EVALUATING NETWORK WIDE EFFECTS OF VMS'S IN THE NETHERLANDS

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1. INTRODUCTION

1.1 Background

Advanced Traveler Information Systems (ATIS) provide traffic information to assist drivers in trip planning and decision making regarding destination, departure time, route choice, congestion avoidance, and to improve their travel efficiency.
Over the past two years a large scale evaluation has been carried out of fourteen new Variable Message Sign's (VMS) that have been installed at the freeway system around Amsterdam. The evaluation of these new VMS's has been commissioned by North-Holland Directorate of the Ministry of Transportation. This evaluation concerns traffic safety, emissions, impacts for the underlying network caused by route diversions, and traffic performance on the freeway system.
To collect data for the evaluation a variety of techniques was applied, including mail back surveys (N=1402), collection of traffic data before- and after the introduction, logging the VMS messages, observing traffic on the underlying network, and interviewing involved parties like road operators and police. The particular focus of this paper is on the quantitative analysis based on traffic data from the freeway system and the logging of VMS messages.

Part of the work that is reported in this paper was carried out within the European Fourth Framework project 'DACCORD' (Development and Application of Co-ordinated Control of Corridors). The objective of DACCORD is to design, implement and validate a practical Dynamic Traffic Management System for integrated and co-ordinated control, see (Kroes *et al.* 1998).

The use of Variable Message Signs (VMS's) is are generally considered to be a powerful tool to influence (en-route) route choice in order to increase safety and comfort while driving, to improve the network performance, and to optimize ally make use of the utilization of the available capacity. Various studies have shown that VMS's have an effect on route choice decisions and network performance, see among many others Emmerink et al (1996), EAVES (1994), Mahmassani and Jayakrishnan, (1991), Mahmassani and Jou (1998), Transpute (1997), Van Berkum and Van der Mede (1993). The effects depend on drivers' attitudinal factors and drivers' observations (e.g. Polydoropoulou et al, 1994). Also drivers' knowledge of the network is an important condition influencing drivers' response to information (e.g. Bonsall and Palmer, 1998). Another important factor is the content and phrasing of the messages (e.g. Bonsall and Palmer, 1998; Speulman et al, 1997). Also the reliability of the information is a very important factor influencing tripmakers en-route switching behavior (e.g. Mahmassani and Liu, 1997). Related to the reliability issue, the update frequency of information appears to be very important for drivers' response to the information (e.g. Polydoropoulou et al, 1994).

Evaluating the impacts of VMS's on network performance is a difficult task, due to the complexity of the network systems and various exogenous factors, such as seasonal impacts or autonomous travel developments (Van der Mede, 1995). Although many publications exist on evaluation methodologies for VMS's (Brand, 1994; EAVES, 1992; Higgings, 1995; Zhang et al, 1996), applying these in practice is not always feasible. Incorporating all exogenous factors into the analysis would soon lead to very detailed and time consuming analyses of specific parts of the network.

In the Netherlands various studies have been conducted to evaluate the impacts of VMS's. These studies focus on technical functioning, impacts on traffic flow and congestion, user acceptance and behaviouural response, environmental and safety issues, and cost-benefits (Emmerink et al, 1996; Van Berkum and Van Der Mede, 1993; Bureau Goudappel Coffeng, 1992, 1995; Goudappel Coffeng, 1996b, 1998a, b, and c). This paper summarizes a recent elaborate evaluation study, of a number of newly introduced VMS's on the Amsterdam orbital motorway, see Goudappel Coffeng (1998c).

This paper presents a number of techniques that can be used for network-wide evaluation of VMS's and presents practical findings resulting from the evaluation.

Part of the work upon which the paper is based was done within the context of the DACCORD project. DACCORD stand for Development and Application of Co-ordinated Control of Corridors. Its main objective is to design, implement and validate a practical Dynamic Traffic Management System for integrated and co-ordinated control, see (Kroes *et al.* 1998). The DACCORD project is one of the projects of the Telematics Applications Program (TAP), which is part of the Fourth Framework initiative of the European Commission.

1.2 Description of the VMS system

Figure 1 shows the freeway network The freeway system around the city of Amsterdam involves involving the ring road A10, the east-west corridor route A9, and five connecting freeways (A1 to the east, A2 to the south, A4 to the south-west, A5 to the west, and A8 to the north-west). Figure 1 displays the freeway network. The city is connected to the ring road by a system of arterials. Two tunnels are part of the ring road, the Coentunnel in the north-west and the Zeeburgertunnel in the east part of the ring road. During the morning peak the southbound lanes of the Coentunnel are usually congested, while during the evening peak its northbound lanes are frequently congested.

In 1991 athe first Variable Message Sign (VMS) of the so-called Route Information Amsterdam system (RIA) was installed on freeway A8 (VMS number 80 in Figure 1). This sign was the first of the so-called Route Information Amsterdam system (RIA). This VMS informed car drivers approaching the ring road around Amsterdam from the North about congestion by displaying queue lengths forof both branches of the ring road. In 1994 three additional VMS's (number 10 on the A1, 20 on the A2, and 40 on the A4) were placed at approaches to the ring road. These signs informed car drivers approaching the ring road from the South-West, the South, and the East about traffic congestion on the ring road. In August 1997 the number of VMS's around Amsterdam have been increased by 14 new signs. Seven signs are used as incident management signs and seven are used as dynamic route informationqueue length displays signs. The present paper focuses on the evaluation of these queue length display VMS's. The new signs inform drivers about traffic conditions on the ring road, as well as on the east-west corridor routes south of Amsterdam.

