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RESEARCH ARTICLE

Effects of Weather Related Safety Messages on the Motorway Traffic Parameters

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Abstract
Intelligent transport systems have a huge importance during adverse weather conditions. These systems call the drivers' attention to possible dangers by the use of variable message signs installed along the motorways. Several researchers have dealt with the connection of weather and traffic safety in the last decades, but they have not investigated the effects of weather related messages. This paper examines the impact of weather-related warning messages on traffic in adverse weather circumstances on the Hungarian motorways. Three independent databases were analyzed in order to compare the speed-reducing effect of specific signs during different weather events and precipitate intensities.

Keywords
variable message signs, traffic safety messages, weather, motorway, traffic flow

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1 Introduction

Studies that deal with the effects of weather activities on traffic flow became more intensive from the '70s. The wide spread of intelligent transportation systems and services (ITS-S), road weather information systems (RWIS) and the use of variable message signs have given new impulse to the research conducted in the 90's. While the primary goals of ITS-S solutions are the increase of traffic safety and traffic efficiency, until then the RWIS systems provide information about the actual weather and road conditions for the road operators and the drivers.

One unique ITS system is the vehicle activated signs – VAS – installed on spots with increased event potential (dangerous curves, near schools, etc.). The systems consist of vehicle detectors and displays that detect the approaching vehicles and measure and display their speeds. VAS solutions warn the drivers and force them to reduce their speed and change their driving behaviour. VAS systems can be used independently or connected to other traffic management and monitoring systems.

The development of info communication technology (ICT), the spread of ITS devices, the possibility of more effective (faster, more accurate) information provision and the investigation of behaviour of drivers have engrossed the attention of several researchers. They have started to study the effects of VMS messages on drivers' behaviour: how do the drivers behave in decision-making situations when they get new information; how do they react to the traffic safety messages in the case of adverse or favourable weather; do they obey the recommendations and suggestions?

In the first period of research (in the '70s and '80s) experts could make post-examination of the effects of weather events based on field measurements, statistics and interviews.

In this time real-time information and data collection systems were not available. Thus there was no possibility to reduce the negative effects of weather events by the help of dynamic information provision and it was also not possible to measure the effects of information on the drivers.

From the '90s variable messages signs started to spread both in America and in Europe as well as. They can display messages and they can be programmed in real-time. VMS is an information interface – related to the ITS – that provides one-directional contact (intervention possibility) between the traffic management centre and the vehicle drivers.

Variable massage signs are primarily used to display messages related to traffic management (diversion, accidents, restrictions, etc.). Such events affect a relatively small proportion of the operation. In order to avoid low utilization of the panels, in those countries where the local regulations allow it, they can be used for the display of road safety messages in accordance with the fundamental goals of ITS solutions.

In the last 10 years several researchers have dealt with the effects of the VMS messages on traffic flow, but their research is limited to speed limit restriction, route guidance and diversion messages. In recent years, some experts have dealt with effects of safety messages; nonetheless most of the studies were concerned with the effectiveness of (television) campaigns. Just a few professionals have investigated the effects of real-time safety messages displayed on VMS – according to the actual traffic and weather situations -, in spite of the fact that they carry significant potential.

2 Literature review

Research about warning and informing messages - that explore the connections between signs and traffic parameters - are relevant from the viewpoint of the current article. Research started in the '70s and '80s. Researchers in the early times investigated the relation between the weather and accidents (Codling, 1974; Satterthwaite, 1976). Examination of the connection of the pavement status and accident risk were also assessed (Polvinen, 1985; Brodsky and Hakkert, 1988).

Investigations from the last 10-15 years characterize the current traffic behaviour well, thus only the results of research conducted after 2000 have been mentioned in this study. Steinhoff et al. researched the spread of VMS panels (Steinhoff et al., 2000). They determined that drivers obeyed the variable speed limits more when they also received information about the reason (speed limit signs were completed with an auxiliary sign – either by text or pictogram). When the speed limit was displayed only with the speed limit signs, the control was not so efficient (fewer drivers reduced their speed), than the combined solution. Furthermore, the research revealed that vehicle drivers could recognize information easier when it was displayed by pictograms, thus road operators should avoid the use of text messages.

