Variable Message Signs

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Please note: The studies included in this synopsis were selected from those identified by a systematic literature search of specific databases (see supporting document). The main criterion for inclusion of studies in this synopsis and the DSS was that each study provides a *quantitative effect estimate*, preferably on the number or severity of crashes or otherwise on road user behaviour that is known to be related to the occurrence or severity of a crash. Therefore, key studies providing qualitative information might not be included in this synopsis.

1 Summary

De Ceunynck, T., Focant, N., February 2018

1.1 COLOUR CODE: LIGHT GREEN

Little recent research was found that directly assesses the influence of Variable Message Signs (VMS) on crashes. Usually effects are measured on a behavioural level (mainly speed). Results show that VMS can significantly affect drivers' behaviour. Several studies found that VMS significantly reduce driving speed, which is a strong indicator of crash frequency and severity. Therefore, it is concluded that VMS probably have a favourable effect on road safety when used in the right conditions and using appropriate messages.

1.2 KEYWORDS

Variable Message Signs, Dynamic Message Signs, intelligent transportation systems, driving speed

1.3 ABSTRACT

Variable Message Signs (VMS) are electronic traffic signs that can be used to deliver various messages to passing drivers, such as warnings for adverse weather conditions, incidents, congestion or roadwork zones. It should be emphasised that Dynamic Speed Limits (DSL – message signs that provide different speed limits, depending on traffic and environmental conditions) are not included in this synopsis. Various studies were identified that investigated VMS. However, most studies investigated drivers' behavioural adaptations to the VMS rather than the effect on crashes.

Only one recent study looked into the effects of VMS on crashes (Norouzi, 2012). The results were mixed; a comparison of road sections with VMS and without VMS showed no significant results, but a comparison of sections with VMS active, versus inactive, showed a significantly lower crash rate when the VMS were active.

Other studies looked into the behavioural effects of VMS, either on the road or in a driving simulator experiment. Several studies found that VMS significantly reduce driving speed (Rämä & Kulmala, 2000; Sui & Young, 2014; Ulfarsson et al., 2001). Rämä & Kulmala (2000) found indications that the impact of VMS on driving speed might somewhat reduce over time. Ulfarsson et al. (2001) found indications that the deviation in driving speed could increase when VMS are in operation. Yan & Wu (2014) found that VMS location and information format have a major influence on the resulting behavioural adaptations of drivers.

In general, it can be concluded that VMS significantly affect drivers' behaviour. When used in the right conditions and using appropriate messages, VMS could contribute in a positive way to road safety.

1.4 BACKGROUND

1.4.1 What are Variable Message Signs (VMS)?

Variable Message Signs (VMS) present traffic-related information and guidance to drivers through electronic signs beside or above the roadway (Chatterjee & Mcdonald, 2004). VMS provide the

operator the possibility to communicate various information messages in real-time to passing drivers.

The messages usually consist of short written messages and/or pictograms. VMS are an advanced traffic guidance system that is usually intended to warn/inform drivers for various situations and risks, such as adverse weather conditions, incidents, congestion or roadwork zones. VMS are particularly useful in the event of incidents when traffic conditions are unpredictable to drivers.

It should be noted that Dynamic Speed Limits (DSL – message signs that provide different speed limits, depending on traffic and environmental conditions) are not included in this synopsis; DSL are the topic of another synopsis (Daniels & Focant, 2017).

1.4.2 Description of the main research methods

Very little research towards VMS has made use of crashes to assess the safety effects. Ususally, driving speed and/or other behavioural indicators are used to study the effects of VMS. These indicators were either measured on field or in a driving simulator experiment. No meta-analysis is available.

1.5 OVERVIEW OF RESULTS

1.5.1 Effects on crashes

Only one recent study was found that directly investigated the effects of VMS on crashes (Norouzi, 2012). The results were mixed; a comparison of road sections with VMS and without VMS showed no significant results, but a comparison of sections with VMS active, versus inactive, showed a significantly lower crash rate when the VMS were active. Based on this limited information, the direct effect of VMS on crashes remains uncertain.

The previous edition of The Handbook of Road Safety Measures (Elvik, Høye, Vaa, & Sørensen, 2009) included estimates for the impact of VMS on crashes. However, given the fact that these estimates are all based on only one or a very limited number of quite old studies, and given the fact that the most recent update of this chapter in the Norwegian version of The Handbook of Road Safety Measures (Høye, 2012) no longer includes these estimates, we recommend to interpret these numbers with caution. The previous edition of the Handbook (Elvik et al., 2009) reports that:

- Accident warning signs lead to a significant reduction in the number of crashes on motorways by 44% (95% confidence interval: [-59; -22]);
- Fog warning signs lead to a significant reduction in the number of crashes in fog by 84% (95% confidence interval: [-93%; -63%]);
- Queue warnings on motorways significantly reduce the number of rear-end injury crashes by 16% (95% confidence interval: [-26%; -4%], but significantly increase the number of rear-end property damage only crashes by 16% (95% confidence interval: [+1%; +34%]

1.5.2 Effects on behavioural indicators that can be related to road safety

The most commonly studied safety-relevant behavioural indicator is mean speed. Ulfarsson et al. (2001) and Sui & Young (2014) found that VMS significantly reduce mean speed. Rämä & Kulmala (2000) found a significant reduction in mean speed at two research sites, but a significant increase in mean speed at the third research site. Generally, these findings indicate that VMS likely lead to a reduction in mean speed, which has an expected favourable effect on road safety. Rämä & Kulmala (2000) find indications that the impact of VMS on driving speed might somewhat reduce over time after the installation.

