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Effects of Variable Message Signs on driving behaviour and traffic safety: a literature survey

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M.H. Martens and J.H. Hogema

SUMMARY

The primary goal of Variable Message Signs (VMSs) is to inform road users in order to improve road safety, to make better use of existing road capacity and to reduce environmental pollution and fuel consumption.

This literature review, which is a part of the TROPIC project, contains an overview of the existing knowledge on a number of effects of VMSs on driving behaviour and traffic safety. The report concentrates on the type of information that needs to be displayed, the placement of VMSs in the longitudinal profile, combining several types of signals on one VMS, and signal changes in place and time.

Literature on the type of information that needs to be displayed is quite diverse, since different criteria for success are used in different studies. Some studies show that the length of the traffic queue needs to be provided, whereas other studies recommend to display travel time or time delay. Literature reveals that road users are able to make better use of the provided information if some additional information is provided. The exact effect of providing additional information still needs some further investigation.

Studies on the placement of VMSs concentrate on dynamic route guidance. VMSs for route guidance should be provided at a sufficient distance before the actual route diversion is required and they should not interfere with more urgent information or required manoeuvres. Little or no literature is available on required spacing between VMSs dealing with section control.

A driving simulator study, evaluating the effect of combining different VMSs revealed that combining did not lead to problems in the required time to process all the information. However, a triple combination, where variable speed limits, dynamic route information and guide signs were combined, caused a change in driving behaviour. Driver interviews have shown that when using pictograms, best results are to be expected if they are well-known, if some information redundancy is used, and if text is used to provide reasons for the restriction. Further research should provide insight in the effect of combining different functions of VMS information on information processing times, diversion rate and traffic safety.

Experimental data on the effect of signal changes are rather limited. One study, that used a driving simulator, investigated the behavioural effect of speed limit changes in a fog warning system. More filtering led to lower driving speeds, and driving speeds were reduced with signal changes in time, even if the new sign was less restrictive then the former one. The effects of sign changes in time always seem to work in a safe direction. No literature was available on sign changes in route choice VMSs.

Although quite some literature deals with the technical and operational specifications for VMSs, the amount of experimental data on the effect on driving behaviour and traffic safety is rather restricted. Further research is required in order to come to a more extensive fundamental basis for using VMSs.

reden te geven voor de beperking. Verder onderzoek zal inzicht moeten verschaffen in het effect van het combineren van verschillende functies van VMS informatie op het verwerken van informatie, op het nemen van een alternatieve route en op verkeersveiligheid.

Experimentele data over het effect van beeldwisselingen zijn vrij beperkt. Een rijsimulatorstudie onderzocht de gedragseffecten van beeldwisselingen in snelheidsimieten in een mistsignaleringssysteem. Meer gefilterde informatie leidde tot lagere rijsnelheid, en rijsnelheid werd gereduceerd bij beeldwisselingen in tijd, zelfs wanneer het nieuwe beeld minder restrictief was van het vorige. De effecten van beeldwisselingen werkten altijd in een veilige richting. Er was geen literatuur beschikbaar over beeldwisselingen in DRIP informatie.

Alhoewel er heel wat literatuur beschikbaar is aangaande technische en operationele specificaties voor VMS, is de hoeveelheid experimentele data over effecten op rijgedrag en verkeersveiligheid vrij beperkt. Nader onderzoek is vereist om tot een meer fundamentele basis te komen voor het gebruik van VMS.

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Effecten van Variable Message Signs op rijgedrag en verkeersveiligheid: een literatuur overzicht

M.H. Martens en J.H. Hogema

SAMENVATTING

Het primaire doel van Variable Message Signs (VMS) is om weggebruikers te informeren teneinde de verkeersveiligheid te verbeteren, om optimaal gebruik te maken van de beschikbare wegcapaciteit en om luchtverontreiniging en brandstofverbruik te reduceren.

Deze literatuurstudie is een onderdeel van het TROPIC-project en verschaft een overzicht van de bestaande kennis over een aantal effecten van VMS op rijgedrag en verkeersveiligheid. Het rapport concentreert zich op het type informatie dat verschaft dient te worden, het plaatsen van VMS in het longitudinale profiel, het combineren van verschillende soorten informatie op een VMS en beeldwisselingen in plaats en tijd.

