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Title	**Evaluation of Warning Elements for Matrix Displays**
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Summary	**Several alternatives of danger warnings to the traditional way, based on the use of a surrounding triangle, were compared. Findings indicate that optimizing pictograms for full usage of VMS matrix displays is possible, as there are alternatives which are associated with warning at least as much as the traditional version.**
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Summary

The use of a surrounding element leads to a significant reduction of matrix elements of variable message signs left for displaying the specific message. Applying a comprehension and a rating task as well as measuring understanding time, several alternatives of danger warning to the traditional way - based on the use of a surrounding triangle - were compared.

Results available indicate that there are alternatives which are associated with warning at least as much as the traditional version of displaying danger warning. Further results concerning measures of understanding time and rating task support the possibility of using alternative solutions on variable message signs.

1 Introduction

When symbols are used on matrix displays, as this is the case with Variable Message Signs (VMS), it is most important to use as much as possible of the available space for displaying the symbol. With traffic signs symbols often are presented within some specific surrounding element to signify a specific category of messages, be it regulatory, informative or danger warning. The use of a surrounding element leads to a significant reduction of matrix elements left for displaying the specific message. In the case of danger warning based on the use of a surrounding triangle, depending on the thickness of the triangle, at least two thirds of the space available on a square matrix display is lost. Therefore it is essential to find alternative ways of displaying the major signing functions, especially danger warning. Among these alternatives there are also solutions based on using flashing lights or flashing warning triangles. Regarding alternatives with flashing elements concerns of introducing an additional categorization like two levels of importance of messages (Lucas, 2005) have to be considered. Other positive as well as possible negative effects of flashing elements have been reported in several studies (e.g. Rämä, 2001; Rämä, Schirokoff & Luoma, 2005).

The current study is focused on programmable multi purpose VMS which also allow for animated solutions, but the alternatives examined also include options like the use of flashing lights.

There is a wide range of testing procedures available for evaluating the effectiveness of symbols (see for example Foster, 1994). To assess the efficacy of such danger warning elements only a limited set of testing procedures are appropriate. According to Dewar (1999) comprehensibility or ease of understanding is probably the most important aspect symbol effectiveness. Several methods to measure comprehensibility have been described. An exact description of two procedures can be found in ISO 9186, a standard on testing public information symbols. But especially in traffic applications processing time can be critical.

As detailed in Mackett-Stout & Dewar (1981) more than one measure should be applied to judge the effectiveness of symbols.

2 Method

2.1 Procedure

Based on the fact that using more than one measure should be applied especially to judge the effectiveness of traffic signs, test participants had to fulfill a comprehension and a rating task. To assess the efficacy of the danger warning elements also understanding time in the comprehension task was registered. Each participant had to process six alternatives of danger warnings, each in combination with a different symbol. The process was computer controlled with stimuli presented on a LCD screen.

2.1.1 Comprehension task

After a brief introduction each respondent had to process an instructive item illustrating the task: After a countdown a traffic sign was shown, using a simulated matrix display. The respondent was instructed to press a mouse button as soon as he was sure to know what the traffic sign was supposed to mean. The time span starting with the presentation of the stimulus until the mouse click was registered automatically and regarded as understanding time. Immediately after the mouse click a grey screen was shown and the respondent was asked to tell the meaning of the traffic sign. The conductor then registered the answer. After confirming correct understanding of the task the test started, repeating the task for each variant tested.

Since attention was not supposed to be focused on the aspect of varying modes of danger warning in the comprehension task, four additional distracting items were inserted: *First aid post* after the first stimulus*, No passing for trucks* after the second stimulus and *End of right of way* followed by *Side wind* after the third stimulus.

2.1.2 Rating task

The rating task followed immediately after the comprehension task was finished. Each respondent was instructed to judge for each sign how far he/she has regarded it as a warning. Before showing each sign once more, a short description on how to proceed was given. Using the representation of an analog scale on the screen, the mouse pointer had to be moved to the desired position. The mouse button had to be pressed to confirm the position only. No more corrections were possible after the mouse click. The ends of the scale were labeled *unclear*, *weak* on the left and *clear, strong* on the right. A screen-shot of the rating input is shown below (Figure 1).