One study by Ulfarsson et al. (2001) looked into the effects of VMS on deviation of speed as well. They found that there is a significantly higher deviation of speed when VMS are active vs. when they are inactive. An increase in deviation of speed might have a negative effect on road safety.

Yan & Wu (2014) investigated the effect of the location and format of the VMS messages on a number of behavioural indicators in a driving simulator study. They found that the position of the signs and the message format can have significant effects on various safety-relevant behavioural indicators.

1.5.3 Effects of VMS at non-treatment sites and during inactivity

The results of two studies (Rämä & Kulmala, 2000; Ulfarsson et al., 2001) suggest that there are no measurable effects at non-treatment sites or when VMS are not active, but Sui & Young (2014) found that drivers not only reduce their speed at the VMS location itself, but continue to reduce their speed over a substantial distance downstream of the VMS' location as well.

1.5.4 Other effects

It has been shown that VMS can be very effective in influencing route choice (Chatterjee & Mcdonald, 2004).

1.6 TRANSFERABILITY

The small sample sizes, high level of heterogeneity in the applied research methods and in the found results limit the transferability of the study results. It should be mentioned that all studies that made use of real-world measurements were conducted on rural road sections. Transferability of the results to other types of locations cannot be guaranteed.

In addition, three of the studies were each conducted at a particular interstate road in the United States. Only one study took place in Europe, so transferability of the study results to the European context remains uncertain.

2 Scientific overview

2.1 ANALYSIS OF STUDY DESIGN AND METHODS

Table 1 provides information on the sample and the design of the coded studies on the effects of VMS. Quite some studies have been identified that investigated effects of VMS. Nevertheless, the number of studies that could be used to assess the road safety impact of VMS appeared to be relatively limited. Particularly studies that assess the influence of VMS on crashes appear to be in short supply, a master thesis by Norouzi (2012) being an exception.

Many publications investigated the effects of VMS on route choice and other mobility-related parameters such as diversion rate, reduction of total delay. Since such indicators cannot be directly linked to the safety impact of VMS, such publications are beyond the scope of this synopsis.

In the absence of a sufficient amount of publications that directly investigated the effect of VMS on crashes, studies have been selected that assess the effect of VMS on behavioural indicators that can be reasonably assumed to have a relation to the risk of crashes. Through such indicators, the safety effects of VMS are assessed in an indirect way. Three relevant publications were identified that made used of real-world observations (Rämä & Kulmala, 2000; Sui & Young, 2014; Ulfarsson et al., 2001). The study by Rämä & Kulmala (2000) made use of a before-after study design with controls, while both other studies made use of an observational design. All three studies measure the effects on mean speed. In addition, Ulfarsson et al. (2001) investigate the effect on deviation of speed, Sui & Young (2014) analyse the effect on the continuation of speed reduction after the VMS sign, and Rämä and Kulmala (2000) measure the effect on the percentage of short headways.

The study by Yan & Wu (2014) applies an experimental driving simulator design. Various behavioural indicators are applied to assess the behavioural effects of VMS for different types of messages (text only, graphics only, and text and graphics combined) at different locations (400 m, 200 m and 0 m before a signalized intersection).

The design of the included studies seems fairly robust, and confounding factors such as weather conditions seem adequately accounted for.

Table 1 Information on sample and design of coded studies.

Author(s), year, country	Measure description and sample	Study design	Types of location included	Outcome indicators
Norouzi, 2012, United States	- Effects of presence of VMS on crashes - 70 geometrically homogeneous segments with a length of 900 feet each - Various messages	- Cross-sectional study design; comparison of road sections with vs. without VMS, and VMS on vs. off on the same section	- Interstate 95 highway Maryland - Two lanes per direction	- Number of crashes - Crash rate (per million vehicles)
Rämä & Kulmala, 2000, Finland	- Effects of presence of VMS on behaviour at 3 sites (six experimental sign conditions) - Warning sign for slippery road conditions	- Before-after study with controls; - Real-world measurements	- Speed limit 80 km/h	- Mean speed - Percentage of short headways
Sui & Young, 2014, United States	- Effects of various VMS messages on speed at 13 sensor locations - Wide range of messages	- Observational design with controls; - Real-world measurements	- Interstate 80, Southeastern Wyoming	- Mean speed - Continuation of speed reduction after VMS sign
Ulfarsson et al., 2001, United States	- Effects of VMS on speed at 2 locations - Messages related to adverse conditions	- Observational design with controls: - Real-world measurements	- Interstate 90, Snoqualmie Pass through Cascade mountain range - Rural location with high elevations and high levels of precipitation	- Mean speed - Deviation of speed
Yan & Wu, 2014, China	- Effects of various VMS messages at various locations on behaviour - 52 participants - Congestion warning messages	- Experimental design - Driving simulator study	- Simulated four-lane road segments with 80 km/h speed limit and signalized intersections	- Lane changing time - Lane changing position - Lane changing length - Lane changing speed - Lane changing deceleration

2.2 OVERVIEW OF STUDY RESULTS

2.2.1 Effects on crashes

A master thesis by Norouzi (2012) investigated the effects of VMS on crashes. Two comparisons between VMS and no VMS showed no significant effect on crashes and crash rate. A comparison of a number of locations between VMS that are active and VMS that are inactive shows a significant reduction in crash rate when VMS are active. Based on this limited information, the direct effect of VMS on crashes remains uncertain.

