VIRTUAL REALITY EXPERIMENTS ON THE IMPACT OF WAY-FINDING LIGHTING SYSTEMS ON EGRESS FROM SMOKE-FILLED RAILWAY TUNNEL

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Report 5455, Lund 2014

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Report 5455

ISSN: 1402-3504

ISRN: LUTVDG/TVBB—5455--SE

Number of pages: 70

Illustrations: 17

Keywords

Virtual Reality, Tunnel Evacuation, Human behaviour, Fire Safety.

Abstract

The thesis presented below presents an experimental study, performed at Lund University, Sweden, focused on the evacuation of a railway tunnel filled with smoke. The experiment is aimed at the evaluation of the efficiency of high-bright and dynamic lights located at the intersection between the tunnel walls and the sidewalk. The experiment is carried out in a Virtual Reality environment using a head mounted display. The behaviour of 60 test participants has been investigated given the presence or absence of this particular way-finding installation. The final goal of this study is to determine if the use of dynamic and flashing lights can reduce the total time needed to evacuate in an emergency situation.

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DEPARTMENT: Department of Fire Safety Engineering

Academic Year 2013-2014

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Master thesis submitted in the Erasmus Mundus Study Programme

International Master of Science in Fire Safety Engineering

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28/04/2014

Abstract

The thesis presented below presents an experimental study, performed at Lund University, Sweden, focused on the evacuation of a railway tunnel filled with smoke. The experiment is aimed at the evaluation of the efficiency of high-bright and dynamic lights situated at the intersection between the tunnel walls and the sidewalk. The experiment is carried out in a Virtual Reality environment using a Head Mounted display. The behaviour of 60 test participants has been investigated given the presence or absence of this particular way-finding installation. The final goal of this study is to determine if the use of dynamic and flashing lights can aid the evacuation process in an emergency situation.

La tesi presentata di seguito riguarda uno studio sperimentale, eseguito presso l'università di Lund, in Svezia, basato sulle vie di fuga in un tunnel ferroviario riempito di fumo. L'esperimento, effettuato in una realtà virtuale attraverso l'uso di uno schermo montato sulla testa, è incentrato sul comportamento e sulla reazione di sessanta partecipanti alla presenza e/o assenza di strisce luminose e lampeggianti. Il dispositivo si attiva in una situazione di emergenza, indicando il percorso per l'uscita più vicina disponibile. L'obiettivo ultimo di questo elaborato è determinare se questo insieme di luci possa ridurre il tempo di reazione delle persone in caso di emergenza.

Acknowledgments

This document would have been impossible without the help and support of several people.

First of all, I would like to thank my supervisor Enrico Ronchi, who introduced me to the research field and supported me completely, sharing with passion all his knowledge.

I would like also to thank my colleagues with whom I enjoyed sharing an office and drinking infinite mugs of coffee for the entire duration of our last semester at Lund University.

Thanks to my parents who allowed me to take part of this amazing experience. Finally, I would like to thank my girlfriend Camilla Frigerio who supported me and sustained me every single day of the last two years.

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CFD = Computational Fluid Dynamics

FDS = Fire Dynamics Simulator

LED = Light-Emitting Diode

VR = Virtual Reality

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1. Introduction and Objectives

In recent years more attention has been given to fire safety in tunnels. Several fire disasters, highlighted the importance of safety egress from tunnels (Carvel and Beard, 2005). Even though the majority of the recent experiments and studies concerned road tunnels (Ingason et al., 2012), fire safety in rail tunnels and underground stations has also been object of dedicated research (Fridolf and Nilsson, 2012). More attention has been given to human behaviour in fire in rail tunnels and subway or underground stations, due to several fire accidents occurred in the last 20 years, such as the fire in the Hirschengraben tunnel in Zürich in 1991, the Channel Tunnel fire in 1996, the Kitzsteinhorn accident in 2000 in Austria, the Daegu subway fire in 2003 up to the most recent accident occurred in Moscow's subway in 2013 where thousands of people had to evacuate through smoke in the underground station and tunnels (Ponomareva, 2013).

Europe has three of the longest railway tunnels in the world, namely the UK's Channel Tunnel (50.5 km), Lötschberg Base Tunnel in Switzerland (34.6 km) and the Guadarrama Rail Tunnel located in Spain (28.4 km) (Leuzinger and Oster, 2006). Moreover, due to its geological configuration, Europe can be considered as the main "rail-tunnel continent" in the world. The total length of railway tunnels in Europe exceeds 1500 km (Micolitti, 2010). The main European "rail-tunnel countries" can be identified as: Italy (608 km of rail tunnels), Switzerland (298 km), Germany (274 km), France (197 km), Norway (126 km), Austria (89 km), UK (90 km) and Spain (79 km) (Micolitti, 2010).

1.1 Background and Literature review

One of the latest experiments in evacuation from an underground environment was performed in a tunnel in Stockholm. The experiment was carried out by Lund University (Fridolf et al., 2013). In tunnels, where critical conditions can be achieved very quickly, fire safety design becomes a challenge for engineers. In case of fire breaking out in a tunnel, one of the most severe problems is the smoke spread, which in most cases leads to fatal conditions (Carvel and Beard, 2005). Heavy and dense smoke may make the evacuation difficult for tunnel users, since people can easily lose their orientation (Mulholland, 1995). In order to achieve an adequate level of safety, it is important to study how people behave and react to different way-guidance installations and it is relevant to study what can help people to evacuate through smoke. One of the earliest experiments concerning evacuation through smoke was carried out by Jin and Yamada (Jin and Yamada, 1989,)(National Fire Protection Association Chapter 2-4, 2002) who found that the walking speed of participants was significantly reduced by decreasing the visibility, i.e. with an increased smoke production. Moreover Jin and Yamada reported that the behaviour of participants through smoke was similar to the human behaviour in darkness (Jin and Yamada, 1989), meaning that the subjects walked close to walls, touching them in order to orientate themselves.

Due to the obscuring effect of smoke, evacuees may miss emergency signs and get lost in the built environment (Ronchi et al., 2012). Recent tests have shown that smoke affects the evacuation movement and it significantly influences the walking speed and therefore the evacuation time (Jeon and Hong, 2009). Another series of experiments were performed by Wright (Wright et al., 2001) in order to analyse and study the walking speed of participants in smoke. The experiments consisted in walking in a non-harming and white smoke-filled corridor with the presence of several signage designs and way-guidance systems. The results of these experiments indicated that overhead lighting systems and normal lighting systems performed poorly compared to the tested way-guidance installations.

The most widely measured properties related to smoke are visibility and light extinction coefficient (Widmann, 2005; Mulholland, 1995). A short description of these two concepts is given below.

The extinction coefficient refers to several different measures of the absorption of light in a medium. The physics behind this concept can be found in Bouguer's law (Society of Fire Protection Engineers Chapter 13, 2002), where it is related the intensity of an incident light of wavelength λ, and the intensity of the light transmitted through the path length of the smoke (Mulholland, 1995). Other further studies carried out by Jin and Yamada (Jin and Yamada, 1989) found a correlation between walking speed and visibility. On the other hand, visibility depends on several factors such as the absorption and scattering coefficients of the smoke, the wavelength of the light, the conditions of the surroundings and the individual's visual acuity. Choi and Jin (Choi et al., 1995) discovered a linear relationship between the extinction coefficient and visibility.

One of the most recent experiments regarding walking speed in smoke-filled environments has been carried out by Frantzich (Frantzich et al., 2006). By varying the extinction coefficient with artificial smoke and by adding irritants, it was observed that the walking speed of the participants was fluctuating from 0.2 m/s to 0.8 m/s. Recent tests carried out by Jeon (Jeon et al., 2011) on human behaviour and evacuation performances showed a variety of values for walking speeds under different conditions of visibility. More precisely, the evacuation experiment was conducted in underground facilities, where four different visibility conditions were used. According to these tests, the walking speed of 63 participants, with an age ranging from 14 to 70 years old, was varying from 0.64 m/s to 1.24 m/s with a variation of the extinction coefficient from 0.13 m^{-1} to 0.60 m^{-1}. Consequently, the change in visibility condition by indoor ordinary lights was fluctuating from 3 to 10 meters. More information about the adopted walking speed and visibility conditions are given further in the document.

In the questionnaire study of Fahy and Proulx (Fahy and Proulx, 1995), it has been reported that 75 per cent of the evacuees from the Trade Center Towers turned back due to the presence of smoke, breathing difficulties and poor visibility. Further studies carried out by Bryan (Bryan, 1995), highlighted that almost one-third of the participants in his experiments decided to turn back and retrace their steps instead of continuing moving forward into smoke-filled environment.

In the early 90's, Jensen (Jensen, 1993) carried out an experiment evaluating the walking speed in smoke-filled environments. In his studies, statistical data have shown that 90% of participants of smoke-filled environment tests, could not walk more than 16m (Jensen, 1993). Thus, a possible way to make the evacuation easier from smoke-filled tunnels is to install different way-guidance installations, which can help people to find their way out to the emergency exits.

Many experiments have been performed in the past years (Fridolf et al., 2013, 2011; Ingason et al., 2012; Jin and Yamada, 1989) in order to evaluate the quality and efficiency of different way-guidance installations in a variety of smoke-filled environments (Fridolf et al., 2011). From these experiments it was found out that human behaviour in fire is a complex process, difficult to analyse and constantly affected from a huge variety of variables.

Recently, Fridolf (Fridolf et al., 2011) resumed and investigated a list of issues that can arise during an underground station evacuation. For instance people usually tend to maintain their role, i.e. passengers. This behaviour is theorized in the role-rule model and was developed after several experiments conducted in the past (Zimbardo, 1973). Other factors having effects on the efficiency of the evacuation were found to be related to the door-opening system, the lack of lighting and the uneven surface inside the tunnels.

1.1.1 Human Behaviour Theories

During daily activities, such as going to work, shopping or attending meetings, people are used to engage a routine behaviour (Kuligowski, 2011). When an emergency situation occurs, people are faced to new and exceptional scenarios where the normal actions and interactions with other individuals may not apply anymore (Kuligowski, 2011). In these emergency crisis, such as a building on fire or smoke spreading in a room, people are required to create a new set of actions which are completely different from those which became routine (Kuligowski, 2011). The Emergency Norm Theory (ENT) (Turner and Killian, 1957) explains this kind of performance and precisely, it explains the collective behaviour in which norms can emerge through a process of social collaboration, in which people seek for cues and signs indicating various possibilities of what they might expect (Turner and Killian, 1957). Furthermore, a decision-making framework has been developed in order to extend and apply ENT's explanation of the meaning-making process in emergency situations. This framework has been summarized in The Protective Action Decision Model (PADM), which is built on years of studies of hazards and disasters (Mileti and Sorensen, 1990; Sorensen and Sorensen, 2007). This model theorizes that cues from the environment, such as the sight of smoke or fire and the information given from emergency messages or warnings, if perceived as representing the presence of a threat, can interrupt normal routine activities of the individuals. Depending on the information received about the threat, people will either seek additional evidences, or they will try to protect people or property, or they will resume normal activities (Kroll-Smith et al., 1997).

