Interim Report: Traffic Information Signs, Colour Scheme of Emergency Exit Portals and Acoustic Systems for Road Tunnel Emergency Evacuations

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Abstract. A literature review and a questionnaire study with 62 participants were carried out to provide recommendations on the design of a set of evacuation systems for road tunnels: 1) Traffic Information Sign (TIS) - message and size of the sign (large or small), colour scheme, and use of pictograms and/or flashing lights, 2) Emergency exit portal layout - colour scheme, 3) Acoustic systems - voice message and/or warning signals. The TIS is recommended to include the use of two panels which present text (in amber) and flashing lights in one panel and the emergency exit pictorial symbol in green in the other panel. An increased size of the panels has a positive effect on capturing participants' attention. The recommended colour scheme for the emergency exit portal is safety green for the portal and a "green darker than the safety green" for the door. Vocal messages are not recommended since they may be quite difficult to perceive in tunnels. The use of a warning signal (F_SAW signal) based on British Standards is recommended.

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This document is an interim report, which summarises the main results of the research. Detailed information can be found in the final report of the project. The final report is due to be published in 2014.

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1. Introduction

The present document describes the analysis of a group of selected systems adopted for way-finding and notification during emergency evacuation in road tunnels. A literature review and a questionnaire study were carried out. This analysis is associated with the Stockholm Bypass project of the Swedish Transport Administration, which requires recommendation on the design of the following evacuation emergency systems:

1) Traffic Information Sign (TIS) - message and size of the sign (large or small), colour scheme, and use of pictograms and/or flashing lights.
2) Emergency exit portal layout - colour scheme.
3) Acoustic systems - voice message and/or warning signals

The present study analyses scenarios in which motorists are expected to leave their vehicles and walk towards a safe place, i.e., way-finding systems are not intended to encourage users to evacuate the tunnel using their vehicles.

The framework employed for the analysis of the effectiveness of emergency way-finding systems is the Theory of Affordances (Gibson, 1986; Hartson, 2003). This framework is used to explain perception in terms of what the object can afford people in relation to their goals. In other words, an affordance is what the object can offer (or afford) to the individuals in relation to the fulfilment of their goal. Four types of affordances are taken into consideration, namely sensory, cognitive, physical and functional affordance. The Theory of Affordances has been previously successfully employed in fire safety research to understand evacuation behaviours (Joo et al., 2013; Kim et al., 2011; Nilsson, 2009).

This document is intended to assist road tunnel safety designers and operators in the assessment of the appropriate emergency systems in the case of road tunnel evacuation. Different systems for road tunnel evacuation emergencies are tested and evaluated within this research document. The results presented in this report will be used to assist the design of the emergency systems in the Stockholm Bypass project.

This interim report only summarises the main aspects of the study and a more detailed presentation will be provided in the following report:

> Ronchi E., Nilsson D., 2014. *Traffic Information Signs, colour scheme of emergency exit portals and acoustic systems for road tunnel emergency evacuations.* Report 3173, Department of Fire Safety Engineering, Lund University, Lund, Sweden.

2. Traffic Information Signs

Traffic Information Signs (TIS), also called Variable Message Signs, is a technology used in tunnels to provide users with real-time information. A TIS is a programmable electronic panel capable of displaying messages of different nature. Depending on the type of technology employed, the panel is capable of displaying messages composed of text, pictograms or a combination of them. Recent visualization technologies employed in TIS, e.g., LCD screens, include dynamic features such as the use of animation, flashing, scrolling, etc. This leads to a great flexibility of content and type of information to be displayed to the users (Wang et al., 2006). On one hand, this allows a great range of possibilities for the designer of the TIS. On the other hand, it poses several questions on the information to be displayed in order to provide understandable and effective messages (Dudek and Ullman, 2002; Dudek, 1991).