2.2.2 Effects on behavioural indicators that can be related to road safety

The most commonly studied behavioural indicator that can be related to road safety is mean speed. Ulfarsson et al. (2001) and Sui & Young (2014) found that VMS significantly reduce mean speed. Rämä & Kulmala (2000) found a significant reduction in mean speed at two research sites, but a significant increase in mean speed at the third research site. Generally, these findings indicate that

VMS likely lead to a reduction in mean speed. Since research indicates strong correlations between driving speed and crash risk as well as crash severity (Aarts & van Schagen, 2006; Elvik, Christensen, & Amundsen, 2004; Nilsson, 2004), a reduction in mean speed is expected to have favourable effects on road safety. This favourable effect might be stronger than expected, given the fact that VMS often provide information to road users in potentially risky situations, such as adverse weather conditions, traffic incidents, etc. Sui & Young (2014) find stronger reductions in observed speeds for more severe warning messages compared to less severe warning messages. Rämä & Kulmala (2000) find indications that the impact of VMS on driving speed might somewhat reduce over time after the installation.

Ulfarsson et al. (2001) investigated the effects of VMS on deviation of speed as well. They found that there is a significantly higher deviation of speed when VMS are active vs. when they are inactive. While the impact of deviation of speed on crashes is less researched than the impact of mean speed on crashes, it is usually assumed that a higher deviation of speed, which indicates a higher heterogeneity in the traffic flow, is unfavourable for road safety (Aarts & van Schagen, 2006). It should however be mentioned that empirical analyses by Salusjärvi (1990) indicate that small increases on the deviation of speed were not found to have a measurable effect on the number of crashes.

Rämä & Kulmala (2000) found some indications of a favourable effect on the percentage of short headways as well, although it must be mentioned that the majority of significant effects were found at one treatment site that in the after period not only had VMS installed but also a static (non-VMS) sign that provided a recommendation of a minimum headway. It can therefore not be concluded that VMS have a significant influence on headways.

Yan & Wu (2014) investigated the effect of the location and format of the VMS messages on a number of behavioural indicators. They found that the position of the message has a significant effect on lane changing deceleration; generally it seemed that an earlier delivery of the message leads to less strong lane changing decelerations. They also found that the information format has a significant effect on lane changing position, lane changing length and lane changing speed. Generally, it seems that graphic information formats have more favourable effects than text only formats.

2.2.3 Effects of VMS at non-treatment sites and during inactivity

Rämä & Kulmala (2000) found no significant differences in driving speed between the before condition (no VMS) and the after condition where the VMS were inactive. Similarly, Ulfarsson et al. (2001) found no significant difference in driving speed at (non-treatment) locations downstream of VMS sites between the VMS active and the VMS inactive condition. The results of both studies therefore suggest that there are no measurable effects at non-treatment sites or when the VMS are not active.

On the other hand, Sui & Young (2014) find that drivers not only reduce their speed at the VMS location itself, but continue to reduce their speed over a substantial distance downstream of the VMS' location as well.

2.2.4 Other effects

This synopsis has focused on the effects of VMS that can be reasonably assumed to have a relation to the risk of crashes. However, literature indicates that VMS have other effects on traffic as well, mostly related to route choice. A review by Chatterjee & McDonald (2004) indicates that VMS that are used for route guidance information can induce substantial diversions when the provided route advice differs from that given normally. Travel time information was found to be effective in inducing route changes as well. In general, it is concluded that deployments of VMS to inform

drivers of traffic conditions have proved successful in terms of improving network travel times and reducing environmental impacts.

Table 2 Summary of study results.

Authors and country	Dependant / outcome type	Further specification of sites, measure or condition	Impact on road safety
Norouzi, 2012, United States	Crashes	VMS vs. no VMS	/
	Crash rate	VMS active vs. no VMS (section immediately after VMS)	/
	Crash rate	VMS switched on vs. VMS switched off	↗
Rämä & Kulmala, 2000, Finland	mean speed	VMS (various sign conditions for each of 3 treatment sites) vs. no VMS (before situation)	↗↗↗↗↗↗↗↗↗↗ ↗↗↗↗↗↗↗↘↘↘↘
		VMS (not active) vs. no VMS (before situation)	/////
	Percentage of short headways	VMS (various sign conditions) vs. no VMS (before situation)	↗↗////↗↗///↗↗ ↗////
Sui & Young, 2014, United States	Mean speed	3 levels of severity conditions vs. no message	↗↗↗
	Continuation of speed reduction after VMS	/	↗
Ulfarsson et al., 2001, United States	Mean speed	VMS site – VMS on vs. VMS off	↗↗
		Non-VMS site (downstream of VMS) – VMS on vs. VMS off	/
	Deviation of speed	VMS site – VMS on vs. VMS off	↘↘
		Non-VMS site (downstream of VMS) – VMS on vs. VMS off	/
Yan & Wu, 2014, China	5 behavioural indicators (see table 1)	VMS location – earlier vs. later delivery of message	////↗
		VMS information format – better vs. inferior message format	/↗↗↗/

