetermeer on the A12 from The Hague in the direction of Gouda and Utrecht

Common properties

- Red-yellow-green traffic lights, with a design that differs from the standard traffic lights.

- Only **one car per green** period is allowed to mount on the main roadway. Traffic properties (flows and speeds) are measured 500 m upstream of the merging point and 500 m downstream, as well as on the on-ramp.

1.3 Effects

The effects aimed for are shortly indicated as follows:

- **Travel time** / delay time / speeds: improvements, mainly due to congestion prevention.
- **Flow**: increase of the net flow through the network, mainly due to less congestion.
- **Capacity**: a slight increase of capacity, caused by favourable driving behaviour.
- **Queues**: less congestion on the main roadway.
- **Rat-running**: the problem that is tackled in the *space-spreading* control strategy, but a possible negative side-effect in the *time-spreading* strategy.
- **Redistribution** over neighbouring on-ramps: if required, this is a positive effect; if not, it is called rat-running.
- **Shock waves** and other disturbances: a reduction in shock waves, yielding better driving conditions.

1.4 Control strategy

The core of the control strategy is described as follows. Intensity and velocity are measured upstream and downstream from the merging point, as well as on the on-ramp. Every lane is measured separately; the values for the whole carriage-way are calculated from this by means of a weighted average.
The algorithm must make two decisions:
1) whether the machine should switch on or off,
2) what the cycle time of the control strategy should be, whilst metering.

1) Metering or not depends on the intensity and velocity upstream and downstream of the merging point, on the main roadway as well as on the on-ramp (e.g. metering a small on-ramp flow does not make sense). When both carriage-way intensities are above their respective thresholds, or both velocities are below their respective levels, the installation switches on. For switching off, lower threshold intensities and higher threshold velocities are used (cf. hysteresis).
   In order to prevent switching off and on too often (blinking), the measured quantities are led through an exponentially-smoothing filter.

2) Seen from the point of view of the main traffic stream, the intensity of traffic merging in from the on-ramp should be limited to

$$I_{\text{ramp|main}} = C_{\text{main}} - I_{\text{main}}$$

   Where I denotes intensity or flow, and C capacity. From this 'maximum' on-ramp flow, the corresponding cycle time is calculated, knowing that every cycle one car will merge (for every lane on the on-ramp). Another cycle time is calculated from the on-ramp volume $I_{\text{ramp|ramp}}$. The cycle time T_c used in operation is a weighted average:

$$T_c^{-1} \sim I_{\text{ramp}} = a\, I_{\text{ramp|main}} + b\, I_{\text{ramp|ramp}}$$

   These formulas concern smoothed values, the cycle-time is adjusted in a step-wise manner to a new value. The weights a and b, set by an operator, can take values from zero to unity. The weight b of the on-ramp intensity, for instance, may be set to zero.

> The durations of green and yellow light are vehicle dependent, as the transitions to yellow and red, respectively, are determined by the passages of the vehicles over induction loops just after the halting line. Counting with rule-of-thumb values of these durations, the only way the cycle-time can be controlled is through the red light period.

Clearly, the algorithm contains a lot of parameters for thresholds and smoothing, etc. The most important **parameter** is the capacity of the main roadway. This parameter is set by the operator; the installation does not try to estimate the current capacity from measurements, as is the case for ramp metering near Birmingham, England. The ALINEA control strategy, applied on the Boulevard Périphéerique of Paris, for instance, is implemented in some Dutch installations, as an alternative control strategy.

For the time-spreading control strategy, *lower level* measures are taken with respect to the situation on the on-ramp and on the surrounding network, and also to prevent strange situations as controlling in absence of on-ramp traffic. Most important is the congestion detection at the beginning of the ramp. The space-spreading strategy does not involve this event, but the time-spreading does. If traffic halts at that point, the cycle time is set to its minimum, regardless of the situation on the main roadway. With this minimum cycle time, as much traffic as possible is put through without switching off the lights.
Another measure taken on the ramp is the correction for red-light infringements, effectuated during subsequent cycles.

For reasons of management and evaluation, relevant data is logged every minute on a microcomputer, present in the road-side unit, or in a remote control room. Data includes lane counts, red light infringements, smoothed data and cycle times.

2 MEASUREMENTS

2.1 Dates and times

The situation with ramp metering is to be compared with the situation without ramp metering. Rule-of-thumb arguments require a number of 15 days for either situation in order to average out the day-to-day variation in traffic demand.
In the case of space-spreading control strategies a learning effect may occur: shortly after installing ramp metering, the route choices of the public will alter only slightly. After a few months, the routes will be chosen according to a new equilibrium, where perceived travel or delay time are the criteria of the individual driver.
As long as the route choices are not affected, a different scheme can be followed, where the installation is alternatively switched on and off. This can be done on a dayly or a weekly basis. 'Switched on' means that the installation starts metering if the traffic conditions meet the criteria described in the previous chapter. One should consider the entire day or fixed part of the day, and not only the time intervals during which the system is active; periods from 'off-days' comparable to the active intervals can not be found.
Data is collected during a period that includes evening rush hour. It is important to start measuring before the start of any congestion. At Zoetermeer the time interval was taken from 4 pm until 7 pm. The current study on the ring road around Amsterdam starts earlier, as the problems start earlier.