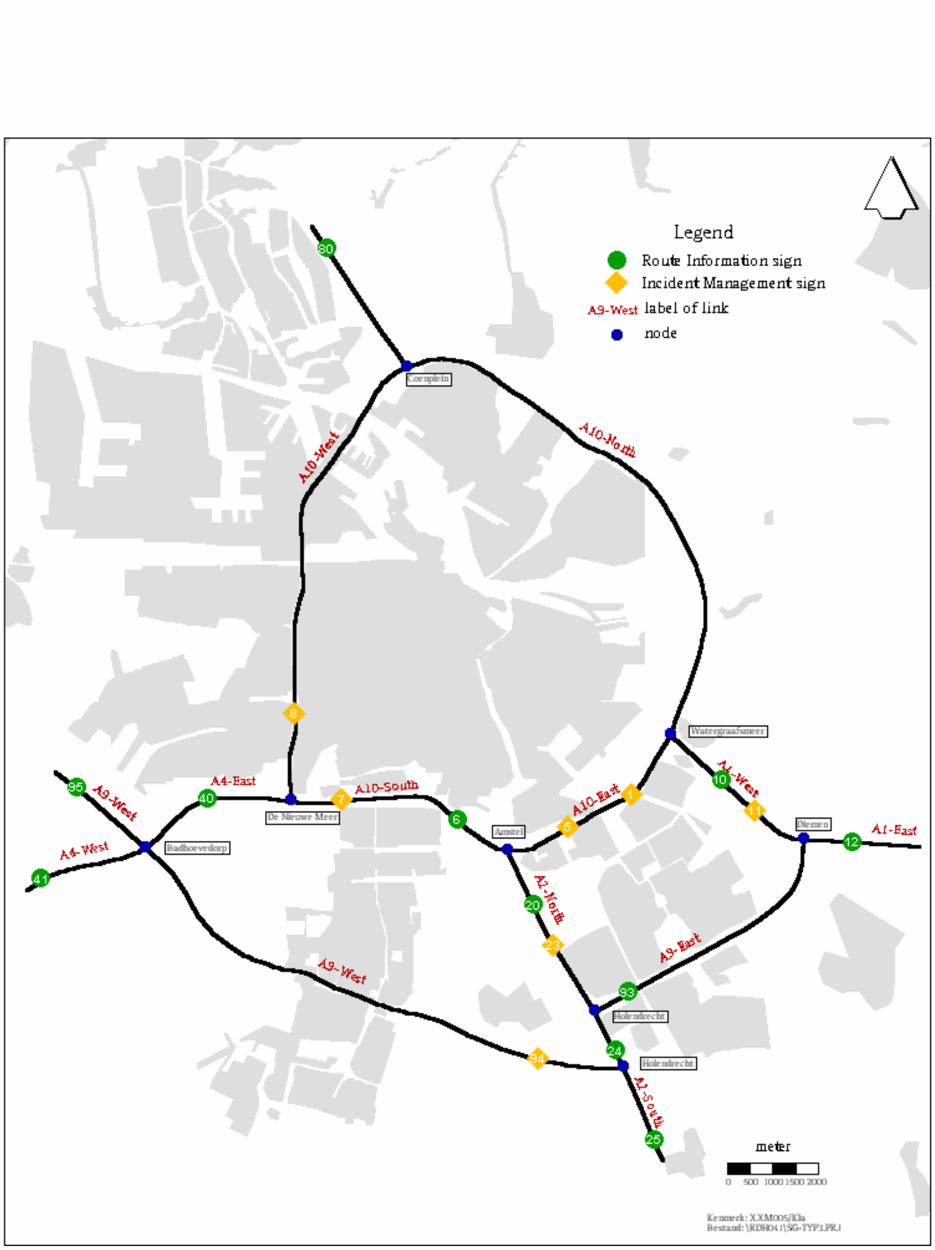

Figure 1: The freeway system around Amsterdam.

Whereas The incident management signs provide drivers with information about incidents, road works, etc., and are not in use otherwise, the queue length VMS If incidents are absent no message is shown. The incident management signs are not considered here. This paper only deals with the route information signs.

permanently display

The dynamic route information signs provide car drivers with information about traffic congestion on the freeways around Amsterdam. These VMS's are used to influence route choice and optimally make use of the available capacity in order to improve comfort, safety and overall network performance. Each route information sign is placed before a junction where drivers can choose between two route alternatives. The information provided on the sign consists of queue lengths in each of the two travel directions. If no congestion exists the sign displays the message "no congestion". Speulman et al (1997) showed that Dutch drivers prefer traffic information consisting of queue lengths, instead of travel times, because drivers are familiar with this type of information. In the Netherlands traffic information on radio broadcast have always been provided in terms of queue lengths. If no congestion exists the sign displays the message “filevrij” (“no congestion”). Each sign consists of three rows of text. The first row usually shows the common destination. The second and third rows show the queue lengths on either route alternative.

The information displayed on the VMS’s is generated automatically using the data of the Motorway Control and Signalling System (MCSS, in the Netherlands also known as MTM) data (Rijkswaterstaat, 1992). This system uses (double) loop detectors to measure traffic volumes and speeds. The pairs of detectors are approximately 600 meters apart. Data, including an indicator for the occurrence of congestion,The data is updated are logged every minute. The data also contains an indicator for the occurrence of congestion.

1.3 Objectives

The main objective of the study described in this paper was to evaluate the impacts of the seven new route information VMS’s added to the existing system. The aim of this paper is to analyze the evaluation techniques used to study the effects of the VMS’s on network performance, including traffic flows and congestion. This paper focuses on the east-west corridor south of Amsterdam, consisting of the freeway links A4, A10 south, A10 east, A1, A2, and A9 east and west.

In line with the guidelines provided by Zhang *et al*, (1996), Tthe research has been subdivided into impact assessment, technical assessment, and an analysis of the drivers' responseuser acceptance assessment, and socio-economic assessment.

The impact assessment study involves aggregate performance of the network and is based on indicators of calculations of factors describing aggregate traffic conditions. The aim of the VMS’s is to improve aggregate performance of the network. Therefore it is sufficient to consider aggregate factors of traffic conditions. The factors considered are severity of congestion (length and duration of queues), traffic performance or (vehicle-miles-traveled), and travel time delays on the route alternatives.