Due to the fact that tunnels represent non-familiar environments, the routine behaviour described above may no longer apply. In such environments, where rescue teams can help evacuees only after long delays, more studies need to be carried out focusing on the reaction and behaviour of people in presence of new way-guidance installations. In particular, in the present thesis, an evacuation experiment is performed with the goal of studying the behaviour of participants in presence and absence of high-bright and dynamic lights in a smoke-filled railway tunnel. More details on the analysed way-guidance installation are given further in the text.

As previously mentioned, human behaviour in fire is a complex process which is difficult to analyse. In the past, useful theories have been developed to study human behaviour. For instance, the behaviour sequence model, the theory of affordances, the egress time-line model and the affiliative model can be taken into account. Furthermore, the study of social influence should be examined in order to analyse human behaviour in fire (International Symposium on Human Behaviour in Fire, 2004; Nilsson, 2009; Kinateder et al., 2013).

Due to the characteristics of the experiment presented in this paper, only the theory of affordances and the affiliation theory will be used and analysed. In particular, this paper aims to analyse the efficiency of a new proposed way-guidance installation. The experiments have been conducted in order to investigate if the way-guidance installations can have a significant role in the evacuation process. In particular, the experiments aim at studying if the proposed way-guidance installations can reduce the total time to evacuate, the total travelled distance and the distance from the vertical walls of the tunnel. Furthermore, a questionnaire has been administered to each participant in order to collect their opinions regarding the way-guidance installation. The questionnaire was developed in order to gather data to understand and study how participants perceived the information given by the way-guidance installations. A short description of two considered theories is given in the next paragraphs.

1.1.1.1 Theory of Affordances

The theory of affordances was firstly introduced by Gibson in 1977 (Gibson, 1977) to provide an explanation on how people perceive objects and how people interpret the functionality of a particular device. This theory was revised few years later by Gibson (Gibson, 1979) who introduced and extended this concept of perceiving objects with the concept of what it can offer or afford to people. In 2003, Hartson (Hartson, 2003) modified the original theory proposed by Gibson by introducing four categories or groups of different affordances that an object can offer to its user. These categories are summarized and presented below:

- **Sensory Affordance**: The design of the object must help the person in sensing the object, i.e. the object has to be easily seen, heard or felt.
- **Cognitive Affordance:** The design of the object must help the user to understand the functionality and the purpose of using the device.
- **Physical Affordance:** The object is designed to help the user in doing something. Moreover the object cannot require much effort from the user in order to achieve the final goal.
- **Functional Affordance**: The object has to achieve the final goal of the user. In other words is the achievement of the previous bullets.

In fire safety engineering the theory of affordances has been especially used in the human behaviour field (Nilsson, 2009, 2014). This theory is employed in order to explain why certain designs of emergency exits may not work or why they perform in a poor way. Since the theory of affordances goes step by step in parallel with the design of an object it is useful to understand the basic principles of this theory in order to achieve the best quality and the best functionality of a certain object.

The way-finding installation analysed in this document has been further evaluated through a questionnaire based on the principles of the affordance theory. The questionnaires were given to each participant after completing the experiment in order to have a comparison and a validation of the examined system. The questionnaire administered to the participants is presented further in this document.

1.1.1.2 Affiliation Theory

The affiliation model, or theory, was first introduced by Sime in 1984 in his PhD research and improved in the following years (Sime, 1985). The model proposed by Sime is an integration of psychology and engineering in order to obtain the best design for a building in case of an evacuation. The model is based on the basic principle that people chose to evacuate, or move, through familiar exits or routes. It is also explained that occupants tend to move towards familiar people in case of emergency. This theory explains that people usually exit from the same way they came in since it's the only familiar and known exit. In order to demonstrate his hypotheses, Sime studied the Showbar fire (Sime, 1985), on the Isle of Man, United Kingdom, where 50 people lost their lives. After a long analysis of police interviews from survivors, Sime concluded that the most severe factors which affected the direction of the evacuation of people were a combination of three components. These three components are listed below:

- Other person's role, i.e. visitor or staff member
- Person's bonds, i.e. other family members or friends inside the building
- The proximity of people to emergency exits

Sime established that staff members used a secondary emergency exit because it was the entrance for staff members during a normal working day. Instead visitors used the main entrance of the building since it was the only exit they knew.

Other experiments were carried out in recent years and it was found that behaviours observed in evacuation are in line with Sime's theoretical model (Canter, 1991; NIlsson, 2003). In the last years this model has been improved with the concept of discarding emergency exits when these are 90 degrees from evacuees' path (NIlsson, 2003). Figure 1 explains graphically this concept.

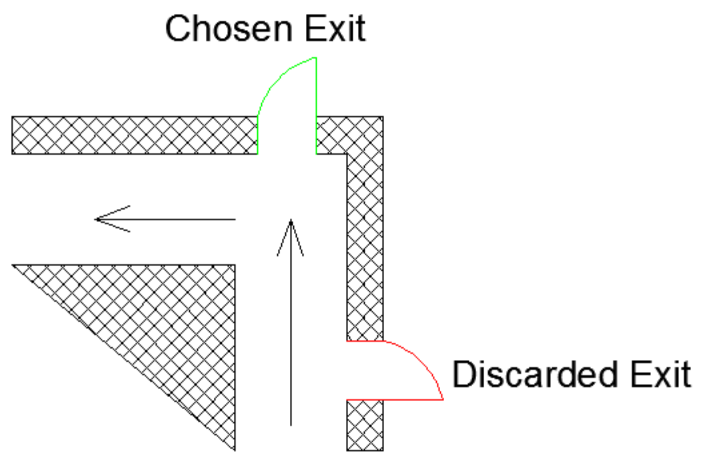


Figure 1 - Exit Choice scenario based on Nilsson's experiments [2003]

Thus, this discarding exit behaviour can be seen as an issue for this thesis. In case of emergency, tunnel users have to evacuate through exits which are always placed perpendicularly to the travelling path.

1.1.2 Colour of Emergency Signs

Recent studies (Nilsson, 2009) have found that flashing lights at emergency exits can influence the exit choice. In particular it was found that green was more suitable for the experiments because this colour is usually associated with positive aspects, i.e. safety (Nilsson, 2009). It was found that the human eye is more sensitive to certain wavelengths (Judd, 1975). In particular, it was discovered that the human eye is more sensitive to a wavelength of 555 nm (Judd, 1975), which corresponds to a bright green light. Further studies carried out by McClintock (McClintock et al., 2001), discovered that the flashing blue lights should be used for emergency situations due to the fact that this colour is linked to the emergency services. Nevertheless, green is usually associated with the concept of *safety* or *go* (Nilsson, 2009), even though colours can have different meanings according to different cultures (Wickens, 2013). For instance, a red light might be counter-productive and therefore can lead people to a wrong understanding of the signage intention (Nilsson, 2009). Thus, it is important to use colours which are associated with the concepts of *safety*. For this reason, it has been decided to adopt the green colour for the analysed way-guidance installation.

1.2 Purpose

An important aspect in evacuation concerns the effectiveness of the signage and of the way-guidance systems (Xie, 2011). General guidelines for fire safety in rail tunnels are available in many international standards. Due to the fact that these standards differ from country to country, it was decided to follow the guidelines proposed by the International Union of Railways (UIC) and by the UN/ECE (Micolitti, 2010; Railway Group, 2007). The measures proposed by the UN/ECE apply to any railway tunnel, with no distinction in length or number of trucks. However it is stated that these measures shall be adapted and modified in case of undersea tunnels, very long tunnels (with a total length greater than 15 km) and very steep mountain tunnels. These guidelines were followed in order to create the tunnel in the virtual environment.

Although several legislations and standards (Railway Group, 2007) provide guidance on how to displace signage, there is no certainty if the way-guidance systems are effective in practice. Thus, it is important to understand if occupants can uptake the information given by the emergency signs and by the way-guidance systems.

Therefore, the purpose of this experimental thesis is to demonstrate if a new and simple installation, such as stripes of high-bright and dynamic lights, can support participants' evacuation from a simulated railway tunnel accident. This thesis aims to establish if the proposed way-finding installations can help people to find the closest exit in the shortest time and to investigate if the installation can influence participants' exit choice.

Moreover, the thesis' intention is to determine if the participants will be comfortable or not with this new system. In other words, the series of tests want to prove that the analysed way-guidance installations have positive effects on participants' exit choice. In order to collect this information, a questionnaire has been administered to each participant after the tests. The questionnaire is described further in this document.

2. Methodology

The cornerstones of the thesis are experiments carried out in a virtual reality environment. The experiment reproduces the evacuation from a smoke-filled railway tunnel. This thesis aims at establishing if the analysed installations can help people to find the closest exit. The structure of the experiment is presented in the following paragraphs.

Due to the goals of the experiments, it has been decided to perform a between-group experiment. This particular design consists in dividing the participants into two or more groups where one group is generally associated with the control group (Sekaran, 2013). The control group usually performs experiments with neither variables nor modifications. Thus, the obtained results are usually used as reference in order to prove if any deviation from other groups is present. In order to avoid bias during the experiments, participants were kept "blind", meaning that they were not informed about which group they were belonging to. Thus, participants knew only that they were going to perform an experiment regarding tunnel safety. Another major concern regarding between-group designs is that skewed data results are common to obtain, leading to false conclusions to be stated (Sekaran, 2013). In order to prevent any problem related to subject-expectancy biases, the experiments were randomly assigned to the participants. On the other hand, the advantage in using a between-group experiment is that multiple variables can be tested simultaneously (Sekaran, 2013).

2.1 Virtual Reality

Virtual reality (VR) is a term that applies to computer-simulated environments that can simulate physical presence in places in the real world, as well as in imaginary worlds (Steuer, 1992). Most virtual reality environments are primarily visual experiences even though it is possible to have additional sensory information, such as sounds, touch and it is also possible to reproduce odours through the use of olfactometers (Lundström et al., 2010). It is important to highlight that in the experiment presented in this document participants performed only a visual and auditory experience neglecting the possibility to touch objects or interact physically with the surroundings.

It is possible to find the first VR systems at the beginning of the 1950s, where the device was mainly used as a vehicle simulator (Cline, 2005). Even though it might be hard to represent accurately the real world (Interscience Communic, 2013, pp. 565–570), the usage of VR systems became common and increasingly frequent in the fire safety field (Smith and Ericson, 2009; Wang and Li, 2010). Many studies have been carried out in the recent years (Jeon and Hong, 2009; Rebolledo-Mendez, 2009), focusing on the use of the VR as a training system for fire-fighters and for fire evacuation.