Rämä conducted research in Finland (Rämä, 2001). He investigated the traffic reactions (speed and minimal headways) to vehicle activated weather warning signs during adverse weather situations. The results showed that the slippery road sign mitigated the speed by 1-2 km/h. When the road operator used the information sign with speed control, the speed was reduced by 3.4-5.3 km/h and the standard deviation was also smaller. These results were shown when the maximum speed limit was reduced from 100 to 80 km/h and they were also dependent on the measurement location, the displayed information and the form of information provision (flashing or steady signs).

In Sweden the road operators have connected the road weather information system with VMSs. The system displays the recommended speed according to the prevailing road and weather circumstances. Effects of the system was investigated (Karlberg, 2002). Because of the recommendation the mean speed was decreased by 10%, speeds became smoother and headways increased too.

VMSs can be used for the dissemination of general and traffic management related information simultaneously. A survey combined with questioning was conducted (Craen, 2002). Vehicle drivers stated that they do not pay much attention to the general information. The researchers established that contrary to the assumptions the displayed auxiliary information messages do not have any negative effects.

Several researchers and research groups have dealt with the effects of vehicle-activated signs in England. In (Changing attitudes towards speeding, 2002) the research team investigated the effects of non-enforcement roadside speed control display signs at 10 locations. The aim of the system was to decrease the number of speeding vehicles. The research showed that on the affected area (during the on-site inspections) the average speed was reduced by 11 km/h. Research about the effects of speed control displays installed at several locations in the country was conducted (Winnett and Wheeler, 2002). Speeding vehicles activated the devices and they displayed different messages depending on the location. Accident and traffic data were compared before and after the installation and the results showed a significant speed decrease: 6-22 km/h depending on the location and the sign.

In England, (Cooper and Sawyer, 2005) studied the effects of a fog warning system that automatically detects the decrease of visibility and informs users by VMSs before the affected area – 0.8-3.8 km depending on the visibility. As a result of the messages the speed decreased by 2.9 km/h on average (the decrease was more intensive in the fast lanes and the faster vehicles mitigated their speed below the average speed).

In the Netherlands (Hogema and Goebel, 2000) and in the United States (Boyle and Mannering, 2004) conducted simulator based research. They compared how drivers react in a virtual environment for the messages of (1) VMS panels and (2) in-vehicle devices. In the Netherlands drivers got information about the queue length, in the USA they got information about the weather and accident risk. Results have shown that drivers reduce their speed due to the messages and the effect is more intensive when they get the information via VMS panels.

Researchers measured the effects of two different speeding-related messages in Canada. Results have confirmed the outcomes of the questionnaire, which said that drivers slow down more when psychological (emotional) messages are displayed instead of general messages, which call drivers' attention to punishment (Tay and Barros, 2010).

3 Methodology

In the first step, it was important to assess the characteristic of the Hungarian motorway network and the currently applied operation routines in order to measure the effects of messages displayed by variable message signs. The investigation was started with the assessment of the location of the devices installed along the motorway. The location of the VMS panels, traffic counting stations and weather stations and their distance from each other were relevant from the viewpoint of the research.

3.1 Infrastructure

Weather stations are installed averagely 10-15 km from each other along the motorways on spots with high weather event potential (for e.g. bridges, valleys where glaciation occurs more readily).

Traffic counting stations are located less frequently. Generally they are installed between the junctions (so called line traffic counting stations), thus the number of the stations are significantly influenced by the amount of motorway ramps. Counting stations have a double-looped design, thus they are able to measure the speed and they have piezoelectric sensors, which enable them to distinguish vehicle categories. Devices can alert the dispatcher in the case of queuing or slowing traffic.

Variable messages signs (VMS) are installed at locations with high traffic event potential, where the traffic or accident characteristics justify it (congestion areas, sports with high accident risk, etc.). The number of VMS panels has continuously grown in recent years with the spread of intelligent transport systems and services.