In line with the objectives of the present study, a specific layout of TIS system is investigated. It consists of 2 rectangular panels conveying information to motorists and three intermediate smaller squared signs (see schematic representation in Figure 1). This layout is based on the design of a real-world tunnel (the Stockholm Bypass project) in which the results of the current study will be applied. The TIS panels have a fixed dimension of 240x90 cm on the opposite side of the emergency exit and two possible dimensions on the side of the emergency exit, either 240x90 cm or a larger size of 240x170 cm. The intermediate signs have fixed dimensions corresponding to 90x90 cm. In the case of emergency, the smaller panels will be used to show red crosses, which are used to encourage tunnel occupants to stop their vehicles.

Layout 1 – two TISs of the same dimension (both 240x90 cm).

Layout 2 – TIS on the side of the emergency exit is larger (240x170 cm and 240x90 cm).

Figure 1. Schematic representation of the layout of information signs under consideration. The layout may include two panels of the same size (top) or a larger panel on the side of the emergency exit (bottom).

A literature review has been carried out to investigate the possible characteristics of the TISs in terms of their colour code, type of information provided (e.g., written message, use of pictorial symbols, use of flashing lights). Based on the literature review, eleven TIS designs have been identified (see Figure 2a-2b). These designs have been evaluated using the Theory of Affordances (Gibson, 1986; Hartson, 2003) to find a manageable set of designs for a subsequent questionnaire study.

