Route Level Evaluation of Queue Lengths Display at the Amsterdam Orbital Motorway: Evaluation of Route Information Amsterdam, Phase 4

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Februari 2000

Ministry of Transportation,

North-Holland Directorate

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Date: Februari 2000

Transportation Planning and Traffic Engineering Section **Delft University of Technology**

1. Report number VK 2000.001	**2. ISSN-number** LVV-rapport 0920-0592
3. Report Title Route Level Evaluation of Queue Lengths Display at the Amsterdam Orbital Motorway: Evaluation of Route Information Amsterdam, Phase 4	**4. Author(s)** N.J. Van Der Zijpp
5. Published by Delft University of Technology, Transportation Planning and Traffic Engineering Section	**6. Commissioned by** Ministry of Transportation, North Holland Directorate
7. Research theme Traffic Engineering	**8. Research subject** Traffic flow analysis
9. Category of report Professional	**10. Date of publication** Februari, 2000

11. Abstract

The use of Variable Message Signs (VMS's) is generally considered to be a powerful tool to influence (en-route) route choice in order to improve safety and comfort while driving, to improve the network performance, and optimally make use of the available capacity. Assessing whether such effects actually occur when VMS's are installed is a difficult task. This report presents the results of an extensive evaluation study carried out at installing 14 new VMS's at the Amsterdam orbital motorway. The study involves a number of issues. First, the relation between the messages displayed at the VMS and the travel times experienced by drivers is analyzed. Second, a stimulus response analysis is used to find out how drivers respond in reality to the messages is described. Finally, a network-wide analysis of aggregate performance indicators, like queue length, distance traveled, and time spent on the network is included.

The study showed that the use of VMS's has a positive impact on network performance in the Amsterdam freeway system. Total congestion has slightly decreased, while traffic performance has slightly increased. Variation in congestion has decreased, as well as variation in average travel speed. This implies that travel time has become more reliable and that the traffic flow is more homogeneous. The technical assessment showed that the displayed queue lengths, if interpreted correctly by the drivers, are a good measure for the expected delay. User response analysis, measured by modeling route choice as a function of information provided, showed that information has a significant effect on route choice.

In general, the VMS's were found to be a tool to improve the efficiency and reliability of the system.

12. Key words Traveltime, VMS, Amsterdam, Evaluation	**13. Accompanying reports**	
14. In Co-operation with DACCORD consortium Goudappel Coffeng	**15. Number of pages** 48	**16. Price** *f* 25,- excluding costs of mail

Sectie Verkeerskunde **Technische Universiteit Delft**

1. Rapportnummer
VK 2000.001

2. ISSN-nummer
LVV-rapport 0920-0592

3. Titel rapport
Route Level Evaluation of Queue Lengths Display at the Amsterdam Orbital Motorway: Evaluation of Route Information Amsterdam, Phase 4

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7. Onderzoeksthema
Verkeersmodeltechniek

8. Onderzoeksrichting
Verkeersafwikkeling op autosnelwegen

9. Categorie rapport
Vakpublicatie

10. Datum publicatie
Februari, 2000

11. Samenvatting

Dynamische Route Informatie Panelen (DRIP's) worden beschouwd als een krachtig hulpmiddel voor het bevorderen van verkeersveiligheid en netwerk benutting. Ook wordt door verlaagde onzekerheid voor de reiziger een gunstige werking verwacht op het welbevinden van deze reiziger. Het is echter moeilijk om daadwerkelijk vast te stellen dat deze effecten ook werkelijk optreden in de praktijk.

In dit rapport worden de resultaten gepresenteerd van een uitgebreide studie die werd uitgevoerd naar aanleiding van het in gebruik nemen van 14 nieuwe DRIP's op en rond de ringweg van Amsterdam.

De studie besteed aandacht aan een aantal aspecten. Ten eerste wordt het verband geanalyseerd tussen de getoonde filelengte boodschappen en de reistijd die daadwerkelijk word ervaren door de bestuurders die deze boodschappen te zien krijgen.

Ten tweede is een stimulus-response analyse uitgevoerd die het verband aantoont tussen de getoonde boodschap en het keuzegedrag van de reiziger.

Tenslotte is een netwerkbrede analyse uitgevoerd naar een aantal aggregate performance indicatoren zoals file lengte, voertuigkilometrage en voertuigverliesuren. Hierbij wordt steeds een voorsituatie met een nasituatie vergeleken.

De studie toont aan dat het gebruik van DRIP's een positieve bijdrage levert aan de benutting op en rondom de Amsterdamse ringweg. De totale congestie is licht afgenomen, terwijl het aantal voertuigkilometers is gestegen. Ook de variatie in congestie is afgenomen, hetgeen als een hogere reistijd betrouwbaarheid mag worden uitgelegd. Analyses op route niveau tonen tevens aan dat de getoonde filelengtes, mits correct geïnterpreteerd door bestuurders, een goede maat voor de te verwachten vertraging zijn. De stimulus-response analyse toont aan dat de aanwezigheid van de DRIP's een significante invloed op de route keuze heeft.

Samenvattend kan gesteld worden dat de nieuwe DRIP's een goede bijdrage aan de efficiency en de betrouwbaarheid van het verkeerssysteem hebben geleverd.

12. Trefwoorden
Reistijd, DRIP, Amsterdam, Evaluatie

13. Bijbehorende rapporten

14. Externe contacten
DACCORD consortium
Goudappel Coffeng

15. Aantal pagina's
48

16. Prijs
f 25,-
exclusief verzendkosten

TABLE OF CONTENTS

1 INTRODUCTION

Over the past two years a large scale evaluation has been carried out of the impacts of seven new Variable Message Sign's (VMS) installed at the motorway system around Amsterdam (commissioned by North-Holland Directorate of the Ministry of Transportation). This evaluation concerns traffic performance on the motorway system, traffic safety, emissions, and impacts for the underlying network caused by route diversions.

The VMS's were installed to provide travellers with en-route information about congestion on the Amsterdam motorway system. This is believed to help travellers with avoiding congestion. When a traveller is avoids congestion, this reduces the individual travel time of this traveller. Even more important, it reduces travellers of other travellers because of the reduced extent of the congestion. Apart from these efficiency considerations, en route travel time provision is believed to reduce stress level for drivers and therefore contribute to drivers' comfort.

Characteristic for the way how VMS's are operated in the Netherlands is that they display queue lengths related to two alternative routes. In general the VMS's are located directly upstream of the fork where drivers have to decide which of the two alternative routes to use (see Figure 1).

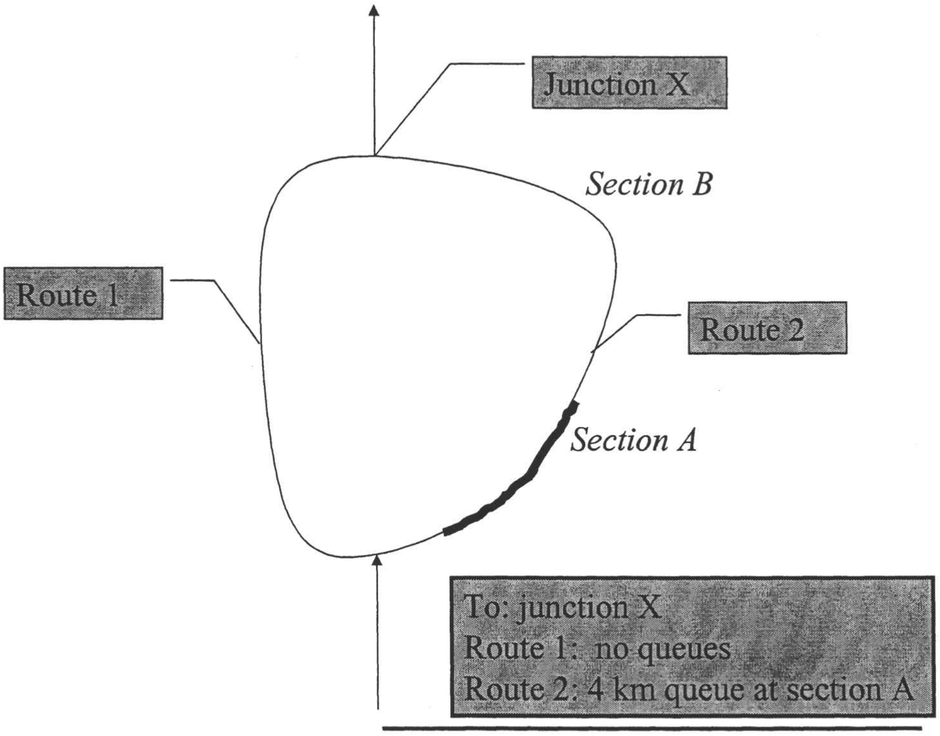

Figure 1: Each queue lengths display informs road users on two routes. If possible, information is given on specific sections of each route. If no queue is present, a message 'no queue' is displayed.

The evaluation is subdivided as follows:

- *Technical assessment*. The emphasis in the technical assessment is on the correspondence between displayed queue length and experienced travel delays. An off line estimator of travel delays was used to enable this assessment.
- *Impact assessment*. The impact assessment is done at three different levels;

- *Analysis of user response.* This analysis focuses on the influence of queue lengths display on the split proportions at the first downstream diverge of a VMS that displays queue lengths.
- *Analysis of aggregate traffic characteristics.* This analysis consists of a comparison of aggregate traffic characteristics, like speeds, length and duration of queues, total time spent and total distance travelled.
- *Analysis of travel time on specific corridors.* This analysis focuses on the travel time on specific corridors before and after the introduction of the VMS's. Also an analysis is included that compensates for differences in travel demand between the before and after study.

In addition to these topics the report contains an historic overview of the evolution of RIA (section 2), a site description (see section 3) and conclusions (see section 8).

A large part of the evaluation has been carried out by GC (see [Goudappel Coffeng, 1998a-c]). The second part of the evaluation is performed at TU Delft. This latter part especially focuses on route level analysis. This report is based on both the work of GC and the work performed at TU Delft.

2 RELATED RESEARCH ON VMS IMPACTS

Variable Message Signs (VMS's) are generally considered to be a powerful tool to influence (en-route) route choice in order to optimise the utilisation of the available capacity, to increase safety and comfort, and to improve the network performance. 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 experiences with the first VMS that was installed in Amsterdam have been quite positive. Not only was a positive impact observed during periods of incidental congestion, where drivers were able to avoid congestion. Unexpected advantages were observed during periods of recurrent congestion: drivers who normally accepted a detour via the less congested route in order to avoid the risk of extreme congestion, made more use of their shortest route after the VMS was installed.

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 behaviour (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 behavioural 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 report summarises a recent elaborate evaluation study of a number of newly introduced VMS's on the Amsterdam orbital motorway, see Goudappel Coffeng (1998c).

3 DESCRIPTION OF THE VMS SYSTEM AT THE AMSTERDAM SITE

Figure 2 shows the motorway network around the city of Amsterdam involving the ring road A10, the east-west corridor route A9, and five connecting motorways (A1 to the east, A2 to the south, A4 to the south-west, A5 to the west, and A8 to the north-west). 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 the first VMS of the so-called Route Information Amsterdam system (RIA) was installed on motorway A8 (VMS number 80 in Figure 2). This VMS informs car drivers approaching the ring road around Amsterdam from the North about congestion by displaying queue lengths for 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 queue lengths displays. The present report focuses on the evaluation of these queue lengths display VMS's.

Whereas incident management signs provide drivers with information about incidents, road works, etc., and are not in use otherwise, the queue lengths VMS permanently display information about traffic congestion on the motorways around Amsterdam. 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”. 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 data from the Motorway Control and Signalling System (MCSS) (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, are logged every minute.

The VMS evaluation will focus on a specific corridor, consisting of the motorway links A4, A10 south, A10 east, A1, A2, and A9 east and west. This corridor is analysed in two directions: East-West (EW) and West-East (WE) (see Figure 6 on page 20 for an illustration of these corridors). In specific instances so called *reference corridors* are used, consisting of the North-South route via the A10-west and the A10-north respectively (see Figure 7 on page 20). The hypothesis is that these corridors can be considered to be left unaffected by the recent extension of the VMS system because the number of VMS encountered on these two reference corridors has not increased during the latest extension of RIA.

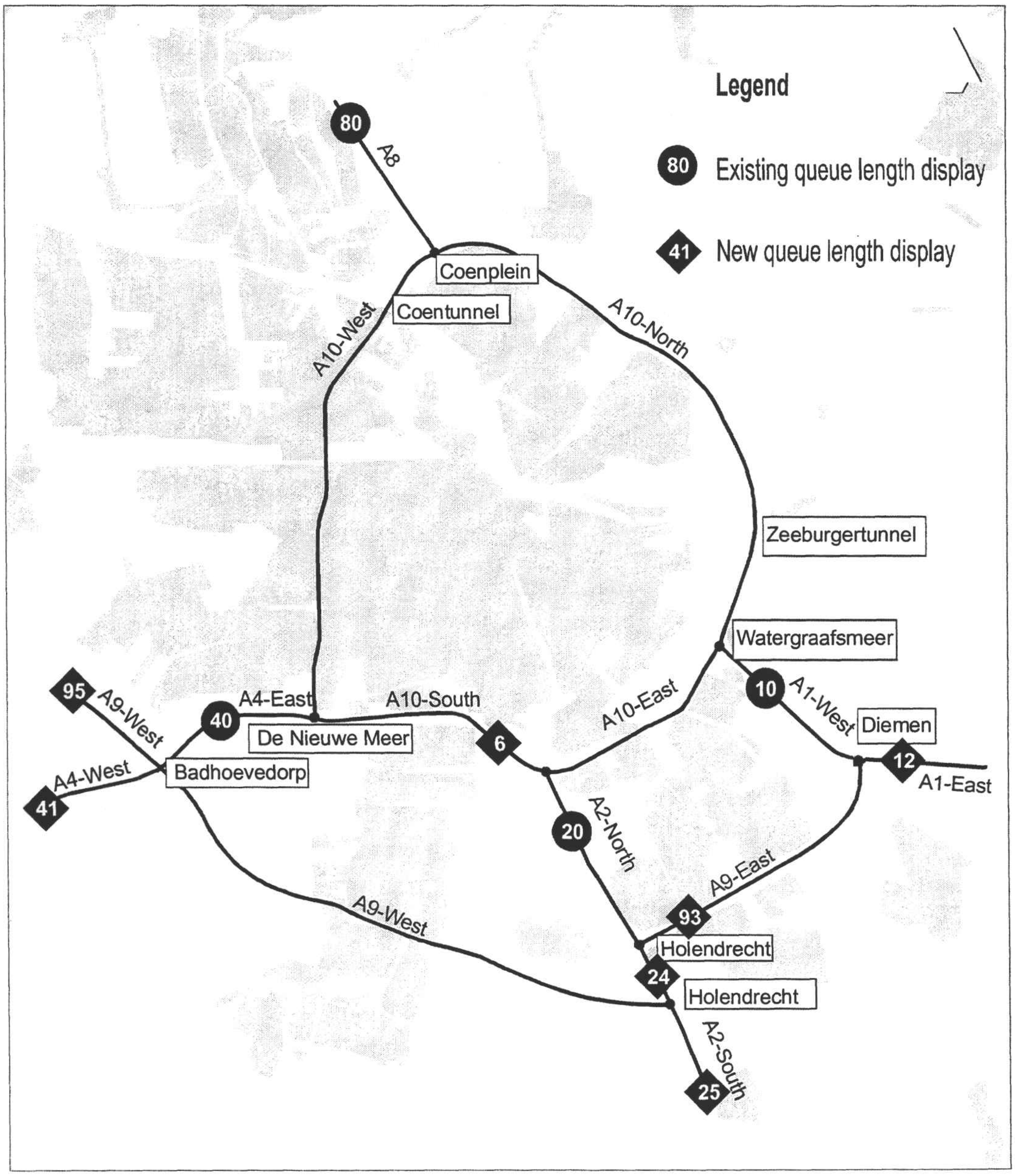

Figure 2: Positions of new and existing queue lengths display signs at the motorway system around Amsterdam.