The purpose of using VR experiments is to overcome the incapability of representing a full scale test or objects, which are most of the times bulky or difficult to build. On the other hand, field studies, such as unannounced drills, provide good ecological validity (Andree et al., 2013). However, it is hardly possible to obtain from real world studies complete experimental control. Instead, VR experiments are highly experimental controlled (Persky and McBride, 2009) and it is possible to easily design replicable experiments with acceptable efforts and costs. Another critical aspect of using VR is that it can reproduce complex and dangerous situations with maintaining the complete control of the experiment in a safe environment such as a laboratory (Boyle and Lee, 2010). For instance, the VR can reproduce smoke-filled environments but it avoids the use of irritant smoke.

With the development of new technologies and software it is possible to reproduce and visualize a non-harming and realistic smoke. It is also possible to combine the results obtained from different computational fluid dynamics (CFD) software with the virtual environment (Yongxhe et al., 2013). In this thesis a simulation ran with FDS5 (McGrattan et al., 2010) has been used to analyse, and afterwards reproduce, the smoke behaviour inside the VR. It must be highlighted the fact that FDS has been ran only to have a general idea of the smoke behaviour inside the tunnel rather than performing a direct implementation of the FDS visibility output. Thus, the goal of the present thesis is not programming or relating FDS to the use of the virtual environment. More specifically the results obtained by the simulations ran with FDS5 were mainly focusing on the visibility output. Then, the results were used as a base for the smoke which has been only rendered and not calculated. More details about the FDS analysis is given further in the document. With the use of the VR, participants can observe in first-person the spread of smoke inside the built environment and move freely in any direction. Without the presence of irritant smoke, test participants are not subjected to any harm. Another advantage in using this particular and artificial environment concerns the time consumed, which is significantly reduced if compared to real and full scale experiments.

Although VR can have many benefits, some ethical and methodological aspects must be considered. The main limitation of using a VR is that participants will always know that they are taking part in a simulated environment (Andree et al., 2013). Thus, it must be questioned if the external validity of the experiment will be affected. An experiment is said to be externally validated if participants show the same behavioural, emotional and cognitive response both in the VR and in the real world (Anderson and Bushman, 1997). An ethical aspect, which needs to be considered, is that the VR must be designed in a way that will not traumatize participants. For instance, participants need to be able to distinguish real and virtual world after having performed the experiments. Thus, it must be highlighted the fact that the use of VR cannot substitute any real field experiment but it can be used as a complementary analysis (Andree et al., 2013).

2.2 Oculus Rift

The experiment presented in this study has been carried out with Oculus Rift® (Oculus VR Inc., 2014), a virtual environment head-mounted display, which lets the user step inside the created environment. This device has an 18 cm screen in which a tracking system is mounted. This tracking technology allows the user to turn the head up to 360° by keeping the field of view more than 90° horizontal and 110° diagonal (Oculus VR Inc., 2014).

Figure 2 - Participants wearing the head mounted display during the experiment

Moreover, the device uses a stereoscopic 3D view which creates parallel images to each eye. The headset has a dial on each side that can be turned with a screwdriver which allow the user to adjust each display and to move it closer or further away from the eyes. The resolution of the device is set up to 1280×800, with a 16:10 aspect ratio, leading to an effective resolution of 640×800 per eye with a 4:5 aspect ratio (Oculus VR Inc., 2014). To set up the VR environment, one freeware software and one open source were used (Trimble Navigation Limited, 2013; Unity Technologies, 2014).

It is important to emphasise that the experiment has been carried out in a controlled laboratory environment. One of the main benefits in using a controlled laboratory environment is that the researcher has control over the entire experimental settings (Nilsson, 2009). This method allows the study of single variables or aspects of interest. Furthermore, it has been notice that the use of a VR has positive aspects regarding the external validity of the experiments (Anderson and Bushman, 1997, pp. 19–41), i.e. participants revealed similar behaviours compared to the real world. Nevertheless, certain features, such as directions and walking speed of the agent inside the VR environment, are mostly dependent on the settings provided in the virtual reality world and are imposed to the participants of the tests. In the last decade some experiments were carried out in order to validate the use of the VR (Kobes et al., 2010; Smith and Ericson, 2009; Tan et al., 2006). In these studies it was discovered a good correlation and a good correspondence between results obtained from the virtual tests and results obtained by running the same experiments in the real life (Tan et al., 2006). Another example of using the VR to study human behaviour in fire was carried out by Lund University and University of Würzburg (Andree et al., 2013). The employment of the VR methods was used to analyse the design of rescue chambers in underground. The aim of the tests was to study and improve the design of the rescue chambers and to collect information regarding people's reaction and perception of the different proposed solutions. Recently, Kobes (Kobes et al., 2010) performed a number of experiments trying to validate and confirm a correlation between the results obtained from a real life evacuation from a hotel and the same type of experiment carried out in a VR. Kobes' results showed that the two groups of results did not differ significantly (Kobes et al., 2010).

2.2.1 VR Setting

In this particular evacuation test, values for walking speed has been fixed to 1.2 m/s according to previous study cases (Jeon et al., 2011) and according to the visibility conditions calculated through CFD simulations. More information regarding the CFD calculation and the walking speed is given further in this document.

At the beginning of each experiment, before interacting with the virtual environment, a video has been shown to participants. The video was meant to give to the participants the idea of being actually traveling inside a train. The video has been taken from a computer game (Railworks, 2013) and it has been modified and adapted with several software, such as Avidemux (Mean, 2009), Fraps99 (Beeta, 2013) and VirtualDub (Gnu, 2013), in order to make it more suitable for the experiments.

The virtual environment has been created with the game engine Unity3d (Unity Technologies, 2014). The main structure of the virtual environment has been firstly made in a 3d modelling tool (Trimble Navigation Limited, 2013) and then imported into the game engine in order to create animations and sounds. The sounds were found on open source webpages (Music Technology Group, 2014).

Figure 3 - Screenshots of the initial video (Railworks, 2013)

2.2.2 Procedure

As mentioned before, the set of experiments has been carried out completely in a virtual environment. Each test is composed by three steps, namely (1) a short reproduction of a video at the beginning of the trial, (2) the interaction of the test participants with the VR environment and (3) the fulfilment of an administered questionnaire. After having completed the questionnaire, participants were informed about the experiment' purpose and they were given the chance to ask further questions. The figure below shows the procedure of the experiment.

Figure 4 - Experiment procedure, namely, (1) reproduction of the video, (2) experiment, (3) administration of the questionnaire and (4) open discussion with the participant

The experiments were carried out in a room of about 6x6m, located on the third floor of the Kemicentrum building at Lund University. The room did not present any window and it was acoustically insulated.

Three groups of participants have attended the experiments. A total number of 60 people took part in the tests. The participants were divided into 3 groups. The first group, labelled as the control group, performed the experiment without any way-guidance installation. Thus, the participants had to rely only on the standard tunnel lighting conditions and emergency signs (Micolitti, 2010). The second and the third group completed the tests with the presence of way-guidance installations. The second group performed the experiments with a new way-guidance installation, which consists in LED stripes of 10mm wide, 2 mm thick and 10 m long. The illuminated LED creates a horizontal traveling line of approximately 2 meters of length. An alternation of illuminated and switched off LED is formed, creating an optical illusion of movement. Thus, in 10 meters-long stripe, three illuminated lines are present while 4 meters of LED remained turned off. Several stripes have been set in order to cover all the length between the starting point of the experiment and the emergency exits.

The third group, instead, performed the experiments with a modified dynamic way-guidance installation. This proposed system is derived from the previous system and it consists of a long continuous LED stripe. Thus, the illuminated led stripe shows the entire path from the starting point to the emergency exit. As the previous system, the LED stripe creates an optical illusion of movement by alternating one LED switched on and one off.

At the end of the experiment a questionnaire has been handed out to each participant. The questionnaire consisted in 32 questions, divided in 20 multiple choice questions and 12 open questions. The survey was meant to rate the different way-guidance installations in the experiments. It was asked to give feedbacks and comments on the analysed systems in order to evaluate the utility and the functionality of the tested way-guidance installations. At the end of the questionnaire, one question has been included asking participants to give comments related to any possible improvement and upgrade that can be applied to the experiment. An example of the delivered survey is presented in Appendix A.

People have been recruited by posting announcements at different faculties at Lund University, Sweden. In particular, flyers have been attached to some notice boards inside university departments. Moreover, other flyers have been posted at the entrances of university dorms in Lund, Sweden.

Participants have also been recruited with the use of social media. In particular, it was decided to create an email account and a Facebook group where people could subscribe or ask information regarding the tests. People who participated to the tests also spread the word to other people. Before starting the trial, each participant had to sign an informed consent in which it was explained a general overview of the experiment. Moreover, the informed consent included a list of participants' rights which were further explained orally. More information about the sample characteristics is given in section 2.3.

Due to the fact that test participants could spend an unlimited amount of time inside the VR, it has been decided to set up a limit of 15 minutes to each set of experiment.

2.2.3 Tunnel

The railway tunnel used in the experiment consists of a squared-shaped single tube concrete structure, with a cross section area of 38.64 m^2. The tunnel is 5.6 m wide with a total height of 6.90 m and 1200 m long. Besides the railway tunnel, two road tunnels were placed in order to let the participants evacuate and complete the tests. Thus, in this study, the parallel tunnels served as egress path in case of emergency (Railway Group, 2007).

UNECE guidelines suggest a minimum and maximum value for walkways width, namely 0.7m and 1.2 m. Thus, it was decided to insert two lateral walkways in the rail tunnel with a width of 1.10 m each. Figure 5 illustrates the structure of the central part of the railway tunnel.