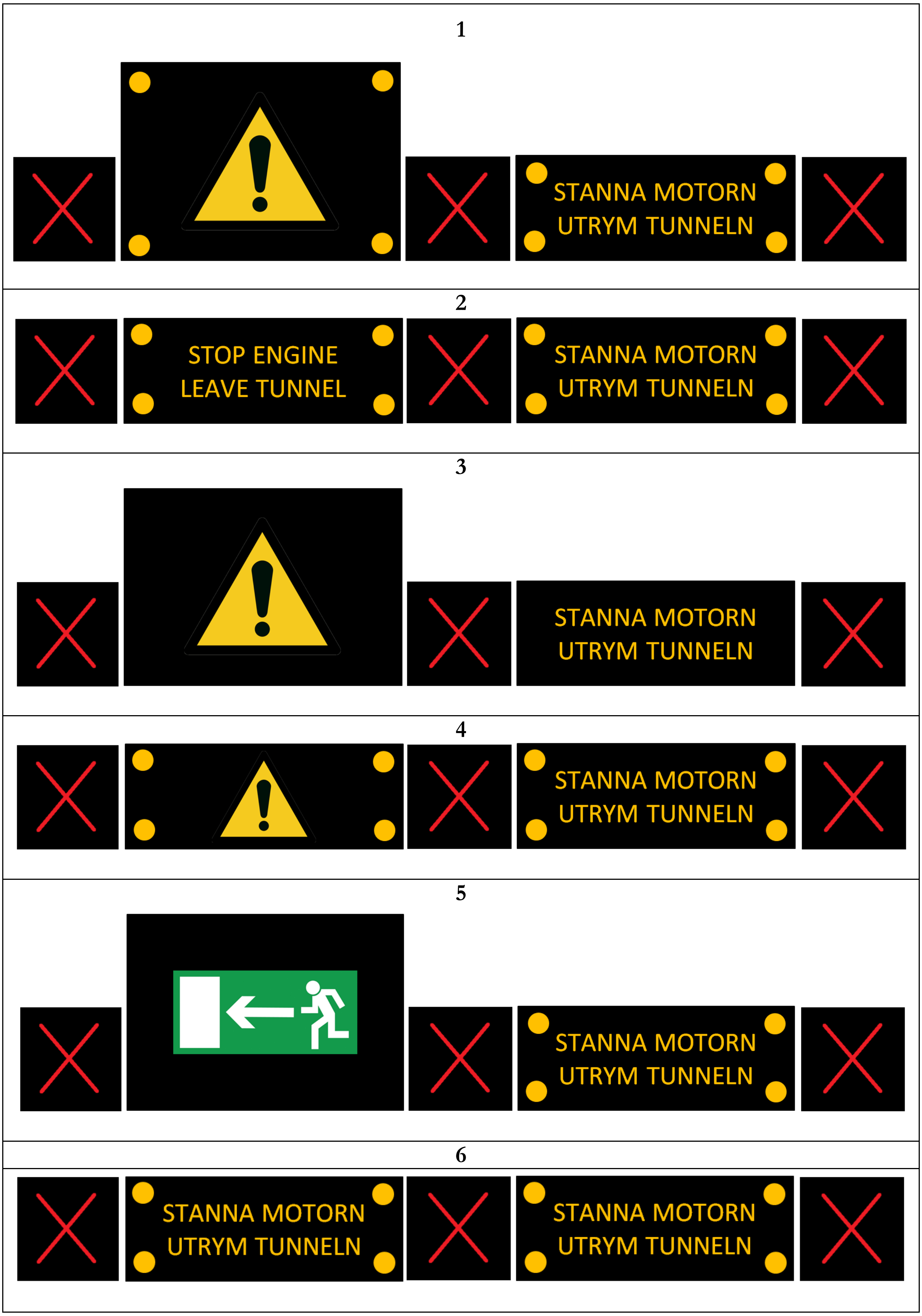


Figure 2a. Schematic representation of the preliminary list of TIS designs (1-6).