The technical assessment involves the technical functioning and reliability of the system. The experienced travel times are calculated for the various route alternatives on the corridor. These travel times are then compared with the traffic information provided by the VMS’s. Finally, the

In the user acceptance study different types of users are distinguished, such as drivers, operators, and residents of the area. Car drivers were asked about acceptance of the system and their responses to the provided information. Operators managing the system were asked about their experiences with the system. Residents of the area might consider traffic diverting from the congested freeways over local network as a nuisance. This paper reports the main findings of the user acceptance study. Also user route choice responses to the information are analyzed using a technique known as stimulus response analysis.

Finally, the socio-economic impacts study involves cost-benefits analysis of the system. The costs and benefits are based on the results of the technical assessment, user acceptance, and impact assessment (network performance). It also includes safety and environmental aspects. This part of the research is still ongoing and is not presented here.

1.4 Outline of the paper

The next section describes the details of the impact assessment. Section 3 describes the technical assessment. Section 4 focuses on user acceptance and user response analysis. The sections describe both the research method and the results. A summary and discussion are given in section 5.

2. IMPACT ASSESSMENT

2.1 Research Method

In order to evaluate the effects of the dynamic route information VMS's on traffic flows, aggregate indicators of the network performance are calculated. Only the east-west corridor between Diemen and Badhoevedorp (see Figure 1) is considered in this analysis. Two route alternatives on this corridor are analyzed in both directions. The first alternative consists of the links A1, A10-east, A10- south, and A4. The length of this route is approximately 19 km. The second route amounts 20 km. and is composed of the links A1, A9-east, A2-Holendrecht, and A9-west.

The evaluation consists of a before-study, before the latest VMS's became operational and of a after-study after installation of the new signs. For the before-study ten workdays in May 1997 were selected while for the after-study ten workdays in September 1997 were chosen. Selection was based on the level of congestion during the day. Days with extreme levels of congestion were not included. Only week days were selected. The objective was to evaluate effects on recurrent congestion. The analysis focuses on the peak periods during each day. The morning peak period is defined between 6 and 10 AM and the evening peak period from 3 to 8 PM. If sSeasonal impacts exists they are likely to have an adverse impact during the after study, because during this period travel demand is slightly higher, while weather and light conditions are less favorable.

, due to the selection of before- and after-study (May and September), are minimized because the days have been selected on the average traffic volume during the day.

The MCSS traffic data were used to calculate aggregate performance indicators. These data consist of traffic volumes (in vehicles per hour), travel speeds (in kilometers per hour), and a binary variable indicating the presence of congestion for each link in the network for every minute. With these data the following indicators were calculated.

Traffic performance

Traffic performance, or vehicle-miles-traveled (VMT), is calculated as a product of the traffic volumes q_i and the length of the links l_i, summed over each peak period, averaged over the days. The mathematical equation is given by:

$$VMT = \sum_{i,t} q_{i,t} \cdot l_i \tag{1}$$

The unit of this indicator is vehicle-kilometers.

Severity of congestion

Severity of congestion considers both the length and duration of congestion. Each link i in the network for which the MCSS traffic data is available has length l_i. For each minute t and each link i the binary variable indicating congestion $c_{i,t}$ is 1 when congestion occurs and 0 otherwise. The severity of congestion, SC, is now calculated by taking the sum of the lengths of all links over all minutes when congestion occurs. The mathematical equation is given by:

$$SC = \sum_{i,t} c_{i,t} \cdot l_i \qquad (2)(1)$$

Here $c_{i,t} = 1$ in case there is congestion on link i at time t and $= 0$ in case of no congestion. The unit of the indicator SC is kilometer-minutes.

This severity of congestion is calculated as a total over each peak period, averaged over all days in both the before- and after-study. But also the standard deviation of this measure over the ten days is calculated. This standard deviation is considered to be a useful meaningful indicator of quality of service; a kind of reliability or stability of traffic conditions. It is hypothesized expected that the presence of the VMS's has a positive influence on this indicator, as the VMS's offer feedback to the drivers who may be assumed to avoid congestion provided they are informed about itthis standard deviation may have decreased as a result of the VMS extension, thus showing the improved performance of the network.

Traffic performance

Traffic performance, or vehicle-miles-traveled (VMT), is calculated as a product of the traffic volumes q_i and the length of the links l_i, summed over each peak period, averaged over the days. The mathematical equation is given by:

$$VMT = \sum_{i,t} q_{i,t} \cdot l_i \qquad (2)$$

The unit of this indicator is vehicle-kilometers.

Instantaneous travel time delay

The instantaneous travel delays are defined as the difference between free flow travel time and realized instantaneous travel time, weighted by traffic volumes. The free flow travel time is defined by the ratio between the length of the network link l_i and the free flow speed. This free flow speed is set to 100 km/h. The realized travel time is the ratio between link length and actual link speed v_i.

$$DL = \sum_{i,t} \left(\frac{l_i}{v_i} - \frac{l_i}{100} \right) \cdot q_i \qquad (3)(3)$$

Also this indicator is summed over the total peak period and averaged over the ten days. The unit of this indicator is vehicle-hours. When a travel speed of more than 100 km/h was measured, the delay has a negative value and is excluded from the calculation.

In addition, the average travel speed over the routes is analysed. In particular the standard deviation of the speed. It is expected that improvement of network performance leads to a decrease in the variation of travel speed, indicating more reliable travel times.

2.2 Results

Traffic performance

Table 1 shows the traffic performance (VMT) as a product of the number of vehicles on the network links and the length traveled. This indicator is summed over the whole peak period and averaged over the ten days.