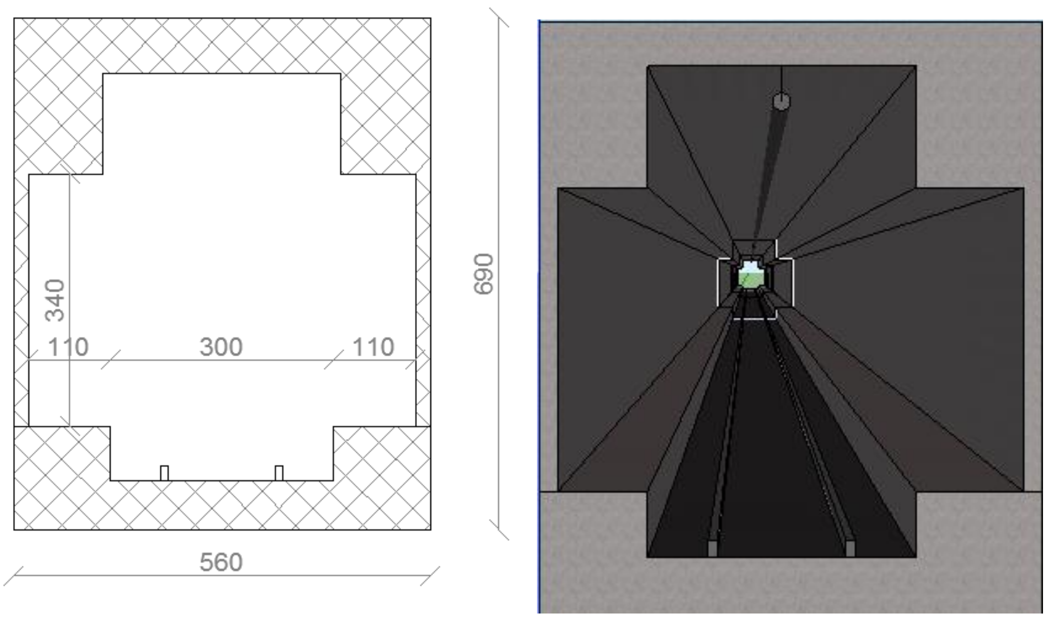


Figure 5 - Rail Tunnel Cross Section and Rail Tunnel Rendering

2.2.4 Lighting

In the UN/ECE standard it is stated that Emergency Tunnel lighting should be installed in one or both sides of the tunnel, regardless of whether the tunnels is a single or double tube. It is also stated that escape walkways shall be properly lit. Nevertheless it is not specified the intensity or the minimum distance between the lights (Railway Group, 2007). Thus, an average value of intensity and distance among the lights has been calculated considering the European rail-tunnel countries previously categorized.

Lighting and emergency signs should be powered through battery sets in order to prevent any power loss or failure. The emergency signs must be switched on permanently during normal operative conditions. The safety lighting must provide at least 1 lux (Micolitti, 2010; Railway Group, 2007) at the walkway level and a minimum of 2 lux in staircases. The lighting system must be placed at a minimum height of 0.6m from the walkway level and a maximum of 2m. The distance between lights varies from 5 m to a maximum value of 50 m (Railway Group, 2007).

2.2.4.1 Tunnel lighting

The following assumptions were made:

- The lights were located at 1.5 m height, measured from the walkway level;
- The distance between the lights has been set up to 10 m;
- The lights were installed in one side of the tunnel walls;

Moreover tunnels should be marked with standard signs pictograms. Emergency signs include: exits, cross passages, telephones, etc. The background colour of the emergency signs should be green as specified in the standards ISO 6309 and ISO 7010 (*Fire Protection -- Safety Signs*, 1987, *Graphical symbols -- Safety colors and safety signs -- Registered safety signs*, 2011).The picture below shows the lighting system reproduced in the virtual environment.

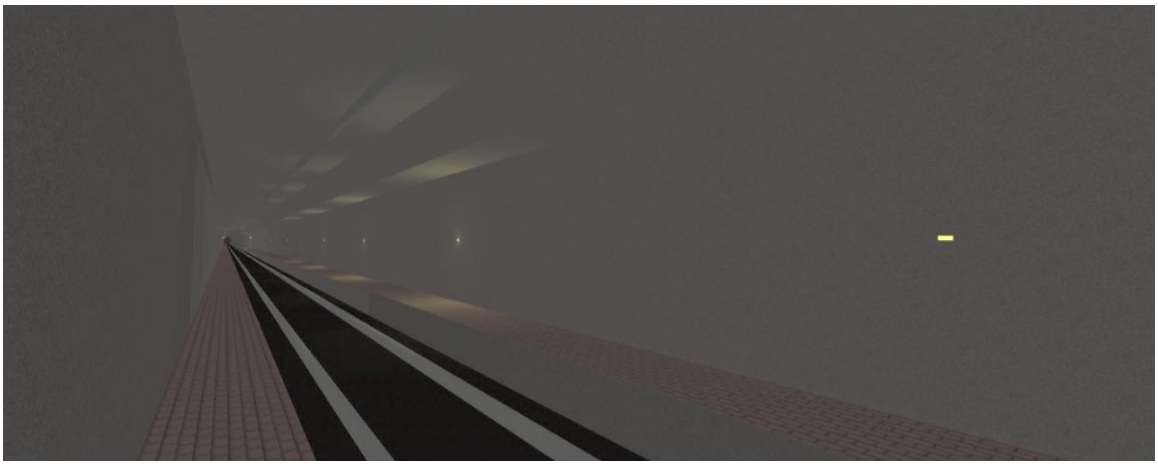


Figure 6 - Tunnel Lighting in the VR*

*The brightness of the figure has been increased by 20% with a modified contrast of -40% in order to be more visible

2.2.5 Emergency Exits

The tunnel is 1200 m long and it contains 6 emergency exits. In the UN/ECE standard it is recommended to have a maximum distance between two safe places, such as portals, cross passages or emergency exits, in order to enable an easy and quick self-rescue process. It is not mentioned an exact distance and it is stated that this gap depends on the local situation and on the operating parameters. Generally, the maximum distance between two safe places varies from 300 to 500 meters, as mentioned in the UIC Report IF 4/91 or Fiche 779-9 (Micolitti, 2010).

For the purpose of the analysed experiment it was decided to locate the exits at 600 m away from each other. Due to the fact that two emergency exits are more than 500 m away, the UN/ECE standard imposes a direct connection between the railway tunnel and a road tunnel. The proposed structure of the experiment meets these minimum criteria and measures.

There are 6 emergency doors in the tunnel. Each of them has dimensions of 2.25 m x 2.25 m as recommended by the standards (Micolitti, 2010). As mentioned above, each door is marked with signs pictograms based on the ISO7010 standard. All the emergency signs are reflective according to the standard ISO7010 (*Graphical symbols -- Safety colours and safety signs -- Registered safety signs*, 2011).

Even though the doors will automatically open during the experiment, they present the required and classical emergency exit structure with pushing bar systems. Figure 7 shows the reproduced emergency doors in the virtual environment.

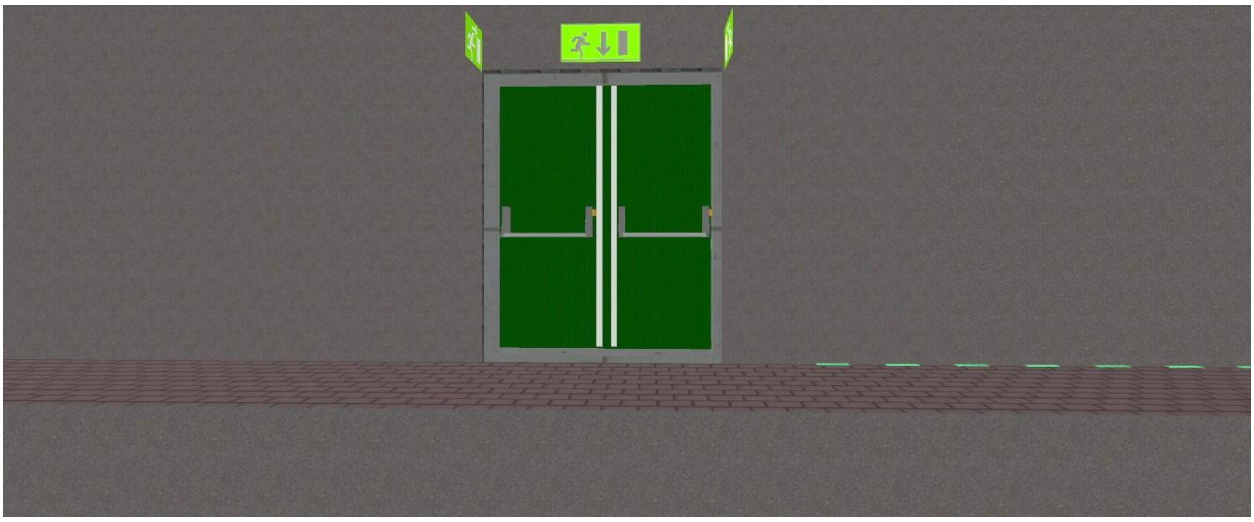


Figure 7 - Emergency Exit in the VR*

*The brightness of the figure has been increased by 20% with a modified contrast of -20% in order to be more visible

For the purpose of the experiments, the initial location of participants is at the same starting point, i.e. inside the train. The initial point is located 275 m away from the first couple of emergency doors and 325 m away from the second group of exits. Two last doors are located 600 m away from the starting point and they have been located with the idea of giving a last chance for participants to evacuate in case they got lost. Thus, more attention and importance have been given only to 4 emergency exits and they will be addressed as “main emergency exit”, namely EXIT A, B, C and D. Figure 8 and Figure 9Figure illustrate the location of the main emergency exits.

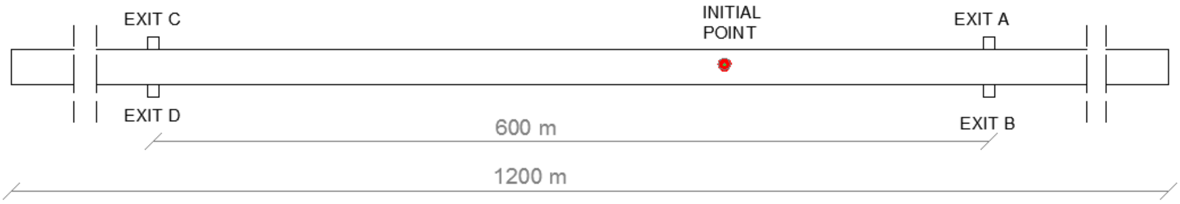


Figure 8 - Tunnel top view

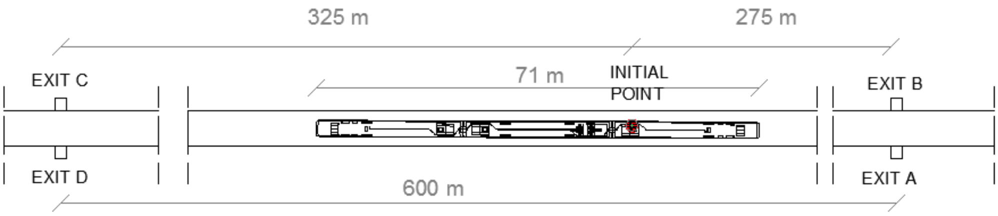


Figure 9 – Train top view and Exits distances

2.2.6 Way-guidance system

In the present experiments two way-guidance installations have been analysed and have been tested in a VR environment. In particular, the way-guidance installations are composed by LED stripes with high bright and two-direction-traveling lights. As mentioned before, the human eye is more sensitive to a colour corresponding to a wavelength of 555 nm, which corresponds to a colour between yellow and green (Judd, 1975). Nowadays the way-guidance installations tested in this experiment are available on the market.

The proposed way-guidance installation consists in LED stripes of 10mm wide, 2 mm thick and 10 m long. The illuminated LED creates a horizontal traveling line of approximately 2 meters. An alternation of illuminated and turned off LED has been created, generating an optical illusion of movement. Thus, in 10 meters long stripe three illuminated lines are present while 4 meters of LED remain turned off. This proposed way-guidance installation will be referred with the name *AlterLi*. Several stripes have been set in order to cover all the distance between the starting point of the test and the emergency exits. Figure 10 shows graphically the concept of alternation of illuminated and non-illuminated LED.