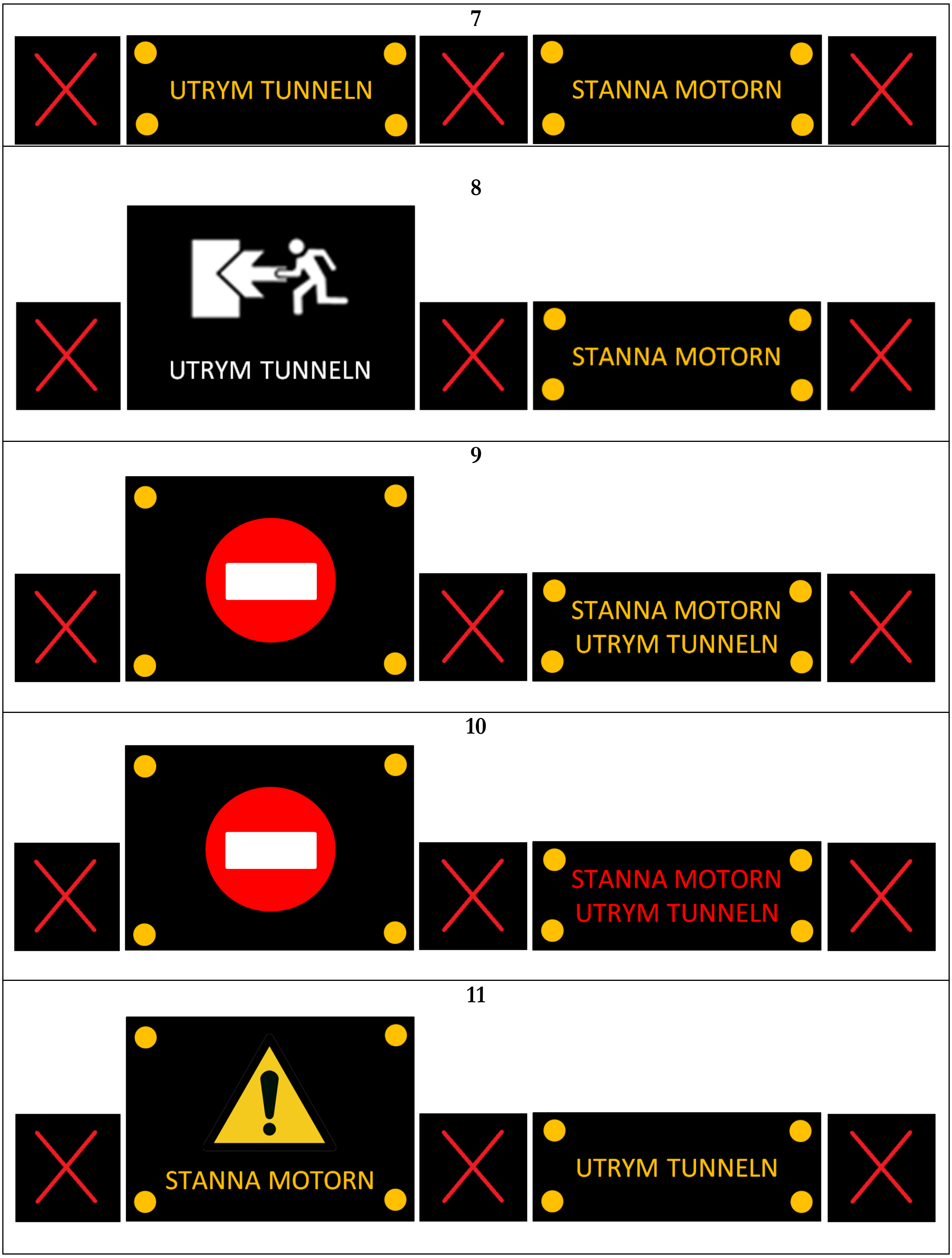


Figure 2b. Schematic representation of the preliminary list of TIS designs (7-11).

2.1. Preliminary analysis of TIS designs

A preliminary analysis of the eleven TIS designs has been carried out using the Theory of Affordances in order to exclude the TIS designs that were deemed to not perform well. The Theory of Affordances is used considering four types of Affordances, namely Sensory, Cognitive, Physical and Functional Affordances. This report presents a summary of the results of the analysis. Complete information on the analysis conducted can be found in the full report of this study (Ronchi and Nilsson, 2014).

2.1.1. Sensory affordance

Sensory affordance is determined in TIS systems by their capability of attracting the attention of the motorists and their subsequent ability in seeing the message provided. This is associated with the location (which is constant in this study) and size of the panels (large or small panel on the side of the emergency exit), the colour in use and the type of code displayed in the sign (text, pictorial symbols, and flashing lights) and its characteristics. In order to have a quick response, TIS written message should be with no or minimum flashing, very specific wording, without abbreviations and displayed in a solid amber (Wang and Cao, 2003). In fact, certain colours of the written message are not quickly perceived (Lai, 2012, 2010, 2008, Wang et al., 2006), i.e., white and red colour, e.g., TIS design 8 and TIS design 10. Single-line and triple-line messages generally lead to a slower reading if compared with double-line messages, thus TIS designs 7, 8 and 11 are not recommended.

2.1.2. Cognitive affordance

Cognitive affordance in the case of TIS is associated with the effectiveness of the panel in providing information that motorists can understand. TISs can contain three different types of information such as 1) the problem (i.e. the accident), 2) the location of the problem and 3) the recommended motorist action. Given sign space and legibility constraints, it is not always possible to provide information on all elements (Dudek and Ullman, 1991). The intended cognitive message in the present study is to encourage motorists to leave their vehicles and walk towards an emergency exit, i.e., way-finding systems are not intended to encourage users to evacuate the tunnel using their vehicles. In all TIS designs, the action messages, i.e. stop of the engine and evacuation of the tunnel, is necessary since it provides the with motorists the crucial information they need. Previous experimental research (Nilsson, 2009) performed in the Göta tunnel in Sweden successfully tested the written message recommending the motorist actions to stop the engine and evacuate the tunnel ("STANNA MOTORN", UTRYM TUNNELN"). Understanding a TIS is dependent on the code employed (text, pictorial symbols, flashing lights) and the written message design and their combination. The use of pictorial symbols of different colours than the text (TIS 5, 8, and 9) is deemed to potentially create confusion among the motorists. This solution is not recommended, but experimental tests were employed to verify that this negative effect may be balanced by the use of an extremely effective pictorial symbol (e.g. TIS design 5). The use of pictorial symbols in an unusual colour may decrease cognitive affordance (e.g. TIS design 8). Since the information to be transmitted concerns an emergency, it is deemed that the use of a white colour scheme for the text (TIS design 8) may decrease cognitive affordance on the message if compared with the use of amber or red, i.e. motorists may not perceive the emergency and the urgency of the situation. The combined use of pictorial symbols and flashing lights with text is deemed to increase cognitive affordance.