2.3 DESCRIPTION OF ANALYSIS

Five key studies establishing the effects of VMS have been identified, coded, analysed and summarized. Four out of these five studies made use of non-crash indicators to (indirectly) assess the effects of VMS on road safety. Given the small number of studies and the heterogeneity of applied research methods, a review-type analysis was conducted for the main effects of each of the coded studies. The results are included in Table 2. Effects on road safety are coded as: positive (favourable) (↗), negative (unfavourable) (↘) or not statistically significant (/). For reasons of brevity and clarity, a simplified representation of the results was considered advisable. For full details, the interested reader is referred to the filled in codebooks of the respective publications.

Measurements of speed are the most commonly used behavioural indicators. The majority (but not all) of the indicators suggest that VMS could have a favourable effect on road safety. Several studies found that VMS significantly reduce driving speed, which is a strong indicator of crash frequency and severity. The study that made use of crash data found one statistically significant positive effect on road safety and two non-significant effects.

Because of the fact that the majority (but not all) indicators suggest a favourable effect on road safety, and because the indicators used are mostly indirect (non-crash) indicators of road safety, it is concluded that VMS probably have a favourable effect on road safety when used in the right conditions and using appropriate messages. Therefore, a light green colour code is selected for this measure.

2.4 CONCLUSION

It is not possible to be conclusive about the road safety effects of VMS since very few studies directly measured the effect of VMS on crashes. The only study that made use of crash data remained inconclusive on the effects of VMS on crashes. Most of the selected studies made use of behavioural indicators (mostly speed), that have a more indirect link with safety.

Variable Message Signs

Results show that VMS can significantly affect drivers' behaviour in various ways. The majority of behavioural measurements indicated expected effects that could be favourable to road safety. Most importantly, several studies found that VMS significantly reduce driving speed, which is a strong indicator of crash frequency and severity. Therefore, it is concluded that VMS likely have a favourable effect on road safety when used in the right conditions and using appropriate messages.

3 Supporting document

A literature search for studies that assessed effects of section control and speed fixed cameras was carried out in three databases (ScienceDirect, TRID, Scopus) with combinations of search terms and operators. These studies were assessed and checked for their relevance. The description below provides an overview of the search terms, logical operatiors and the number of hits for the searches in the different databases.

Note that this search was executed simultaneously for Variable Message Signs, Dynamic Speed Display signs and Variable Speed Limits. This synopsis only deals with Variable Message Signs; the latter two topics are the subject of two other SafetyCube synopses.

3.1 METHODOLOGY

3.1.1 Literature search strategy

Principles

Excluded:

- Publications related to Dynamic Speed Display signs and Variable Speed Limits
- Messages in workzones or related to railroad
- Message within vehicles, on-board traffic messages
- Driver, environmental or infrastructural factors affecting understandability / comprehension of the message
- Factors affecting driver's compliance to the messages
- Publications that do not include crash analyses or analyses of drivers' behaviour that could be related to safety
- Traffic diversion and route choice behaviour
- Animal advisory messages (during seasonal animal movement)
- Parking guidance system
- Visibility/readability/legibility of the message; viewing comfort; text layout; display format; impact of bilingual messages. However, studies towards the content of the message are included
- Driver's opinion, driver's satisfaction
- Energy efficiency, composition/materials
- Environmental effect/impact
- Implementation guidelines

Research terms and hits

Database: ScienceDirect **Date:** 3rd February 2017

Limitations/ Exclusions:

- Search field: TITLE-ABS-KEY
- Published: 1990 to current
- Document Type: ALL

search no.	search terms / operators / combined queries	hits
#1	TITLE-ABSTR-KEY("variable message sign*") and TITLE-ABSTR-KEY(effectiveness or "road safety" or "efficiency" or "impact" or "effect")	45
#6	TITLE-ABSTR-KEY("dynamic message sign*") and TITLE-ABSTR-KEY(effectiveness or "road safety" or "efficiency" or "impact" or "effect").	3
#2	TITLE-ABSTR-KEY("dynamic speed*" or "variable speed limit*") and TITLE-ABSTR-KEY((effectiveness or "road safety" or "efficiency" or "impact" or "effect"))	69
#3	TITLE-ABSTR-KEY(weather and "variable speed*") and TITLE-ABSTR-KEY(((effectiveness or "road safety" or "efficiency" or "impact" or "effect"))).	9
#4	TITLE-ABSTR-KEY(weather and "dynamic speed*") and TITLE-ABSTR-KEY(effectiveness or "road safety" or "efficiency" or "impact" or "effect").	2
#5	TITLE-ABSTR-KEY(weather and "message sign*") and TITLE-ABSTR-KEY(effectiveness or "road safety" or "efficiency" or "impact" or "effect")	4

Database: Scopus **Date:** 6th February 2017

Limitations/ Exclusions:

- Search field: Abstract, title, keywords
- Published: 1990 to current
- Document Type: ALL
- Subject Area: ALL

search no.	search terms / operators / combined queries	hits
#1	(TITLE ((("variable message sign*") OR ("dynamic message sign"))) AND TITLE ((effectiveness OR "road safety" OR efficiency OR impact OR effect OR evaluation))) AND PUBYEAR > 1989	50
#2	(TITLE (("dynamic speed*" OR "variable speed limit*")) AND TITLE ((effectiveness OR "road safety" OR efficiency OR impact OR effect OR evaluation))) AND PUBYEAR > 1989	59
#3	(TITLE (((weather AND "dynamic speed*") OR (weather AND "variable speed*") OR (weather AND "message sign*"))) AND TITLE ((effectiveness OR "road safety" OR efficiency OR impact OR effect OR evaluation))) AND PUBYEAR > 1989	3

Database: TRID **Date:** 6th February 2017

Limitations/ Exclusions:

- Published: 1990 to 2017
- Document source: ALL, Document Type: ALL, Subject area: ALL
- Language: English and French

search no.	search terms / operators / combined queries	hits
Not selected	[Keywords] "variable message sign*"	3127
Not selected	[Title] "variable message sign*"	312
#1	[Title] (("variable message sign*") OR ("dynamic message sign")) AND (effectiveness OR "road safety" OR efficiency OR impact OR effect OR evaluation)	58
#2	[Title] ("dynamic speed*" OR "variable speed limit*") AND (effectiveness OR "road safety" OR efficiency OR impact OR effect OR evaluation)	53

#3	[Title] ((weather AND "dynamic speed*") OR (weather AND "variable speed*") OR (weather and "message sign*")) AND (effectiveness OR "road safety" OR efficiency OR impact OR effect OR evaluation)	6

Results Literature Search after removal of duplicates – screening of title and abstract

Total number of studies to screen title (in order to evaluate the relevance to the topic)	60
Number of articles remaining after screening of the title and abstract	5

Table 2 – Justification in-/exclusion of identified references (reasons for exclusion highlighted in red; included papers highlighted in green shading).

Authors	Title	Year	Country	Full text?	Scientific journal?	Impact of …	On…	Relevant?	Codable ?	Crashes or relevant indicators?	Include ?
Misokefalou E, Papadimitriou F, Kopelias P, Eliou N,	Evaluating Driver Distraction Factors in Urban Motorways. A Naturalistic Study Conducted in Attica Tollway, Greece	2016	Greece	Y	No - Transportation Research Procedia	VMS (no precision) + factors related to the driver (age, gender, driving experience)	Driver's distraction	Yes	No	Maybe	No
Mostafa, Said, Osman, Gadallah	Effectiveness of variable message signs in improving the road network through route guidance	2016	Egypt	Y	No - 2016 Annual Conference of the Canadian Society for Civil Engineering	choice of two alternative routes (one of these routes was congested and to use an alternative route)	Diversion rate/route choice	Yes	Yes	No	No
Fallah Zavareh M., Mamdoohi A.R., Nordfjærn T.	The effects of indicating rear-end collision risk via variable message signs on traffic behaviour	2016	Iran	Y	Yes - Transportation Research Part F	messages containing risk level information	Behaviour (speed, time to collision and safety margin)	No – type of messages are off-topic	Yes		No
Li M., Lin X., He F., Jiang H.	Optimal locations and travel time display for variable message signs	2016	US	Y	Yes - Transportation Research Part C			No - develops a network equilibrium model		No	No
Gan H., Ye X.	Whether to enter expressway or not? the impact of new variable message sign information	2015	China	Y	Yes – Journal of advanced transportation	Travel time of both an expressway route and an alternate arterial road route. + influencing factors	Diversion/route choice	Yes	Yes	No	No
Sharples, Shalloe, Burnett, Crundall,	Journey decision making: the influence on drivers of dynamic infrmation presented on variable message signs	2015	UK	Y	Yes - Cognition, Technology and Work	Severe weather, Safety and information messages, Incident warning messages	Behaviour (speed, route choice)	Little – emphasis on differences between different measures	Yes	Little	No
Kim S., Choi J., Jeong S., Tay R.	Effects of variable message sign on driver detours and identification of influencing factors	2014	South Korea	Y	Yes - IET Intelligent Transport Systems	VMS incident-related traffic information + influencing factors (additional travel time, traffic, distance to a detour road)	Diversion/route choice	Yes	Yes	No	No
Ouyang X.-J., Zhang X., Wang H.	Effect evaluation and modeling of variable message signs on route choice behavior	2014	China	Y	Yes - Applied Mechanics and Materials	red/yellow guidance information + influencing factors (driver's personal property, travel attribute and attribute)	Diversion/route choice	Yes	No	No	No
Sui Y., Young R.	Impact of dynamic message signs on speeds observed on a rural interstate	2014	USA	Y	Yes - Journal of Transportation Engineering	real-time travel information (congestion, crashes, adverse weather)	Speed	Yes	Yes	Yes	Yes
Yan X., Wu J.	Effectiveness of variable message signs on driving behavior based on a driving simulation experiment	2014	China	Y	Yes - Discrete Dynamics in Nature and Society	VMS (no precision) + influencing factors (Driver characteristics, VMS location, and information format)	Behaviour in driving simulator (route choice, speed, lane changing)	Yes	Yes	Yes	Yes