4 TECHNICAL ASSESSMENT OF THE VMS SYSTEM

In the framework of the Technical Assessment two aspects are investigated:

- The availability of the system, i.e. which percentage of the time is the system up and running?. This aspect has only been assessed in a qualitative way. According to the operators the availability of the system is 'good'.
- The quality of the displayed messages. This part of the Technical Assessment of the queue lengths display system focuses on the correspondence between the displayed queue lengths and the travel times experienced by drivers. The level of correspondence is used as an indicator of the utility that drivers may derive from the presence of the system.

4.1 Method of Analysis of the Queue length Display Accuracy

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:

- Displayed queue lengths are not equal to currently existing queue lengths
- 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 physical queue length and the queue length experienced by a driver,
- The perception of traffic conditions qualifying as 'queue' differs among drivers.

To determine to what extent the displayed information is in line with the amount of congestion experienced by drivers, *average, or prevailing travel* delay was used as a measure for the amount of congestion experienced by vehicles that traverse the corridor during a specific period. The average travel delay is defined as the average experienced travel time that is needed to traverse the corridor.

To estimate the travel delay, 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. This estimator hence generates 'quasi observations' of travel delay.

The route travel times computed in this way are compared to travel times that were predicted based on a linear regression model that was estimated using route travel time as the dependent, and the displayed queue length as the independent variable:

$$t_r^{est}(l) = \alpha . l + \beta \qquad (1)$$

with:

$t_r^{est}(l)$	The estimated travel time
l	The displayed queue length
α, β	The parameters in the regression model

As a measure of effectiveness of the displayed information, the percentage of variation in the experienced travel times, explained by the variation in the displayed queue lengths, is used. This measure is computed by dividing the residual error of the regression model by the variation in experienced travel times:

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

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
$t_r^{obs}(p,d)$	The 'quasi observed' route travel time, estimated by reconstructing trajectories for vehicles departing *at the beginning* of period *p* of day *d*
$l_r^{qldisplay}(p,d)$	The displayed queue length for route *r* *during* (a one minute) period *p* of day *d*.
$t_r^{est}(l)$	The estimated route travel time based on a linear regression model, see equation (1) and see figure 2.
$\bar{t}_r^{obs}$	The quasi observed route travel time, computed off-line, averaged over all days and all periods.

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 as follows:

$$R_r^{2,historic} = \left(1 - \frac{\sum_{p=1}^{P}\sum_{d=1}^{D}\left(t_r^{obs}(p,d) - \bar{t}_{rp}^{obs}\right)^2}{\sum_{p=1}^{P}\sum_{d=1}^{D}\left(t_r^{obs}(p,d) - \bar{t}_r^{obs}\right)^2}\right).100\% \qquad (3)$$

with:

$\bar{t}_{rp}^{obs}$	The 16 minute moving average centered around period *p* of the quasi observed route travel time for route *r*, 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:

$$\hat{t}_r^{qldisplay+historic}(p,d) = \bar{t}_{rp}^{obs} + \beta.(l_r^{qldisplay}(p,d) - \bar{l}_{rp}^{qldisplay}) \qquad (4)$$

with:

β	A regression parameter that is to be estimated (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 indicator for this predictor is denoted as $R_r^{2,qldisplay+historic}$.

A final indicator is the amount of variation in the experienced travel times that can be explained by the instantaneous travel time. The instantaneous travel time on route *r* is the travel time of an imaginary vehicle that at each section of that route would maintain the speed that prevailed at that section at the moment the vehicle started on the route (see Figure 3). The corresponding indicator is denoted with $R_r^{2,inst}$.

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

with:

t_{rp}^{inst} The instanteneous travel time on route r for period p on day d.

The instantaneous travel time is similar, but not equal to the experienced travel time (see Figure 3). The experienced travel time can only be computed with hindsight, because at the time a vehicle sets of on a route, the section speeds of the route sections are not yet known. With predictive tools one can try to forecast these section speeds for a time horizon that is large enough to complete a trip. A naïve predictor for these sections speeds is implied by the assumption that remain constant. The instantaneous travel time can therefore be seen as a naïve predictor of the experienced travel time.

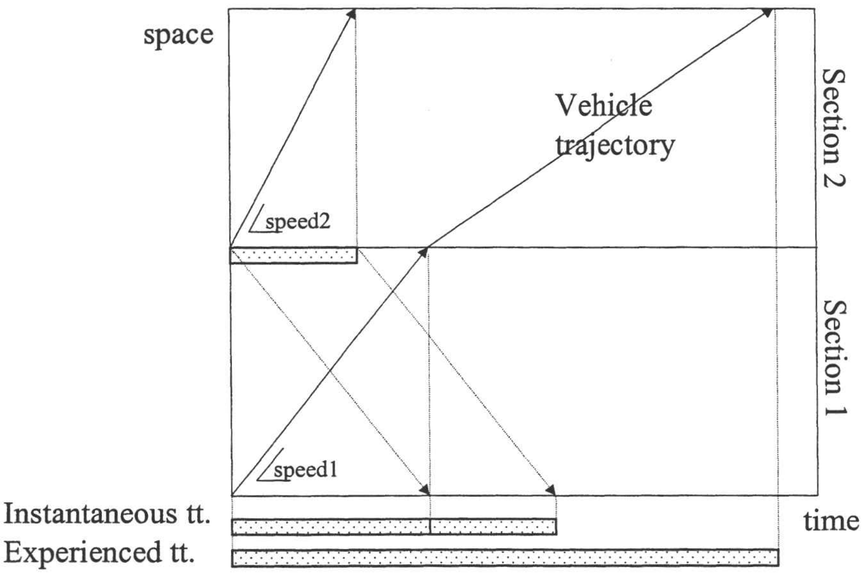

Figure 3: Illustration of the computation of Instanteneous travel time and experienced travel time.

The queue lengths display is, like the instanteneous travel time, based on observations of the present situation. Instead of observing the present queue lengths, one can try to forecast the queue lengths for a short time horizon. In this case one would expect a better correspondence between displayed queue lengths and experienced 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 proxy for the maximum gain that can be achieved in this particular case by changing the current queue length information with better 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 analysed, including days with severe congestion.

4.2 Findings on the Quality of the VMS Messages

Figure 4 shows a typical result of the analysis that was carried out to assess whether the queue information displayed on the VMS is a good prediction of the travel time delay experienced by drivers. The horizontal axis displays the queue length, while the vertical axis displays the experienced route 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.

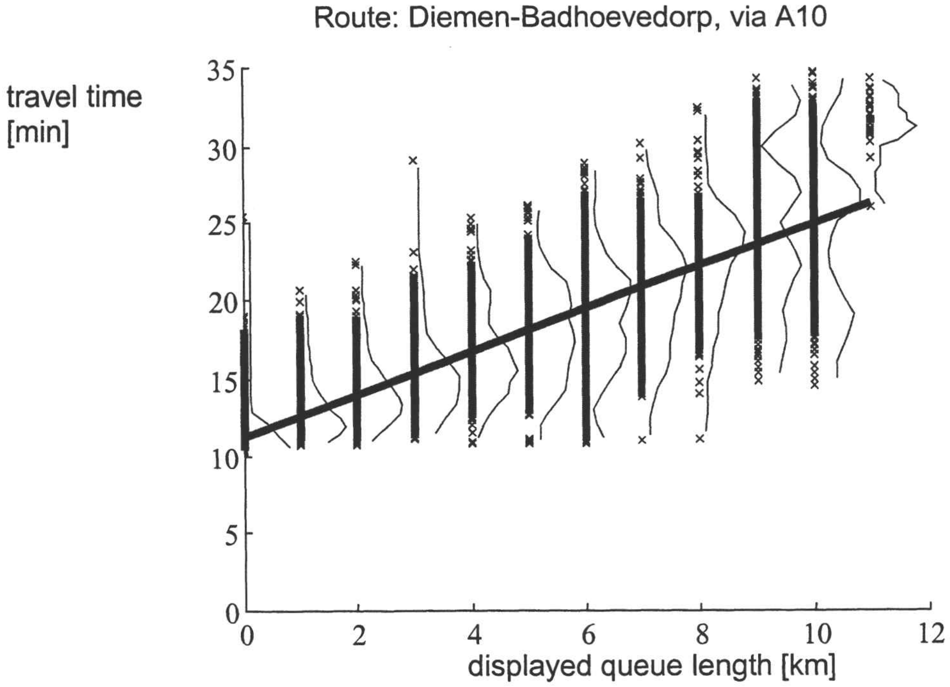

Figure 4: The off-line estimated travel time for the Route 'Diemen-Badhoevedorp, via A10', plotted against the queue length reported on the VMS for that route.

The expected travel time in absence of a VMS queue message for this route based on the regression curve (i.e. the intercept of this curve) is 11.23 minutes, while the mean travel time is 13.48 minutes. Each additional 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 summarised in Table 1.

			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 time 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 1: Results of experienced travel time analysis.

Provided that travellers 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 figures should be seen against the background of the amount of travel time variation that is explained by the historic average travel time ($R_r^{2,historic}$). For the westbound corridor these figures 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 1) 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 1 contains a measure of the correspondence between the instantaneous travel time and the experienced travel time. The remaining discrepancy is mainly caused by the fact that the instantaneous travel time responds slower to changes in traffic conditions than the experienced travel time.

Existing queue detection algorithms, which are closely related to algorithms to compute instantaneous travel time. The values of $R_r^{2,inst}$ (see row 8 of Table 1) also indicate the room for improvement, if the existing queue detection algorithms would be extended with predictive capabilities. This improvement varies in the range between 11% and 20% (100% - $R_r^{2,inst}$) for the routes considered.

A driver with knowledge of average delays as a function of time can reduce his uncertainty about the route travel time with approximately 45% relative to the totally uninformed driver. 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%.

5 IMPACT ASSESSMENT PART I: ROUTE CHOICE USER RESPONSE ANALYSIS

The aim of the impact assessment is to find out the effect of displaying the queue lengths on the route choice behaviour of drivers and on traffic flows. This chapter deals with the impact of the queue lengths messages on the splitting proportions that can be observed at the first junction downstream of the VMS signs. The aggregate analysis of traffic flow impacts is described in chapter 6 .

5.1 Method of Analysis of route choice shifts

To study user responses to the route information on the VMS's, drivers' route choices are analysed in relation to the provided queue length 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 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 a detailed description of the stimulus response methodology see Transpute (1997). 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 analyse the responses. For the westbound routes VMS 12 and 93 are analysed. 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.

5.2 Findings on Route Choice Adaptations

The regression results for the VMS's considered are given in Table 2.

VMS	Beta	t-statistic	R2
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 2: 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 example of a scatter diagram with regression line is given in Figure 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. This figure illustrates 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 in line with the expectations.

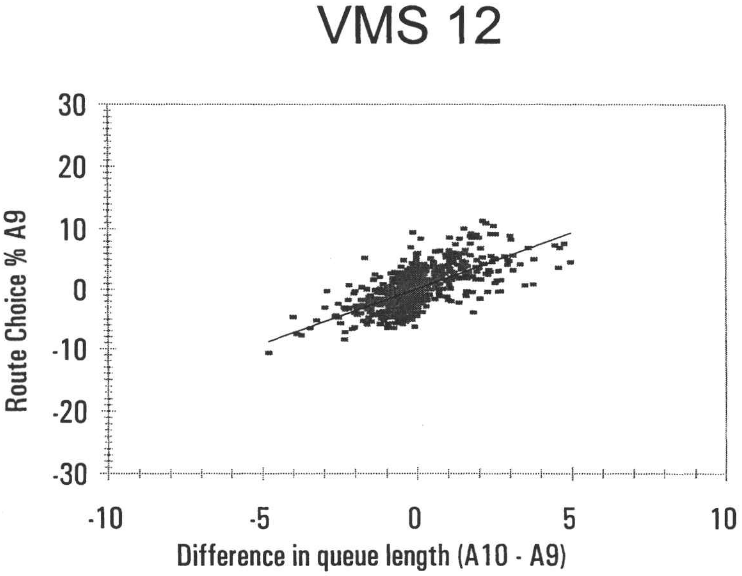

Figure 5: Scatter plot and regression of route split (response) by difference in queue lengths (stimulus) for VMS 12. On the x-axis: The difference in queue lengths between two alternative routes that is displayed on the VMS. On the y-axis: the split proportion at the next downstream fork of VMS, relative to the average split proportion at that fork.

6 IMPACT ASSESSMENT PART II: AGGREGATE TRAFFIC VOLUME IMPACT ANALYSIS

The objective of the aggregate impact assessment is to find out if at an aggregate level a relation can be detected between the extension of the VMS system and changes in the flows, speeds, and travel time spent on the network.