2.1.3. Physical affordance

Physical affordance supports the user physically performing an action. The TIS is a sensory system which does not require a physical interaction with the object under consideration. For this reason, physical affordance is deemed to be not applicable during the analysis of TIS through the Theory of Affordances.

2.1.4. Functional Affordance

Functional affordance is associated with the goals of the motorists in the tunnel. Main goals of the tunnel occupants include reaching a safe place overcoming possible property attachment (i.e. the reluctance to leave the vehicle) and social influence. All systems under consideration are designed in line with the same goals. For this reason, it is argued that functional affordance can be directly derived as a consequence of the factors affecting the other affordances.

2.1.5. Selected designs for questionnaire-based evaluation

Based on the evaluation made using the Theory of Affordances, five TIS designs were deemed to not perform well and six TIS designs (TIS design 1-6) were selected and further evaluated through a questionnaire study with a sample of 62 participants.

2.2. Questionnaire study

An affordance-based questionnaire was administered to the participants. Detailed information on the questionnaire can be found in the full report of the study (Ronchi and Nilsson, 2014). The designs are evaluated experimentally performing dedicated pairwise comparisons of designs which permit the testing of different variables. Test participants were required to sit in a room where two screens were shown (see Figure 3), each one presenting one TIS design in a hypothetical tunnel evacuation scenario. Participants were required to fill out a questionnaire about which designs they preferred in case of an emergency evacuation in a tunnel. The variables under consideration and the corresponding pairwise comparisons are presented in Table 1.

Figure 3. Example of pairwise comparison with two screens visualizing the hypothetical tunnel evacuation scenarios provided with two different TIS systems.

Table 1. Summary of the pairwise comparisons of TIS designs.

Test	Comparison of TIS designs	Variable under consideration
A	4 vs 6	Use of pictorial symbols vs written text (Swedish)
B	5 vs 1	Type of pictorial symbol/flashing
C	4 vs 1	Size of the panel on the side of the emergency exits
D	1 vs 3	Use of flashing lights
E	4 vs 2	Use of pictorial symbols vs written text (Swedish and English)

A total of 62 participants were recruited for the questionnaire study. Participants answered to all or a part of the questions about the TIS designs. Participants were recruited among students and staff at Lund University. Test participants' age ranged from 18 to 54 years old. Fifty-eight of the 62 participants (93.5%) were of Swedish nationality, two participants had double citizenship (Swedish and another citizenship) and 2 participants were not Swedish. All participants knew Swedish and 60 participants were able to read and understand English as well. Participants did not declare any sight impairments with the exception of one participant who declared difficulties in distinguishing colours. Most of the participants (93.5 %) did not have previous experiences concerning tunnel evacuations. Four participants (6.5%) mentioned previous experiences of tunnel evacuation such as experiencing the traffic being stopped while inside the car in a tunnel due to an accident (two participants) and two cases of full evacuation of the tunnel (one case including visible smoke from the car involved in the accident). Most of the participants (89%) had a driving license. The majority of the participants were not very frequent tunnel users, with the most common tunnel use frequency being once per year (46.8%), followed by less than once per year (27.4%) and once per month (22.6%). This is considered a conservative sample since a critical scenario would involve tunnel users without experience about tunnel evacuations.