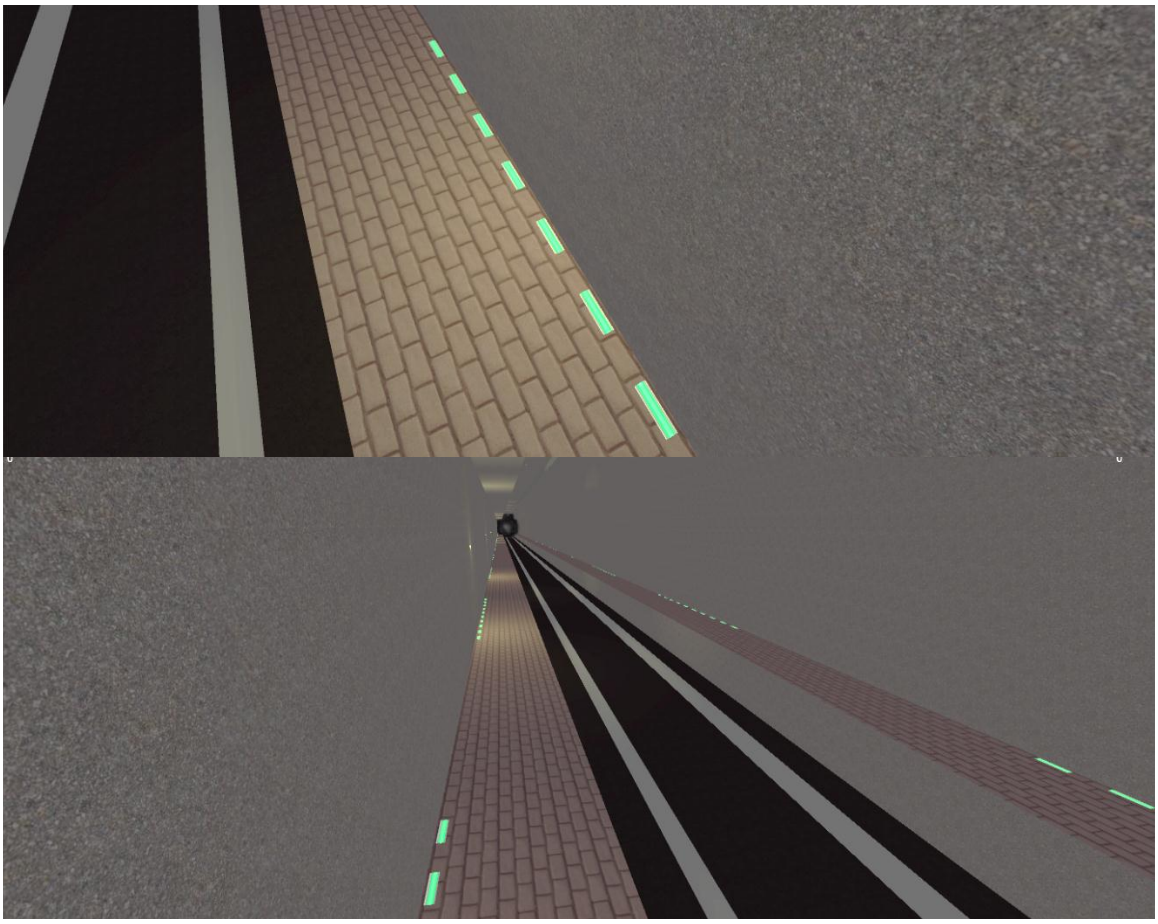


Figure 10 – Proposed way-guidance installation shown in VR environment (AlterLi)*

*The brightness of the figure has been increased by 20% with a modified contrast of -40% in order to be more visible

The third group of participants performed the experiment with a modified way-guidance system. The proposed way-guidance installation is derived from the previous system and it consists of a long continuous LED stripe. Thus, the illuminated LED stripe shows the entire path from the starting point to the final exit. Therefore, only one stripe has been used per each emergency exit. This system is composed by a 10mm wide and 2mm thick stripe. As the previous way-guidance installation, the LED stripe creates an optical illusion of movement by alternating one LED switched on and one off. This proposed way-guidance installation will be referred with the name of *ExtenLi*. For the reasons mentioned before, it has been decided to set the colour of the lights to green. Figure 11 shows graphically this concept.

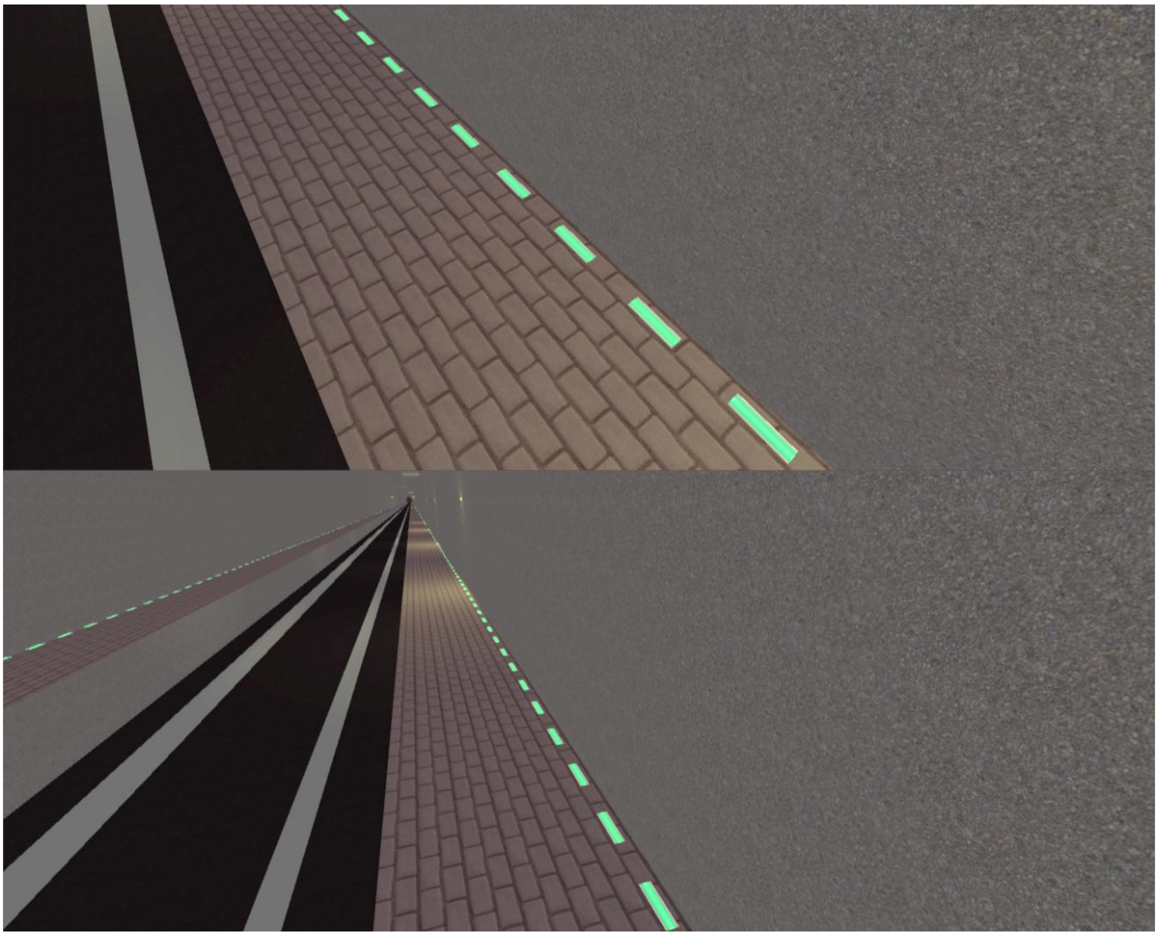


Figure 11 - Modified way-guidance system shown in the VR environment (ExtenLi)*

*The brightness of the figure has been increased by 20% with a modified contrast of -40% in order to be more visible

2.2.7 Questionnaire

At the end of each experiment, a questionnaire has been administered to the participants. The questionnaire was meant to have a comparison and a validation of the examined way-guidance installation systems. Furthermore, participants were asked to answer general questions regarding themselves, such as nationality, gender and age, and specific questions regarding their experience during the experiment. A total number of 32 questions have been inserted in the questionnaire. The complete list of questions can be found in Appendix A at the end of this document.

In particular, participants were asked to answer six questions regarding the way-guidance installations present in the experiment that they have performed. Precisely, the questions were assembled into 3 groups. Each group contained two questions. The questions were meant to follow the basic concepts of the theory of the affordances which has been previously explained.

Thus, the six questions inserted in the questionnaire aimed to understand three different concepts, namely, (1) if participants could see the installations, (2) if participants could understand the purpose of the installations and (3) if participants had the perception to be influenced by the installations.

The first two questions concerned the participants' ability to see the way-guidance installations. In particular, participants were asked if they have seen something unusual on the sidewalk of the tunnel and afterwards if they have seen the way-guidance installation on the sidewalk of the tunnel. The second group of coupled questions concerned participants' ability to understand the purpose of the way-guidance installation during the experiment. In order to find out if participants understood the real purpose of the way-guidance installation, two questions were inserted in the questionnaire. In the first question, participants were asked to give their own opinions regarding the purpose of the installation. However, in the second question, participants were asked to choose between 3 different explanations. In particular, participants were asked which definition was the best representative for the purpose of the installation. The three definitions were, namely, (1) the installation serves as a decorative tool in the tunnel, (2) the installation is intended to illuminate the tunnel, (3) the installation is meant to show the direction of the exits.

In the third section of coupled questions, participants were asked to state and then to rate the degree of influence of the way-guidance installation on their choice of the evacuation path. In the first question participants were asked if the way-guidance installation supported their choice of the evacuation path, while in the second question participants were asked to rate on a scale from 1 to 5 (where 1 meant poor and 5 meant high), how the way-guidance installation influenced their decision on the direction of evacuation. The analysis regarding participants' answers is shown further in the document.

2.2.8 FDS Simulation

In order to perform the virtual experiment and understand the possible smoke spread, a CFD analysis has been carried out. In particular, the CFD simulation was developed in order to have a general idea of the smoke behaviour inside the tunnel. Thus, the purpose of running a CFD simulation was to understand and afterwards to render the smoke spread inside the built environment. In order to set up the simulation, real values for heat release rate (HRR) were chosen from full scale experiments.

In the last decade several studies have been conducted worldwide on HRR from burning railway cars (International Symposium on Tunnel Safety and Security et al., 2010). One of those projects, named EUREKA (Stahlanwendung, 1995), was developed by 9 different European countries in order to evaluate, through full scale tests, thus permitting to identify a model to represent the HRR of burning rail passenger coaches located inside a tunnel.