6.1 Method of Analysis of Traffic Flow Changes

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 analysed 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 last VMS's became operational and of an 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. Days with extreme levels of congestion were not included. 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 seasonal impacts exist they are likely to have an adverse impact during the after study, because during the after study the travel demand has been slightly higher, while weather and light conditions were less favourable.

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.

6.1.1 *Traffic performance*

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

$$VMT = \sum_{i,d} q_{i,d} \cdot l_i \tag{6}$$

with:

q_{id}	The total flow over section i during the full peak period on day d
l_i	The length of section i in kilometres
VMT	The vehicle mileage travelled in vehicle-kilometers.

6.1.2 *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 (one-minute) period p and each link i and each day d, the binary variable indicating congestion c_{ipd} 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:

$$SC = \frac{1}{10} \sum_{i,p,d} c_{ipd} \cdot l_i \tag{7}$$

Here $c_{ipd} = 1$ in case there is congestion on link i during period p during day d, and =0 in case of no congestion. The unit of the indicator SC is kilometer-minutes. This indicator does not take into account the number of lanes on each link.

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 meaningful indicator of reliability. It is hypothesised 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 it.

6.1.3 *Instantaneous travel time delay*

The instantaneous travel delays are defined as the difference between free flow travel time and realised 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 realised travel time is the ratio between link length and actual link speed v_i.

$$DL = \frac{1}{10} \sum_{i,p,d} \left(\frac{l_i}{v_{ipd}} - \frac{l_i}{100} \right) \cdot q_{ipd} \tag{8}$$

with:

q_{ipd}	The total flow over section i during period p of day d
v_{ipd}	The average speed on section i during period p of day d

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.

6.2 Findings on Traffic Flow Impacts

6.2.1 *Traffic performance*

Table 3 shows the traffic performance (VMT) as a product of the number of vehicles on the network links and the length travelled. This indicator is summed over the whole peak period and averaged over the ten days.

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

Table 3: 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 peak. This may be caused by the reduction of congestion on its competing route over the A10 during the after period (see Table 4).

6.2.2 *Severity of congestion*

Table 4 shows the calculated severity of congestion for the corridor in the before and after periods. 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.

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

Table 4: Severity of congestion (and standard deviation) for corridor West- and eastbound, averaged over ten days (in km.min).

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.

6.2.3 *Instantaneous travel time delay*

Table 5 shows the travel time delay in vehicle-hours, total over the whole peak period. Between brackets the day to day standard deviation of this delay 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 5: Travel time delay (in vehicle-hours) for corridor, averaged over the days.

In addition, average travel speeds on the corridor have been analysed. Table 6 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 demand, 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 6: Average travel speed (and standard deviation) for the corridor, in kilometers per hour, averaged over the days.

7 IMPACT ASSESSMENT PART III: ROUTE LEVEL ANALYSIS OF TRAVEL TIME

In the previous chapter we have considered the impacts of the extension of the VMS system on aggregate indicators like total distance travelled, severity of congestion, total time spent and average speed. Although such an analysis is an essential first exploratory step in the impact assessment, it does not tell us all about the impacts of the new system on the travel time that is experienced by drivers. The reason for this is that changes in aggregate indicators like total time spent reflect both changes in traffic volume and changes in average travel time per driver.

This section presents the results of an analysis that was carried out at route level. The advantage of an analysis at route level is that it corresponds directly with travel times experienced by drivers. The following aspects were considered:

- the travel time on the corridor
- the variation in the travel time on the corridor

7.1 Method of Analysis of Route Level Impacts

Indicators like the travel time on a corridor and the day-to-day variation in that travel time were checked before and after the extension of the VMS system, and for different routes. Among the six routes that were considered also two routes were selected that at are not directly affected by the extension of the VMS system: the so-called *reference corridors*.

An analysis at route level enables us to consider the impacts of queue lengths display more in detail than is possible with an aggregate analysis, like presented in chapter 6. Also, a route level analysis corresponds better to the experiences of individual drivers.

The route level analysis presented in this section consists of the following items:

- *Analysis of the mean travel time as a function of time of day, before and after the introduction of the queue lengths display.* This analysis gives a general impression of the changes in travel time that have occurred on the different routes.
- *Analysis of the standard deviation of the travel time as a function of time of day, before and after the introduction of the queue lengths display.* The standard deviation of travel time is a good measure of reliability of a route. The variation in travel time is highly relevant to travellers because this enables them to judge how much time is needed to reach their destination with a sufficient measure of certainty.
- *Analysis of a weighted sum of travel time and travel time deviation as a function of time of day, before and after the introduction of the queue lengths display.* From the viewpoint of a driver, the weighted some of expected travel time and the variation in travel time is a good measure for the time needed to reach a specific destination with a certain level of certainty. The relevant measure is derived and analysed.
- *Analysis of the mean travel time as a function of the traffic performance on each route, before and after the introduction of the queue lengths display.* A problem with comparing the before and after situation is that travel demand and weather conditions are not comparable in the before and after situation. In general the circumstances under which the 'before' data have been collected are favourable compared to the conditions under which the after data have been collected. Especially the travel demand has been slightly higher in the 'after' study. To remedy this the traffic conditions have been ranked, using the traffic performance on a corridor as a criterion. This makes a better comparison possible.
- *Analysis of the mean travel time as a function of the traffic performance on each route during the morning peak, before and after the introduction of the queue lengths display.* Here, the same remarks apply as in the previous case. The difference is that the analysis is limited to the morning peak.

- *Analysis of the mean travel time as a function of the traffic performance on each route during the evening peak, before and after the introduction of the queue lengths display.* Here, the same remarks apply as in the previous case. The difference is that the analysis is limited to the evening peak.

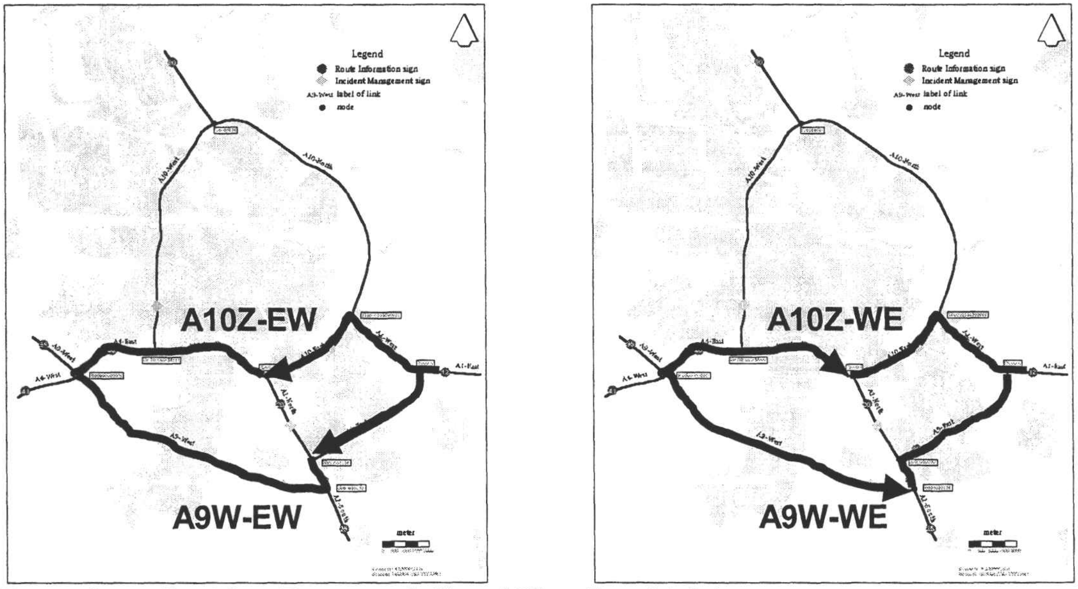

Figure 6: Corridors East west (left) and West-East (right)

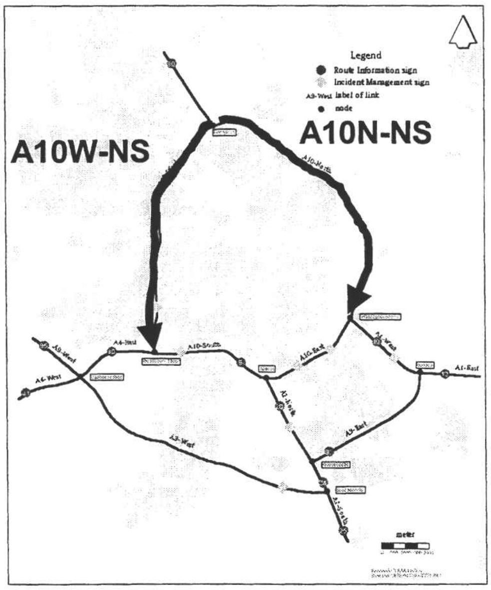

Figure 7: Reference corridors

In all cases the analysis is based on an off-line estimator of travel time. This estimator is based on reconstructing 'average' trajectories and hence is similar to the 'dynamic travel time'. The dynamic travel time is one of the travel time estimators that is used as a reference while interpreting the results of travel time estimators and predictors within DACCORD. Figure 8 illustrates this estimator. With respect to this off-line estimators the following remarks apply:

- The travel time estimator does not distinguish between cars, motorcycles and trucks. It hence generates, 'average' travel times.

- The travel time estimators may contain error; It has not been validated at the location where it was used.
- There is no reason to assume however, that these errors have a significant influence on the conclusions of this section, because they affect the 'before' and the 'after' study in the same manner.

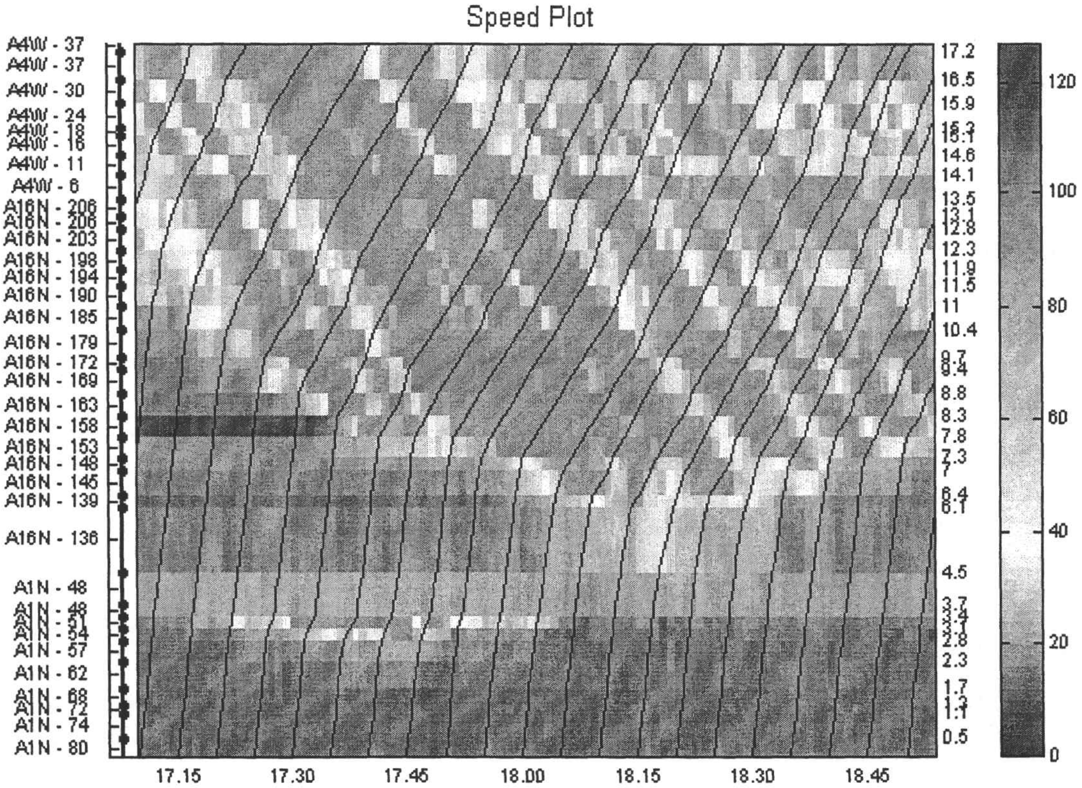

Figure 8: Screen view (converted from colour to grey shades) of the software tool that was used to estimate prevailing route travel time. Left: layout of the route, including reference to the loopdetectors. Middle: time-space diagram.
The grey shades indicate average speed per detector for one-minute periods, the lines correspond to hypothetical vehicle trajectories. These trajectories are used to compute the prevailing travel time for the route. Right. Legend, indicating the speed in km/hr.

7.2 Mean travel time as a function of time of day

Figure 9 shows the travel times that were computed off-line for six routes. The routes have been indicated in Figure 6 and Figure 7. The circles correspond to the period before extension of the queue lengths display system while the crosses correspond to the period after the extensions. Each circle or cross corresponds to the prevailing travel time on a specific route for vehicles that depart at that specific time instant. To promote a good legibility of the figure, it has been limited to only 100 randomly selected datapoints for the before case and 100 datapoints for the after case.

Due to the high dispersion in travel time, both in the before and in the after situation, it is quite difficult to draw conclusions based on Figure 9. Therefore the travel-times corresponding to one minute periods have been averaged over 15 minute time intervals. The results are shown in Figure 10.

The graph shows clearly that the mean travel times after the extension of the VMS system has decreased relative to the before period for all four routes that have been directly affected by the extension. Also one of the two reference corridors (Figure 9, bottom right) shows a decrease in average travel time. A possible explanation for this effect is that due to a reduction of spill backs the amount of congestion on the A10W has reduced.

Note that the introduction of the new VMS's is just one of the differences between the before and after situation. Also the travel demand may differ substantially, because the before period took place during the summer holiday period, while the after period did not. In later sections methods will be used that aim to exclude the influence of travel demand.

7.3 Standard deviation of the travel time as a function of time of day

One of the hypotheses about the introduction of new VMS signs is that this leads to a reduction of the variation in travel time. This is because the VMS functions as a feedback loop: if there is very little congestion on a specific route, traffic that normally avoids this route, might be attracted to this route after being informed by the VMS. On the other hand, if there is above average congestion on a route, a number of drivers are expected to divert to another route.