Authors	Title	Year	Country	Full text?	Scientific journal?	Impact of …	On…	Relevant?	Codable ?	Crashes or relevant indicators?	Include ?
Zhou Y.-F., Jia S.-P., Guan W., Liu S.	Evaluation on traffic congestion mitigation in beijing with variable message signs	2014	China	Y	Yes – Journal of Transportation Systems Engineering and Information Technology	guidance message vs notice message	mitigation of congestion	No	Not sure	No	No
Edara P., Sun C., Keller C., Hou Y.	Evaluation of dynamic message signs on rural freeways: Case study of a full freeway closure	2014	USA	Y	Yes - Journal of Transportation Engineering	Route closure VMS	benefits of DMSs in diverting traffic during full freeway closures. (travel time savings + monetary benefits)	No	No	No	No
Ratrout N.T., Issa Y.F.	Effectiveness of newly introduced variable message signs in Al-Khobar, Saudi Arabia	2014	Saudi Arabia	Y	Yes - Intelligent Transportation Systems	messages related to traffic conditions (proposition of alternative route) + influencing factor (reason of the proposition, driver's age)	Diversion/route choice (declared)	Yes	Yes	No	No
Norouzi A., Haghani A., Hamedi M., Ghoseiri K.	Impact of Dynamic Message Signs on occurrence of road accidents	2013	USA	Y	No - master thesis	DMS (no precision)	Crashes	Yes	Yes	Yes	Yes
Guattari C., Rosaria De Blasiis M., Calvi A.	The Effectiveness of Variable Message Signs Information: A Driving Simulation Study	2012	Italy	Y	No - Procedia - Social and Behavioral Sciences	Message's format/complexity, Understanding of the DMS	speed and lateral position	No – too much about message content alone	Yes	Yes	No
Kusakabe T, Sharyo T, Asakura Y	Effects of Traffic Incident Information on Drivers' Route Choice Behaviour in Urban Expressway Network	2012	Japan	Y	No - Procedia - Social and Behavioral Sciences	Traffic Incident Information	Diversion/route choice + estimatation of travel time	No	Not sure	No	No
Murashige Y.,	Countermeasure Strategies against Traffic Congestion on Motorways in Japan	2011	Japan	Y	No - Procedia - Social and Behavioral Sciences			No	No		No
Høye et al.	Evaluation of variable message signs in Trondheim	2011	Norway	Y	No - English summary of TØI report in Norwegian	VMS on travel times, road safety and the environment	Travel time, crashes, route choice	Yes	No		No
Chen X., Kong T., Xie D.	Evaluation of variable message signs on urban expressway	2010	China	Y	No - 2010 International Conference on Logistics Engineering and Intelligent Transportation Systems			Yes	No		No
Tay R., De Barros A.	Effectiveness of road safety messages on variable message signs	2010	Canada	Y	Yes - Journal of Transportation	Anti-speeding messages	Driver attitudes and traffic speed	No – sensitization	Yes		No

Authors	Title	Year	Country	Full text?	Scientific journal?	Impact of …	On…	Relevant?	Codable ?	Crashes or relevant indicators?	Include ?
					Systems Engineering and Information Technology						
Shang H., Huang H., Gao Z.	Impacts of variable message signs on traffic congestion	2009	?	Y	Yes - Science in China Series E Technological Sciences			No - Theoretical model	No	No	No
Wang, JH.; Keceli, M. Maier-Speredelozzi, V.	Effect of Dynamic Message Sign Messages on Traffic Slowdowns	2009	USA	Y	No - 88th Annual Meeting of the Transportation Research Board	various DMS messages	speed variations on traffic approaching and passing the signs (slow-downs)	Yes	No	Yes	No
Roshandeh A.M., Puan O.C.	Assessment of impact of variable message signs on traffic surveillance in Kuala Lumpur	2009	Malaisia	Y	No - 2010 International Conference on Logistics Engineering and Intelligent Transportation Systems	display messages of varying lengths and formatting	Congestion / Driver response	Yes	No, few detailed results	Little	No
Lee C., Abdel-Aty M.	Testing effects of warning messages and variable speed limits on driver behavior using driving simulator	2008	?	Y	Yes - Transportation Research Record: Journal of the Transportation Research Board	variable message signs (VMSs) that warn of an impending speed change	Speed (variation) in driving simulator	No, type of messages are off-topic	Yes	Yes	No
Chen et al.	Effects of Variable Message Signs (VMS) for Improving Congestions	2008	China	Y	No - 2008 International Workshop on Modelling, Simulation and Optimization			Yes	No		No
Erke A., Sagberg F., Hagman R. + Erke	Effects of route guidance variable message signs (VMS) on driver behaviour + EFFECTS OF VARIABLE MESSAGE SIGNS (VMS) ON DRIVER ATTENTION AND BEHAVIOUR	2007 + 2006	Norway	Y	No - TOI report (Association for European Transport and contributors 2006)	route guidance Variable Message Signs (closed route, alternative route)	Route choice, speed and braking behaviour	Yes	No	Yes	No
Shuyan H., Wei G.	Evaluation of the effects of variable message signs at urban traffic network	2006	China	Y	No - ICIT 2006. IEEE International Conference on Industrial Technology			Yes	No	No - time-dependent traffic assignment model	No