The field work has to be carried out during **representative days**. The selection has to be done very carefully. Mid-winter, Christmas, Easter holidays, Summer holidays etc. should be excluded. One also has to be on the alert for strikes in public transport or otherwise, leading to anomalous traffic volumes, and of course for road constructions nearby. Occurrence of incidents also makes the data useless for the analysis of the subtle effects of ramp metering.

Traffic conditions are quite different when it is raining, or when the pavement is wet. The data collected during these moments or days can not be compared with data obtained on dry days. In general there are very few rainy days anyway.

2.2 Sites

We give a more detailed overview **only** for the Zoetermeer situation, see Figure 1.

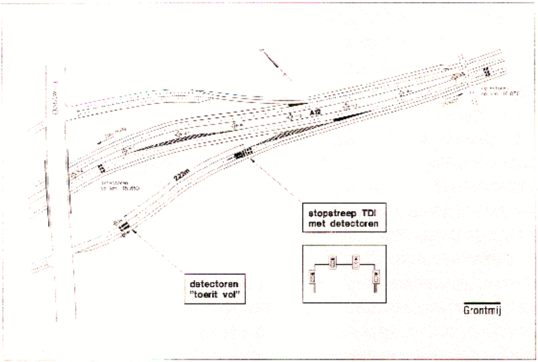

Figure 1 Layout of the ramp at Zoetermeer. 'TDI' = Toeritdoseerinstallatie = ramp metering installation. 'Stopstreep' = halting line. 'Toerit vol' = ramp full.

2.3 Electronic data

Motorway data for the evaluation near Zoetermeer is collected by five systems at the road side. For Delft (A13), as well as for the present study on the A10, data was/is used from the Motorway Control and Signalling System (MCSS), with induction loops every 500 m. During the Delft study and the Zoetermeer study, extra modules for collecting *individual vehicle data* were built in.

On-ramp data is taken from the log files of the installation (minute counts and minute averaged velocities). One of the entries in the logging concerns the number of red-light infringements, an indication of the degree of acceptance.

2.4 Visually obtained data

Data on **queuing** is collected by (human) observers. At Zoetermeer and Delft this was restricted to travel times and queue lengths on the on-ramp, near the Coentunnel in Amsterdam also the queues on the main roadway and the surrounding network are observed, as well as counts of the different directions on some relevant intersections.
In addition, on the A10, a license plate survey is/was carried out for measuring the **travel times** from the on-ramps to the end of the study area.

2.5 Video

In order to capture the effects on the drivers' **merging behaviour**, video camera's were used during the evaluation near the Coentunnel and near Delft.

3 ANALYSIS

This chapter briefly indicates the methods that have been used for the evaluation. Throughout the study, it is important to distinguish both the systems' functioning and its effects on the on-ramp, and the effects on the main-roadway traffic.

First of all, an accurate **data selection** has to be done, for arguments we already mentioned in section 2.1.

Part of the data selection is that we have to make sure that the main roadway **intensities** are comparable. The day-to-day variation during fore- and after-situation has to be the same. This is for the traffic on the main roadway. Effects on the intensities on the on-ramp, however, have to be analyzed. These include both wanted and unwanted effects.

For the **capacity**, the data is classified according to intensity. For every intensity, the probability that congestion occurs is determined. Use is made of the parallel between this problem and *survival analysis*. If a certain intensity does not lead to congestion within 10 to 15 minutes, it is classified as a 'surviving' intensity. The time scale on which the traffic intensity pattern is correlated is of about 5 minutes (Ref. 5). Independent intervals (in this respect) are those with a longer duration. 10 or 15 minutes will do. 'Dying' intensities are ten- or fifteen-minute counts for which the next interval shows congested traffic, while at sites further downstream there is no congestion. We define an interval to show **congestion** if the average velocity is below 80 km/h (50 mph). From this probability distribution (see next chapter for an example), the capacity can be defined in several ways. We define it as the intensity where the congestion probability equals one half. This is a way of defining the *practical capacity*. Note that in general this is *less* than the highest observed intensity in the fundamental diagram.

The **velocities** on the motorway are aggregated to a 10-minute level. Next, an aggregation step is carried out through all days in the fore-situation: e.g. the average over all days of the velocity between 4 pm and 4.10 pm is calculated.