Figure 11 shows the standard deviation of travel time, which is computed as follows:

$$\begin{aligned} \sigma_p &= \sqrt{\frac{1}{15D-1}\sum_{d=1}^{D}\sum_{m=1}^{15}\left(t_{pmd}^{obs}-\mu_p\right)^2} \\ \mu_p &= \frac{1}{15D}\sum_{d=1}^{D}\sum_{m=1}^{15} t_{pm}^{obs} \end{aligned} \qquad (9)$$

with:

d, m, p	Indices for day, minute and (15 minute) period
D	The total number of days considered
t_{pmd}^{obs}	The quasi observed travel time for vehicles departing in minute m of period p at day d.
μ_p	The mean of the quasi observed travel time over all minutes and days.
σ_p	The standard deviation (root of the sample variance) within the group of observations that corresponds to (15 minute) period p.

Note that two components contribute to this standard deviation:

- The day to day variation of the 15 minute averaged travel times
- The minute to minute within-day variation of the travel time

However, the difference between the two can not be observed by individual drivers as they do not make multiple trips within one 15 minute period.

Like the mean travel time, the variation in the travel time has reduced in the after period for all the corridors that have been directly affected by the extension of the VMS system (the top four plots in Figure 11). However, the reduction of the variation in travel time seems to be proportional to the reduction in mean travel time. In other words: the reduction of the travel time variation can not be shown to be a separate effect of the extension of the VMS system.

Also on one of the control corridors (A10W_NS) the travel time variation has reduced. This weakens the argument that the reduced travel time variation is *only* due to the extension of the VMS system. Of course, the possibility exists that the reduction of travel time variation on the A10W-NS control is due to a reduction of congestion caused by spill back from road sections that are affected by the new VMS's. However, this has not yet been verified.

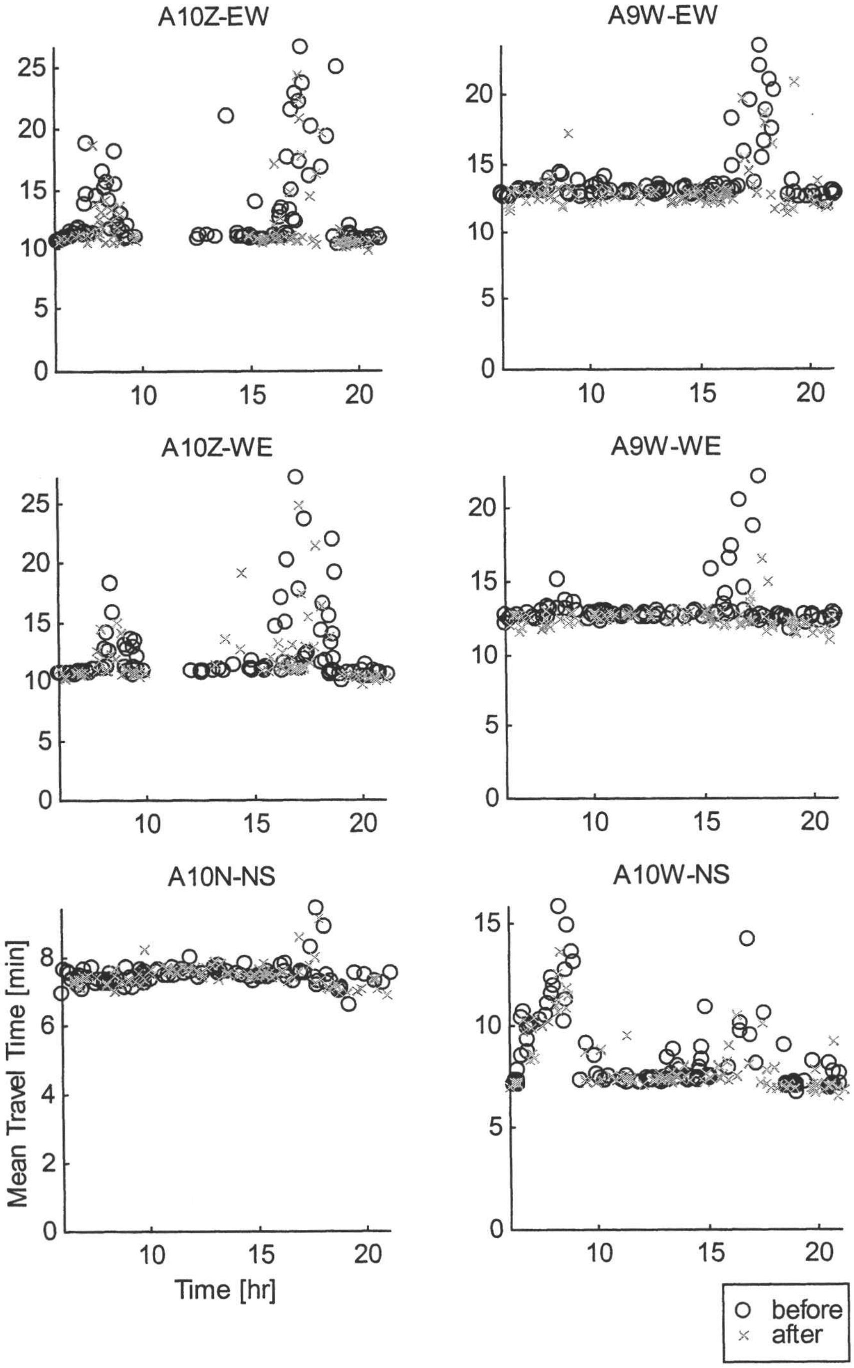

Figure 9: *Travel time as a function of departure time, computed from data before the introduction of queue lengths display (circles) and after the introduction of queue lengths display (crosses). Each point in the graph corresponds with the travel time in a one-minute period. The graph is confined to a random selection of 100 dataperiods.*

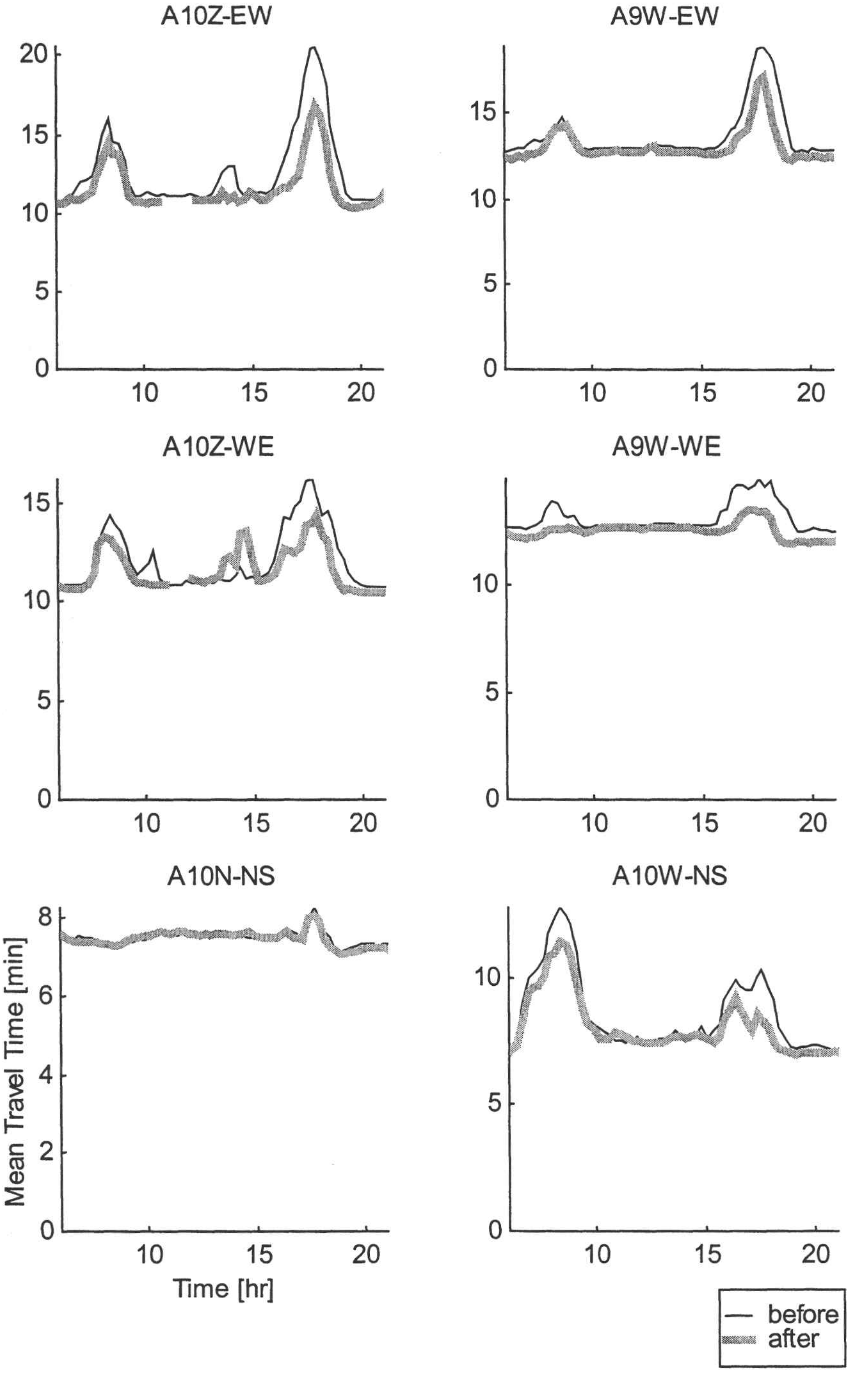

Figure 10: Mean travel time as a function of departure time for both the before and the after period. The travel times have been averaged using 15 minute bins. Top four graphs: corridors East-West and corridors West –East. Bottom two graphs: reference corridors.

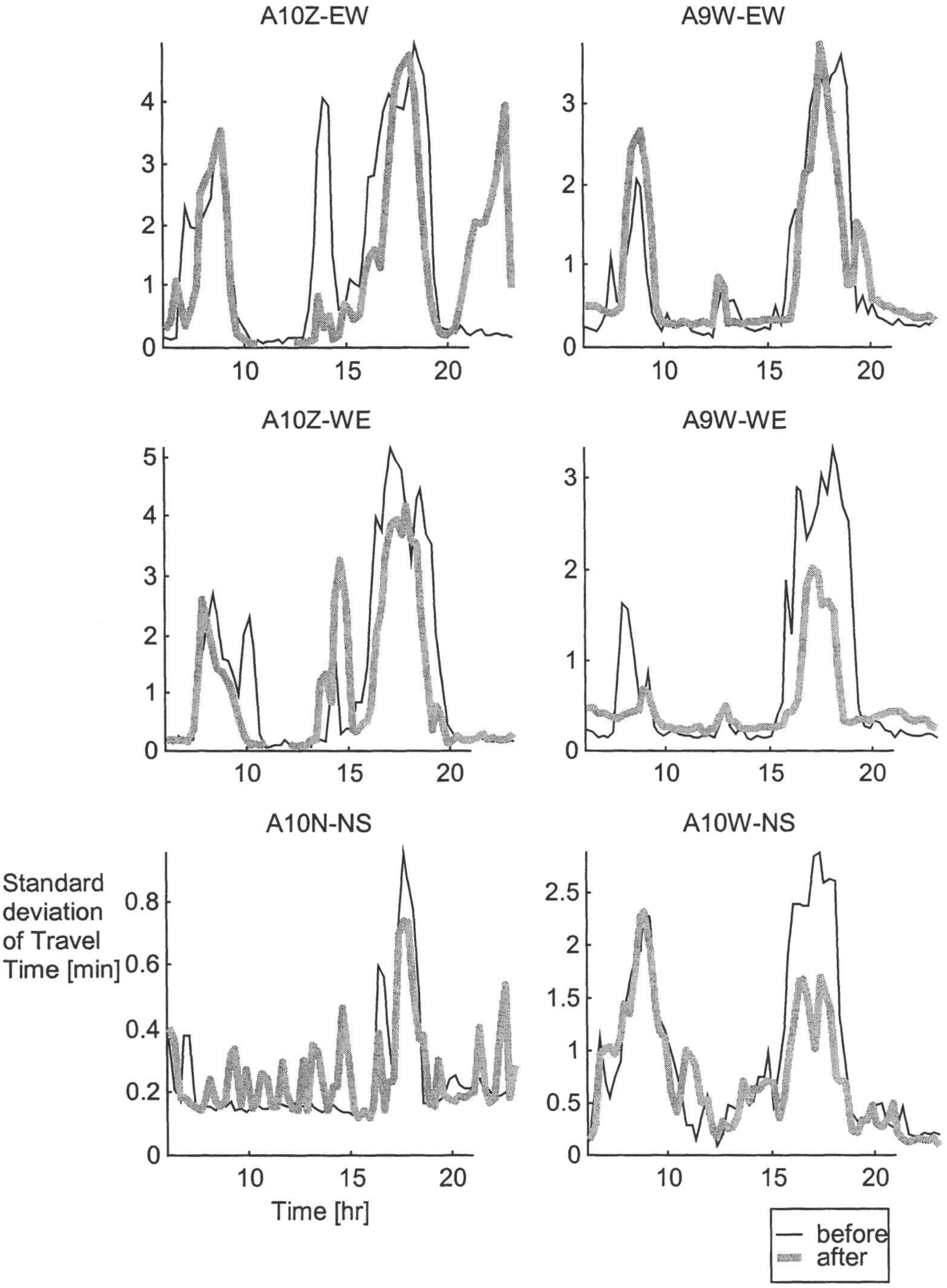

Figure 11: Standard deviations of travel times over 15 minute periods (these values relate to both day-to-day and within period variance)

7.4 Weighted sum of travel time and travel time deviation as a function of departure time

From the viewpoint of individual travellers the variation in travel time is highly relevant because this enables them to judge how much time is needed to reach their destination with a sufficient measure of certainty. Based on the assumption that from the viewpoint of a driver the travel time on a route at a specific time of day is a normally distributed random variable, the reliability interval for the travel time can be established as follows: Given a mean travel time μ and a day-to-day standard deviation σ of this travel time during a particular period, the following table defines this reliability interval.