	Corridor Westbound: Diemen – Badhoevedorp		**Corridor Eastbound: Badhoevedorp – Diemen**	
Traffic performance (vehicle.km)	**via A10**	**Via A9**	**via A10**	**via A9**
Morning Peak (6:00 – 10:00)				
Before-study (May 1997)	302278	245826	252058	216580
	(11547)	(8987)	(12771)	(7806)
After-study (Sept 1997)	316471	246140	261946	222249
	(9774)	(3226)	(4893)	(3955)
Evening Peak (15:00 – 20:00)				
Before-study (May 1997)	337005	286310	416642	323262
	(8611)	(12370)	(23058)	(17313)
After-study (Sept 1997)	340352	286961	427370	312667
	(7735)	(15093)	(10112)	(11961)

Table 1: Traffic performance (and standard deviation of daily traffic performance) for corridor (in vehicle.km), averaged over ten days.

In general the traffic performance has increased. In the light of the standard deviations that can be computed for the *mean* traffic performance, most of these changes are statistically significant at a 5% confidence level. Clear exceptions are the traffic performance levels on the westbound route via the A9 which remain unchanged. The only route for which traffic performance has dropped is the eastbound A9 route during the evening peek. This may be caused by the reduction of congestion on its competing route over the A10 during the after period (see table 2).

Severity of congestion

Table 1 2 shows the calculated severity of congestion for the corridor in the before and after periods. The values represent the product of length and duration of queues over the whole peak period. The total length of the corridor is approximately 19 km. The route along the A9 is approximately one kilometer longer. The severity of congestion in Table 1 shows that during the morning peak the one-minute average queue length is less than 1 km, while in the evening peak the one-minute average length is more than 1 km. The number between brackets denotes the standard deviation of queue length over the ten days that constitute the data set. This can be considered as an indicator for the reliability of the route.

	Corridor Westbound: Diemen – Badhoevedorp		**Corridor Eastbound: Badhoevedorp – Diemen**	
Severity of congestion (km-.min)	**via A10**	**Via A9**	**via A10**	**via A9**
Morning Peak (6:00 – 10:00)				
Before-study (May 1997)	223	130	187	102
	(267)	(110)	(138)	(68)
After-study (Sept 1997)	182	99	212	145
	(88)	(93)	(120)	(48)
Evening Peak (15:00 – 20:00)				
Before-study (May 1997)	416	368	481	175
	(289)	(261)	(237)	(176)
After-study (Sept 1997)	421	294	125	57
	(327)	(157)	(63)	(95)

Table 12: Severity of congestion (in km-min) (and standard deviation) for corridor west- and eastbound, averaged over the ten days (in km.min). For each period the number of days is N=10.

Based on the table, it can be seen that the total severity of congestion on the corridor has dropped from 2082 to 1535. The sum of all standard deviations has dropped even more, from 1546 to 991. An interesting finding is that for the two eastbound routes in the morning peak the severity of congestion has increased, while the day to day variation in this indicator has decreased. Only the eastbound route over the A10 during the morning peak and the corresponding westbound route during the evening peak displays higher congestion levels. The table shows that in general the standard deviation in congestion has decreased between May and September 1997. However, an increase in congestion has occurred on the westbound route along part of the ring road A10 in the evening and for both eastbound routes in the morning. This is mainly caused by increase in congestion along the A4 and A10-south. All eastbound routes in the evening show a remarkable decrease in congestion.

Traffic performance

Table 2 shows the traffic performance (VMT) as a product of the number of vehicles on the network links and the length traveled. This indicator is summed over the whole peak period and averaged over the ten days. In general the traffic performance has increased, while the standard deviation has decreased. This indicates that utilization of the network has improved. Drivers divert from the congested route to a longer route.

	Corridor Westbound: Diemen – Badhoevedorp		**Corridor Eastbound: Badhoevedorp – Diemen**	
Traffic performance (vehicle-km)	**via A10**	**Via A9**	**via A10**	**via A9**
Morning Peak (6:00 – 10:00)				
Before-study (May 1997)	302278	245826	252058	216580
	(11547)	(8987)	(12771)	(7806)
After-study (Sept 1997)	316471	246140	261946	222249
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After-study (Sept 1997)	340352	286961	427370	312667
	(7735)	(15093)	(10112)	(11961)

Table 2: Traffic performance (in vehicle-km) for corridor, averaged over the days.

Instantaneous travel time delay

Table 3 shows the travel time delay in vehicle-hours, total over the whole peak period. Between brackets the day to day standard deviation of this delayver the total period is given. In the morning travel time delay has generally increased, while it has decreased in the evening. The westbound route along the A10 shows the opposite. The standard deviation over the days in travel time delay has in general decreased. This suggests that travel times have become more reliable along the corridor.

	Corridor Westbound: Diemen – Badhoevedorp		**Corridor Eastbound: Badhoevedorp – Diemen**	
Travel time delay (vehicle-hrs)	**Via A10**	**Via A9**	**via A10**	**Via A9**
Morning Peak (6:00 – 10:00)				
Before-study (May 1997)	440	284	394	103
	(350)	(200)	(203)	(74)
After-study (Sept 1997)	421	293	439	195
	(121)	(136)	(162)	(67)
Evening Peak (15:00 – 20:00)				
Before-study (May 1997)	597	517	919	190
	(346)	(333)	(367)	(173)
After-study (Sept 1997)	678	444	424	134
	(383)	(194)	(93)	(67)

Table 3: Travel time delay (in vehicle-hours) for corridor, averaged over the days.

In addition, average travel speeds on the corridor have been analyzed. Table 4 shows these values. In general, the average travel speed has decreased along the corridor. Also the variation over the days in speed has generally decreased. Again, although total travel times have increased, due to an increase of demandmore mileage driven, reliability in travel time has improved.