From one-minute averages for the velocities, it is possible to estimate the **travel time** for a motorway stretch. This seems in any case reasonable for a stretch of about 300 - 500 meters, as this is roughly the correlation length. A chain of measuring sites, spaced 500 m, along a stretch of the road, allows an estimation of the travel time over the whole stretch. The estimate remains reasonable when the spacing is taken longer (Ref. 6)

When a clear shift in route choices is expected to occur, a relevant quantity is the **total distance travelled** in the network. Near Zoetermeer, the effects remain local, so we did not investigate the travelled distance. For the A10 around Amsterdam, however, it is important to investigate this effect, for the space-spreading character of the control strategy directly affects the distance travelled.

On the on-ramp, **queue lengths** and **travel times** are important quantities. Important is the 'obedience' of the public; red-light runners are counted.
Incidental red-light running does no harm; when it occurs too often, measures should be considered for upholding.

On a microscopic scale, the difference between metering and not metering can be destillated from the relation between subsequently passing vehicles. Two phenomena can be identified here. First the follow-up times or **headways**, where especially series of short gaps ($t < 0.6$ s) are important. These contribute to the occurrence of shock waves. As the first car of a series has to suddenly lower its speed, the combination of accumulating reaction times and accumulating corrections towards safe distances, leads to a sharp drop in velocity. With high enough density, this disturbance propagates backwards through the traffic, and often has the character of a shock wave.

Both **shock waves** and headways are analyzed from the individual vehicle data, collected by the electronic road-side equipment.

4 RESULTS

In this chapter we present the main results obtained from the evaluation studies. For a description of the methods used in the analysis, we refer to the previous chapter.

4.1 Macroscopic effects

Queues on main roadway
The evaluation study near the Coentunnel does not show clear effects for the queuing on the main roadway, either for the lengths or for the duration.
Near Delft, the amount of queues has been dramatically reduced: with 95 %.
The Zoetermeer study shows only a slight decrease, but a clear improvement in the sense that congestion less often means 'lining up'. Without ramp metering the traffic gets 'jammed', with ramp metering it keeps flowing, although at a considerably reduced speed.

Queues on ramp and surrounding network
Near the Coentunnel, the redistribution of queues has settled down, as could be expected.

Near Zoetermeer, the queuing on the on-ramp was observed. Although without ramp metering the queue sometimes fills the on-ramp completely, with metering this happens much more often. When the queue gets longer than that, problems arise immediately on the crossing road. However, detailed observations of blocking have not been done.

Capacity

For the ramp metering system near the Coentunnel, no detailed analysis has been carried out. Inspection of the realised intensities has not shown a manifest capacity gain. At that location, a wide variety of disturbing phenomena makes a detailed analysis impossible.

The results of the Zoetermeer study are depicted in Figure 2. Here, a clear bottle-neck can be distinguished. In Figure 2, its capacity is described in terms of congestion probability. The bottle-neck lies downstream of the Bleiswijk measuring site (about 1 kilometer downstream of the merging point). The study does not reveal the nature of the bottle-neck, or the origin of congestion. What can be concluded, however, is that the traffic stream is more robust, i.e. is less disturbed by whatever congestion cause when ramp metering is in operation. The capacity gain is about 3 %.

The Delft study gives results for the capacity that point in the same direction. There is no real bottle-neck, however, and the intensity does not exceed the capacity very often.

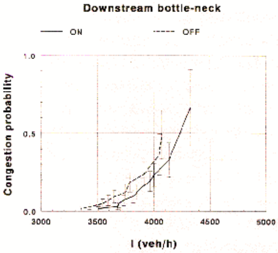

Figure 2 The congestion probability near the Bleiswijk measuring site, 1.1 km downstream of the merging point at Zoetermeer

Speed

The effects on the average speed are visualised in Figures 3 to 6.

Near the bottle-neck the effect is not very large; clearest is the improvement after 18 h. Further upstream the positive effect of ramp metering starts earlier; about 1 km upstream of the ramp a clear positive effect is seen for the whole rush-hour period.

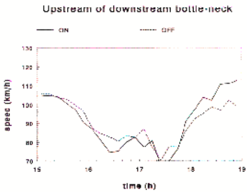

Figure 3

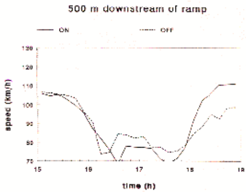

Figure 4

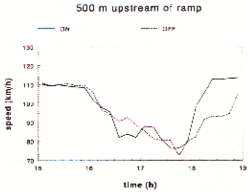

Figure 5

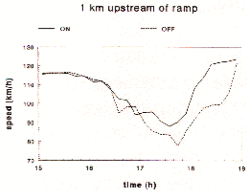

Figure 6

Travel times

Coentunnel
Travel time losses on the trip from the on-ramp adjacent to the metered one to the other side of the tunnel are reduced with 20 %. Time losses from the beginning of the *metered on-ramp* have increased, of course. The travel times via the first and second on-ramp have equilibrated. For trips from the other, more remote on-ramps, no significant gain has been concluded.
Delft
Due to the near disappearance of queuing on the main roadway, also the time losses have also become negligible.
Zoetermeer
Over a stretch of 5,1 km of freeway, the travel times have been reduced from 300 to 270 seconds. The free flow travel time is 167 s, and the reduction of time losses is 37 %.