3.2 Supporting information system

Traffic management of the Hungarian motorway network is done by the Traffic Control System (TCS) of the Hungarian Public Road Non-profit Private Limited Company (MK Zrt). This system supports the three-level structure, which is general for all ITS systems:

1. Data collection and data acquisition systems,
2. Processing and decision support systems,
3. Intervention and information provision systems.

During the data collection the TCS processes the traffic and meteorological data coming from the roadside data collection devices.

Weather stations transmit the following data every 10 minutes: device ID, temperature, dew point, freezing point, relative humidity, precipitation type, intensity, pavement condition, pavement temperature, salt concentration on the pavement, water depth on the pavement, wind direction, wind speed and wind gust. Traffic counting stations transmit data in every 6 minutes about the preceding 6-minute interval. The data contains the number of vehicles that have passed and their average speed in three categories: all vehicles, cars and trucks. TCS contains information about the signs displayed on the variable message signs on the dot, thus it is able to look after the displayed signs on each cross-section.

The IT system supports the export of traffic, meteorological and the logged VMS signs data. MK Zrt. handed over the necessary data in a text format that can be converted to excel or other chart based file.

3.3 Current operational routine

In case of adverse weather conditions (aquaplaning, ice, fog, wet pavement, etc.), the motorway operators are entitled to display warning or informational messages according to the national roads technical specifications (ÚT 2-1.153, 2008; ÚT 2-1.165, 2009) and their own company regulations (M-HÜ-8, 2012; M-FS-3, 2013). The National Weather Service, weather stations and road patrols provide weather data. Weather stations – located on the motorway network – can automatically alert the dispatchers, when the measured values reach predefined limits.

In accordance with the guidelines for the operation of the VMS, the messages should be displayed according to the following priority:

1. Accident
2. Lane closure, congestion
3. Weather related information (slippery surface, fog, snowstorm)
4. Road works, rerouting, closures
5. Traffic events on other motorways
6. Other information

Moreover, the distance and the danger must be taken into consideration: in case of the same degree of danger, more dangerous and closer hazards have to be displayed; while in case of different degrees of danger the more dangerous hazard has to be displayed.

Weather related messages could be displayed when there is no accident or traffic restriction on the affected section. At this time, pictograms (Table 1) and messages (Table 2) can be displayed. Operation and maintenance centres (OMC) are responsible for the display of signs and messages. Code for the Winter Operations regulations (M-HÜ-8, 2012) and Operation of Traffic Control Devices (M-FS-3, 2013) define many regulations but the OMCs have significant scope for action in the assessment. In the case of alarm or perception of danger the dispatcher decides the possible intervention according to the actual traffic and weather situation. VMS are programmed based on the decisions.

Table 1 Weather related pictograms

		
slippery road (rain, ice, other contamination)	fog	poor road and visibility conditions
		
slippery road (snow), de-icing	limited visibility (in case of dust storm or smoke)	strong or stormy cross wing

Table 2 Weather related signs and messages

Sign	Message and content
ERŐS OLDALSZÉL! SEITENWIND! CROSSWIND!	In the case of strong wing-gust and crosswind
VIHAROS SZÉL!	"*Storm-wind!*" In the case of windstorms, when strong wind can spill the trucks
KÖD KÖDFOLTOS ÚTSZAKASZ! FOGGY SECTIONS AHEAD! ACHTUNG NEBEL! KÖD	When the nebular area is after the VMS panel.
KÖD KÖVETÉSI TÁVOLSÁG! ABSTAND HALTEN KEEP DISTANCE KÖD	When VMS is within the nebular area.
NEDVES BURKOLAT CSÖKKENTSE A SEBESSÉGÉT!	"***Wet pavement, reduce the speed!***" In the case of wet or slippery road surface.
CSÚSZÁSVESZÉLY! SCHLEUDERGEFAHR! SLIPPERY ROAD!	When circumstances can cause immediate slipping (e.g. oil spills, water flow). In such cases it can be completed with the distance or length.
CSÚSZÁSVESZÉLY! SCHLEUDERGEFAHR! SLIPPERY ROAD!	In the case of winter road conditions, when circumstances can cause immediate slipping (snow, ice).
SÓSZÓRÁS! SALZSTREUUNG! GRITTING ROAD!	In the case of winter maintenance, when the de-icing is in progress.
HÓÁTFÚVÁS! SCHNEEVERWEHUNGEN! SNOW DRIFTS!	On sections with snowstorm and snowdrifts.
FAGYVESZÉLY! GLÄTTEGEFAHR! RISK OF ICE!	In case of frost.
ÓNOS ESŐ! GLATTEIS! BLACK ICE!	During freezing rain.
KORLÁTOZOTT LÁTÁSI VISZONYOK! BAD VISIBILITY!	During limited visibility (in case of dust storm or smoke).