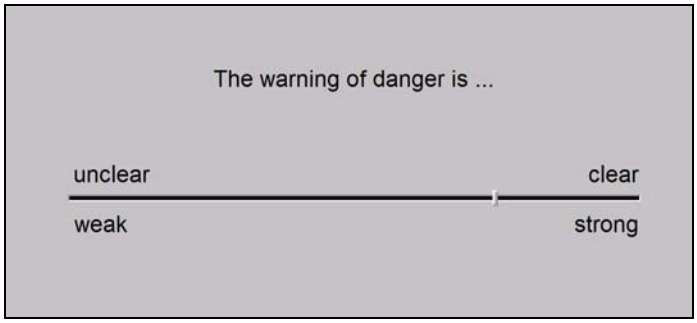

Figure 1: Screen design used for rating input

The stimuli were presented in the same order as in the comprehension task, but without distracting items. Each stimulus had to be rated immediately after its presentation.

2.1.3 Warning elements

The table below (Table 1) gives a description of the five alternatives that were tested along with the traditional way of displaying warning content within a triangle:

Individual danger warning elements tested		
Abbreviation	Description	Example
TRI	Symbol within triangle (traditional way of displaying warning content)	
B2	Symbol with two alternating flashing amber lights above. Each light is turned on for 0.5 seconds, then turned off for 0.5 seconds. When one light is on, the other is off.	
B4	Symbol surrounded with four simultaneously flashing amber lights, one at each corner. Lights turned on for 0.5 seconds, then turned off for 0.5 seconds.	
TRL	Red triangle presented left of symbol	
TRR	Flashing smaller red triangle presented at right edge of matrix used for symbol presentation	
TRF	Flashing triangle: Symbol presented on matrix display for 0.8 seconds without warning element, then triangle added for 0.2 seconds within matrix display, covering part of the symbol. The sequence is repeated for full time of presentation.	

Table 1: Danger warning elements tested

The alternatives B2 and B4 were derived from solutions already in use in several countries. While current real life usage of these two alternatives is based on lights with reflectors, the variants tested emulate LED-displays.

2.1.4 Referents

Six referents differing widely concerning familiarity were used to cover most effects that could yield from the interaction of the warning elements and the symbols presented. The variants were selected from the compilation available for the meeting of the SOMS / InSafety Design Panel (2005).

Referents used with danger warning elements		
Abbreviation	Name of referent	Variant tested
ACC	Accident	
JAM	Traffic Jam, Queue	
FOG	Fog	
VBD	Vehicle Broken Down	
SRD	Slippery Road	
CON	Construction	

Table 2: Referents used in combination with danger warning elements

2.1.5 Series

Individual warning elements were paired with referents in such a way that each kind of danger warning and each referent were used only once within a series. As displayed in the table below (Table 3), to avoid position effects each danger warning took a different position within each series, always combined with a different referent. So a total of six series of presentations were implemented.

Position	Series					
	1	**2**	**3**	**4**	**5**	**6**
1	ACC TRF	CONS B2	VBD TRI	FOG TRL	JAM TRR	SRD B4
2	JAM B4	SRD TRI	CONS TRL	VBD TRR	CONS TRF	FOG B2
3	FOG TRR	VBD TRL	JAM B2	SRD TRF	VBD B4	ACC TRI
4	VBD B2	FOG B4	SRD TRR	JAM TRI	ACC TRL	VBD TRF
5	SRD TRL	JAM TRF	ACC B4	ACC B2	FOG TRI	CONS TRR
6	CONS TRI	ACC TRR	FOG TRF	CONS B4	SRD B2	JAM TRL

Table 3: Assignment of referent/warning pairs to test series

2.1.6 Presentation modes

Since legibility distance is an important aspect concerning road signs, two different viewing conditions were applied for the comprehension task to cover potential effects of varying viewing distances:

Mode	Approximated symbol size	Approximated viewing distance	Approximated viewing angle
Large size presentation	90 mm x 90 mm	1,5 m	3.5°
Small size presentation	35 mm x 35 mm	3,5 m	0,6°

Table 4: Presentation modes

Compared to real traffic situations, small size presentation is fairly equivalent to a viewing distance of 150 m with 150 cm x 150 cm matrix display.

2.2 Participants

The study was conducted in three countries, Austria, Czechia and The Netherlands. In Austria a total of 72 persons participated in this study, 42 with large size presentation (7 per series) and 30 with small size presentation mode (5 per series). In Czechia and The Netherlands only small size presentation was used, with 96 participants in Czechia and 24 in the Netherlands.

Detailed sample characteristics are shown below in Table 5.

		Austria	Czechia	Nether-lands
Average age		34,8 years	41,7 years	40,6 years
Gender	Men	69 %	86 %	83 %
	Women	31 %	14 %	17 %
Education	Primary	37,5 %	35,4 %	8,3 %
	Secondary	43,1 %	63,5 %	45,8 %
	University	19,4 %	1,0 %	45,8 %
Driving experience	Average distance/year	11.800 km	8.500 km	3.400 km
	Years	15	20	21

Table 5: Values for average distance/year rounded.