	Corridor Westbound: Diemen – Badhoevedorp		**Corridor Eastbound: Badhoevedorp – Diemen**	
Average travel speed (km/hr)	**Via A10**	**Via A9**	**via A10**	**Via A9**
Morning Peak (6:00 – 10:00)				
Before-study (May 1997)	95	93	93	97
	(4.3)	(5.2)	(3.5)	(3.0)
After-study (Sept 1997)	94	91	91	92
	(1.7)	(3.5)	(2.4)	(2.5)
Evening Peak (15:00 – 20:00)				
Before-study (May 1997)	95	94	91	99
	(3.2)	(4.0)	(3.2)	(2.3)
After-study (Sept 1997)	93	90	95	97
	(3.5)	(3.0)	(1.0)	(1.0)

Table 4: Average travel speed (and standard deviationin kilometers per hour) for the corridor, in kilometers per hour, averaged over the days.

3. TECHNICAL ASSESSMENT

3.1 Research Method

The VMS's display information on current queue lengths. These queue lengths need not be equal to the queue length experienced by drivers for the following reasons:

- A queue may grow or dissipate between the moment a message is displayed to a passing driver and the moment a driver arrives at the location to which the message refers,

- Queues may move through the network (usually in the upstream direction), resulting in discrepancies between the displayed queue length and the queue length observed by a driver,
- The perception of traffic conditions qualifying as 'queue' differs among drivers.

To objectively determine to what extent the displayed information is in line with the amount of congestion experienced by drivers, *travel delay* was used as a measure for the amount of congestion experienced. To this end, an *off-line* estimator of experienced travel time was implemented. This estimator is based on reconstructing average vehicle trajectories from the prevailing speeds on each section of the network during each minute. The travel times computed in this way are compared to travel times that were predicted based on a linear regression model that was estimated using the travel time as the dependent, and the displayed queue length as the independent variable. As a measure of effectiveness of the displayed information, the percentage of variation in the experienced travel time, explained on the basis of displayed queue length, is used. This number is computed by dividing the residual error of the regression model by the variation in experienced travel time:

$$R_r^{2,qldisplay} = \left(1 - \frac{\sum_{p=1}^{P}\sum_{d=1}^{D}\left(t_r^{\exp}(p,d) - \hat{t}_r^{\exp}(l_r^{qldisplay}(p,d))\right)^2}{\sum_{p=1}^{P}\sum_{d=1}^{D}\left(t_r^{\exp}(p,d) - \bar{t}_r^{\exp}\right)^2} \right).100\% \qquad (4)(4)$$

with:

r, p, d	Indices denoting route, (one minute) period and day respectively
P, D	The number of periods and days respectively
$R_r^{2,qldisplay}$	The explained percentage of experienced travel time variation by displayed queue length messages
$t_r^{\exp}(p,d)$	The experienced travel time, estimated by reconstructing trajectories for for vehicles departing *at the beginning* of period p of day d
$l_r^{qldisplay}(p,d)$	The displayed queue length *during* (one minute) period p of day d.
$\hat{t}_r^{\exp}(l)$	The estimated experienced travel time based on a linear regression with observed travel time as the dependent variable and displayed queue length as the explanatory variable, i.e. $\hat{t}_r^{\exp}(l) = \alpha.l + \beta$ (see figure 2)
$\bar{t}_r^{\exp}$	The experienced travel time, compute off-line, averaged over all days and all periods.

Period length p is 1 minute.

This indicator may be compared with the amount of variation that is explained by a naïve predictor of travel time based on the historic average travel time for each specific period of day. This indicator is denoted with $R_r^{2,historic}$ and is computed in a similar way to (4), substituting for $\hat{t}_r^{\exp}(l)$ the centered moving average over 16 minutes of the experienced travel time, averaged over all days.
, expressed as:

$$R_r^{2,historic} = (\,1 - \frac{\sum_{p=1}^{P}\sum_{d=1}^{D}\left(t_r^{\exp}(p,d) - \bar{t}_{rp}^{\exp}\,)\right)^2}{\sum_{p=1}^{P}\sum_{d=1}^{D}\left(t_r^{\exp}(p,d) - \bar{t}_r^{\exp}\right)^2}\,).100\% \tag{5}$$

with:

$\bar{t}_{rp}^{\exp}$	The 16 minute moving average of the experienced travel time, centered around period *p*, averaged over all days

More advanced predictors of experienced travel time are possible, e.g. by combining time of day with displayed queue length. As a first attempt at refinement, the following predictor was implemented:

$$\hat{t}_r^{qldisplay+historic}(p,d) = \bar{t}_{rp}^{\exp} + \beta.(l_r^{qldisplay}(p,d) - \bar{l}_{rp}^{qldisplay}) \tag*{(5)(6)}$$

with:

β	The gradient of the above mentioned regression line (see also figure 2)
$\bar{l}_{rp}^{qldisplay}$	The 16 minute moving average of the displayed queue length, centered around period *p*, averaged over all days

The corresponding An indicator that reflects the effectiveness offor this predictor is denoted as $R_r^{2,qldisplay+historic}$ .fined as follows:

$$R_r^{2,qldisplay+historic} = (\,1 - \frac{\sum_{p=1}^{P}\sum_{d=1}^{D}\left(t_r^{\exp}(p,d) - \hat{t}_r^{qldisplay+historic}(p,d))\right)^2}{\sum_{p=1}^{P}\sum_{d=1}^{D}\left(t_r^{\exp}(p,d) - \bar{t}_r^{\exp}\right)^2}\,).100\% \tag{7}$$

A final indicator that was computed is the amount of variation in the experienced travel time that can be explained by the *instantaneous* travel time. The instantaneous travel time is the travel time of an imaginary vehicle that along at each section of its route would experience maintain the speed that prevailed at that section when entering that sectionat the moment the vehicle started on the route. The corresponding indicator is denoted with $R_r^{2,inst}$.

$$R_r^{2,inst} = (\,1 - \frac{\sum_{p=1}^{P}\sum_{d=1}^{D}\left(t_r^{\exp}(p,d) - t_r^{inst}(p,d))\right)^2}{\sum_{p=1}^{P}\sum_{d=1}^{D}\left(t_r^{\exp}(p,d) - \bar{t}_r^{\exp}\right)^2}\,).100\% \tag{8}$$

with:

$t_r^{inst}(p,d)$	The instantaneous travel time

The amount of variation in the experienced travel times that can *not* be explained by the instantaneous travel time (i.e. $1 - R_r^{2,inst}$) can be seen as a measure of the maximum gain that might be achieved in this particular case by changing the current queue length information with best ideal predictive information.