On the motorway M7 in two cross-sections (right carriageway 33+000 km section and left carriageway 49+700 km section), - where roads become slippery in case of rain and in the Váli valley (33+000 km section) strong wind-gusts frequently occur -, weather warning and traffic management pilot systems were installed with prismatic signs. Panels consist of two signs one above the other and each sign can display two messages plus one empty (regulatory and warning signs, with an auxiliary sign when necessary). Signs can be controlled independently. See Fig. 1, 2 and 3. According to the situation, speed limit can be put in place (100 km / h) in addition to the warning messages. The sign-change is realized mechanically with the rotation of a three-side lamella.

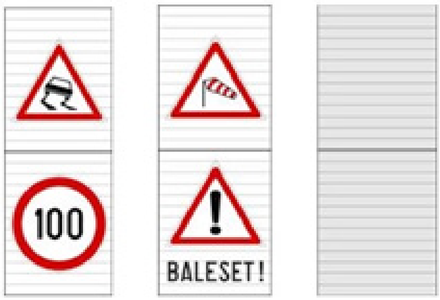

Fig. 1 Displayable signs on the prismatic VMS panel (right carriageway 33+000 km section) regulations (M-HÜ-8, 2012)

Fig. 2 Displayable signs on the prismatic VMS panel (left carriageway 49+700 km section) regulations (M-HÜ-8, 2012)

Fig. 3 Prismatic VMS panel during operation [source: MK Zrt.]

Table 3 Location of data collection devices on motorway M0

Left carriageway			cross-section with device for each carriageway	Right carriageway		
Location of VMSs	Speed limit	Remarks for the location		Remarks for the location	Speed limit	Location of VMSs
67+500	110					
66+280	110	straight track three lane	66+280 traffic counter	straight track two lane	110	
						65+690
64+230						
	110	straight track two lane	63+750 traffic counter			
			60+200 weather station			
59+908	100	in curve, near an intersection three lane	59+908 traffic counter	in curve, near an intersection two lane	110	
						59+290
58+400						
	110	straight track three lane	58+100 traffic counter	straight track three lane		
					110	**57+840**
56+240	110	slight curve three lane	56+240 traffic counter			
52+955	110	slight curve three lane	52+955 traffic counter	slight curve three lane	110	
						52+640
			51+945 weather station			
			50+653 traffic counter	straight track two lane		**50+635**
					110	**50+265**

3.4 Site selection

For the investigation, motorway sections were selected where all necessary data collection and information devices were available. Moreover, it was necessary to choose sections where there were no slip roads between the data collection and information devices and the traffic counting station was located 5-600 meters after the VMS panel. This distance is enough for the drivers to modify their driving behaviour according to the message after reading it. For the specific traffic analysis, two sections were selected where the test conditions were fulfilled and these two sections are characterized with different traffic loads:

- M31 motorway between 6-10 km section and
- M0 expressway between 50-67 km section.

Figure 4 illustrates the locations. Table 4 and Table 5 contain the locations of data collection devices for each carriageway. Grey cells indicate the investigation sites. All the indicated traffic counters were used for the analysis. Cells with thick contour indicates the investigation sections. Each section has one data collection device and one or two VMS panels. Each section was analysed independently.