Sample characteristics show significant differences between the participating countries concerning all parameters available.
For comparison: The driving experience in Austria based on average distance per year was about 10.150 km in 2005.

3 Results

In the following description of the findings a significance level of .05 is assumed. Therefore differences are called significant, if the likelihood that there is a difference between the results compared is 95% or higher.

3.1 Comprehension task: frequency of caution/warning responses

The frequency of the words *Attention* (*Achtung* in German), *Caution* (*Vorsicht* in German), *Warning* (*Warnung* in German) and *Danger* (*Gefahr* in German) found within the responses registered could be taken as an indicator of the intensity of the danger warning perception.

The largest proportion of responses with such words was registered in combination with warning elements TRL (red triangle presented left of symbol) and TRF (flashing triangle), the least with TRI, the traditional version based on the symbol within triangle.

Based on Wilcoxon signed-rank tests all alternative ways of danger warning included significantly more words implying danger than the traditional version based on the symbol within triangle. Detailed data on frequencies of wording implying danger warning for all warning element variants are shown in Table 6.

Warning element	Frequency	Percent
TRL	60	35,7 %
TRF	53	31,5 %
B2	47	28,0 %
B4	44	26,2 %
TRR	38	22,6 %
TRI	20	11,9 %

Table 6:
Frequencies and percentages of wording implying danger warning (N = 168)

Statistical data shows superior performance of the alternative ways of displaying warning elements, but the importance of additional factors can be shown by comparing these numbers with results for two distracting items, both presented without any additional warning elements: 59 cases of such words were registered for *Side wind* and 1 for *First aid post*. This illustrates the strong effect of aspects of danger already associated with specific messages or symbols, which probably can be enforced by adding specific warning elements.

3.2 Understanding time

Since understanding times available show large differences between countries, which might be based on differences in test administration, the following analysis is based on the results from Austria only.

3.2.1 Signaling Caution/Warning

Friedman's test for differences between understanding times for all ways of danger warning is not significant. The shortest median understanding time was registered for the condition with a triangle presented left of symbol (TRL), with the traditional version (TRI) on second place. Danger warning based on two and four blinking lights (B2, B4) are linked with the longest median time spans for understanding the meanings of the traffic signs. Since maximum understanding times also include outliers always found in reaction times, values of Q3 could be taken as an indicator of the understanding time, as they also include a higher proportion of then small size presentation sample. In this case again TRL performs best, followed by TRR and TRF.

The maximum interquartile ranges were registered with B4 and TRI (see Table 7).

Warning element	Q1	Q2 / Median	Q3	Q3-Q1 / IQR
TRL	2.2 s	2.8 s	5.7 s	3.5 s
TRI	2.1 s	3.1 s	7.9 s	5.8 s
TRR	2.4 s	3.2 s	6.7 s	4.3 s
TRF	2.2 s	3.7 s	6.6 s	4.4 s
B4	2.5 s	4.0 s	9.8 s	7.3 s
B2	2.7 s	4.4 s	7.1 s	4.4 s

Table 7

For all kinds of warning elements used, there is a tendency of longer understanding time for small size presentation mode compared with large size presentation. Differences are significant for TRR only, and almost significant for TRI and TRL.

3.2.2 Referents

To correctly judge the differences in understanding time between the different types of warning elements, it might be helpful to have a look at the ranges of understanding times for the different referents used. Detailed numbers are shown below in Table 8.

Referent	Q1	Q2 / Median	Q3	Q3-Q1 / IQR
Construction	1.9 s	2.6 s	3.7 s	1.8 s
Slippery Road	2.0 s	2.6 s	3.7 s	1.7 s
Traffic jam	2.4 s	4.0 s	7.5 s	5.1 s
Fog	2.6 s	4.8 s	10.6 s	8.0 s
Vehicle broken down	2.6 s	4.9 s	10.0 s	7.4 s
Accident	3.1 s	5.2 s	12.2 s	9.1 s

Table 8

Already well known traffic signs or symbols like *Construction* and *Slippery road* reach significantly shorter understanding times than rather new variants. The results indicate that the individual pictogram variants tested had a much stronger influence on understanding time than the specific ways of warning about danger.

3.3 Rating

For all variants tested normal distribution could not be confirmed for the judgments on how far the individual warning elements were regarded as warning of danger.