The methods have been applied to two westbound routes and two eastbound routes considered within the Amsterdam orbital motorway network. The westbound routes connect Diemen and Badhoevedorp via the A10 and the A9 respectively (see figure 1). The queue length messages

for these routes are displayed just upstream of the junction at VMS 12. The two eastbound routes correspond with the return directions and VMS 41. Sixteen days of data where analyzed, including days with severe congestion.
The period length used was 1 minute.

3.2 Results

Figure 2 shows a typical result of the analysis that was carried out to assess whether the amount of congestion displayed on the VMS is in line with the amount of congestion experienced by drivers. On tThe horizontal axis displays the amount of congestion is set out, on, while the vertical axis displays the experienced travel time. The dataset refers to the route from Diemen to Badhoevedorp via the A10. The frequency distribution of the experienced travel time for each VMS's setting is shown by the thin vertical curves. Also the regression line is plotted in this figure.

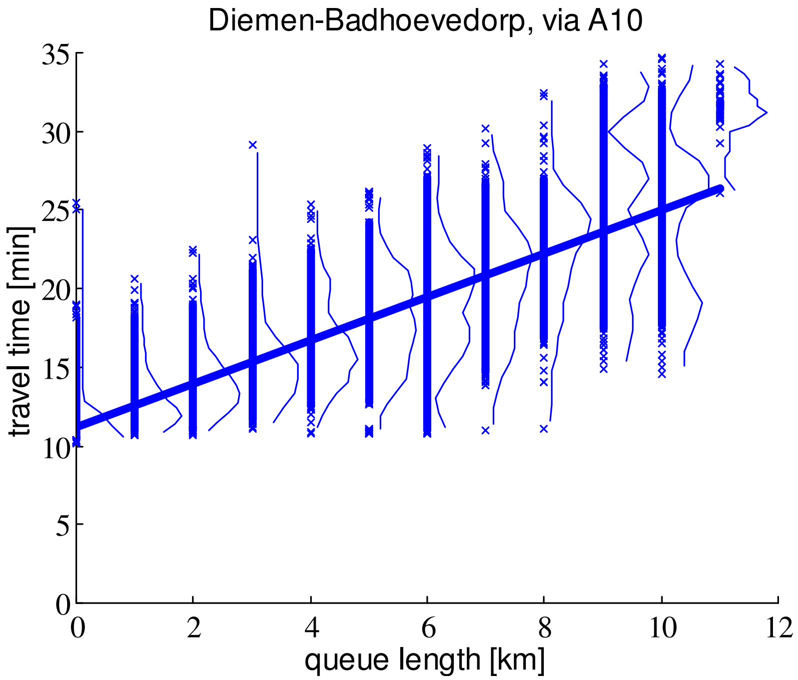

Figure 2: The off-line computed experienced travel time, plotted against the queue length reported on the VMS

The expected travel time in absence of a VMS queue message for this route (i.e. the intercept of the regression line) is 11.23 minutes, while the mean travel time is 13.48 minutes. Each kilometer of queue length displayed on the VMS increases the expected travel time by 83 seconds. The standard deviation of the travel time is 3.78 minute. The linear regression model explains 76% of this variation.

For all routes the experimental results are summarized in Table 5.

			Corridor Westbound: Diemen – Badhoevedorp		Corridor Eastbound: Badhoevedorp – Diemen	
			via A10	**Via A9**	**via A10**	**via A9**
1	'Free flow' travel time	[min]	11.23	13.05	11.18	12.71
2	extra travel per km queue	[sec]	83	69	96	67
3	Average travel time	[min]	13.09	13.82	12.45	13.2
4	$\sqrt{\text{travel time variation}}$	[min]	3.78	2.15	3.31	1.84
5	$R_r^{2,qldisplay}$	[%]	76	66	72	74
6	$R_r^{2,historic}$	[%]	58	59	35	25
7	$R_r^{2,qldisplay+historic}$	[%]	83	70	77	79
8	$R_r^{2,inst}$	[%]	88	80	86	89

Table 5: Results of experienced travel time analysis.

Provided that travelers are able to interpret the displayed queue lengths in the correct way, the VMS messages give a good prediction of the amount of travel time that can be expected on the routes ahead. The explained variation varies between 66% and 76%. These numbers should be seen against the background of the amount of travel time variation that is explained by the historic average travel time. For the westbound corridor these numbers are relatively high (58% and 59%) which indicates a high proportion of delays due to recurrent congestion. If historic travel times and the information displayed at VMS's are combined (see row 7 in table 5) the percentage of explained variation increases even more. The difference between $R_r^{2,qldisplay+historic}$ and $R_r^{2,historic}$ provides some information about the usefulness of the displayed information to experienced drivers on the corridor. The increase of the explained variation varies between 11% and 54%.

Row 8 of Table 5 contains a measure of the correspondence between the instantaneous travel time and the experienced travel time. This discrepancy is mainly caused by the fact that the instantaneous travel time responds slower to changes in traffic conditions than the experienced travel time. This is illustrated in figure 3. In this plot the instantaneous travel time is plotted against the experienced travel time for a specific day (25 Sept. 97). Apart from the morning peak (8.00) and the evening peak (18.00) all datapoints are in the area where both the experienced and the instantaneous travel time indicate free flow conditions. During the buildup to the evening peak (17.00) the experienced travel time increases faster than the instantaneous travel. After the evening peak (19.00) the reverse happens. This leads to the hysteresis that is visible in the plot.