De literatuur over het type informatie dat moet worden vertoond is vrij uiteenlopend, aangezien in verscheidene studies verschillende criteria voor succes worden gehanteerd. Sommige studies geven aan dat de lengte van de file getoond moet worden, terwijl andere studies adviseren om reistijden of vertragingstijden weer te geven. De literatuur laat zien dat weggebruikers beter in staat zijn om gebruik te maken van de verschafte informatie wanneer aanvullende informatie beschikbaar is. Het exacte effect van het verschaffen van aanvullende informatie moet nog verder onderzocht worden.

Studies over het plaatsen van VMS richten zich op dynamische routekeuze informatie. VMS voor routekeuze moet op voldoende afstand voor de eigenlijke verandering in route vereist is worden aangeboden en de VMS mag niet interfereren met meer urgente informatie of met vereiste manoeuvres. Er is weinig of geen literatuur beschikbaar over de vereiste ruimte tussen VMS, aangaande verkeerssignalering.

Een rijsimulatorexperiment, dat het effect van het combineren van verschillende VMSen onderzocht, liet zien dat het combineren niet tot problemen leidde voor de benodigde tijd om alle informatie te verwerken. Een drievoudige combinatie, waarbij variabele snelheidslimieten, dynamische route informatie en ANWB-bebording werden gecombineerd, veroorzaakte echter een verandering in rijgedrag. Interviews met weggebruikers hebben laten zien dat met pictogrammen de beste resultaten verwacht worden indien ze algemeen bekend zijn, wanneer er sprake is van redundantie in het bericht en wanneer tekst gebruikt wordt om een

1 INTRODUCTION

More and more Variable Message Signs (VMSs) are being installed throughout Europe. The primary goal of Variable Message Signs is to inform road users in order to influence driving behaviour individually and traffic flow and safety collectively. By providing dynamic information along the route, road safety can be improved, a better use of existing road capacity can be realised, road users can be informed and environmental pollution and fuel consumption can be reduced.

There are several systems that fall into the category of Variable Message Signs (VMSs). One of them is section control. Section control is used for lane allocation and speed control. The goal of section control is a more efficient use of the available road capacity, prevention of accidents, warning for interruptions in traffic flow, and prevention of secondary accidents. Variable speed limits serve the purpose of homogenizing traffic, warning for discontinuities in the longitudinal profile, and providing weather-related speed limits, for instance in case of fog. Lane allocation can be used for guidance in the longitudinal profile and warnings for discontinuities in the lateral profile, for instance during road works.

Another type of VMS is the Dynamic Route Information Panel (DRIP), used for route guidance. DRIPs are used to provide information on traffic queues, traffic delays or road obstructions. On the basis of this information, drivers can adapt their travel choices such as divert from the route and select another route from the major road network.

Besides these two types of VMSs, more general VMSs can be used to provide additional information regarding weather-related road conditions, notification of construction ahead, control access to high-occupancy-vehicle lanes or the notice of public events.

The European DG-VII project TROPIC (Traffic OPtimisation by the Integration of information and Control) seeks to increase the knowledge on VMS in order to expand the implementation and to achieve consistent applications, especially on the Trans European Road Network. This report is part of Work Package 08, "Levels of Quality of Service". The objective of this work package is to provide guidelines about the level of provision of infrastructure, features and VMS systems in order to obtain the greatest benefit from the use of the signs. The Dutch Ministry of Transport, Public Works and Water Management is leader of WP08. Under contract with the Dutch Ministry, the TNO Human Factors Research Institute is involved in Task 08.1, dealing with an identification of existing knowledge on Quality of Service aspects of VMSs. This literature review provides an overview of the results from Task 08.1.

Although a lot of literature is available on technical aspects of VMSs, the review concentrates on specific VMS features, related to driving behaviour and traffic safety. In consultation with the Dutch Ministry of Transport, Public Works and Water Management, the literature search concentrates on:

a Selection of the type of route guidance information to be displayed (queue length/travel time/delay time)
b Placement of VMS in the longitudinal profile
   - for route guidance applications: with respect to decision points
   - for section control applications: distance between subsequent signs.
c Combining several types of signals on one VMS
d Changes in signals that are displayed (in place and in time).