Warning element	Q1	Q2 / Median	Q3	Q3-Q1 / IQR
TRI	63	90	99	36
TRL	73	90	97	24
TRR	66	89	97	31
TRF	59	89	97	38
B4	48	87	96	48
B2	48	85	96	48

Table 9: Descriptive statistics for ratings based on data from three countries (N = 192)

Median values of ratings concerning the intensity of warning of danger show only small differences. The maximum interquartile ranges were registered with B4 and B2, indicating widely differing opinions concerning the intensity of warning of danger.

The importance of using a balanced test-design is demonstrated by the fact that ratings concerning the intensity of warning of danger are also significantly influenced by the symbols that are presented in combination with the warning elements (Friedman's test for differences between ratings based on referents is significant). Corresponding to the results noted for understanding time ratings of well known variants are better than for new variants. Below ratings based on well known variants *Slippery road* and *Construction* only are shown in detail.

Warning element	Q1	Q2 / Median	Q3	Q3-Q1 / IQR
TRF	84	96	99	15
TRL	86	94	99	13
TRI	83	94	99	16
B4	80	94	98	18
TRR	78	93	99	21
B2	70	91	97	27

Table 10: Descriptive statistics for ratings based on data for *Slippery road* and *Construction* only (N = 64)

Again median values of ratings concerning the intensity of warning of danger show only small differences. While median values between various ways of displaying warning elements differ by five points at most, the range of median values based on referents reaching from 75 to 94 is much bigger (see below Table 11).

Referent	Q1	Q2 / Median	Q3	Q3-Q1 / IQR
Slippery Road	83	94	99	16
Construction	79	92	99	20
Traffic jam	70	91	98	28
Accident	39	77	96	57
Vehicle broken down	31	77	95	64
Fog	19	75	93	74

Table 11: Descriptive statistics for ratings separated by referents

If warning elements are looked at on the level of individual referents applying Kruskal-Wallis one-way analysis of variance, significant differences regarding ratings concerning the intensity of warning of danger can be found with referents *Vehicle broken down* and *Traffic jam* only.

Ratings concerning B2 and TRF show significant differences between the countries participating, and for TRI and TRR differences between ratings are almost significant (based on Kruskal-Wallis one-way analysis of variance). Detailed data for the participating countries are shown in Table 12: Median ratings of each of the three participating countries (N = 192).

Warning element	Austria N = 72	Czechia N = 96	Netherlands N = 24	Total N = 192
TRI	94	91	74	90
TRL	88	92	85	90
TRR	90	92	74	89
TRF	86	92	74	89
B4	78	91	77	87
B2	73	92	72	85

Table 12: Median ratings of each of the three participating countries (N = 192)

4 Discussion of the findings

The observed frequencies of the words *Attention*, *Caution, Warning* and *Danger* in the responses indicate that all of the alternatives tested are associated with warning significantly more often than the traditional version of displaying danger warning. Results show that there are cases where individual messages themselves are already associated with danger warning very strongly without any additional visual warning elements.

Findings concerning measures of understanding time show no significant differences, with static variants of danger warning performing slightly better than versions with flashing elements. The two static alternatives perform just as well as the traditional version of displaying danger warning. Due to large individual differences in responses concerning understanding time, these measures are only of limited use.

Based on rating results all forms of displaying warning elements show only minor differences. Compared to these differences, the individual pictogram variants tested had a much stronger influence on the ratings concerning the warning of danger.

Translating these finding into real traffic applications additional aspects have to be regarded:

The dynamic nature of traffic introduces further perceptual parameters not examined in this study, like changing viewing angles as well as limitations of viewing time, depending on the speed of movement. These characteristics might have significant effects, especially if flashing elements covering parts of the pictogram are used. These elements might obscure the message and increase the amount of time needed for identifying the correct meaning.

The high impact of the individual pictogram variants on the parameters registered also demonstrates the importance of optimizing comprehensibility and therefore increasing familiarity. To identify the best way of warning about danger research must not be limited to a few facets. It has to regard interactions between a multitude of parameters.

Furthermore the effect of using flashing warning elements on the amount of attention given to all other static warning signs has to be observed closely. The possibility of creating two categories of warning signs and its consequences as pointed out by Lucas (2005) should not be ignored.

Last but not least technical and economical aspects have to be taken into consideration. While variants with flashing amber lights might be rather easy to implement, alternatives for warning about danger like the red triangle presented left of symbol require much more space and increase cost significantly. Solutions that can be implemented on the basis of already existing technology within the limits of the standard matrix display probably should be preferred.

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