2.2.1. Results

A statistical evaluation of the TIS systems was performed based on the preferences provided by the test participants (see Table 2). The non-corrected significance level was set to 0.05. Exact two-tailed binomial tests with Bonferroni corrections indicated three strong trends:

- TEST B: The "emergency exit" pictorial symbol is preferred over the warning symbol (p=0.00)
- TEST C: Bigger size of the panels are preferred over signs with smaller size (p=0.00)
- TEST D: Signs including the use of flashing lights are preferred over signs without flashing lights (p=0.00)

Exact binomial tests with Bonferroni corrections indicated no significant statistical differences between the use of small pictorial symbols vs text in Swedish (p=0.015 for Test E) or Swedish and English (p=0.012 for Test A). Although no statistical evidence has been found in the results of Test A and Test E, participants indicated a preference of the small pictorial symbol over the text in Swedish (69% of the participants selected the TIS with pictorial symbol) and a preference of the text in English and Swedish over the small pictorial symbol (67% of the participants selected the TIS with text in English and Swedish). This may indicate that TIS including Swedish and English may be more effective than TIS with text only in Swedish. Nevertheless, this may be associated with the sample under consideration (mostly composed by English speakers). Further testing may be necessary to address this issue in relation to the type of population involved, i.e. text in English may become less effective if a higher percentage of the sample is non-English speakers.

Table 2. Results of the questionnaire on TIS systems.

TEST	TIS Design	Observed Proportion (%)	Two-tailed binomial test (p)
A	4	71	0.012
	6	29	
B	5	81	0.000
	1	19	
C	4	15	0.000
	1	85	
D	1	100	0.000
	3	0	
E	4	66	0.015
	2	34	

2.3. Recommended TIS design

Based on the questionnaire study and the analysis with the Theory of Affordances, the selected TIS system has been identified (see Figure 4). The TIS is recommended to include the use of two panels that present text in one rectangular panel and a pictorial symbol in the other rectangular panel. Amber is the colour recommended for the written text in the panels. Flashing lights are particularly effective for increasing the attention catching ability of the TIS and they are recommended in the panel with the written message. The use of flashing lights is not recommended in the panel with the emergency exit pictogram since they may provide contradictory information, i.e. the emergency exit pictogram conveys a message about safety while flashing lights convey a warning message. An increased size of the panels available in the TIS has a positive effect on capturing participants' attention. The amount of information contained in a single sign should be kept as small as possible in order to reduce people viewing time and the feeling of pressure. In addition, information should be appropriately separated. Written messages should be presented in double lines.

Figure 4. Recommended TIS design.

3. Emergency exit portals

The design of emergency exit portals should be made in order to increase the likelihood of motorists noticing and using the exits. To achieve this goal, different types of affordances should be taken into consideration. Colour coding is an efficient tool to enhance cognitive affordance, i.e., it may improve the recognition and understanding of an object given the colour employed (Wickens, 2004).

Different colour schemes are initially selected for the design of the emergency exit portal. In the Stockholm Bypass project, emergency exit portals are painted in the typical "safety green" since this colour is associated with safety in transportation and it increases cognitive affordance. The door design in the Stockholm Bypass project includes a circular window and a light is lit in the compartment behind the door. This is deemed to improve people's door recognition. Preliminary emergency exit door colours are the "safety green", a "green darker than the safety green", white or grey. Schematic representations of the colour combinations are presented in Figure 5. The background colour of the environment is assumed to be grey in line with the standard colour of concrete.