Interval		**Probability of arriving later**
From	**To**	
0	μ	50 %
0	$\mu + 1.282\sigma$	10%
0	$\mu + 1.645\sigma$	5%
0	$\mu + 1.96\sigma$	2.5%

Table 7: Reliability intervals for various levels of uncertainty

The travel time that is needed to traverse a specific route with 90% certainty will be referred to as the *safe travel time*. An approximation for this 90% reliability interval is the interval $[0, \mu+1.282.\sigma]$, where μ is the mean travel time, σ is the standard deviation (Note that 1.282 is 90% percentile of the cumulative Normal distribution, see Table 7). This quantity is plotted for various periods of the day in Figure 12.

Because the variability of travel time has reduced in the after situation compared to the before situation, the difference between the safe travel time after and the safe travel time before is larger than the difference between the mean travel time after and the mean travel time before.
Because both the reduction in mean travel time and the reduction in variability are most prominent during the peak periods, a comparison of *safe* travel time between before and after study (see Figure 12) shows the same general image as a comparison based on *mean* travel time (see Figure 10). In other words: inclusion of the concept of variability of travel time does not change the conclusions that were drawn before, although theoretically they could have.

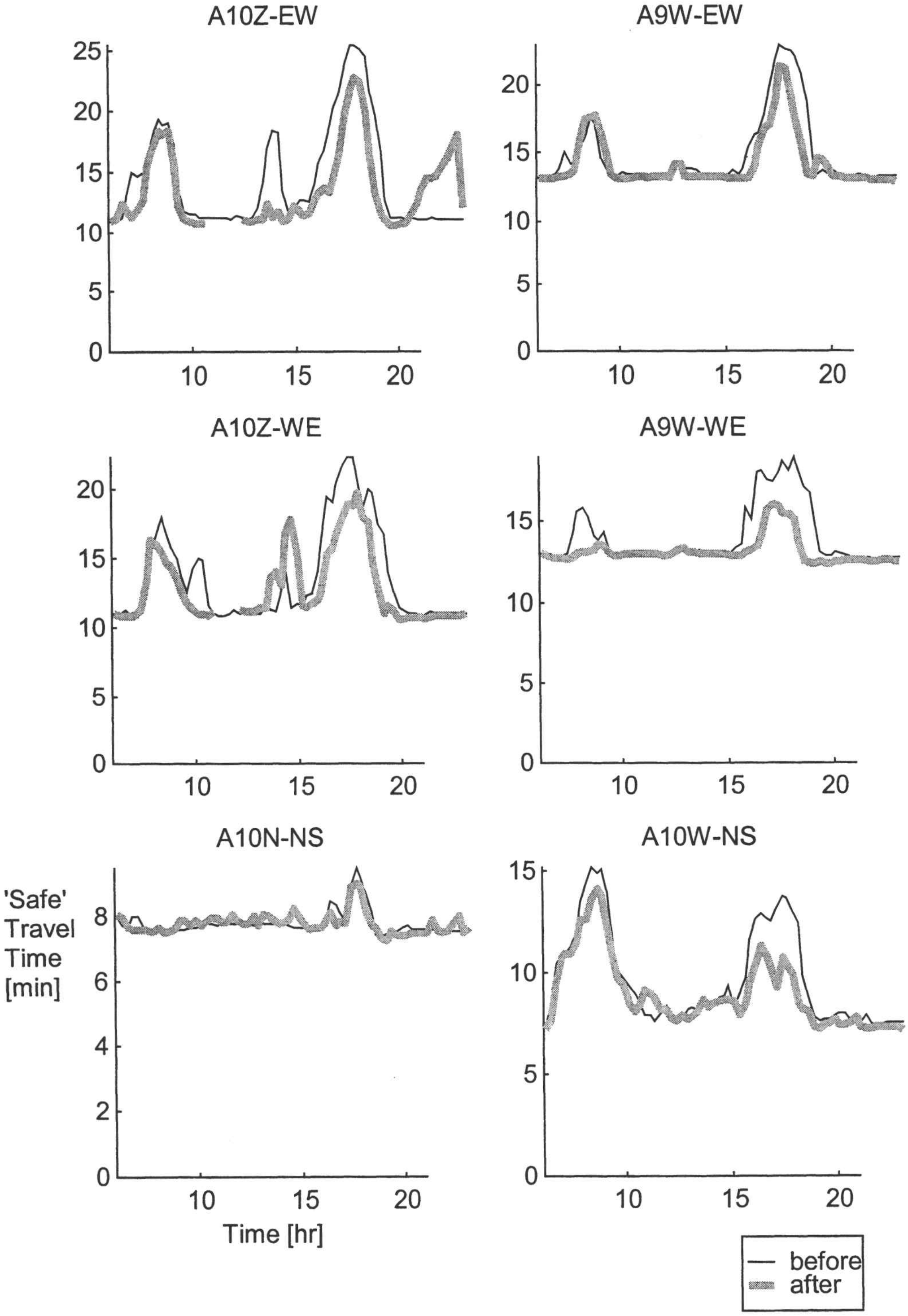

*Figure 12: Time within which the route can be completed with 10% uncertainty (travel time + 1.282*standard deviation)*

7.5 Mean travel time as a function of the traffic performance on each route

A weak point in the analysis that was given in sections 7.2 - 7.4 is that the travel demand between before and after study was not equal. In general the travel demand during the after study has been higher than during the before study, see e.g. Table 3. The before study partially overlapped with the holiday season.

An attempt has been made to compensate for the changes in travel demand by plotting the travel time against the level of travel demand. As a proxy for the travel demand, the traffic performance on a route was used. The traffic performance can be computed by multiplying the length of each section by the traffic volume of that section while adding over all sections:

$$VMT(p,d) = \sum_i q_{i,p,d} \cdot l_i \tag{10}$$

with:

$VMT(p,d)$	Traffic performance of period p on day d
l_i	length of section i
$q_{i,p,d}$	volume on section i of period p on day d

It is hypothesised that introducing extra VMS signs leads to a reduction of the travel time within each class of constant traffic performance. The idea behind this can be explained using Figure 13. This figure explains how queuing delays arise as a result of (temporal) discrepancies between demand and supply. If demand exceeds supply, queues build up. Note that both demand and supply are processes that are subject to random noise.

If by means of extra feedback demand and supply can be synchronised more effectively routes with low travel times will attract more traffic, even if the traffic performance on such a route is already high. Vice versa if the travel time is high, drivers will divert, leading to a reduction of the travel time. All in all this mechanism is expected to cause the random components in demand and supply to be interlinked. This leads to a reduction of travel time.

The hypothesis can be checked by plotting the prevailing travel time against the traffic performance. Note that the prevailing travel time is again computed by reconstruction of trajectories (see Figure 8). Figure 14 shows a number of randomly selected datapoints from this plot (plotting all datapoints would result in a graph showing only a black 'cloud' of points that would not be informative).

The travel time within each class of traffic performance displays a large dispersion. In Figure 15 the travel time has been averaged over 15 minute intervals. The graph shows a clear reduction of travel time within each class of traffic performance for the four corridors that are directly affected by the VMS (A10Z-EW, A9W-EW, A10Z-WE and A9W-WE). The only circumstances under which the decrease was not observed is with very low traffic performance on the route A10Z-EW. This is believed to be caused by the tail of a major incident that took place outside the peak. Also one of the reference corridors (A10W-NS) shows a slight reduction in travel time, but this effect is less distinct. On the other reference corridor the effect is absent.

The next question is whether or not the observed decreases of mean travel time within each class of traffic performance are significant decreases or just coincidental, as a result of random fluctuations in the dataset. To answer this question the variation of the mean travel time within each class has been established. This variation was computed as follows:

$$\sigma_p^2 = \sum_{d=1}^{D} \frac{(t(d,p) - \bar{t}(p))^2}{D-1} \tag{11}$$

with:

σ_p^2	The variation of 15 minute averaged travel time for the 15 period p of the day
$t(d,p)$	The 15 minute *averaged* travel time for period p on day d
D	The number of days
$\bar{t}(p)$	The average travel time for period p for all days, $\bar{t}(p) = \frac{1}{D}\sum_{d=1}^{D} t(d,p)$

Note that this measure potentially overestimates the day to day variance. This is because it is assumed that only D independent datapoints exist. In reality far more datapoints exist because each 15 minute average consists of 15 one-minute observations. However the consecutive one-minute observations are not mutually independent. Computing the day-to-day variation of travel time on the basis of one-minute data would therefore lead to an underestimation of this variation.

The difference of mean travel time between before and after study should be looked at against the background of the day to day travel time variation σ_p^2. Based on the variation and the assumption that the day to day travel time is normally distributed reliability intervals can be drawn up for each period of the day. These reliability intervals are based on the sample variance during the before study and the sample variance during the after study. A 90% interval is computed as follows:

$$\begin{aligned} I_{p,90\%} &= [\bar{t}^{\text{BEFORE}}(p) - \bar{t}^{\text{AFTER}}(p) - \Delta \,,\, \bar{t}^{\text{BEFORE}}(p) - \bar{t}^{\text{AFTER}}(p) + \Delta] \\ \Delta_{p,90\%} &= 1.645\sqrt{\sigma_p^{2,\text{BEFORE}} + \sigma_p^{2,\text{AFTER}}} \end{aligned} \qquad (12)$$

with:

$I_{p,90\%}$	A 90% reliability interval for the difference between mean travel time before and after the introduction of the new VMS's
$\bar{t}^{\text{BEFORE}}(p)$	The average travel time for 15 minute period p averaged over all days of the 'before' period.
$\sigma_p^{2,\text{BEFORE}}$	The sample variance associated with $\bar{t}^{\text{BEFORE}}(p)$
$\bar{t}^{\text{AFTER}}(p)$	The average travel time for 15 minute period p averaged over all days of the 'after' period.
$\sigma_p^{2,\text{AFTER}}$	The sample variance associated with $\bar{t}^{\text{AFTER}}(p)$

These 90% reliability intervals are shown in Figure 16. Note that these intervals are in fact 95% intervals, because only one 'tail' of the distribution is relevant. Viewing Figure 16 reveals that the reductions in travel time that were found in Figure 15 for the four corridors that are directly affected by the new VMS's are indeed significant.

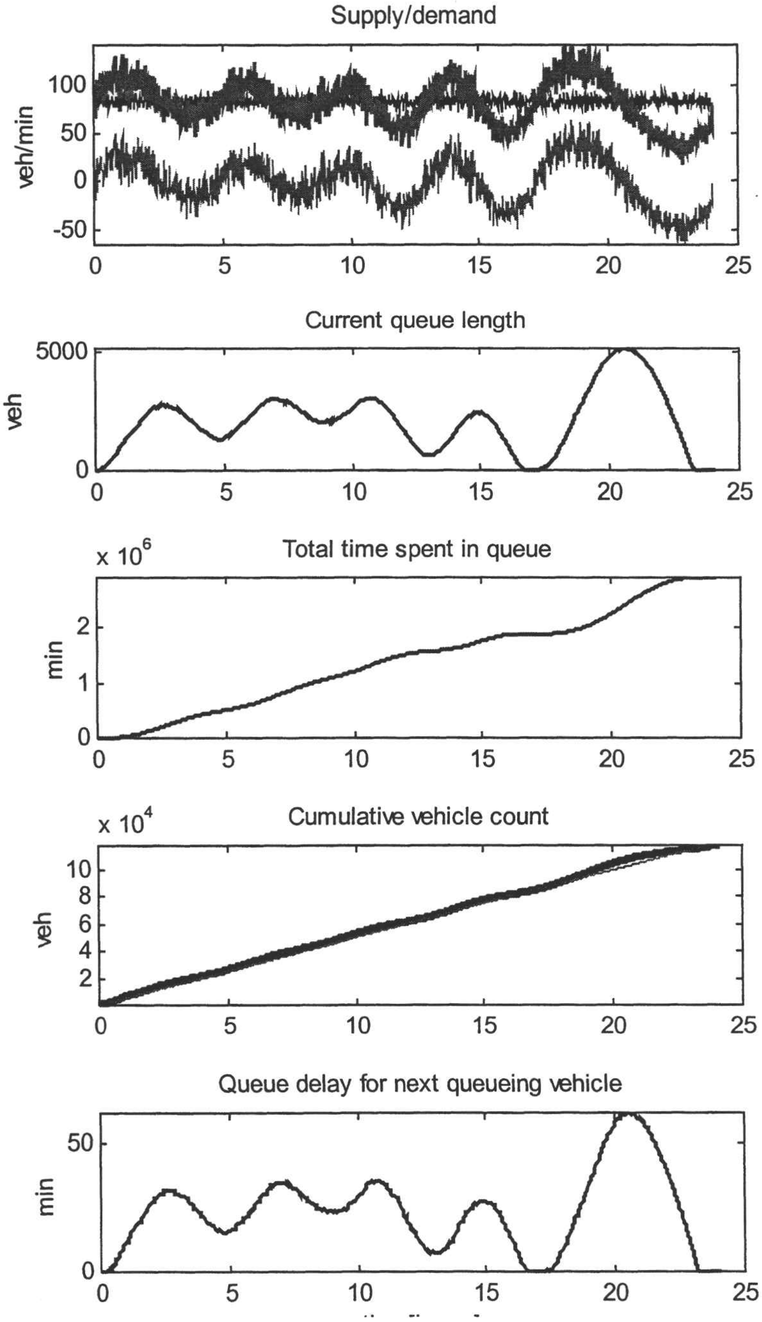

Figure 13: Illustration of mechanism behind travel time delays as a result of queues. Top graph: Demand (bold curve) temporarily exceeds supply. Second graph: All excess vehicles are stored in queue. Third graph: The total time spent in queue can be derived by integrating second graph. Fourth graph: top two graphs imply both actual cumulative vehicle count and cumulative demand count. Bottom graph: the waiting time for the next queuing vehicle is implied by the fourth graph.