The tunnel used for the EUREKA experiments had a total length of 3.2 km. It had a squared section (horseshoe shaped) with a total width varying from 5.3 to 7 meters and height between 4.8 and 5.5 meters. Four rail cars were tested separately in different settings including subway cars and rail passenger cars (intercity coaches). These vehicles were made either by steel or aluminium frames. Several experiments were conducted with different settings. The fire source was always placed inside the cars and isopropanol was always used to initiate the fire. The results from EUREKA experiments are summarized* in Table 1.

Table 1 - Eureka Experiment Results (Stahlanwendung, 1995)

Vehicle type	Fuel load [MJ]	Kg of isopropanol (ignition source)	Result	HRR ±25% [MW]
Subway car in steel (f31)	32.67	0.7	Car burnt out Fire duration 20 min	-
Rail Car in steel	62.48	6.2	Car burnt out Fire duration 70 min	20
Subway car in aluminium	41.36	6.2	Carriage burnt out and roof melted away Fire duration 20 min	35
Rail car in steel	76.89	6.2	Carriage burnt out Fire duration 100 min	14

* Not all the experiments are represented in the above table due to incomplete information reported

Rail cars were calculated to have a peak of HRR varying from 14-35 MW with maximum gas temperatures inside the cabin of 800-1200 °C.

According to the results obtained from the EUREKA experiment, it was possible to set up a CFD calculation. The CFD simulation has been run with FDS 5.6 (McGrattan et al., 2010, p. 5) and it has been used as an input to predict the visibility inside the tunnel. The results obtained from this simulation were reproduced into a game engine. It was decided to analyse and reproduce a rail car made of steel, with a total HRR of 20 MW. Further details are given in the following chapter.

1.3.8.1 FDS results

This paragraph presents a short description of the settings used in the simulation ran with the software developed by NIST (National Institute of Standards and Technology) named FDS5.6 (McGrattan et al., 2010). This section illustrates the results obtained from the simulation.

Given the scope of this study, it was decided to reproduce only a short section of the tunnel, where participants could mostly be exposed to smoke. Thus, only 450 m out of 1200m of tunnel have been computed. The width and the height of the tunnel are consistent with the VR design. Due to the fact that a part of the calculation uses the Poisson solver based on Fast Fourier Transforms (McGrattan et al., 2007) in the y and z directions, the second and third dimensions of the mesh should each be of the form $2^l\ 3^m\ 5^n$, where *l*, *m* and *n* are integers (McGrattan et al., 2007). In order to achieve this relationship it was decided to choose a uniform grid with cell size of 20 cm in each direction (Gissi, 2010). Therefore the total number of cells is equal to 2488320.

The total time of the simulation has been set up to 300 seconds. The results obtained from 150 to 300 seconds have been averaged and used as a starting point to build up the virtual environment conditions. This approach was followed due to the fact that the experiment consists in studying the participants' behaviour in smoke-filled tunnel in presence/absence of way-guidance installations. Therefore the information of the initial stage of the fire was discarded. In particular the simulation aimed at identifying the extinction coefficient and visibility inside the tunnel. In order to do so, several command lines, such as &DEVC VISIBILITY and &DEVC EXTINCTION COEFFICIENT, were inserted inside the FDS input file at different positions. For instance, the extinction coefficient and the visibility conditions were measured in the middle of the train and at 10, 25, 50 and 100 meters away in each direction from the train. Figure 12 shows the position of the measuring points in the FDS simulation.

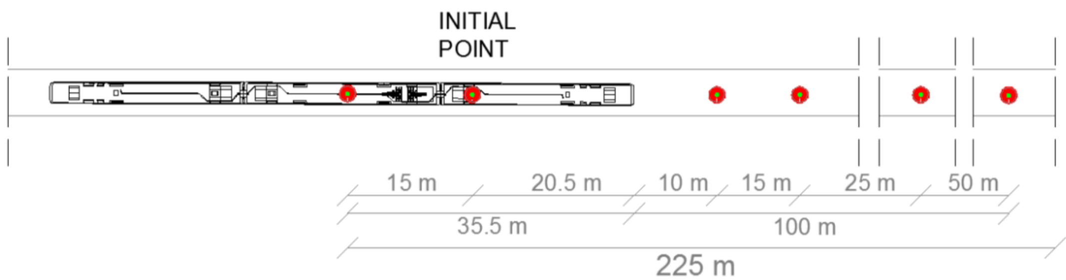


Figure 12 - Position of measuring points in FDS simulations

A total number of three simulations were conducted in which the location of the fire was varied. Firstly, the fire was placed inside the train and it aimed to reproduce the EUREKA experiment mentioned above (Stahlanwendung, 1995). Secondly, the fire was placed on the roof of the train. Finally the fire was placed below the train. The complete input file can be found in Appendix B.

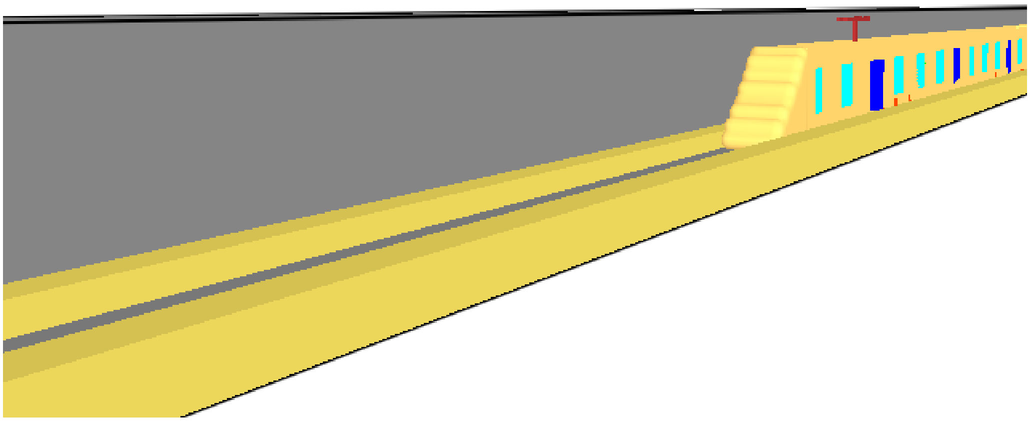


Figure 13 - FDS Simulation Initial Conditions

In the following section pictures from FDS smoke-view are presented. In particular, the pictures show graphically the results obtained from the three different simulations. Specifically, it is shown the smoke-view profile at 300 seconds giving the idea of the smoke layer height. The smoke layer height was measured at the same position for the three simulations. It was found that the smoke layer thickness varied from 0.5 meters, in the case of the fire located on top of the roof of the train, up to 3.6 meters where the fire was located below the train. Furthermore, it is also presented the extension and the expansion of the smoke inside the tunnel for the three different cases. It can be seen that the smoke reached the farthest position in the simulation where the fire was located in the upper part of the train.

Figure 14 - FDS result Smoke spread inside the tunnel: fire below the train

Figure 15 - FDS result Smoke spread inside the tunnel: fire above the train

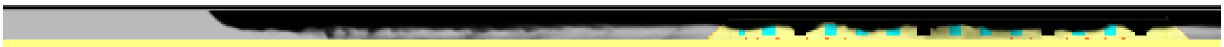


Figure 16 - FDS result Smoke spread inside the tunnel: fire inside the train

The resulting extinction coefficient was found to vary between 0.05 m^{-1} away from the train, up to 1.1 m^{-1} close to the train doors. Thus, it has been decided to render in Unity3d an average extinction coefficient equals to 0.45 m^{-1}. This value was obtained by taking the averaged value between the three simulations during an interval of 150 seconds. Furthermore, it is possible to calculate an averaged visibility S, according to the following equation:

$$S = \frac{3}{K}$$

Where the constant 3 refers to light-reflecting signs (Mulholland, 1995). Solving the above equation, the resulting visibility is found to be equal to S=6.66 meters. Once the visibility and the extinction coefficient are known, it is possible to determine the walking speed which has been imposed to the participants. In order to calculate the walking speed, the graphs from Jin (Jin and Yamada, 1989) have been used. In order to get comparable and realistic results, it has been decided to calculate the walking speed by using the non-irritant curve of Jin's graphs (Jin and Yamada, 1989). With the value of the extinction coefficient obtained from the FDS simulations, it was possible to calculate the walking speed. Thus, the resulting walking speed has been set up to 1.2 m/s. The following picture shows the representation of the smoke considered in the VR.

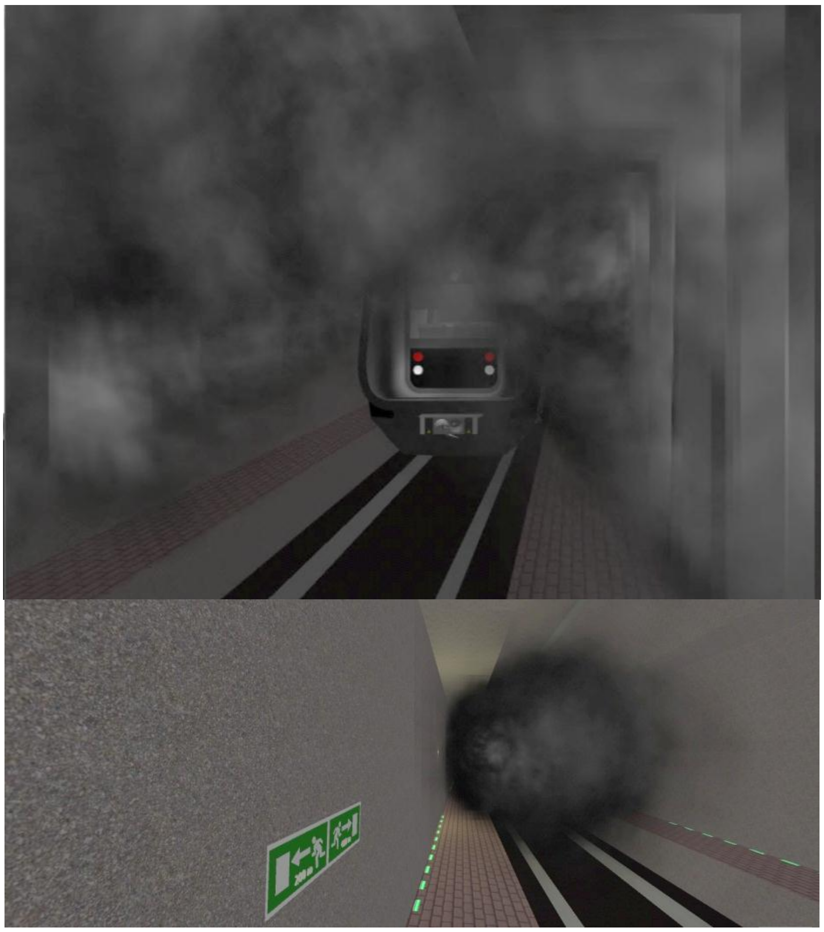


Figure 17 - Rendering of the smoke filled tunnel in VR*

*The brightness of the figure has been increased by 20% with a modified contrast of -40% in order to be more visible

2.3 Sample Characteristics

As mentioned previously, participants have been recruited in three different ways. A total number of 60 persons have participated in the experiment, namely 29 men and 31 women. The participants were mainly international students attending an exchange program at Lund University. Participants came from 26 different countries. The age among the participants ranged from 18 to 40 years with an average value of 24.2.