The values of $R_r^{2,inst}$ (see row 8 of table 5) indicate the possible improvement if existing queue detection algorithms, which are closely related to algorithms to compute instantaneous travel time, are extended with predictive capabilities. This improvement varies in the range between 11% and 20% (100% - $R_r^{2,inst}$) for the routes considered.

The totally uninformed driver cannot reduce uncertainty. A driver with knowledge of average delays as a function of time can reduce uncertainty with approximately 45% while on the basis of the VMS messages the uncertainty can be reduced with approximately 72%. The combined use of historic knowledge and information from VMS's may reduce uncertainty with 87%. The fact that the VMS's only inform on current traffic conditions causes some error, especially during the shoulders of the peak period. The potential for improvement for the routes considered in this study is about 15%.

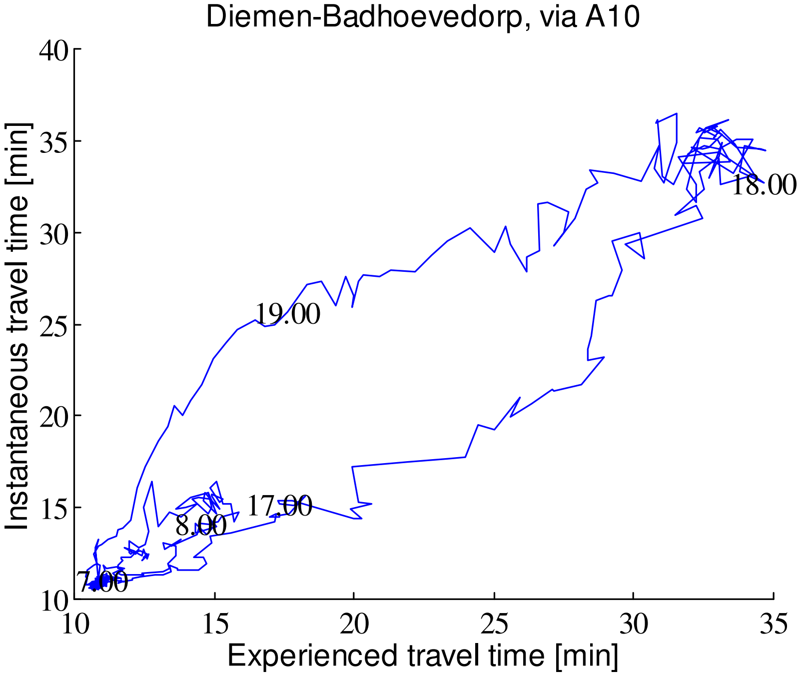

Figure 3: The instantaneous travel time at 25 September 1997, plotted against the off line computed experienced travel time.

4. USER ACCEPTANCE AND RESPONSE BEHAVIOUR

4.1 Research Method

A survey has been conducted among car drivers of the network. Drivers were asked among other about usefulness, reliability, and comprehensibility of the VMS's. Also questions about their behavioral responses to the information and their route choice decisions were included.

In addition, interviews have been held with operators of the system and the police force. They were asked about their experience with and the reliability of the system.

Route choice impacts

To analyze user responses to the route information on the VMS's drivers' route choices are determined in relation to the provided queue lengths information. This analysis is called stimulus-response analysis. The stimulus is given by the difference in queue lengths of the two route alternatives, provided on the VMS's. This stimulus is corrected by the average difference in queue lengths over all selected days. The response is given by the proportion of drivers on each route alternative, corrected by the average proportion over all days.

*Route choice (% on one route) = c + beta * (difference in queue lengths)*

The stimulus-response analysis is conducted for the period after installation of the VMS's. During 17 days in September, October, and November 1997, the information on the signs has been logged. For a detailed description of the stimulus response methodology see Transpute (1997).

4.2 Results

This section reports the main findings of the research on user acceptance. More details can be found in Goudappel Coffeng (1998b). The survey conducted among drivers consisted of 1402 respondents. The survey showed that the VMS's are considered to be very useful. Drivers also stated the messages were clear and understandable. The information on the VMS's was considered reliable by two-third of the drivers. The difference between dynamic route information and incident management signs was not clear.

Operators stated that the system is easy to use. But the system is also very sensitive to electronic failures. The impact of VMS's on network performance is considerable when incidents occur, according to the police department. They also stated that the information is reliable. Route guidance to alternate routes in cases of incidents has not yet been incorporated sufficiently in the system.

Hardly any traffic diverts from congested freeways to the local network. Therefore, it was decided unnecessary to ask residents in the Amsterdam area about diverted traffic.

Route choice

During the months September, October, and November 1997 on 17 days the information shown on the VMS's between 06:00 and 23:00 has been logged. For these days the route choice is calculated. Since only the corridor is considered, only the VMS's informing about this corridor are included in the analysis. For the eastbound routes VMS 41, 95, and 06 are considered. But for VMS 95 no data is available to analyze the responses. For the westbound routes VMS 12 and 93 are analyzed. The time unit used to calculate stimuli and responses is 15 minutes. This can be justified because drivers need some time between observing the message on the VMS and choosing their route.

A linear regression model is estimated on the route choice response as a function of the queue length difference stimulus according to: *response = beta * stimulus + constant*. It should be noted that the stimulus is not an independent variable, but depends on the response. However, this dependency is lagged, because adjustments to the information are made after drivers have chosen their route.

The regression results for the VMS's considered are given in Table 6.

VMS	Beta	t-statistic	R^2
06	1.638	12.31	0.129
12	1.851	25.98	0.412
41	0.982	12.33	0.168
93	0.785	8.82	0.069

Table 6: Results of stimulus-response regression.