Fig. 4 The location of selected motorway sections [own edition]

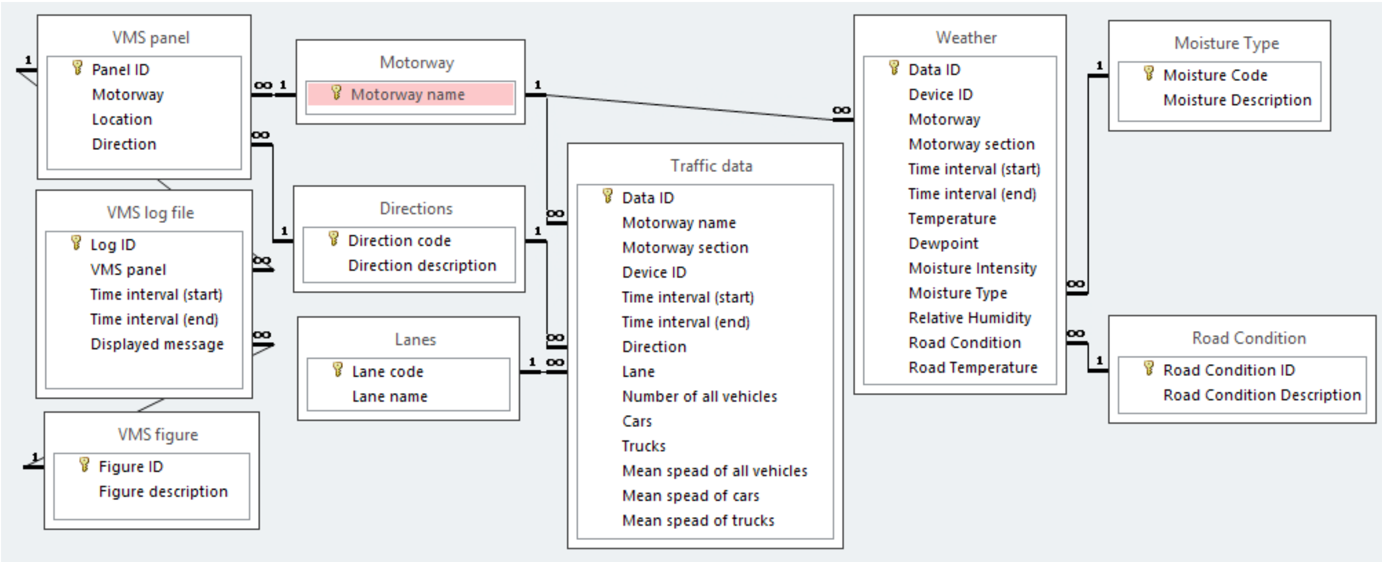

Fig. 5 Structure of the independent database contains all relevant data

Table 4 Location of data collection devices on motorway M31

Left carriageway			cross-section with device for each carriageway	Right carriageway		
Location of VMSs	Speed limit	Remarks for the location		Remarks for the location	Speed limit	Location of VMSs
9+945	110					
9+455	110	it has a gentle slope, after a right curve on a straight section before a left curve two lane	9+455 traffic counter			
			6+190 weather station			

3.5 Data analysis

The research consisted of the manual comparison of three independent databases:

1. weather data (contains the recorded data in hourly resolution),
2. traffic data provided by traffic counting stations (the structure is showed in Table 5),
3. a log file of the displayed signs (tabular format with the following data: portals, activation and deactivation times of the signs).

Common variables were the time and location. The main tasks were to combine the dependent and independent parameters to make one commonly used database where processed data and results can be found. The most complicated part was the manual comparison of the data because each independent database used different intervals. Independent data were uploaded into an independent but comprehensive database. The structure of the integrated database (originated by the proper combination of the three independent databases with joint time-base) is illustrated on Fig. 5.

Speeds of fast and slow lanes were investigated separately also for the different vehicle classes (cars and trucks). Speed differences were analysed before and after the period affected by the weather event (60 minutes interval before and after the events), thus it was possible to compare the effects and determine the results.

After the site selection, MK Zrt. handed over the weather data from the closest weather stations located to the selected sections (MK, 2013). The data was compared with the data of the National Weather Service in order to filter out the false data. All event and precipitation related data were checked manually. Rainfall amounts were compared with the officially published data, precipitation phenomena were checked on the radar images and false data were deleted from the database. Days with significant precipitation activity were selected. For these days the MK Zrt. out sorted for each panel the displayed signs and times from the TCS. In addition, the company handed over the data of the traffic counting stations located near the VMS panels in a simplified chart format from the TCS. Based on the different data, the traffic analysis was executable.