In the administered questionnaire, 55 (91.7%) of the participants reported that they were right-handed and 5 (8.3%) participants were left-handed. Moreover, only one participant declared to be affected by colour blindness.

The participants have been divided into three groups. Table 2 shows participants' demographic.

Table 2 - Participants of the tests

Scenario	Total Participants	Male [%]	Female [%]	Average Age
1	20	55	45	24.1
2	20	40	60	24.1
3	20	50	50	24.4
Total	60	48	52	24.2

Participants were also asked to state how frequently they used trains in the past year. Table 3 shows the collected information. It is possible to notice that the majority of participants (46.6 %) used trains with a frequency of at least once a week. Almost one fourth of participants (26.7%) declared to take trains with a frequency of at least once per month. It is also possible to notice that almost one fifth of the participants (21.7%) declared to use trains every day. Only three participants declared to take trains once a year. The results are shown in Table 3

Table 3 - Frequency of taking trains

Frequency	Participants	Percentage
Every Day	13	21,7 %
Once a week	28	46,6 %
Once a month	16	26,7 %
Once a year	3	5 %
Total	60	100 %

3. Results

The collected data from the experiments is presented in the following chapter. The data collection is based on a combination of behaviours observed during the experiments, such as total time needed to reach an emergency exit, movement patterns, and questionnaire answers. In the questionnaire participants were asked general questions regarding themselves and specific questions regarding their experience in the experiment. The complete list of questions can be found in Appendix A at the end of this document.

As mentioned before, a total number of 60 people participated to the experiments. The participants were divided into 3 groups consisting in 20 persons each. Each group represents one specific scenario, namely:

- Group 1 – Control Test –Scenario 1
- Group 2 – *AlterLi* Test – Scenario 2
- Group 3 – *ExtenLi* test – Scenario 3

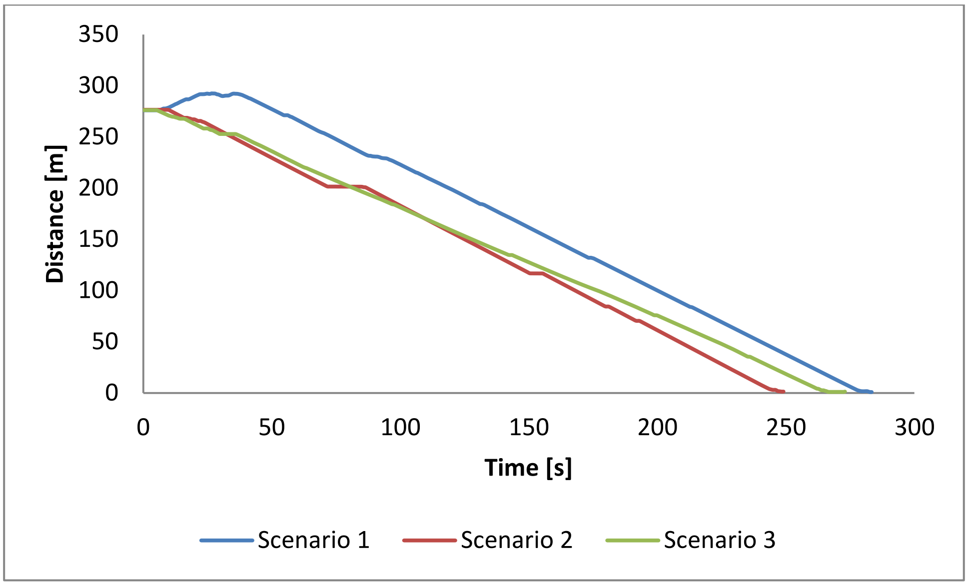
As mentioned in the previous sections, the codes *AlterLi* and *ExtenLi* refer to the two way-guidance installations examined in this document.

In the following paragraph, the results obtained in the three scenarios are shown. By tracking participants' coordinates during the experiments, it has been possible to calculate the travelled distance inside the tunnel. The coordinates were traced every 0.5 seconds. In particular, the by applying the Pythagoras equation, it was possible to observe participants' distances from the starting position to the chosen exit for each time step. The applied formula is:

$$\sum_{i=0}^{n} {d_i}^2 = {x_i}^2 + {y_i}^2$$

Where d_i is the distance from the chosen emergency exit at time step *i*, while x_i and y_i are participants' coordinates inside the tunnel at time step *i*. By plotting the sum of the distances d_i against the each time step t_i, and by integrating the results it is possible to calculate the area underneath the resulting curve (Kinateder et al., 2014). Thus, the total travelled distance is expressed in interaction area. Table 4 shows one example of total travelled distance for each scenario.

Table 4 – Example of travelled distance from chosen exit against time for scenario 1, 2 and 3 (Kinateder et al., 2014). Vertical axis represents the travelled distance [m]. The horizontal axis represents time expressed in [s]



Thus, by calculating the area beneath the respective curves it is possible to observe participants' movement patterns inside the tunnel.

Table 5 presents the mean values and standard deviations of each scenario respectively for (1) the averaged time needed to reach the emergency exit, expressed in seconds, (2) the averaged distance travelled by the participants, expressedin interaction area, (3) the averaged distance to the tunnel wall, expressed in meters.

Table 5 - Mean values and standard deviations regarding total time needed to evacuate, travelled distance and average distance form lateral walls

Scenario		Time [s]	Area [-]	Distance to walls [m]
Scenario 1 ***Control Test***	Mean St. Deviation	297.83 49.8	49748 14654	1.37 0.53
Scenario 2 ***AlterLi Test***	Mean St. Deviation	283.08 52.99	45256 14546	1.04 0.43
Scenario 3 ***ExtenLi Test***	Mean St. Deviation	285.19 46.31	45827 13970	1.06 0.43

One of the most frequently asked questions in the research field is whether the means between two or more groups of respondents on some behaviour are significantly different (Sekaran, 2013). In particular, a statistical analysis has been carried out regarding the means of (1) the total time needed to evacuate, (2) the total travelled distance and (3) the distance from the lateral wall. The analysis is focused on two main categories, namely group 1 and group (2+3). Group 2 and 3 have been merged due to the fact that they have in common a way-guidance installation. Thus, the resulting mean values and standard deviations for the new configuration of groups are summarized in Table 6

Table 6 - New Configuration Group Statistics

	Way-Guidance Installation?	Number of cases	Mean	Std. Deviation	Std. Error Mean
Time	Yes	40	284.4	49.1	7.7
	No	20	297.8	49.8	11.1
Travelled Distance	Yes	40	45541	14080	2226
	No	20	49169	13713	3066
Lateral Distance	Yes	40	1.43	0.42	0.05
	No	20	1.05	0.53	0.1

Therefore, the results are studied in a manner to prove if the presence/absence of the analyzed way-guidance installations can create significant differences between the two groups.

In order to statistically analyse the results, a software has been used (IBM, 2014). The results were firstly analysed in order to understand if the data set is well-modelled according to a normal distribution. Moreover, this analysis serves to compute how likely it is for a random variable to be normally distributed. In order to examine if the results follow a normal distribution, a frequentist test has been used (Sekaran, 2013). The results are presented in Table 7.

Table 7 - Normality Test

	Way-Guidance Installation	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Time	No	.170	20	.133	.951	20	.377
	Yes	.159	40	.013	.891	40	.001
Area	No	.140	20	.200	.933	20	.175
	Yes	.209	40	.000	.849	40	.000
Lateral Distance	No	.175	20	.112	.909	20	.061
	Yes	.212	40	.000	.883	40	.001
a. Lilliefors Significance Correction							

It can be seen that the Kolmogorov-Smirnov test gives a significance value (sig.) greater than 5% (0.133>0.05) for the results obtained in scenario 1 regarding the dependent variable time. Meanwhile, for scenario 2 and 3, the significance value regarding the variable time is lower than 5% (0.013<0.05), which is the usual statistical confidence interval (Sekaran, 2013). It can be seen that for scenario 1, 2 and 3 the significance is greater than 5% concerning the variable travelled distance and lateral distance from the tunnel walls. Therefore, it has been decided to treat the results as non-normally distributed. Thus, only non-parametric tests are going to be used in order to analyse the results.

To study the quantitative data set, it has been decided to examine few hypothesized relationships to see if any kind of appropriate conclusions can be found. The hypothesized relationships are expressed in terms of null hypotheses. Thus, six null hypotheses have been stated. Four hypotheses are related to the total time needed to evacuate and they are labelled with the capital letter H and they are:

- H_0 = the presence of the way-guidance installation will not reduce the total time to evacuate from the tunnel;
- H_0 = having previous experience in evacuation drills will not influence the total time to evacuate and reach an emergency exit;
- H_0 = having previous experience in VR environments will not reduce the total time to evacuate from the tunnel;
- H_0 = the frequency of taking the train will not influence the total time to evacuate from the tunnel.

The other two null hypotheses determine whether or not the presence of the way-guidance installation can reduce the total travelled distance and the distance from the tunnel walls. These two null hypotheses are labelled with the capital letter H'. Thus, the two remaining null hypotheses are:

- H'_0 = the presence of the way-guidance installation will not reduce the total distance to travel inside the tunnel;
- H'_0 = the presence of the way-guidance installation will not reduce the lateral distance from the tunnel walls.

In order to describe if any set of relationship is present inside the model, a cross-tabulation test has been carried out. A non-parametric method has been, namely the Chi-square test (χ^2). This method has been used to test whether the frequencies of two variables are related. Thus, six different tests were carried out. Firstly, the dependent variable *Time* has been analyzed in correlation with four independent variables, namely, (1) presence of any way-guidance Installation, (2) experience in evacuation drills, (3) experience in VR and (4) frequency of taking a train in the last year. Secondly, the distances travelled by the participants have been tested with the independent variable of having the way-guidance installation present during the experiment. Thirdly, the distances from the lateral walls of the tunnel have been set as dependent variable without varying the independent variable, i.e. the presence of the way-guidance installation. In order to determine if participants have had previous experiences regarding evacuation drills and virtual realities, a set of questions have been inserted in the questionnaire. It is worth noting that with the term VR, any experience with video

games is also included. Moreover, participants were asked to state the frequency they used to take trains in the past year. Table 8 and
Table 9 summarize the percentage of participants having previous experience in evacuation drills and virtual environments, and the frequency of taking trains.