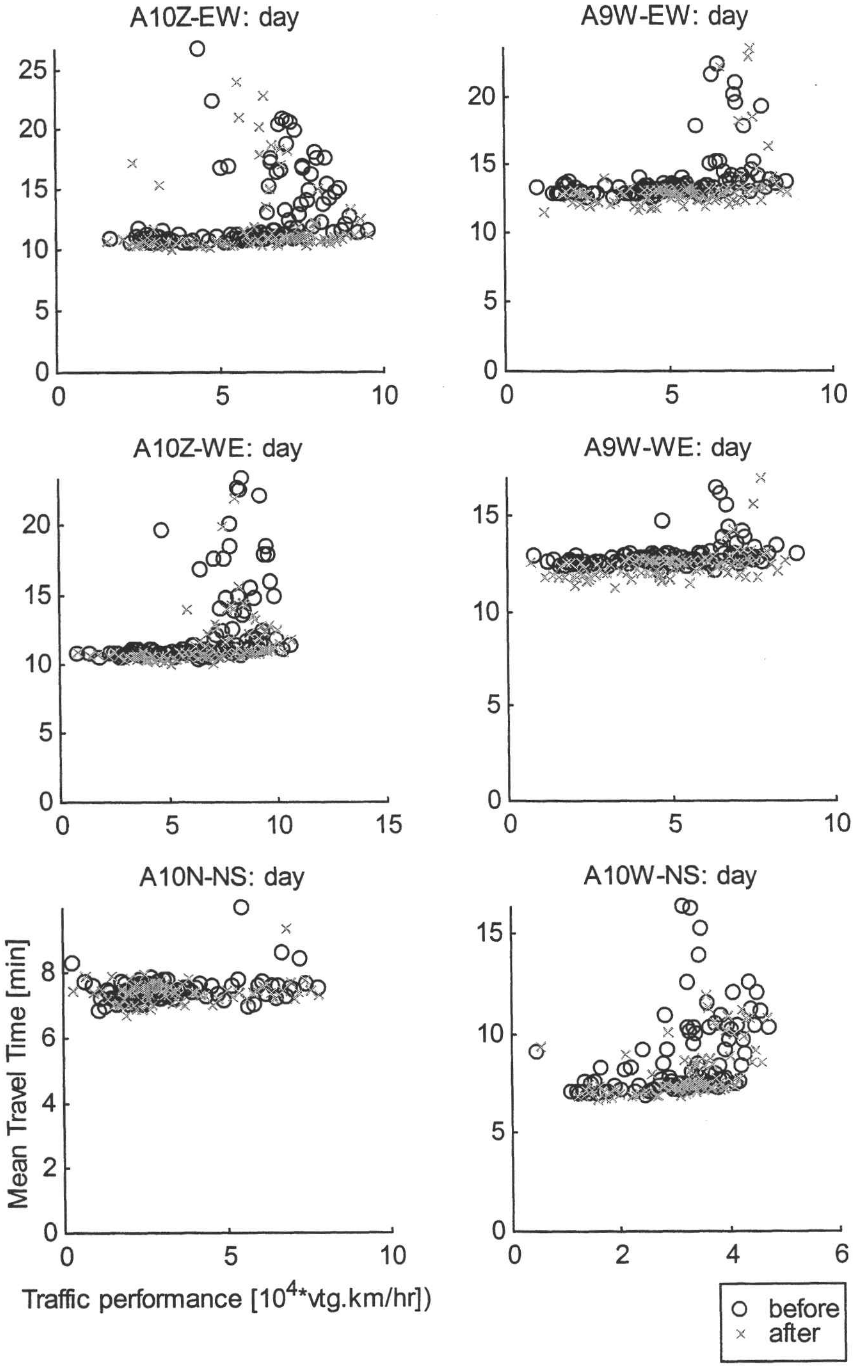

Figure 14: Route-travel time plotted against route-traffic performance, before and after the introduction of new VMS's

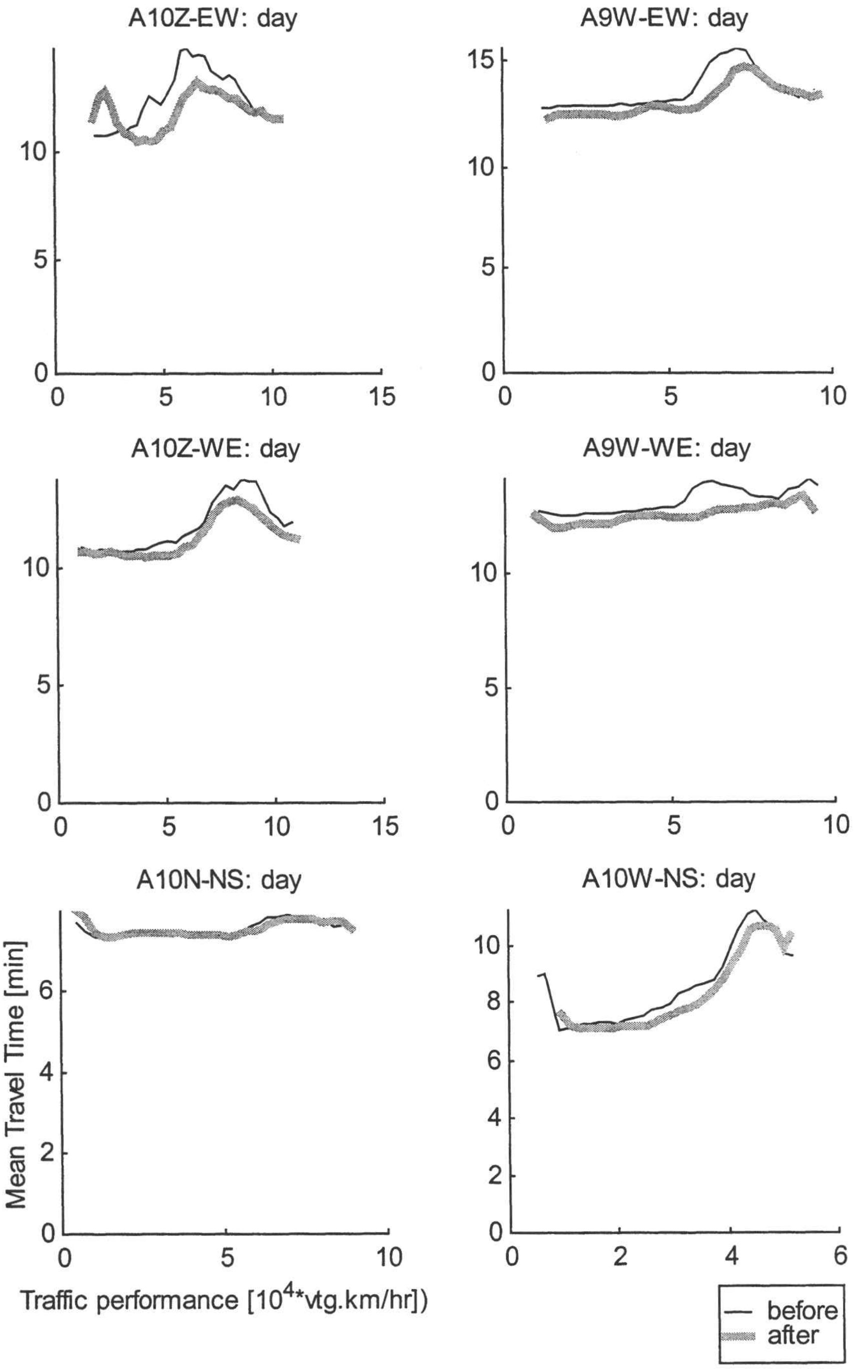

Figure 15: Averaged route-travel-time, plotted against traffic performance, averaged over 15 minute bins, no selection of data applied

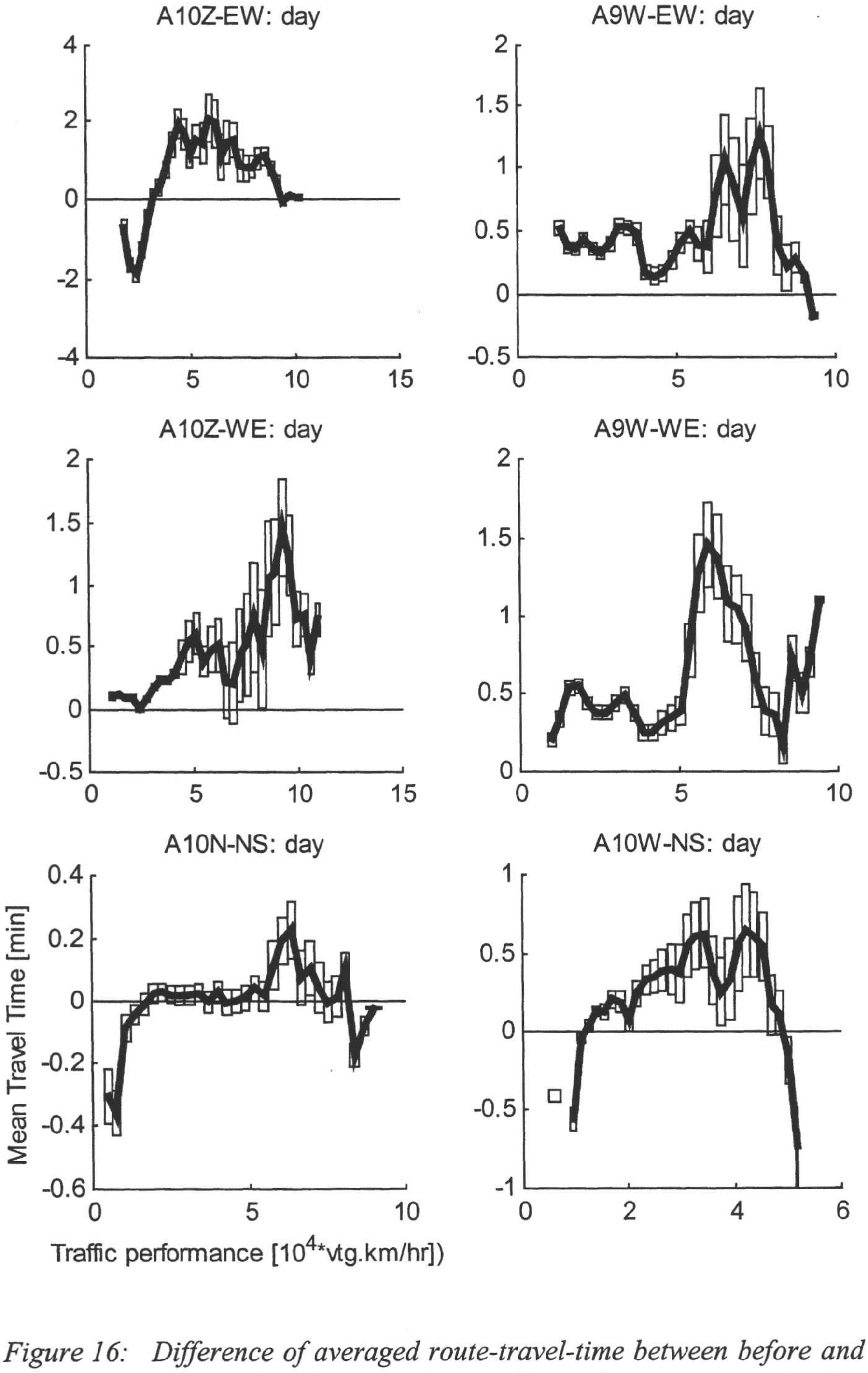

Figure 16: Difference of averaged route-travel-time between before and after study plotted against traffic performance, no selection of data applied. Positive numbers indicate a reduction of travel time. The bars indicate 90% reliability intervals.

7.6 Mean travel time as a function of the traffic performance on each route during the morning peak

The analysis performed in section 7.5 can be repeated for specific periods of the day, like the morning peak and the evening peak. For the morning peak the resulting graphs are shown in Figure 17 and Figure 18. From these figures the same image emerges as from the data that relate to a full day: for the same levels of traffic performance the travel time has dropped during the after period. A similar effect can be witnessed on one of the control corridors.

This indicates that, relative to the rest of the day, situations where VMS's have a large impact on route travel time do not occur more frequently during the morning peak. Such situations are, for example, extreme incidents.

7.7 Mean travel time as a function of the traffic performance on each route during the evening peak

Figure 19 and Figure 20 show the results for the evening peak. The results are even more convincing than the results for the full day and the morning peak. All routes show a distinct reduction of travel time, except for one of the control corridors.

This indicates that relative to the rest of the day, situations where VMS's have a large impact on route travel time occur more frequently during the evening peak.

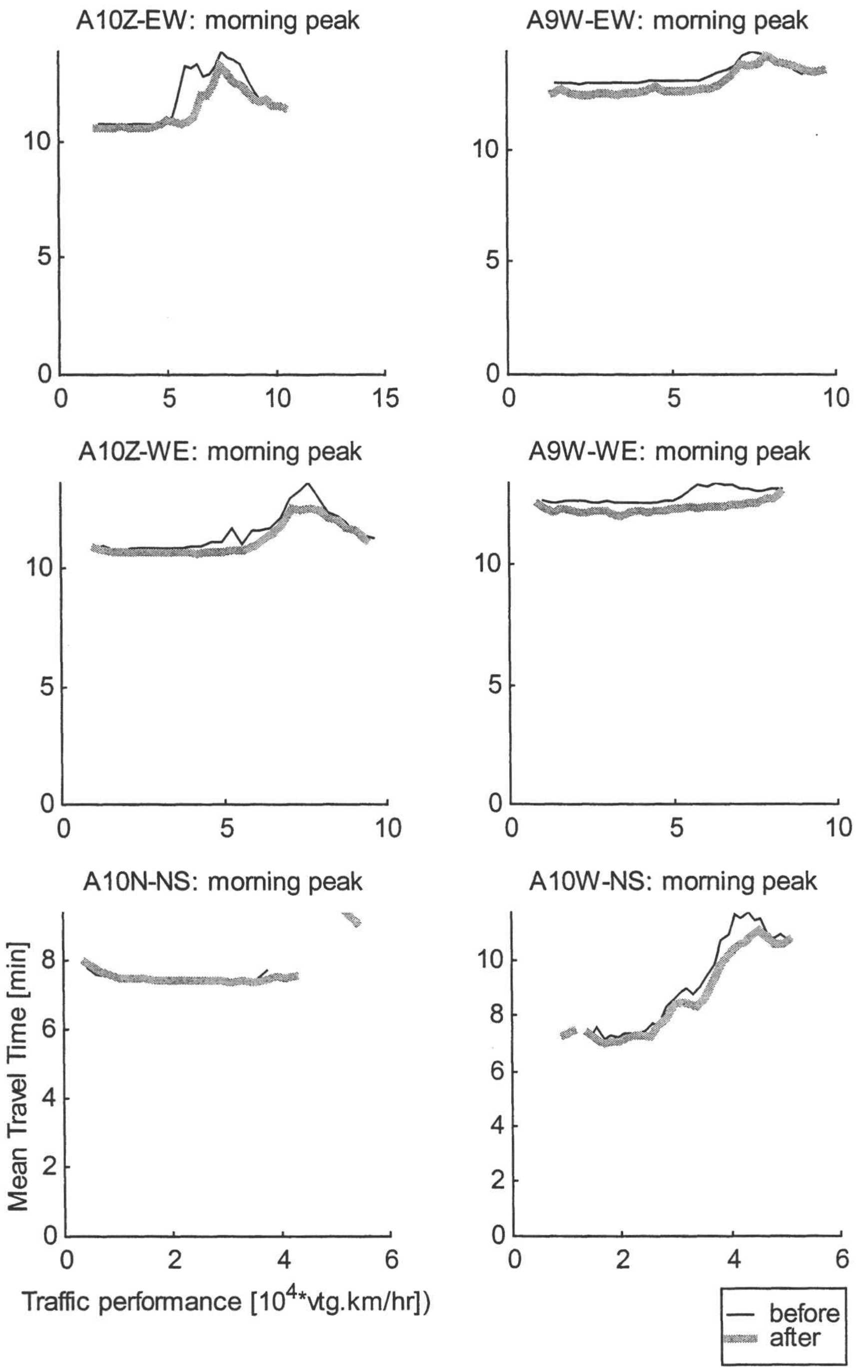

Figure 17: Averaged route-travel-time plotted against traffic performance, only data from the morning peak selected