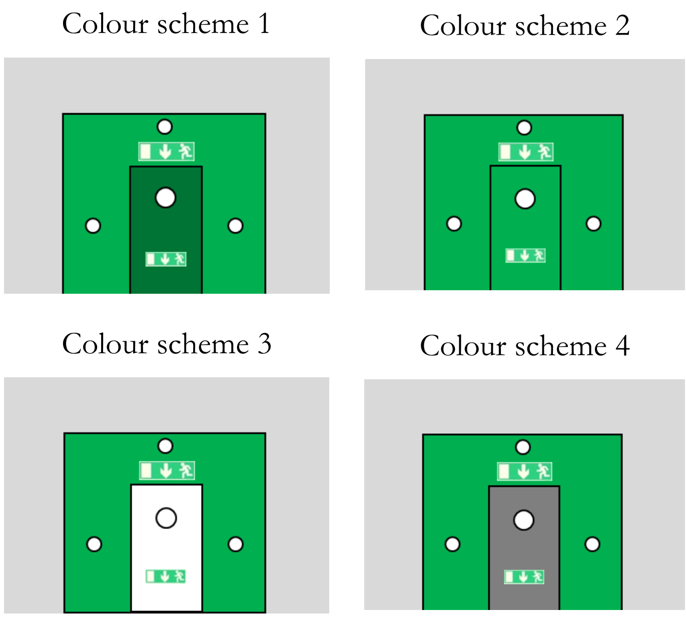


Figure 5. Schematic representation of four possible colour schemes for the emergency exit portals.

3.1. Qualitative evaluation using the Theory of Affordances

The qualitative system evaluation using the Theory of Affordances permitted the identification of the best performing colour scheme for the design of emergency exit portals.

3.1.1. Sensory affordance

Appropriate contrast of colours should be provided in order to increase sensory affordance, i.e. the emergency exit portal and door are visible and noticed. This is reflected by the fact that the emergency exit doors inside the portal should be easy to notice and distinguish in comparison with the other colours. This issue appears when using the same colour for the portal and the emergency exit door (e.g. Colour scheme 2) or using a door which has the same colour of the light coming from the window (e.g. Colour scheme 3).

3.1.2. Cognitive affordance

Green colour is generally associated with safety, thus the use of this colour for the door may generate a higher cognitive affordance than the white and grey colour for the door.

3.1.3. Physical affordance

Physical affordance is not taken into account since it is assumed to be equal in all portal designs, i.e., no changes in the physical elements of the door are considered.

3.1.4. Functional affordance

Functional affordance is associated with the goals of the tunnel occupants. Main goals of the tunnel occupants include reaching a safe place and social influence. The system designs under consideration are designed in line with these goals. For this reason, it is argued that functional affordance can be directly derived as a consequence of the factors affecting the other affordances.

3.2. Recommended portal colour scheme

Given the qualitative analysis made using the Theory of Affordances, the recommended colour scheme is colour scheme 1, i.e. safety green for the portal and a "green darker than the safety green" for the door (see Figure 6). Colour scheme 4 (grey door on a safety green portal) may be an acceptable alternative design.

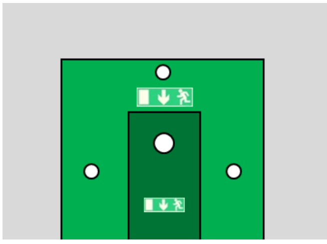


Figure 6. Recommended colour scheme of the portal.

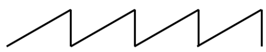
4. Acoustic systems

Acoustic guidance can be a useful tool to improve self-evacuation in road tunnel emergencies. This has been demonstrated in different experimental studies (Boer and Veldhuijzen van Zanten, 2007; Fridolf et al., 2013; Mellert and Welte, 2012; Nilsson et al., 2009). Acoustic systems may also be useful to direct evacuees during their path if appropriate instructions are provided in the global message. In line with the Bypass Stockholm project design, this study investigates the use of global messages only, i.e., sound beacons are not taken into consideration.

