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The dynamic signalization of calamity routes – a driving simulator study

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Abstract

Calamities (e.g. accidents) in the vicinity of freeway interchanges can simultaneously block several branches of the interchange for road traffic, resulting in heavy congestion or unsafe driving conditions. Therefore, drivers should be informed in time about these calamities. Digital displays alongside freeways are an excellent medium to warn drivers approaching the interchange and provide some rerouting alternatives. The objective of this study is to investigate the effectiveness of a sequential message strategy (including digital displays) announcing that a calamity has occurred and therefore advise the drivers to reroute. In this study, different types of messages and two types of digital displays (gantry and cantilever) are used to indicate that an accident occurred at the interchange and that one or more branches are blocked. Furthermore, these messages instruct the drivers to take the exit and follow a calamity route (i.e. diversion). After leaving the freeway, the calamity routes are indicated using different letters (e.g. 'A') for the possible destinations. Sixteen subjects participated in the simulator study and drove through five scenarios after receiving instructions concerning their destination. The apparatus used consisted of a medium fidelity simulator mock-up equipped with an eye tracking system. Instead of being exposed to a virtual driving environment, participants drove through a real-life full HD video recorded road environment in which 3D virtual traffic signs had been digitally integrated. Participants' route choice and their visual behavior were monitored while navigating through the scenarios. Results indicate that most of the participants obeyed the instructions on the digital displays and thus made the correct route choice. However, some participants neglected the advice and did not take the appropriate exit. Furthermore, small differences were found between the two types of digital displays. In general, cantilever displays generated longer fixation times than the gantry displays.

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Keywords: Interchanges and freeways; Driving simulation; Route choice; Traveler Information Systems; Ex-ante evaluation; Calamity routes

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1. Background

Calamities (e.g. accidents) in the vicinity of freeway interchanges (i.e. a crossing of two freeways) can simultaneously block several branches of the interchange for road traffic, resulting in heavy congestion. Therefore, drivers should be informed in time about these calamities. Digital displays alongside freeways are an excellent medium to warn drivers approaching the interchange.

This paper describes the case study of the dynamic signalization of calamity routes at a Belgian freeway interchange. Figure 1 gives an impression of the interchange in Lummen, with the crossing of the freeways E313 (Liège – Antwerp) and E314 (Aachen – Brussels). Each day, more than 100,000 vehicles pass this interchange with incoming traffic out of four directions. The port of Antwerp is nearby and many trucks from/to the port are passing by this interchange.

If an accident happens at an interchange, unsafe conditions and an unstable (saturated) traffic flow can arise. Some branches of the interchange even can be blocked for the road traffic. This might have an impact on the traffic safety and the upcoming traffic should be rerouted to the secondary road network [1], [2].

The study focuses on the tactical information for road users (i.e. max. 5km from the accident or calamity) and not on the strategic information [1], [3]. In this case, the road users will receive sequential information about the calamity and consequently the rerouting advice [1], [3], [4, p. 8], [5], [6]:

- What is the problem?
- Where is the problem located?
- Who is the intended audience (i.e. maybe not all the branches of the interchange are blocked due to the calamity)?
- What is the effect of the problem?
- What should the road users do (e.g. reroute, which direction)?

The effectiveness of traffic signs in general depends upon four factors (see figure 2): (1) sign detection, (2) sign readability, (3) sign comprehension and (4) behavior [7]. Traffic signs should be designed and positioned correctly in order to achieve that road users will successfully pass through these four stages and take the appropriate action.

The need for (proactive, ex-ante) evaluation of infrastructural measures and road design becomes more important nowadays. Road users should be involved in this evaluation because otherwise some issues might arise:



Fig. 1. Freeway interchange E313-E314 in Lummen, Belgium.



Fig. 2. Traffic sign processing phases [7].

- *Road user perception*: does the road user understand what we want to build?
- *Road user behavior*: does the road user behave as we had in mind when designing the infrastructure?
- Design errors may lead to serious collisions
- Correcting for errors after construction of the infrastructure is expensive and causes additional disturbance.

This involvement of the road users should be: (1) as early as possible during the design process, (2) in a naturalistic setting, (3) in a cost-efficient way and (4) in an evidence-based way by means of scientific and verifiable parameters.