Studies that include measured behaviour are preferred over "stated preference" surveys, that investigate what drivers prefer. Although stated preference data can educe preferences on new alternatives, the major disadvantage is the possibly low correspondence between the stated preference results, received under hypothetical scenarios and actual driving behaviour (Ben-Akiva, Morikawa & Shiroishi, 1989). The type of information that is preferred is not necessarily the most effective type in terms of the desired effect on traffic flow. Other information on the motivation of VMS system design choices might be useful as well, but technical descriptions of systems as such will not be included.

2 SELECTION OF THE TYPE OF INFORMATION TO BE DISPLAYED

The objective of the majority of VMS systems is to alter driving behaviour. Relatively many studies discuss what type of information—queue length versus travel time versus time of delay—should be presented for route guidance applications. In many studies, stated preferences are used to determine what type of information should be provided to road users, but some experimental data are available.

In a driving simulator, Janssen, Van der Horst and Hoekstra (1992) investigated the effects of different kinds of information about the ordinary route and an alternative route on the quality of route choice behaviour. The experiment was designed in such a way that, in case of an obstruction of the ordinary road, the alternative route was the best choice. With highly reliable information, the largest tendency to divert is realised by indicating the length of the traffic queue. However, in case of uncommon queues, travel times work quite well in realising diversion rates. With lower reliability of traffic queue information, the tendency to divert decreases. With less reliable information, the difference in diversion rates between the different information presentations is small, where travel time or time delay information is not very vulnerable to the amount of reliability of the information. If the quality of the route choice is being considered, which is a crucial criterion in providing route guidance information, travel times offer the road user the best possibility to make optimal choices for them, also if this information is relatively unreliable (Janssen, Van der Horst & Hoekstra, 1992). Descriptive information offers the possibility of fine-tuning, that cannot be realised with prescriptive messages. An additional message "accident!" leads to a diversion of almost 100%. In this study, it could not be proved that there is a relation between stated preference responses to the route choice questionnaire and the tendency to divert as found in the driving simulator experiment.

In simulation runs in the ASTRID project, the largest tendency to divert was found by indicating the length of the traffic queue (Van der Vlist, Westerman & Droppert-Zilver, 1996). In these runs, travel time information scored second best. However, quality of the route choice was not under consideration.

Bonsall (1994a) found slightly different effects of type of information. His driving simulator study showed that the provision of time of delay more often leads to a larger adaptation in behaviour than does the provision of length of the queue. This was also found in a route-choice simulator study (Bonsall, 1994b). It was found that the more informative the message, the more impact it will have. This was also confirmed by Madanat, Yang and Yen (1995). The provision of queue information with an indication of cause led to a larger adaptation of behaviour, so impact is increased by giving the reason for a delay or diversion. This might also be related to a reduction in uncertainty. Road users indicate to be prepared to deviate from their standard route or even make extra time or kilometres if this results in more security about the total travel time (Abdel-Aty, Kitamura & Jovanis, 1995). When the variation in travel time is used as a measure for insecurity (experienced by the individual road user who may or may not experience a traffic queue), this variation becomes less important by providing information (Van Berkum & Van der Mede, 1993).

In an empirical German study (Balz, 1995), a compliance rate of 5 to 15% was found when a rerouting recommendation was supported by the text "Staugefahr" (danger of congestion). However, when the supporting text was changed to "Stau" (congestion), the compliance rate increased by approximately 5%.

There has been a relatively large amount of stated preference evaluations of VMS. In a first phase, Lamboley and Baudez (1994) asked a selected panel of road users what type of message they would prefer to see. Road users indicated to prefer travel times. After having displayed estimated travel times on a number of VMSs on the Boulevard Peripherique to the south of Paris, they also questioned road users on the exit from the boulevard. The results of these surveys showed that the travel times displayed were considered to be a useful item of information which would enable them to adjust their behaviour if required.