The table shows small R^2, but large t-statistics. This means that only a small proportion of the variation of the split proportions at the first downstream junctions of the VMS's can be explained by the stimulus. This should be expected because the VMS messages are relevant to only a small proportion of the drivers, and only few drivers have an alternative route that involves deviating from their usual route at the first downstream junction. Nevertheless the large values for the t-statistics indicate that all values are significant. And that difference in queue lengths information displayed on the VMS's are a good explanation for route choice (diversion).

An exampleFor two of the four of a VMS's the scatter diagrams with regression line are is given in Figures 4 and 5. The X-axis indicates the difference in provided queue lengths. On the Y-axis the percentage of drivers choosing one of the routes is shown. These figures illustrate that the larger the difference in queue lengths, the smaller the proportion of drivers choosing the route with the longest queue. This is of course according the expectations.

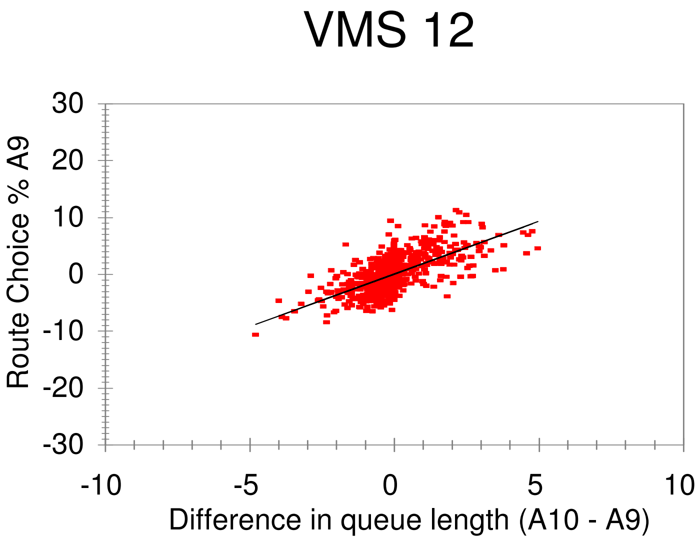

Figure 4: Scatter plot and regression of route split (response) by difference in queue length(stimulus) for VMS 12.
(stimulus) for VMS 12.

Figure 5: Scatter plot and regression of route split (response) by difference in queue length (stimulus) for VMS 41.

5. SUMMARY AND DISCUSSION AND CONCLUSION

This paper analyses the introduction of seven new VMS's around Amsterdam in three different ways:
This paper summarized findings from an evaluation study into the impacts of VMS's, providing dynamic route information, around Amsterdam, in the Netherlands. The study focuses on the east-west corridor south of Amsterdam. On this corridor two alternative routes in both directions have been considered in this evaluation study.

For these route alternatives the evaluated VMS's provide drivers with dynamic route information about the routes. This information consists of queue lengths on the alternative routes.

An iImpact assessment study showsed that total congestion has slightly decreased, while traffic performance has slightly increased. Drivers divert from congested route to slightly longer alternate route. Variation in congestion has decreased, implying that travel time has become more reliable. Average delays have decreasedDelay has decreased in the evening on the eastbound routes and in the morning on the westbound routes.

The technical assessment shows that the displayed queue lengths, if interpreted correctly by the drivers, are a good measure for the expected delay. The amount of variation in the (off-line computed) travel time that can be explained on the basis of a predictor of travel times was used as a measure of reliability of the displayed messages. The totally uninformed driver cannot reduce uncertainty. A driver with knowledge of average delays as a function of time can reduce uncertainty with approximately 45% while oOn the basis of the VMS messages a driver can reduce his or her the uncertainty can be reduced with approximately 72%. The combined use of historic knowledge and information from VMS's may reduce uncertainty with 87%. The fact that the VMS's only inform on current traffic conditions causes some error, especially during the shoulders of the peak period. The maximum potential for improvement for predictive techniquesfor the routes considered in this study is about 15%.

The The user acceptance survey showed that both drivers and operators stated that the VMS's are useful and that the information provided is understandable and reliable. Two third of the driver respondents also stated that they changed their route based on the information provided on the VMS's. User user response analysis, shows that for the routes considered in this project, each extra kilometer of queue length displayed for a route leads to a reduction of the proportion of drivers that selects that route between 0.8% and 1.6%. This may seem low. However one should bear in mind that a large proportion of the traffic observed entering the corridor has no choice because of a predetermined final destination. Moreover, when travel demand exceeds capacity a small reduction of demand leads to large travel time gains.

Especially the impact analysis indicates large advantages of the extension of the Route Information Amsterdam system with seven additional VMS's, with higher traffic performance and at the same time lower travel times. However, the aggregate techniques that were used in the evaluation also have their limitations, resulting in a number of questions that remain. For example:

- which influence has the selection of the days that constitute the before and after period? To obtain comparable data sets, days with similar congestion levels were selected. Because of seasonal effects the after study was carried out in a period where the risk of severe congestion is higher then in the before period. Drivers are aware of this which results in an amount of peak spreading that is likely to be higher in the after study then in the before study. This phenomenon may be responsible for part of the travel time gains that were observed.
- during the after study the day to day variation of traffic performance was lower than during the before study. Is this an effect of the new VMS's or a cause for the reduction in travel time?
- which indicator should be used as a measure of effectiveness for the system? A common indicator is the total travel time. However travelers are likely to base their decisions of destination, travel mode, routes, and departure time on both the *expected* travel time and the day to day variation. If the VMS system is successful, this is likely to lead to a reduction of this day to day variation. This may very well lead to a new equilibrium between supply and demand, with higher expected travel times but lower day to day variation in these travel times.

Having made these reservations, the general conclusion of the research presented in this paper is thatmeasured by modelling route choice as a function of information provided, showed that information has a significant effect on route choice.

In general, the paper showed some techniques that can be used to evaluate the impacts of VMS's in complex systems. The study shows that the use of VMS's has in general a positive impact on network performance in the Amsterdam freeway system, because travel times have reduced and have become more reliable.

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