In order to measure the traffic impact, at each investigation

Table 5 Data structure of the traffic counting stations

Motor-way	Km section	Mesurement interval	Direction	Lane	All vehicle	Cars	Trucks	Mean speed	Mean speed of cars	Mean speed of trucks
...	...	...	...	...	...	...	...	...	...	...
M31	9+455 km	2012.10.27. 10:24 - 10:30	left	slow	26	11	15	85.4 Km/h	94.1 Km/h	79 Km/h
M31	9+455 km	2012.10.27. 10:24 - 10:30	left	fast	9	8	1	108.3 Km/h	108.8 Km/h	105 Km/h
M31	9+455 km	2012.10.27. 10:18 - 10:24	left	slow	28	20	8	92.5 Km/h	96 Km/h	83.8 Km/h
M31	9+455 km	2012.10.27. 10:18 - 10:24	left	fast	3	3	0	108.3 Km/h	108.3 Km/h	-
...	...	...	...	...	...	...	...	...	...	...

spot uneventful periods (weather aspects) with the same traffic parameters were selected – day, period, traffic load, traffic composition. They were the control data. Historical traffic data were used for this action. Deviations were allowed in the working days (e.g. instead of Wednesday, Thursday data were used) but other parameters were fixed. Only 10% deviation were permitted during the analysis.

Based on the data of the traffic counting stations only speed-change could be investigated. In Hungary, traffic counting devices belong to MK Zrt. can only record speed and vehicle categories (during the elaboration of this study). Thus it was not possible to analyse the traffic density, occupancy, headways (time and distance) and other parameters.

The analysis covered the assessment of 176 "events" included four messages – slippery road (82), wet pavement (83), de-icing (7), fog (1). Speed changes were analysed for different precipitate types and in the case of frost too:

- M0 (expressway): slippery road (69), wet pavement (82), fog (3) ***between 15th May 2011 and 18th March 2013***.
- M31 (motorway): slippery road (13), wet pavement (1), de-icing (7), fog (1). During the winter period ***between 26th October 2012 and 7th December 2012.***

4 Results

4.1 General observations

In case of low traffic (night, below 200 vehicles / hour) the investigation of the fast lane did not lead to meaningful results due to the low volume of traffic by the reason of "Keep to the right!" rule (maximum 1-2 vehicles in each 6 minutes intervals).

The weather event triggers a speed decrease, which depends on the intensity of the event. Speed changes are in line with the previously observed findings (Sándor, 2013). By the help of the signs, it is possible to increase the drivers' attention, moreover messages help to mitigate the negative effects of inconspicuous events (icy pavement, foggy sections, etc.) and they force the drivers to drive more carefully.

Displayed signs and messages do not have any effects on the transportation of trucks. This can be explained by the dynamic features of trucks and the 70 and 80 km/h speed limit (70 km/h on expressway and 80 km/h on motorway). In case of precipitation after the speed reduction the average speed of all vehicles were always higher that 70 and 80 km/h (depending on the locations and the type of the clearways).

4.2 Sign and message specific results

Expressway M0:

Messages related to foggy areas and wet pavement have a low effect on traffic. Speed drops by just 0,5 km/h on the slow lane and 2 km/h on the fast lane. One reason for the phenomena: the foggy areas are not just after the VMSs and traffic counting stations. However drivers decrease their speeds when they enter an area with reduced visibility.

Effects of "slippery road" and "wet pavement" signs were the same; no significant difference could be observed. Table 6 and 7 summarize the triggered traffic effects by the signs for each lane per weather event and also for two and three lane sections.

Motorway M31:

Messages related to foggy areas and wet pavement did not have any significant traffic effects. There are several reasons: the sample was too small (it was possible to analyse just 1-1 event); drivers did not decrease their speed but presumably they increased their attention.

Table 8 summarizes the speed decrease triggered by the message "slippery road" and Table 9 summarizes the effects of the message "de-icing".