In a stated preference study, Madanat, Yang and Yen (1995) presented subjects with hypothetical scenarios, and asked them to indicate whether they would divert to an alternative route. When qualitative information is provided, the diversion rate is lowest, with increasing route diversion rates as the information becomes quantitative and as more detail is provided, especially relating to the alternative routes. These results are not in correspondence with the results of stated preferences in Benson's study (1996), where the number of drivers that preferred a quantitative or a qualitative description of travel time was equal. Among those wanting quantitative information, respondents were equally divided among those wanting an estimate of the delay time and those wanting the total travel time. There was also an even split between those wanting a range estimate (e.g. 10–15 min.) and those wanting a point estimate (e.g. 12 min.).

Huchingson and Dudek (1979) conducted a stated preference study, in which subjects had to imagine to drive on a freeway, where they were confronted with a congestion advisory. The driver's task was to indicate which additional message was most likely to persuade them to divert. The messages "Avoid a 15-min delay by taking the bypass", "Save 15 min by taking by-pass", and comparative travel time messages were viewed as essentially indicating the same thing and evoked no strong preferences.

In a study by Witteveen and Bos (1993), approximately 45% of the respondents indicated they would change their route in case of a 5–6 km long traffic queue and 30% with a time delay of 5–10 minutes. The first thing road users require is the location of a traffic queue, then its length, followed by time of delay and alternative route. From research in Rotterdam, it is known that the location of the queue must be provided rather precisely before road users start to divert. Generally an indication of the location with road numbers is sufficient, because it is easy to track them down if one is not really familiar with the network. If one is familiar, there is a slight preference for indications by means of names of intersections and junctions. Most road users only want to be informed about alternative routes if these are routes on motorways (CO-efficient, 1995).

3 PLACEMENT OF VMS

3.1 Placement of route guidance applications with respect to decision points

Positioning of Dynamic Route Information Panels (DRIPs) in relation to conventional guide signs has to take the phases into account, that can be distinguished in the route selection process. This process consists of two phases (Janssen, Theeuwes & Van der Horst, 1994; Janssen, Kaptein & Van der Horst, 1995). The first phase is the preparation phase in terms of "Which route will I take and what is to be expected?". The second phase is the route guidance phase, that ensures that—by means of road signs—the chosen route can be followed (Janssen, Theeuwes & Van der Horst, 1994).

DRIPs serve the purpose of route preparation, where road users make their route choice on the basis of the provided information on the DRIP. Since in the second phase, guide signs indicate how one should behave on a location of route choice, DRIPs should be placed at sufficient distance before the road signs (Janssen, Theeuwes & Van der Horst, 1994; Janssen, Kaptein & Van der Horst, 1995). Combining the two types of sign on one location would mix route preparation and route guidance. DRIPs, providing relatively low-urgent information, should not compete with urgent variable manoeuvre or tactical information, like section control. They should not distract the attention from critical manoeuvres like merging. A DRIP should not be placed in such a way that there is an exit between the DRIP and the exit the DRIP is referring to, since this may lead to confusion about the exit that the sign refers to (Janssen, Kaptein & Van der Horst, 1995).

According to the German guidelines for VMS applications (RWVA, 1997; RWVZ, 1997), the additive VMS should be located 200 m downstream of the first static sign (i.e. 1800 m upstream of the decision point), 200 m upstream of the second static sign (i.e. 1200 m upstream of the decision point), and 200 m downstream of the third static sign (i.e. 300 m upstream of the decision point). The static guidance symbol should be installed at each interchange and access point along the alternative route. These recommendations were established by a group of experts based on theoretical and practical knowledge and experiences.

In the French guidelines for VMSs (SETRA, 1994), it is stated that a VMS should be placed about 500-1000 m before the first guide sign, which is about 2500-3000 m before the diversion point.

No extended research studies were done to investigate the influence of the location of the VMS on driving behaviour.

In summary, DRIPs should not be placed at road parts that require merging manoeuvres, not too close to static guide signs and not just after an exit, since this may lead to confusion whether the DRIP refers to that exit. The optimal approach would be to use a systematic way of positioning DRIPs. In that case road users know when and where to expect a DRIP. A disadvantage is that a systematic way may lead to a less fortunate place at a particular location (Janssen, Theeuwes & Van der Horst, 1994; Janssen, Kaptein & Van der Horst, 1995).