2. Objectives

The objective of this study is to investigate the effectiveness of a sequential message strategy (including digital displays) announcing that a calamity has occurred and therefore advise the drivers to reroute. That is why these research questions should be answered:

- Do road users process the displayed information?
- Do road users follow the rerouting instructions?

3. Methodology

3.1. Participants

Sixteen volunteers (13 men) participated in the study and all gave informed consent. The sample was approximately equally divided over four age categories from 20 to 75 years old (mean age 41.6). All participants had at least two years of driving experience.

3.2. Driving simulator and eye tracker

During the driving simulator experiment, the participant is seated in a fixed-base mock-up in front of a large seamless curved screen on which the HD-video (25 photorealistic frames per second) is projected (see figure 3). Participants can speed up and slow down the video by means of the accelerator and the brake pedal. Readability of traffic signs at longer distances ahead can be a point of concern due to limitations in the resolution of the visual system. Therefore, if needed, participants can press the horn to display an enlarged picture of a specific traffic sign.

The core of the research tool is that participants can really operate a simulator mock-up and thus have active control over their driving when being exposed to a real-life full HD video recorded road environment in which a variety of 3D virtual traffic signs (ranging from signs, pavement markings and variable message signs to signs used in work zones and advertisement panels) have been digitally integrated using specialized software for camera-tracking and 3D video-integration (see section 3.3.).

Eye movements were recorded by faceLAB 5.0 (Seeing Machines) which is a camera-based, dash-mounted eye tracking system (see figure 3). With the current configuration, the system can accommodate head rotations of $\pm 45^\circ$ and gaze rotations of $\pm 22^\circ$ around horizontal-axis, allowing participants to have large freedom of movement. An overlay of the video and the logged eye tracking is used afterwards to derive parameters which are related to the detection of the traffic signs. EyeWorks software was used to carry out these analyses.



Fig. 3. Traffic Sign Simulator mock-up with eyetracking system.

3.3. Scenario production

First, the route(s) of interest are filmed using a high-resolution RED-cam camera with a wide-angle lens that allows to collect video footage in full-HD resolution (4096 x 2304 pixels in 16:9 aspect ratio). The camera is mounted on the hood of a minivan, so that the footage is filmed from the viewpoint of a normal car driver. The minivan navigates at a constant driving speed as much as possible.

Next, the traffic signs of interest are digitally integrated in the video footage by means of an innovative technique using specialized software for camera-tracking and video-integration. This is a semi-automatic process that is executed in four steps (see figure 4 for the final result) [8].

3.4. Scenario design

The message strategy that has been tested is a combination of sequenced messaging and letter coding (see also figure 5):

- Sequenced messaging
 - STEP 1: Digital Variable Message Sign (on freeway)
 - Message unit 1: what has happened (→ pictogram)?
 - Message unit 2: which exit to be taken by whom (→ text)?
 - STEP 2: Static (metal) sign (at exit entry)
 - Message unit 3: which deviation to be followed by whom (→ destinations and corresponding letters)?
- Letter coding
 - STEP 3: Static (metal) sign (at exit end)
 - Message unit 4: which direction to be taken by whom (→ letters)?



Fig. 4. Inserting traffic signs of interest in the Traffic Sign Simulator video.



Fig. 5. Example of message strategy (combined sequenced messaging and letter coding).

This message strategy gives very detailed information to different road users, but this information is divided into different steps (and subsequently different traffic signs).

All participants were exposed to 5 scenarios (i.e. different routes and destinations) in a full *within* design:

1. From Aachen to Leuven (→ direction Brussels), calamity displayed on an RVMS (i.e. roadside variable message sign or cantilever)
2. From Aachen to Liège (→ direction Liège), calamity displayed on an RVMS
3. From Aachen to Antwerp (→ direction Antwerp), calamity displayed on an RVMS
4. From Brussels to Aachen (→ direction Aachen), calamity displayed on a VMS (i.e. gantry)
5. From Brussels to Antwerp (→ direction Antwerp), calamity displayed on a VMS.

The different routes were selected in close cooperation with the federal police department and the Flemish Traffic Control Center.

3.5. Procedure

Participants were asked to fill out a form with some personal data (e.g. gender, driving experience, date of birth, etc.). After a general introduction, drivers acquainted themselves with the Traffic Sign Simulator during a practice trip. Subsequently, the eye tracking equipment was calibrated. Then participants completed the 5 experimental trips, resulting in a randomized within subjects design. At the beginning of each scenario, the subjects were instructed to drive to the different destinations listed in section 3.4. (e.g. destination ‘Leuven’ in scenario 1).