Authors	Title	Year	Country	Full text?	Scientific journal?	Impact of …	On…	Relevant?	Codable ?	Crashes or relevant indicators?	Include ?
Chatterjee K., McDonald M.	Effectiveness of using variable message signs to disseminate dynamic traffic information: Evidence from field trails in european cities	2004	Europe	Y	Yes - Transport Reviews			Yes	No	No	No
Levinson, David; Huo, Hong.	EFFECTIVENESS OF VARIABLE MESSAGE SIGNS.	2003	USA	Y	No - Transportation Research Board Conference, January 12 – 16 2003 Washington DC	effectiveness of VMS on route guidance	Diversion rate, travel time saving, reduction of total delay	No	Not sure	No	No
Srinivasan K.K., Krishnamurthy A.	Roles of Spatial and Temporal Factors in Variable Message Sign Effectiveness under Nonrecurrent Congestion	2003	?	Y	No - TRB 2003 Annual Meeting	VMS (vs In-Vehicle Devices)	network performance	No - spatial and temporal network dynamics induced by VMS	No	No	No
Chatterjee K, N.B Hounsell, P.E Firmin, P.W Bonsall,	Driver response to variable message sign information in London	2002	UK	Y	Yes - Transportation Research Part C	Different messages + Influencing factor (driver, journey and message characteristics)	Route choice	Yes	Yes	No	No
Lam W.H.K., Chan K.S.	A model for assessing the effects of dynamic travel time information via variable message signs	2001	Hong Kong	Y	Yes - Transportation			No - traffic assignment model	Not sure	No	No
Ulfarsson et al.	TRAVELAID	2001	USA	Y	No - Research Office, Washington State Department of Transportation, research report	weather and roadway information	Speed, crashes (number and severities)	Yes	Yes	Yes	Yes
Luoma J., Rämä P., Penttinen M., Anttila V.	Effects of variable message signs for slippery road conditions on reported driver behaviour	2000	Finland	Y	Yes - Transportation Research Part F Traffic Psychology and Behaviour	VMS for slippery road	Behaviour	Yes	No	No - interviews	No
Rämä, P., & Kulmala, R.	Effects of variable message signs for slippery road conditions on driving speed and headways	2000	Finland	Y	Yes - Transportation Research Part F Traffic Psychology and Behaviour	VMS for slippery road	Mean speed, time headway	Yes	Yes	Yes	Yes
Kraan M., Van Der Zijpp N., Tutert B., Vonk T., Van Megen D.	Evaluating networkwide effects of variable message signs in the Netherlands	1999	Netherlands	Y	Yes - Transportation Research Record: Journal of the Transportation Research Board	seven new route information VMS's	Route choice, Congestion, traffic performance, travel time/delay, user acceptance	No – evaluation of extra VMS to already existing VMS	Yes	No	No
Hounsell N.B., Chatterjee K., Bonsall P.W., Firmin P.E.	Variable Message Signs in London: Evaluation in CLEOPATRA	1998	UK	Y	No - Road Transport Information and Control, 21-23 April 1998, Conference	Evaluation of aspects of VMS installations in inner London		Yes	No	No	No

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Emmerink RHM, Nijkamp P, Rietveld P, Van Ommeren JvN	Variable message signs and radio traffic information: An integrated empirical analysis of drivers' route choice behaviour	1996	Netherlands	Y	Yes - Transportation Research Part C	traffic information and variable message sign information + influencing factors	route choice	Yes	Yes	No	No
Yim, Y.; Ygnace, JL.	VARIABLE MESSAGE SIGNS AND LINK FLOW EVALUATION: A CASE STUDY OF THE PARIS REGION.	1995	France	Y	No - California PATH Working Paper	SIRIUS System	Traffic management, Route choice, traffic flow,	Maybe	No	No	No
Basbas, S.; Mintsis, G.; Taxiltaris, C.; Betos, A.; Kyriazopoulos, D.; Nikolaidis, M.;	Evaluation of the Variable Message Signs (VMS) System in the Central Area of Thessaloniki from the User Point of View.	2014	Greece	N							
Bullough, JD; Brons, JA; Skinner, NP.	Preliminary Evaluation of Dynamic Speed Displays with Conditional Messaging.	2014	?	N							
Ahmed, K.; Al-Zoubi, K.; Zaneldin, E.;	Evaluation of Effectiveness of Portable Variable Message Signs in Reducing Speed on Rural Highway in Abu Dhabi Emirate, UAE.	2013	United Arab Emirates	N							
Shao C.-F., Dong C.-J., Zheng C.-Q., Qiao L.	Evaluation model of variable message signs information service	2010	China	N							
Xi C., Xiaojing W., Jisheng Z.	Research on the impact of new variable message sign on route choice in Beijing	2010	China	N							
Hatsuki M.	Sustained effects of increasing queue discharge flow rate by using the variable message signboard	2010	Japan	N							
Collura, J.; Fisher, D.	Evaluation of Dynamic Message Sign Deployments and their Effects on Older Drivers.	2009	USA	N							
Keceli M., Wang J.-H.	A study on the cause and effect of slow-downs due to dynamic message signs	2008	USA	N							
Xing et al.	Mitigation of expressway traffic congestion with simple variable message sign	2007	Japan	N							
Swinea, J D; Verbrugge, D.	The signs are all there [evaluation of different types of variable message signs].	2002	?	N							