3.2 Placement of section control applications with respect to the distance between subsequent signs

The placement of VMS for section control depends on the scope of control functions of the VMS system (speed control, congestion warning, warning for bad weather conditions, lane signalisation in case of road works or accidents, etc.) and on the local situation (number of entries, alignment, traffic load, etc.). Little or no information was found with respect to the required distance between VMS signs in section control, lane signalling or variable speed limit systems.

According to the German guidelines for VMS applications (RWVA, 1997; RWVZ, 1997), section control information should normally be provided every 1500-2500 m (whereas 2500-3000 m was specified in an earlier version of these guidelines). In specific situations, information should be provided every 800-1500 m. It is recommended to install section control downstream of each motorway entry to inform the entering drivers about the current speed limit.

In France, it is recommended that section control signs are installed in such a way that the distances between the signs are somewhat smaller than the sight distance (SETRA, 1994). Sufficient time should be available for road users to adapt their driving behaviour if this is required. In tunnels, it is recommended to use somewhat smaller distances, with 200 m in tunnels in urban environments and about 400 m in other kinds of tunnels.

In the UK, 2 and 3-lane motorways have central reserve post mounted matrices every 3.2 km for section control. For motorways with 4 or more lanes, gantry signs are available every 1.2 km. These spacings vary on approaches to intersections, where spacings are usually less than the standards.

The guidelines for distances between subsequent signs also depend on the kind of VMS that is installed (TÜV, 1995). For speed control, distances of 1000-2000 m are required, whereas for warning systems, for example in case of congestion, fog, snow etc., these distances should be reduced to 800-1000 m. For lane allocation information, diversion signing or speed funnels, 500-1000 m is required. A VMS should not be sited less than 400 m from a turn-off point.

The Dutch Handbook for Motorway Traffic Management (AVV, 1996) recommends a distance of 700-800 m for section control, and specifies a minimum distance of 500 m and a maximum distance of 900 m.

Although some system descriptions were found in which the distances are specified, a motivation of these distances, preferably based on research, was not available.

4 COMBINING SEVERAL TYPES OF SIGNALS ON ONE VMS

Although some more research may be currently in progress, only a limited number of studies have been found, that evaluate combinations of several forms of information on one VMS.

A driving simulator study (Janssen, Martens & van der Drift, 1997) investigated the effect of combining variable speed limits, dynamic traffic queue information and static guide signs on motorways on the ability to process all the information. It was found that in general, combining different kinds of information led to an increase in processing time, compared to providing the signs separately. However, the time that was required to respond to all information was still sufficient for motorway drivers to process all the information before passing the sign. Adding a red rim to the variable speed limits improved performance for processing the information on all kinds of signs, specifically in case of combining two kinds of dynamic signs, since this resulted in a clear distinction between the two kinds of dynamic signs. Caution is required in case of a triple combination, since combining the three kinds of signs led to an increase in speed variability, which might be an indication of a decrease in traffic safety. With more speed variability within the traffic stream, the chance of incidents increases. No effects could be found on course variability or percentage of short headways. A small effect was found of age, where older drivers require some more time to process all information under all conditions. However, this increase in processing time due to older age did not lead to any unacceptable values.

In the European EAVES project, the issue of combining text and pictograms is addressed. Results have shown that this combination does not always provide the best solution, since there are many more text messages than there are pictograms to support them (Cummings & Fournier, 1994). If the supporting pictogram is well known, up to 19% more people will understand the message, especially non-native speakers. However, if a pictogram is not a familiar one, the number of native speakers understanding the sign is reduced by as much as 7%, whilst there is no noticeable improvement for non-native speakers. More positive results are obtained when text is used to support pictograms or speed recommendations by providing reasons for the restriction rather than duplicating the message. To have universally understood pictograms without text would overcome the language problem to some extent.