3.6. Parameters

Participants’ route choices (e.g. indicator and steering wheel) and their visual behavior (using the eyetracking system) were monitored while navigating through the different scenarios. Also, participants could indicate their route choices and lane changes by means of the indicator and by using the steering wheel.

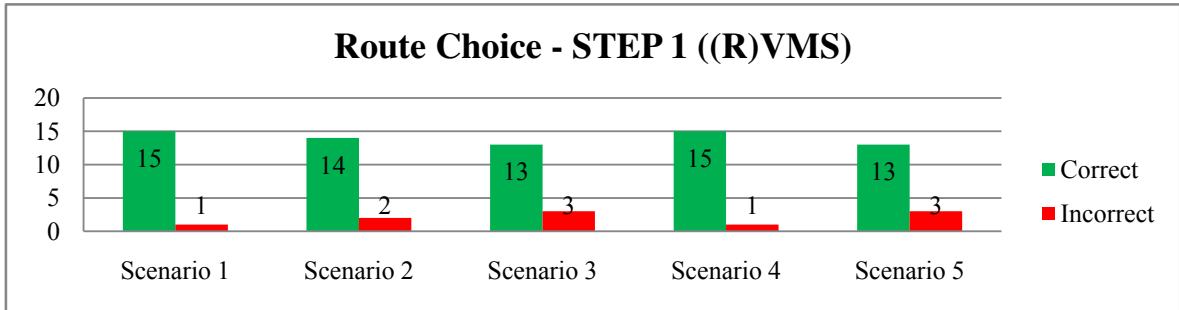
During the test drives, participants’ visual scanning and driving behavior were saved in an overlay video. A recording screen of the eye movements was merged with a simultaneous recording screen of the test drives.

4. Results

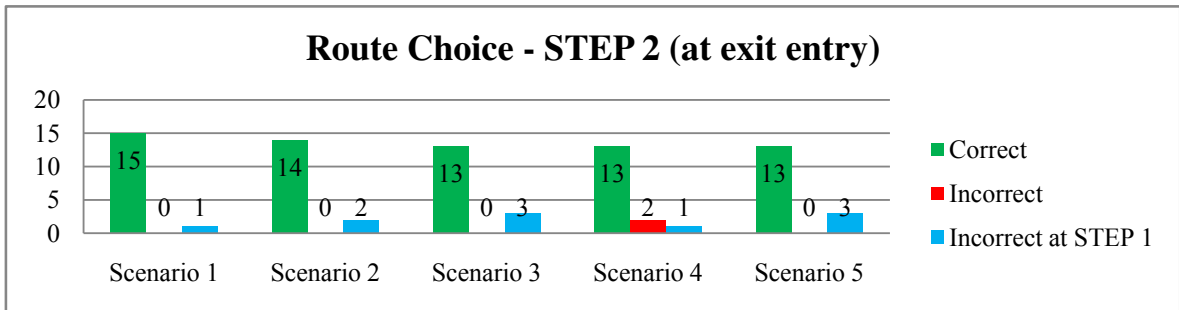
4.1. Route choice

Figures 6a, 6b and 6c show the results of the correct and incorrect decisions of the 16 participants at step 1 (i.e. (R)VMS at freeway), step 2 (i.e. static sign at exit entry) and step 3 (i.e. static sign at exit end) respectively. Most of the participants, at least 13 out of 16, made a correct route choice in step 1.

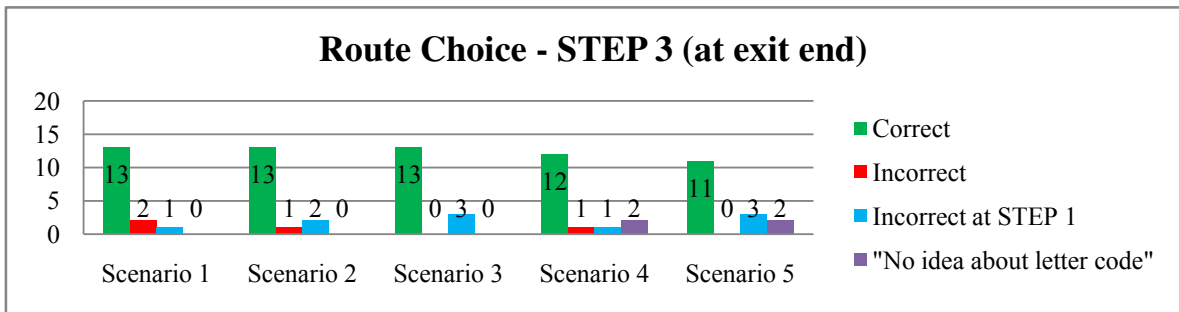
Subsequently, at the exit entry (i.e. step 2) only 2 participants made an incorrect decision in scenario 4. In step 3, at the exit end, a small number of participants made an incorrect decision or even had no idea about the letter code they had to follow (→ drivers forgot the correct letter code corresponding to their destination).