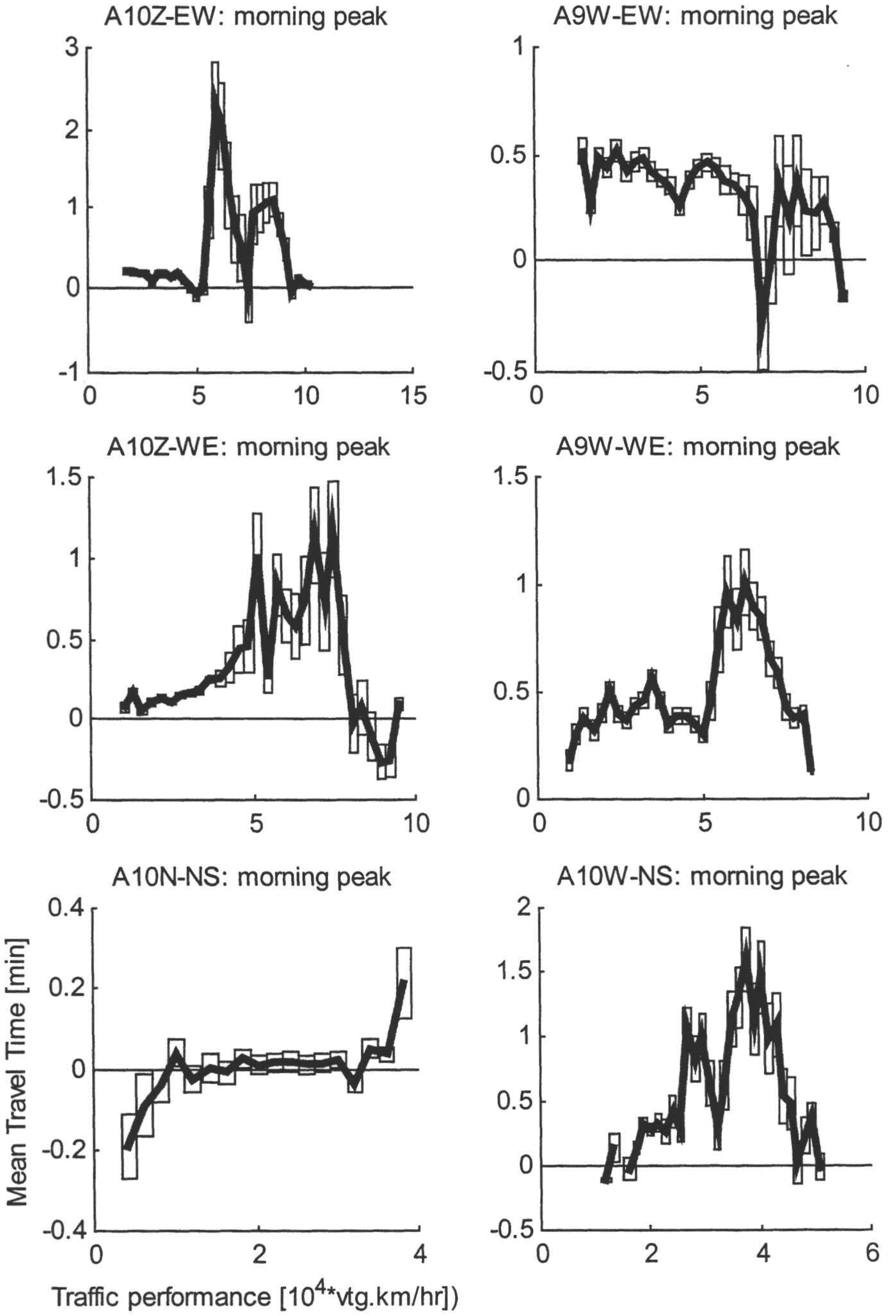

Figure 18: Difference of averaged route-travel-time between before and after study plotted against traffic performance, no selection of data applied. Positive numbers indicate a reduction of travel time. The bars indicate 90% reliability intervals.

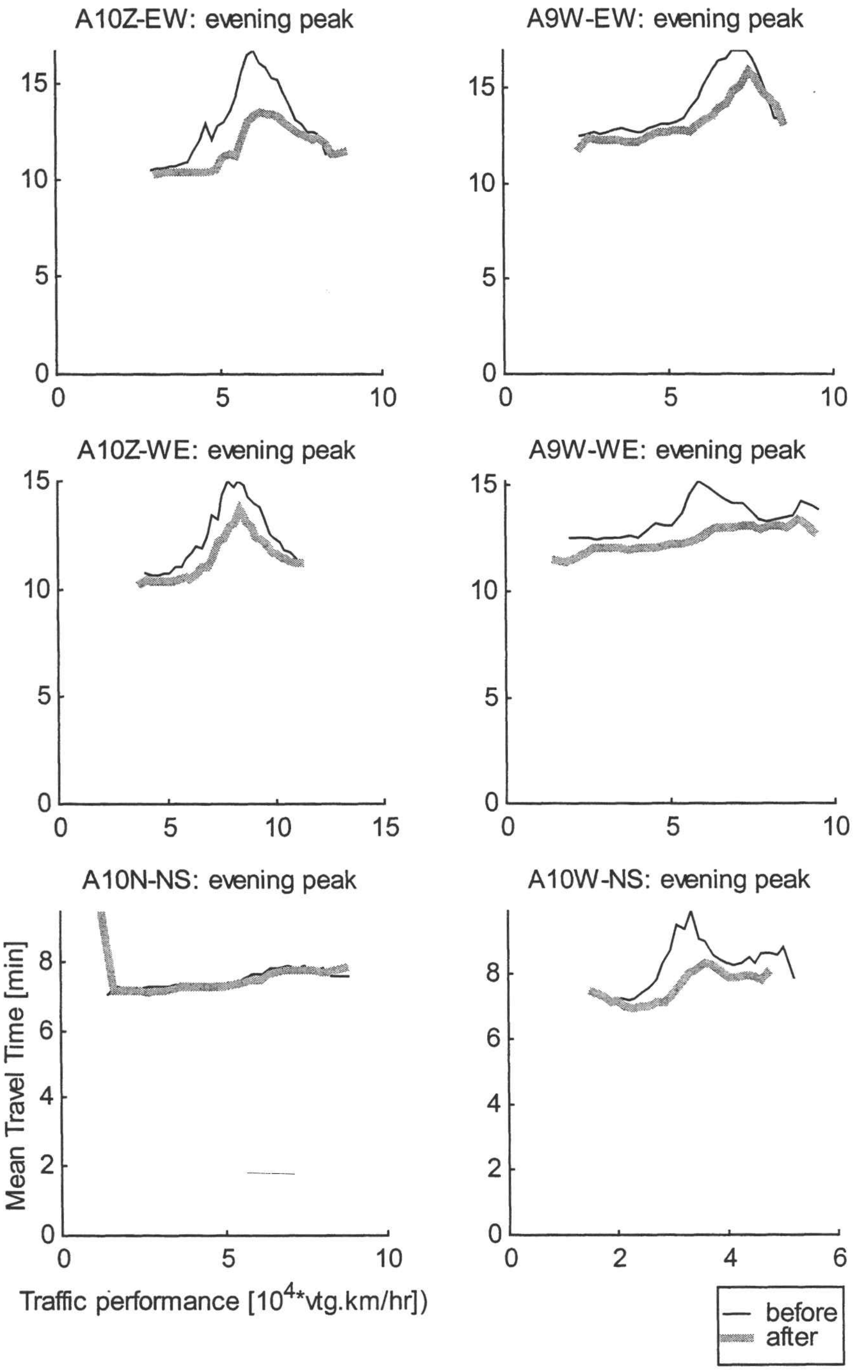

Figure 19: Averaged route-travel-time plotted against traffic performance, only data from the morning peak selected

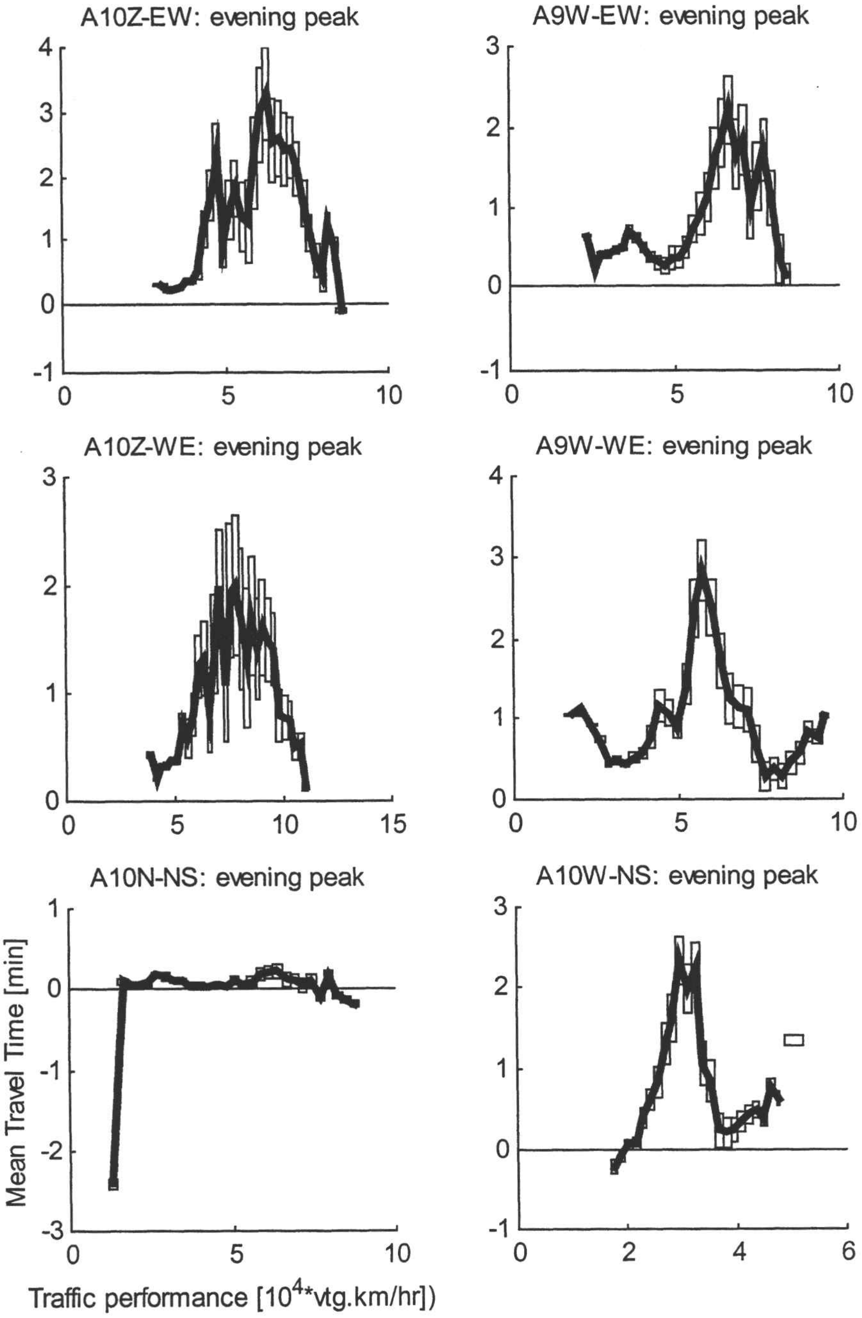

Figure 20: Difference of averaged route-travel-time between before and after study plotted against traffic performance. Only data from the evening peak selected. Positive numbers indicate a reduction of travel time. The bars indicate 90% reliability intervals.

8 CONCLUSIONS

This report analyses the impacts of the introduction of seven new VMS's around Amsterdam in two different ways:

- by means of a *Technical Assessment*,
- by means of an *Impact Assessment*.

The technical assessment shows that the displayed queue lengths, if interpreted correctly by the drivers, are a good indicator 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. On the basis of the VMS messages a driver can reduce his or her uncertainty 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 techniques is about 15%.

The impact analysis was divided in:

- user response analysis
- aggregate impacts
- route level analysis

The 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.

The aggregate 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.

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 travellers 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.

A route level analysis was used to clarify these issues, leading to the following conclusions:

- After the introduction of the VMS's the average travel times have reduced on those routes that are directly affected by the VMS's.
- This effect becomes even clearer if a compensation is applied for changes in travel demand between before and after study.
- The advantages of the new VMS's are most prominent during the evening peak.
- Also on one of the two reference corridors (corridors that are not directly affected by the VMS's) a reduction of congestion is observed.
- The variability of travel time has also been reduced, especially during the evening peak.

The general conclusion is hence that VMS's have a positive impact on network performance in the Amsterdam motorway system, because travel times have reduced and have become more reliable.

9 ACKNOWLEDGEMENTS

Part of this report has been reproduced with permission of the authors from [Kraan *et al*, 1999].