Acoustic systems can be divided into two main groups, namely 1) acoustic (warning) signals and 2) vocal messages. The use of warning signals can have several positive effects on motorists (Nilsson et al., 2009) such as guiding people through smoke (Fridolf et al., 2013; Mellert and Welte, 2012). Warning signals may also enhance evacuees' walking speeds and they can be effective also in the case of good visibility (Boer and van Wijngaarden, 2004). Although the presence of a vocal message can produce a stronger compliance behaviour (Boer and Veldhuijzen van Zanten, 2007; Wogalter et al., 1993), it may be quite difficult to perceive in a road tunnel given the issues associated with the general acoustic conditions (Nilsson et al., 2009). For this reason, the use of a warning signal as the only acoustic system is suggested.

Based on previous research (Oyer and Hardick, 1963, Patterson, 1990; Stanton and Edworthy, 1999) the warning signal should be continuous it should have a pulse rate of at least 1Hz and in a frequency range of 0.8-1 kHz. Possibly suitable signals have been found in either British Standards (British Standards, 2013) or Swedish Standard (Palmgren and Åberg, 2010) and they are presented in Table 3.

Table 3. Main characteristics of the selected warning signals.

Signal	Standard	Frequency pattern	Frequency range [Hz]	Visual image of the frequency pattern
BS	British standard (British Standards, 2013)	Alternating: 0.25 s high, 0-25 low	800-970	
F_SAW	British standard (British Standards, 2013)	Rising:0.14 s (7Hz)	800-970	
SIS_2	Swedish standard	Mechanical bell	-	-

4.1. Qualitative evaluation using the Theory of Affordances

The evaluation of the warning signals is made using the Theory of Affordances.

4.1.1. Sensory affordance

Sensory affordance is associated with the frequency range, sound levels and patterns. Frequency ranges are the same in the BS and F_SAW warning signals. A rising frequency pattern is deemed to increase the chances to be heard by the evacuees, while no discernible frequency changes (as in the case of SIS_2) are deemed to decrease sensory affordance. For this reason, sensory affordance is deemed to be high for the F_SAW and BS warning signals and low for the SIS_2 signal.

4.1.2. Cognitive affordance

Cognitive affordance is affected by the degree of perceived urgency. This is associated with the frequency pattern and the pulse rate. An alternate pattern generates a higher degree of perceived urgency, thus increasing the associated affordance. The F_SAW signal presents a high pulse rate (7 Hz) which is deemed to generate high cognitive affordance. On one hand, BS and F_SAW warning signal are deemed to have a better performance in terms of cognitive affordance than the SIS_2 signal, which does not present discernible frequency changes. On the other hand, SIS_2 is the most common warning signal in Sweden, and familiarity with the signal may increase the understanding of the meaning of the signal in a Swedish population.

4.1.3. Physical affordance

The system under consideration is a sensory system, thus the analysis of physical affordance is not applicable in this case.

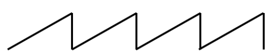
4.1.4. Functional affordance

Functional affordance is associated with the goals of the motorists. Main goals of the motorists include reaching a safe place overcoming possible property attachment (i.e. the reluctance to leave the vehicle) and social influence. The systems under consideration are designed in line with these goals. For this reason, it is argued that functional affordance can be directly derived as a consequence of the factors affecting the other affordances.

4.2. Recommended acoustic system

Vocal messages are not recommended since they may be quite difficult to perceive in tunnels. The use of a warning signal is recommended. F_SAW signal (see Table 4) is the selected signal due to the comparison among the expected performances in terms of affordances produced by the three possible signals. It is recommended to install the F_SAW signal in the tunnel with a sound level defined in accordance with the estimated background noise in the tunnel (e.g., in buildings optimal sound level is generally in a range of 80-100 dB). The suggested acoustic system will need to be tested/measured and calibrated in the tunnel environment with cars. The signal should also be tested from within the cars.

Table 4. Recommended Acoustic system

Signal	Standard	Frequency pattern	Frequency range [Hz]	Visual image of the frequency pattern
F_SAW	British standard (British Standards, 2013)	Rising:0.14 s (7Hz)	800-970	

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