Rat-running / distance travelled
Rat-running is a phenomenon related with ramp metering. It can be the effect/problem that ramp metering is aiming to resolve, as is the case near the Coentunnel, or it can appear as a side-effect one would rather not have.

Coentunnel
The 'rats' running towards the on-ramp are discouraged by the time delay, and they have turned back to their 'own' on-ramp, further upstream, thus reducing their travelled distance on the urban network. A new equilibrium has set. Some drivers who have unjustly been chased away will drive more kilometers on the urban network. This will only be a small fraction.

Zoetermeer
The intensity on the on-ramp has not changed significantly. The improved conditions *withhold* drivers to get off the freeway and use the surrounding network to circumvent the queue on the main roadway. The number of drivers doing this is very small.

4.2 Microscopic effects

Flows on ramp
The intensity distribution on the ramp changes, due to ramp metering. The high minute counts do not occur any more. Due to ramp metering, the distribution becomes sharply peaked around the mean value, corresponding to a very homogeneous flow.

Merging behaviour
Coentunnel: before the installation of ramp metering there were really chaotic situations, including drivers passing each other on the one lane ramp. After installation, the speeds on the main roadway were increased to a reasonable 50 up to 60 km/h or higher. Together with the one-by-one rule, merging has become a lot more pleasant.
Near Delft, no real effects on the merging process have been observed. The merging behaviour at Zoetermeer has not been observed by video, and can only be deduced from the microscopic study of headways, see the discussion below.
One car at a time can be absorbed more easily in the traffic stream. Merging platoons lead to concentration in the main flow and subsequently to series of short followers, with the corresponding instability for sudden changes, leading to shocks, shock waves and congestion.

Shock waves on main roadway
The extensive study near Delft, using MCSS data, yields a decrease of the frequency of shock wave occurrence. The *character* of a shock wave however, is not affected by ramp metering, once it occurs.

Headways

These have been analyzed only in the Zoetermeer study. Data just upstream from the bottle-neck is classified according to intensity. The simple headway distribution is not affected by ramp metering (see Figure 7). The multiple headway distribution does change. A cut-through is presented in Figure 8, where it shows that long series of short headways do occur less frequently when ramp metering is on. This is explained by the one-by-one arrival of cars from the ramp. Due to this, less large blocks will results on the main roadway.

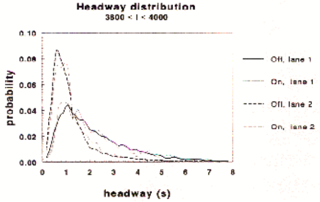

Figure 7 Headway distribution near bottle-neck

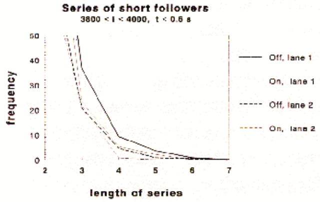

Figure 8 Frequency of series of short followers.

Red-light infringements

The percentage of vehicles running the red light is:
Coentunnel: 3 %, Delft: 15 %, and Zoetermeer: 13 %.
The situation at the Coentunnel presents a clear problem, and was experienced as such by the public. The way in which ramp metering exerts its effect in the other two cases (Delft and Zoetermeer) is less obvious for the public. This explains the relatively high percentage of red-light violations. Nevertheless, the essentials of metered traffic appear to be sufficiently present to have its positive effects on the main traffic stream.

5 CONCLUSIONS

We have indicated the current situation concerning ramp metering in the Netherlands. Emphasis has been put on the aspect of evaluation. The over-all conclusion is that ramp metering has a positive effect. Specific conclusions depend on the precise location and local conditions. Not every effect is present everywhere, but it is possible to resolve some of the problems everywhere. The main goal is reduction of travel time losses. This may be achieved, although not necessarily, by a gain in capacity.

The primary element of ramp metering is to keep some traffic away from the main roadway at the ramp concerned, i.e. reduction of in-flow. A secondary element is the one-car-at-a-time arrival process, 'cutting platoons of vehicles', with its positive effects on the stability of the traffic. For the locations Delft and Zoetermeer, due to the boundary conditions of the control strategy, the primary effect is absent, and the latter becomes the main element.

For more detailed conclusions we refer to the fore-going chapter.

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