Speed decrease effect consists of two part: effects of adverse weather events and the booster effects of the signs. These to effects results together the indicated speed decreases. Significant speed decreases are caused by the weather event, and are not explicitly an effect of the signs. Based on the results it can be submitted that the signs could decrease the speed and this can be by up to 5-10 km/h depending on the location and the prevailing conditions (typically up to 10 km/h.). Effects of the signs were identified when adverse weather circumstances had already terminated but the sign was still active. In these specific situations the unique effects of sign were identifiable.

Table 6 Speed decrease triggered by the message “slippery road” and “wet pavement” for three lane sections

In case of rain		In case of snowing	
Slow lane	between 1 and 22 km/h	Slow lane	between 0 and 6 km/h
Middle lane	between 1 and 23 km/h	Middle lane	between 2 and 6 km/h
Fast lane	between 0 and 27 km/h	Fast lane	between 3 and 10 km/h

Table 7 Speed decrease triggered by the message “slippery road” and “wet pavement” for two lane sections

In case of rain		In case of snowing	
Slow lane	between 1 and 16 km/h	Slow lane	between 1 and 2 km/h
Fast lane	between 1 and 18 km/h	Fast lane	between 0 and 3 km/h

Table 8 Speed decrease triggered by the message “slippery road”

In case of rain and frost		In case of snowing	
Slow lane	between 3 and 5 km/h	Slow lane	between 5 and 33 km/h
Fast lane	between 5 and 6 km/h	Fast lane	between 2 and 39 km/h

Table 9 Speed decrease triggered by the message “de-icing”

In case of rain and frost		In case of snowing	
Slow lane	~ 5 km/h	Slow lane	between 4 and 22 km/h
Fast lane	~ 8 km/h	Fast lane	between 10 and 30 km/h

More intensive speed decrease occurs only in the case of inclement weather situations (during rainfall and snow). The speed reduction was always less than 5 km/h when there was no precipitation but the temperature was below 0°C. Measured values were corresponded with the previously published results (Sándor, 2013). Analysis of the lanes showed that the effects are more intensive in the fast lane. Its reason is the permanent speed difference between the lanes, which are detectable in all conditions. On the investigated section the average speed difference was 15-30 km/h during dry conditions, which was depending on the period, daylight and traffic load.

Exact and qualitative evidence cannot be made because the weather and traffic are extremely complex. Traffic models cannot take each important influencing factor that influences the speed choice and traffic flow into consideration. Decision modelling tools try to describe the complexity but there are lot of hidden factors that are possible to model. Thus only intervals can be shown that describe the results with appropriate reliability.

There were several periods during the analysis when the speed decrease was not detectable. One possible reason is that the sign did not have any relevance. Adverse weather conditions had already ended. Such problems may occur even with the most careful attention.

5 Conclusions

In spite of the fact that the connection between weather and traffic flow has been investigated for more than fifty years, researchers have not fully dealt with the effects of weather related safety messages on traffic parameters. This study, which is based on Hungarian data, would like to replace it. The analysis has established that weather events decrease the speed in itself.

Based on the analysis it can be declared that the signs can mitigate the speed by 5-10 km/h. Although this speed drop seems to be low, it should not be ignored that vehicle drivers will increase their attention (look further, use the mirrors more often, etc.) due to the signs and messages.

It is important to emphasize that measured and indicated values in the Tables are average speed change values. The traffic volume, the tracking of the road, the visibility and the sudden change of the adhesion coefficient can influence them significantly. Values have to be used in accordance with the previous conclusion, which mostly gives guidance on the rate of change.

Research results provide important information for the analysis of the traffic processions on large-scale dynamic networks. Input of data from the article into mathematical and simulation models can produce further useful results for the more accurate description of the operation of networks, because the effect of rainfall can spread for those areas where this impact of the weather cannot be observed directly (Bede and Péter, 2011).