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APPENDIX: REMOVAL OF OUTLIERS

This report has presented a large number of comparisons between the before and after studies. These comparisons were based on travel time estimates computed from data from before and after the extension of a VMS system. Such a comparison can easily be blurred by data that represent conditions that only occur at an incidental basis. If a dataset is small, such data can determine the outcome of an analysis, which then would become quite vulnerable to random factors.

Therefore if a dataset is used for comparative analysis and is not sufficiently large to rule out the influence of random occurrence of incidental conditions, it is necessary to remove outliers. On the other hand, one must be very careful with removing outliers as they can potentially contain valuable information about the effects we want to determine.

In the present study the removal of outliers has been kept to a minimum. After some experimenting, for each route the 0.5% of the datapoints with the highest travel times have been removed. These high travel times are believed to have been caused by incidental conditions.

Figure 21 shows the histograms of the observed travel times for all routes and the 99.5 percentile, the right of which all data have been removed. The value 99.5 has been chosen in such a way that the distribution that emerges from the histogram is left unaffected. The x-axis of Figure 21 has been set in such a way that its maximum corresponds with the maximum observed travel time.

Table 8 lists the data items that have been removed. Visual inspection of these data items is possible using a software tool that was developed especially for this purpose, see Figure 22.

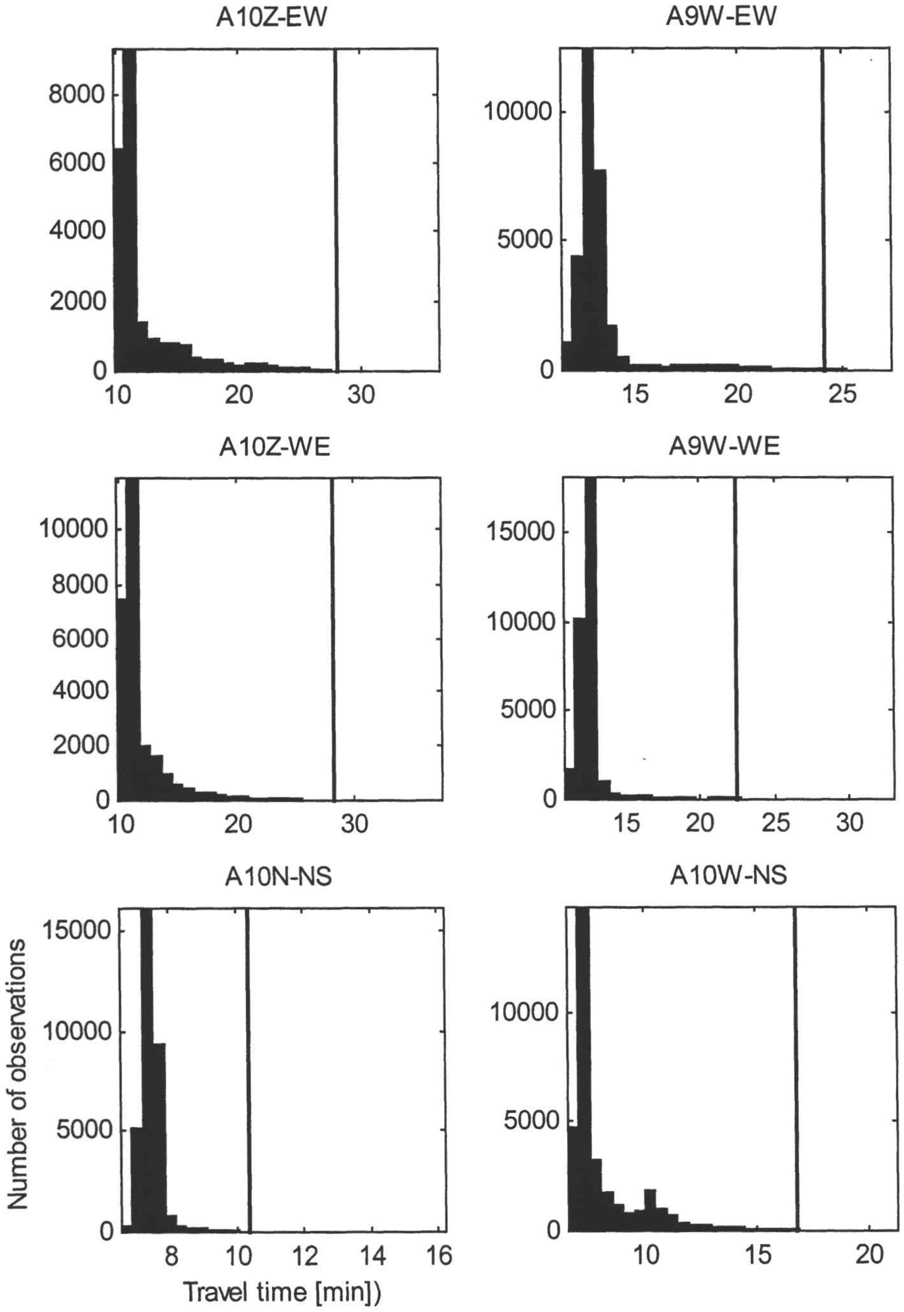

Figure 21: Removal of outliers. The graphs show a histogram (frequency distribution) of the observed travel time per route in the dataset. The vertical line represents the 99.5% percentile. All data items right of the vertical line have been removed.

A10Z-EW	A9W-EW	A10Z-WE	A9W-WE	A10N-NS	A10W-NS
D970925:17.28-18.41	D970516:17.31	D970527:17.18-17.27	D971007:17.35	D970501:13.14-13.36	D970902:8.52
D970925:18.43-18.48	D970516:17.37-17.41	D970527:17.30-17.35	D971007:17.38	D970501:22.25-22.26	D970918:17.26
D971002:17.58-18.14	D970522:17.17	D970527:17.39	D971007:17.47	D970502:13.14-13.17	D970922:7.59-8.02
D971002:18.18	D970526:17.44-17.45	D971008:17.18-18.13	D971007:17.50-17.51	D970507:9.14	D970922:8.04-8.07
D971008:17.30-17.32	D970902:8.42-8.43	D971024:16.53-16.57	D971007:17.59	D970507:11.44-11.51	D970922:8.10-8.37
	D970902:8.45	D971024:17.02-17.06	D971007:18.02	D970507:14.37-14.49	D970922:8.39
	D970902:8.47-8.52	D971024:17.19-17.20	D971008:17.19-17.21	D970515:14.08-14.21	D970922:8.41
	D970904:17.55	D971024:17.34-17.36	D971008:17.23-18.46	D970515:18.02-18.19	D970922:8.45-8.52
	D970918:17.33	D971024:17.41-17.42	D971010:16.24-16.26	D970515:18.58-19.18	D970925:8.11-8.12
	D970925:17.37	D971024:17.45-17.46	D971024:15.57-16.16	D970516:14.34-14.52	D970925:8.22
	D970925:17.46-17.47	D971024:17.55-18.22	D971024:16.18-16.19	D970527:10.40-10.43	D970925:8.27
	D970925:17.54	D971024:18.24-18.36	D971024:16.30	D970527:22.35-22.39	D970925:8.34-8.36
	D970925:17.58-18.03	D971024:18.38	D971024:16.32	D970527:22.41	D970925:8.39
	D970925:18.06-18.14		D971024:16.36	D970527:22.44-22.59	D970925:8.44
	D970925:18.21-18.25		D971024:17.31-17.32	D970925:17.42	D970925:8.56
	D970925:18.32-18.34		D971024:17.35	D970929:18.19	D971008:8.18
	D970925:18.36		D971024:17.38	D971001:17.46	D971008:8.24
	D970925:18.39		D971024:17.40-17.42	D971002:17.47-17.48	D971008:8.27-8.28
	D970925:18.50		D971024:17.47-18.03	D971002:17.51-17.53	D971008:8.33-8.34
	D971001:17.57		D971024:18.11-18.20	D971002:17.55-17.59	D971008:8.36
	D971001:18.01-18.05		D971024:18.22-18.23	D971002:18.05	D971008:8.38
	D971001:18.07-18.08		D971024:18.32	D971002:18.08	D971008:8.40
	D971002:17.52-17.57		D971024:18.34	D971002:18.10	D971008:8.42-8.46
	D971002:18.06-18.08		D971024:18.38		D971008:8.51-8.52
	D971002:18.14		D971024:18.41		D971008:16.14
	D971002:18.21-18.23		D971024:18.44		D971008:16.25
	D971002:18.25		D971104:18.06-18.07		D971008:16.30
	D971002:18.29				D971008:17.22
	D971008:17.21				D971008:17.32
	D971008:17.23-17.35				D971027:8.12-8.14
	D971008:17.40-17.43				D971027:8.18-8.20
	D971008:17.52-17.58				D971027:8.22-8.24
	D971008:18.03-18.05				D971027:8.28-8.29
	D971008:18.07				D971027:8.35
	D971008:18.10-18.20				D971027:16.03-16.04
	D971008:18.23-18.25				D971027:16.13-16.15
	D971008:18.29-18.32				D971027:16.17-16.20
	D971008:18.34				D971027:16.24-16.25
	D971008:18.36-18.41				D971027:16.27-16.37
	D971008:18.45				D971027:16.39-16.52
	D971008:18.50				D971027:16.54
	D971024:17.16-17.17				D971027:17.11
	D971027:17.37-17.41				D971027:17.13-17.14
	D971027:17.43				D971027:17.16
	D971027:17.46-17.50				D971027:17.18-17.20
	D971027:17.56				D971104:8.20-8.41
	D971027:17.58-17.59				D971104:8.45-8.51
	D971027:18.01-18.04				D971104:8.55
	D971027:18.07-18.08				D971104:8.59
	D971103:17.45				

Table 8: For each route the table list the data items that have been removed from the dataset, corresponding to Figure 21

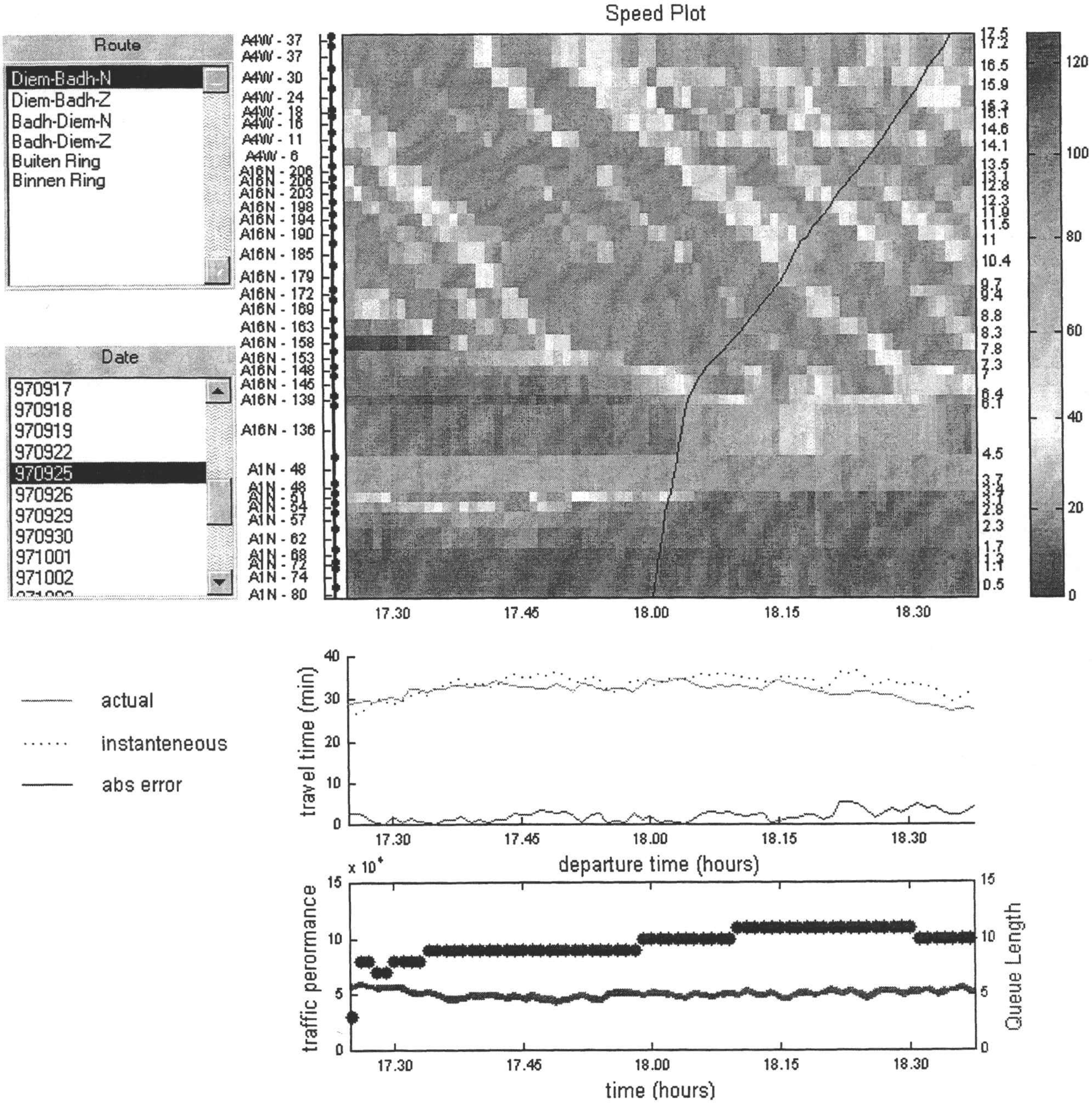

Figure 22: Screen view of software tool that was developed to compute travel time and inspect data that have been retrieved from the monitoring system. The listboxes at the left enable the user to select a route and a date. The top graph represents the speed as a function of time (horizontal) and longitudinal road position (vertical). The middle graph simultaneously plots instanteneous and actual travel time, and the difference. The bottom graph displays traffic performance (left y-axis) and displayed queue length on VMS (right y- axis). The user is allowed to zoom in on the top graph, all other graphs change simultaneously.

Sectie Verkeerskunde

De sectie Verkeerskunde houdt zich bezig met onderwijs en onderzoek op het gebied van planning, ontwerp en exploitatie van verkeerssystemen voor personen en goederen, alsmede het functioneel ontwerp van verkeersinfrastructuur.

De sectie Verkeerskunde participeert in de onderzoekschool TRAIL.

VK 2205.322
ISSN: LVV rapport
0920-0592

000750