In the European TELTEN project (TELTEN, 1997), the effect of adding a pictogram to an existing text only was also addressed. In order to assess this effect, seven pairs of messages were tested within the same or equivalent traffic conditions, providing information about congestion, roadworks, accident, slippery road and salting. The signs were only installed to announce special traffic conditions, and not to warn or control traffic, so no effects were to be expected on driving behaviour. From drivers interviews it was found that for spontaneous memorisation, the pictogram slightly improved the VMS perception, while for suggested memorisation among drivers who did not recall the sign spontaneously, the pictogram seems to reduce the VMS perception. A generalisation of the use of pictograms can be an advantage, if well-known pictograms are used and if some redundancy is used, with text + pictogram being complementary.

In some European countries, like in Germany, it is common practice to combine more than one type of information at one display unit or in a sequence of display units. In Germany, one display unit consists of a gantry sign with lane-related VMSs for section control, and a VMS mounted between the two lane-related VMSs for different traffic or weather related warnings, overtaking prohibitions, etcetera. This allows to display combinations of different types of information. Combinations of static and dynamic signs, like guide signs and section control at one location, are currently not being used in Germany, but this combination is used in France, Italy and in The Netherlands. In French guidelines, it is recommended not to have too many signs on one unique panel (SETRA, 1994). Section control with obligatory crosses and arrows should not be combined with dynamic route information panels on one gantry sign.

Evaluations, dealing with different kinds of VMS information should be carried out in order to come to well-considered European standards. In these evaluations, traffic safety and understanding should be taken into account.

5 CHANGES IN SIGNALS DISPLAYED (IN PLACE AND IN TIME)

Besides effects of the mere presence of VMS information on driving and route choice behaviour, some effects are to be expected from changes in the presented information. In this respect, two changes in information can be identified. A change of information in place refers to the situation where a driver receives some information and further along his route, he receives information with a different content. A change of information in time refers to the situation where a driver approaches a sign, and while he is reading the sign, the information changes, for instance due to an information update.

Interesting questions in this respect are how drivers respond to these changes in information, how frequent the information on a VMS should be updated, and how much variation would be tolerable. On the one hand, too many fluctuations could give the impression that the system is unstable, requiring frequent adjustments in driving behaviour. This may be uncomfortable, and may introduce disturbances in the traffic flow, possibly even resulting in less compliance. On the other hand, if the amount of fluctuations is reduced, the discrepancy between the signals and the actual driving situation as perceived by the driver increases and reliability of the information decreases. Ultimately, this may affect the confidence in the system. In a case study of the VMS system of Northern Virginia, about 85% of the respondents liked the idea of being informed about the time a traffic report was first posted on a VMS (Benson, 1996). There should be a compromise between a system that changes too rapidly and a system that is unreliable since it does not change often enough.

In European section control systems, it is common to automatically filter speed limits in a sequence of display units, using a pre-defined procedure. In principle, speed limits are reduced in steps of 20 km/h (or 20 mph in the UK) (in time and in space). In case of congestion or accident a speed funnel is displayed, depending on the location of the accident and/or on the queue length.

It is important that a driver who has interpreted a VMS registers the display content when it changes in the meantime. For safety reasons, a sign's message should not be changed more frequently than once per minute (TÜV, 1995).

A driving simulator study by Hogema (1996) studied the effects of changes in indicated speed limit for a VMS-based fog signalling system. Four possible ways of filtering the provided images were:

1 filtering in longitudinal direction (for instance if 3 or less images do not display any information, while the signs upstream and downstream indicate a speed limit, 80 is displayed on these signs)
2 filtering in time (delay before the system shows a less restrictive image)
3 hysteresis (the threshold for activating the system may differ from the one that switches the system off)
4 filtering in lateral position (speeds in adjacent lanes are also adapted).

The desired effect of those filtering mechanisms is that the messages do not change too often. This way road users do not have to adapt their driving speed continuously, which will positively affect the traffic flow

In the experiment, subjects were confronted—in case of restrictions in visibility distance—with a fog signalling system, that displayed a speed limit of either 80 or 60 km/h above each driving lane, with an extra "MIST!" sign (fog) in the middle. The speed limits were adapted according to the available sight distances. Hogema found a significant effect of filtering, with filtering leading to a lower mean driving speed. This can be explained by the fact that more filtering leads to more restrictive images. Especially in the condition with 180 m sight, a system with more filtering resulted in a large reduction in driving speed. Less changes in image did not result in a decrease in compliance.