a



b



c

Fig. 6.(a) Route choice step 1; (b) Route choice step 2; (c) Route choice step 3.

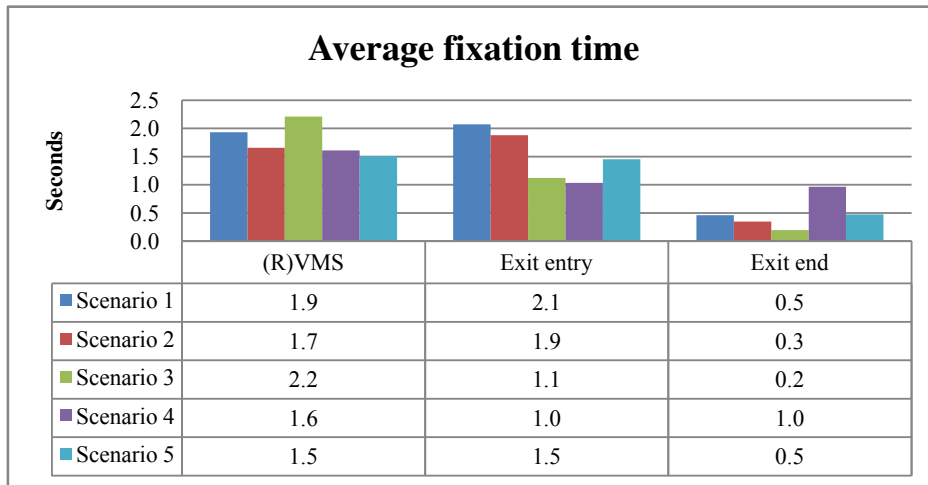


Fig. 7. Average fixation time.

4.2. Looking behavior

Concerning the looking behavior, the average fixation time is calculated for each participant for each traffic sign at the three route choice steps. Due to some calibration problems, the eye tracking data is only available for 13 participants.

Like mentioned in section 3.4., an RVMS was used in scenarios 1, 2 and 3. A VMS was implemented in scenarios 4 and 5.

5. Conclusions

In general, the tested message strategies have been effective in rerouting the drivers. Most of the drivers have noticed the sequenced messaging and letter coding and obeyed it correctly. Therefore, we can conclude that the following message strategy is effective in rerouting road users at (freeway) interchanges in case of calamities:

- **STEP 1:** Digital Variable Message Sign (on freeway)
 - Message unit 1: what has happened?
 - Message unit 2: which exit to be taken by whom?
- **STEP 2:** Static (metal) sign (at exit entry)
 - Message unit 3: which deviation to be followed by whom?
- **STEP 3:** Static (metal) sign (at exit end)
 - Message unit 4: which direction to be taken by whom?

Although the use of this message strategies (including the digital displays) tends to be very effective in informing the drivers about calamities and guiding them to the correct route diversion, we can distinguish six types of drivers:

- Group 1 (= largest group!)
 1. Fixation on time, read and understood the message correctly, made the correct route choice.
- Group 2
 2. Fixation too late, incomplete reading and understanding, wrong route choice.
 3. Fixation on time, inattentive reading, wrong route choice.
 4. Fixation on time, read and understood the message correctly, wrong route choice.
 5. No fixation, wrong route choice.

- Group 3
 6. Fixation time, read and understood the message correctly, but consciously ignored the message (i.e. wrong route choice).

Concerning the effectiveness of the RVMS and VMS, the following conclusions can be drawn based on both the objective and subjective parameters:

- Objective → RVMS generate a slightly (= non-significant) longer average fixation time compared to VMS.
- Subjective → Participants think that RVMS are more difficult to detect (and subsequently to read!) compared to VMS.

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