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References

Bede, Zs., Peter, T. (2011). The development of large traffic network model. *Periodica Polytechnica Transportation Engineering*. (39)1, pp. 3-5. https://doi.org/10.3311/pp.tr.2011-1.01

Boyle, L., Mannering, F. (2004). Impact of traveler advisory systems on driving speed: some new evidence. *Transportation Research Part C: Emerging Technologies*. 12(1), pp. 57–72. https://doi.org/1016/j.trc.2003.09.001

Brodsky, H., Hakkert, A. S. (1988). Risk of a road accident in rainy weather. *Accident Analysis & Prevention.* 20(3), pp. 161-176. https://doi.org/10.1016/0001-4575(88)90001-2

Changing attitudes towards speeding. (2002). *Highways*. 71(9), pp 25-26. Alad Ltd, Kent, United Kingdom.

Codling, P. J. (1974).Weather and Road Accidents. In: *Climatic resources and economic activity: a symposium*, (Taylor, J. A. (ed.)) pp. 205-222, Newton Abbot, UK.

Cooper, B. R., Sawyer, H. E. (2005). Assessment of M25 Automatic Fog-Warning System – Final Report. Washington D.C., *USA: Federal Highway Administration*.

de Craen, S., de Niet, M. (2002). Extra informatie op matrixborden: mogelijkheden en effecten. (Extra information on Dynamic Message Signs: possibilities and effects.) In: *Stichting wetenschappelijk onderzoek verkeersveiligheid SWOV*, R-2002-13, p. 37, Netherlands. (in Dutch)

Hogema, J. H., Goebel, M. P. (2000). In-car versus roadside queue warning information: a driving simulator study. TM-00-D004. Soesterberg, the Netherlands: *TNO Human Factors TM*.

Karlberg, N. O. (2002). Road, weather, action. *Traffic Technology International* (2002/Dec 2003/Jan). Surrey, United Kingdom.

M-FS-3 (2013) State Motorway Management Company: Regulation about the Operation of Traffic Control Devises, Budapest, 2013. (in Hungarian)

M-HÜ-8 (2012) State Motorway Management Company: Regulation about the Winter Maintenance, Budapest, 2012. (in Hungarian)

MK Zrt. (2013) Official supplying of data from the. Budapest, Hungary, 2013. (in Hungarian)

Polvinen, P. (1985). Accident risks in winter road conditions. Helsinki: Tie-ja vesirakennushallitus, Ins. tsto Pentti Polvinen Ky. (TVH 741822)

Rämä, P. (2001). Effects of weather-controlled variable message signing on driver behaviour. Dissertation for the degree of Doctor of Science, VTT: Helsinki 2001. (VTT Publications 447/2001) URL: http://www.vtt.fi/inf/pdf/publications/2001/P447.pdf

Sándor, Zs. (2013). Effects of Rainfall on the Motorway Traffic Parameters. *Acta Technica Jaurinensis*. 6(3), pp. 120-135.

Satterthwaite, S. P. (1976). An Assessment of Seasonal and Weather Effects on the Frequency of Road Accidents in California. *Accident Analysis & Prevention.* 8(2), pp. 87-96. https://doi.org/10.1016/0001-4575(76)90002-6

Steinhoff, C., Keller, H., Kates, R., Farber, B. (2000). Driver Perceptions and the Effectiveness of Preventative Traffic Management Strategies. In: *Proceedings of the 7th World Congress on Intelligent Systems*, Turin, Italy, Nov 6–9, 2000.

Tay, R., de Barros, A. (2010). Effectiveness of Road Safety Messages on Variable Message Signs. *Journal Of Transportation Systems Engineering and Information Technology.* 10(3), pp. 18-23. https://doi.org/10.1016/S1570-6672(09)60040-4

ÚT 2-1.153 (2008) A változtatható jelzéstartalmú közúti jelzőtáblák (VJT) követelményei. (Hungarian Road Technical Specification: Requirements of road traffic variable message signs) (in Hungarian)

ÚT 2-1.165 (2009) Intelligens forgalomszabályozó és információs rendszerek alkalmazása. (Hungarian Road Technical Specification: Deployment of intelligent traffic control and information systems.) (in Hungarian)

Winnett, M. A., Wheeler, A. H. (2002).Vehicle-activated signs – a large scale evaluation. *TRL Report TRL 548. TRL Limited*. United Kingdom.