With respect to changes in time, with sight distance 105 m and a change in speed limit from 60 to 80 km/h on one sign, preceded and succeeded by 80 km/h signs, there was a significant reduction in driving speed after passing the sign (compared to a control condition with an unchanging '80'). Apparently, the initial image 60 is noticed and responded to. At 180 m sight distance, a change from 80 to blanc (no speed reduction), preceded and succeeded by blanc, led to a reduction in the mean speed after the change, while there was no change in speed in the control condition, although mean speed was lower. Altogether, a change of information in time led to a reduction in driving speed under the circumstance that the initial sign was more restrictive than the new image. This low speed continued over the entire road part till the next sign. In three other cases where the initial signal was less restrictive than the new signal, no effect on driving speed could be found.

In summary, if the initial sign was more restrictive than the second sign, subjects reduced their speed. This means that the behavioural effects of sign changes work in a safe direction. However, no other evaluative studies are performed, for instance on the effect of changes during no-fog situations, and no studies examined the effect of changes in queue information on DRIPs.

6 CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

Although a lot of research is available on technical and operational specifications of VMS, not many experimental data are available on the effect of different VMS characteristics on driving behaviour. Most information that is available is based on stated preference studies, where road users indicate what information they prefer and whether a certain message would lead them to divert. The relation between stated preference data and actual driving behaviour is still unclear.

Relatively much information is available on the message that should be provided for route guidance applications. However, the results of the various studies vary a lot. Some studies use the diversion rate as a criterion of success, whereas other studies use preference as criterion, or the quality of the route choice. This leads to different recommendations, where it is sometimes advised to indicate the length of traffic queues, whereas other studies recommend to display travel time or time delay. Besides discussions on what kind of information should be displayed, some attention should also be paid to the information on a VMS in case of absence of traffic information. Consensus on procedures for displaying information might lead to a more uniform use of VMSs, resulting in fewer misinterpretations of the provided information.

VMSs for route guidance should be provided at a sufficient distance before the actual route diversion is required, they should not interfere with more urgent information or required manoeuvres, like merging, and they should not be placed just behind an exit. Little or no information is available on required spacing between VMSs concerned with section control. Further research would be required.

Although some countries use certain combinations of VMSs, only one evaluation could be identified of the effect of combining different VMS systems on the time to process the information and on driving behaviour. Combining did not lead to problems in the required time to process all the information, but in case of a triple combination, where variable speed limits, dynamic route information and guide signs were combined, a change in driving behaviour was found. This indicated that drivers are not able to keep up the same level of performance if these three kinds of information are combined. In the European context, the combination of VMS + pictogram were evaluated by means of driver interviews. Best results are to be expected if well-known pictograms are used and if some redundancy is used, with text + pictogram being complementary. Positive results are also obtained when text is used to support pictograms or speed recommendations by providing reasons for the restriction rather than simply duplicating the message. Further research should provide insight in the effect of combining different functions of VMS information on information processing times, diversion rate and traffic safety.

A driving simulator study investigated the behavioural effect of speed limit changes in the fog warning function of a travel signalling system. More filtering led to lower driving speeds, and with signal changes in time, driving speeds were reduced, even if the second signal was less restrictive than the original one. This indicates the effects of sign changes work in a safe direction. No literature was available on sign changes in route choice VMSs or in section control functions other than fog warning.

Another point of attention is that the development of a variety of text messages on a site by site basis has led to a situation where there is little correspondence between these sets. Procedures need to be put in place to ensure that information output from different sources are consistent.

Furthermore, it would be of interest to investigate if the acceptance of speed limits increases if the speed limit is displayed together with another sign justifying the speed limit.

In summary, more studies are required in the area of placing section control VMSs in the longitudinal direction, combinations of different kinds of VMS, the effect of changes in the information provided on the signs, correspondence between different kinds of route information, the kind of message in case of absence of traffic information, and the effect of additional signs, indicating the reason for the restriction in driving speed or deviation from the normal traffic situation.

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