Authors	Title	Year	Country	Full text?	Scientific journal?	Impact of … On…	Relevant? Codable ?	Crashes or relevant indicators? Include ?
Lee, C; Ran, B; Barrett, B; Johnson, E.	EVALUATION OF THE DRIVER DECISION-MAKING PROCESS BASED ON A VARIABLE MESSAGE SIGNS (VMS) SURVEY.	2002	?	N				
Ulfarsson, GF; Shankar, VN; Vu, P	THE EFFECT OF VARIABLE MESSAGE SIGNS ON THE RELATIONSHIP BETWEEN MEAN SPEEDS AND SPEED DEVIATIONS.	2002	Usa	N				
	PROGRAMME FOR ROAD INFORMATICS: EVALUATION OF VARIABLE MESSAGE SIGNS	1997	Sweden	N				
Cohen, S; Haj-Salem, H.	Comparative evaluation of queue length and travel time displays on variable message signs: the experience of the city of Paris.	1996	France	N				
Frybourg, Michel; Orselli, Jean.	EVALUATION MONETAIRE DE L'INFORMATION SUR LES PMV DE SIRIUS EST [AN ECONOMIC EVALUATION OF VARIABLE MESSAGE SIGN INFORMATION WITHIN THE SIRIUS EST PROJECT].	1996	France	N				
Yim Y. Ygnace JL.	Flow evaluation using loop detector data: traveler response to variable-message signs	1996	France	N				
Cohen, S.	TRAVEL TIME DISPLAYS ON VARIABLE MESSAGE SIGNS: WHAT EFFECT ON ROAD TRAFFIC AND SAFETY? THE EXPERIENCE OF THE CITY OF PARIS. ROADSAFE '96. INFLUENCES AFFECTING ROAD USER BEHAVIOUR.	1996	France	N				
Yim, Y; Ygnace, J -.	SIRIUS evaluation project: variable message signs and traffic behaviour.	1994	France	N				
Upchurch, J E.	EVALUATION OF VARIABLE MESSAGE SIGNS.	1991	?	N				
	Evaluation of Dynamic Speed Signs.	?	?	N				
	Evaluation of Weather Based Variable Speed Limit Systems.	?	USA	N				

3.2 FULL LIST OF CODED STUDIES

Norouzi, A. (2012). Impact of dynamic message signs on occurrence of road accidents (Master thesis). University of Maryland, College Park, Maryland, United States.

Rämä, P., & Kulmala, R. (2000). Effects of variable message signs for slippery road conditions on driving speed and headways. Transportation Research Part F: Traffic Psychology and Behaviour, 3(2), 85–94. https://doi.org/10.1016/S1369-8478(00)00018-8

Sui, Y., & Young, R. (2014). Impact of Dynamic Message Signs on Speeds Observed on a Rural Interstate. Journal of Transportation Engineering, 140(6). https://doi.org/10.1061/(ASCE)TE.1943-5436.0000664

Ulfarsson, G. F., Shankar, V., Vu, P., Mannering, F. L., Boyle, L. N., & Morse, M. M. (2001). TravelAid (No. WA-RD 511.1). Olympia, Washington, United States: Washington State Transportation Center.

Yan, X., & Wu, J. (2014). Effectiveness of Variable Message Signs on Driving Behavior Based on a Driving Simulation Experiment. Discrete Dynamics in Nature and Society, 2014. https://doi.org/10.1155/2014/206805

3.3 EXTRA REFERENCES IN SYNOPSIS

Aarts, L., & van Schagen, I. (2006). Driving speed and the risk of road crashes: A review. Accident Analysis & Prevention, 38(2), 215–224. https://doi.org/10.1016/j.aap.2005.07.004

Chatterjee, K., & Mcdonald, M. (2004). Effectiveness of using variable message signs to disseminate dynamic traffic information: Evidence from field trails in European cities. Transport Reviews, 24(5), 559–585. https://doi.org/10.1080/0144164042000196080

Daniels, S., & Focant, N. (2017). Dynamic Speed Limits. Road Safety Desision Support System, developed by the H2020 project SafetyCube.

Elvik, R., Christensen, P., & Amundsen, A. (2004). Speed and road accidents. An evaluation of the Power Model (No. TØI report 740/2004). Oslo, Norway: Institute of Transport Economics.

Elvik, R., Høye, A., Vaa, T., & Sørensen, M. (2009). *Handbook of Road Safety Measures* (2nd Edition). Bingley, UK: Emerald Group Publishing Limited.

Høye, A. (2012). Trafikksikkerhetshåndboken, kapittel 3.20 Variable Trafikkskilt [in Norwegian]. In *Trafikksikkerhetshåndboken* (Vol. Handbook of Road Safety Measures-Norwegian (online) version). Oslo, Norway.

Nilsson, G. (2004). Traffic Safety Dimensions and the Power Model to Describe the Effect of Speed on Safety. Lund: Lund University.

Salusjärvi, M. (1990). *Speed and safety: research results from the Nordic countries*. Linköping, Sweden: VTI.