Table 8 - Percentage of participants having previous experience with Fire drills and VR

	Yes	No
Previous Experience in Fire Drills	23 (38%)	37 (62%)
Previous Experience in virtual environments	40 (67%)	20 (33%)

Table 9 - Frequency of taking a train

Scenario	Frequency	N° of participants	%
Scenario 1	Every day	2	10 %
	Once a week	10	50 %
	Once a month	7	35 %
	Once a year	1	5 %
Scenario 2	Every day	6	30 %
	Once a week	9	45 %
	Once a month	3	15 %
	Once a year	2	10 %
Scenario 3	Every day	5	25 %
	Once a week	9	45 %
	Once a month	6	30 %
	Once a year	0	0 %
Total	Every day	13	22 %
	Once a week	28	47 %
	Once a month	16	27 %
	Once a year	3	5 %

Table 10, 11, 12 and 13 present the results obtained from the six Chi-square tests. The results are analyzed further in the document.

Table 10 - Time*Way-guidance Installation and Time*Experience in Fire Drills part I

Chi-Square Tests Time-Way-guidance Installation			
	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	55.500[a]	52	.344
Likelihood Ratio	70.837	52	.042
N of Valid Cases	60		
a. 106 cells (100,0%) have expected count less than 5. The minimum expected count is ,33.			
Chi-Square Tests Time-Previous Experience in Fire Drills			

Table 10 - Time*Way-guidance Installation and Time*Experience in Fire Drills part II

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	51.539[a]	52	.492
Likelihood Ratio	68.790	52	.059
N of Valid Cases	60		
a. 106 cells (100,0%) have expected count less than 5. The minimum expected count is ,38.			

Table 11 - Time*Previous Experience in VR and Time*Frequency

Chi-Square Tests Time-Previous Experience in VR			
	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	57.750[a]	52	.271
Likelihood Ratio	73.609	52	.026
N of Valid Cases	60		
a. 106 cells (100,0%) have expected count less than 5. The minimum expected count is .33.			

Chi-Square Tests Time-Frequency			
	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	144.835[a]	156	.729
Likelihood Ratio	126.079	156	.962
N of Valid Cases	60		
a. 212 cells (100,0%) have expected count less than 5. The minimum expected count is .05.			

Table 12 - Distance Travelled*Way-guidance installation

Chi-Square Tests Travelled Distance-Way-guidance Installation			
	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	60.000[a]	59	.439
Likelihood Ratio	76.382	59	.064
N of Valid Cases	60		
a. 120 cells (100,0%) have expected count less than 5. The minimum expected count is .33.			

Table 13 - Distance from lateral walls of tunnel

Chi-Square Tests Lateral Distance-Way-guidance Installation			
	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	60.000[a]	59	.439
Likelihood Ratio	76.382	59	.064
N of Valid Cases	60		
a. 120 cells (100,0%) have expected count less than 5. The minimum expected count is .33.			

In order to asses if any statistical difference is present between the means of the three different categories, a further non-parametric test has been carried out. In particular, the Analysis of Variances (ANOVA) has been conducted. The null hypothesis considered in this test is that the means between the different scenarios are equals. Thus, three different ANOVA tests have been conducted in order to study if any combination of independent variables, such as presence of the way-guidance installation, previous experience in evacuation drills and previous experience in VR, had an effect on the dependent variables. In this study, the dependent variables are defined as, namely, (1) the total time needed to evacuate from the tunnel, (2) the total travelled distance, expressed in interaction areas and measured in m^2, and (3) the distance from lateral walls. The results of the tests are shown in Appendix C. Furthermore, the results of the statistical analysis are discussed in the next chapter.

The following section illustrates the study of the two way-guidance installations described previously. As mentioned in the previous chapter, the theory of affordances is used to give an explanation on how people perceive objects and how people interpret the functionality of a particular device. Thus, this section deals with the six questions regarding the way-guidance installation present in the experiment.

The first two questions concerned the participants' ability to see the way-guidance installations. All the participants belonging to group 2 answered that the lights were visible and they were easily recognizable. On the other hand, eighty-five per cent of participants of group 3 have noticed the way-guidance installation. Thus, it can be said that nighty-two per cent of participants having a scenario with a way-guidance installation, declared that the way-guidance installations were enough visible and recognizable.

The study of movement patterns in the experiments permitted to study of participants' behaviour in terms of way-guidance installation observation as they exit from the train. Thirty-five per cent of the participants of group 2 declared to have noticed the way-guidance installation only after having walked several meters inside the tunnel.

For instance, tester 41 stated:

"*I first followed the smoke flow to get away from the fire, then I saw the lights 1 or 2 minutes later*".

Moreover, thirty per cent of participants belonging to group 3 behaved in the same manner, i.e. they noticed the way-guidance installation after having walked several meters inside the tunnel. Table 14 summarizes the percentage of participants that declared to have seen the way-guidance installation during the experiment and the percentage of participants that actually saw the installation at the very beginning of the experiment, i.e. right after exiting from the train.

Table 14 - % of Participants declaring to have seen the way-guidance installation

Scenario	N° of participants	% of participants declaring to have noticed the installation	% of Participants that saw the installation immediately
Scenario 2 - AlterLi	20	100 %	65 %
Scenario 3 - ExtenLi	20	85 %	70 %
Total	40	92.5 %	67.5 %

By collecting the answers from the second group of coupled open questions, it was possible to notice that eighty per cent of participants of group 2 and eighty-five per cent of group 3 understood the purpose of the way-guidance installation. Nevertheless, by considering the answers received from the multiple choice questions, the percentage of participants understanding the purpose of the installation increases up to nighty-five per cent for group 2 and it drops to seventy per cent for group 3. Table 15 summarizes the percentages of participants who understood the purpose of the way-guidance installation.

Table 15 - % of Participants declaring to have understood the purpose of the way-guidance installation

Scenario	N° of participants	% of participants understanding the purpose of the installation (open question)	% of participants understanding the purpose of the installation (multiple choice question)
Scenario 2 - AlterLi	20	85 %	90 %
Scenario 3 - ExtenLi	20	80 %	70 %
Total	40	82.5 %	80 %

Thus, it is possible to state that an average value of 82.5 per cent of participants understood the purpose of the two way-guidance installations. Furthermore, by analysing the questionnaire answers, it was possible to observe that 87.5% of participants having the scenarios with the way-guidance installations, remembered the colour of the installation, i.e. they declared to have seen green lights on the sidewalk of the tunnel. Furthermore, 94.5% of participants who have noticed the installations declared that the colour was suitable for its purpose. The remaining 5.5% declared that the colour of the installations should be changed. For instance, participants 49 and 52 proposed to change the colour of the way-guidance installation respectively to yellow and red. Table 16 summarizes the answers obtained from the third section of coupled questions regarding the influence of the installations.

Table 16 - % of participants declaring that the way-guidance installation supported their evacuation path

Scenario	N° of participants	% of participants declaring that the installation influenced their decision
Scenario 2 - MiLi	20	90 %
Scenario 3 - ExtenLi	20	65 %
Total	40	77.5 %

Table 17 - participants' rating the influence of the way-guidance installations expressed in %

Scenario	Low	Medium-Low	Medium	Medium-High	High	Total
Scenario 2	5 %	5 %	5 %	25 %	50 %	100 %
Scenario 3	35 %	10 %	0 %	5 %	60 %	100 %
Total	**20 %**	**7.5 %**	**2.5 %**	**15 %**	**55 %**	**100 %**

From the results shown in Table 16 and Table 17, it is possible to state that seventy-five per cent of participants declared that the way-guidance installations supported their evacuation path. Moreover, it is possible to observe that fifty-five per cent of participants declared that the two way-guidance installations have highly influenced their decision on the evacuation path.

By collecting the remaining answers from the administered questionnaire, it was possible to observe which was the first clue or first sign that supported participants' decision to evacuate. In particular, participants were asked to select between four options, namely, (1) siren playing inside the train, (2) the presence of the smoke, (3) a voice message announcing to evacuate or (4) participants could insert their own opinion. It was also possible to select a combination of the stated options. Table 18 summarizes the percentage of participants' answers.

Table 18 - % of Participants' answers regarding first clues that led them to evacuate

	Participants			
Clue(s)	Scenario 1	Scenario 2	Scenario 3	Total [%]
Siren	4	5	2	11 (18.33%)
Presence of smoke	2	2	3	7 (11.67%)
Voice Message	6	3	4	13 (21.67%)
Siren + Smoke	1	3	6	10 (16.67%)
Siren + Voice Message	0	0	0	0 (0%)
Smoke + Voice Message	0	1	2	3 (5.00%)
Siren + Smoke + Voice Message	5	5	3	13 (21.67%)
Other	2	1	0	3 (5.00%)

It was observed that the majority of participants (21.67%) decided to evacuate due to a combination of the siren playing inside the train, the voice message inviting participants to evacuate and the presence of smoke. It is worth to underline the fact that 18.33% of participants chose the siren as the main clue indicating to evacuate. A slightly smaller percentage of participants (16.67%) chose a combination of siren and smoke as the first sign encouraging them to leave the train. A small percentage of participants (5%) answered the question by inserting a different comment. For instance tester 5 and 12 stated:

"*The sound of the train crash heard during the video convinced me to evacuate*" and

"In the given consent form it was mentioned that you are participating in a tunnel evacuation test, so I knew what I had to do".

As mentioned in the previous chapter, 55 (91.7%) participants reported that they were right-handed and 5 (8.3%) participants declared to be left-handed. It is worth to briefly analyse if there is any relationship between participants' master hand and their exit choice. As described in paragraph 2.2.5, four exits were inserted in the tunnel, namely, exit A, B, C and D. Figure 7 shows the distances from the starting point of the experiments and the four different exits. In order to find if any relationship is present, a Chi-square test has been used.

Table 19 presents participants' exit choice in relation with their master-hand.

Table 19 - Cross-tabulation between Master-hand - Exit Choice

Master-Hand * Exit-Choice Cross-tabulation						
Count						
		Exit Choice				Total
		Exit A	Exit B	Exit C	Exit D	
Master-Hand	Left-handed	3	0	1	1	5
	Right-handed	33	8	2	12	55
Total		36	8	3	13	60

It is possible to notice that 36 participants (60%) chose to evacuate through the shortest distance, i.e. exit A. In particular, 33 participants were right-handed and three participants were left-handed. On the other hand, thirteen participants (21% of the total number of participants) chose the longest path, i.e. exit D. Only a small percentage of participants chose to evacuate through exit B and C, respectively 13% and 5%. In order to apply the Chi-square test, a null hypothesis has been determined. In particular, the null hypothesis is expressed as follows:

H_0= There is not a relationship between participants' master hand and their exit choice.

The results of the Chi-square are presented in Table 20.

Table 20 - Chi-square test results for Mast-hand and exit choice

Chi-Square Tests			
	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	3.189[a]	3	.363
Likelihood Ratio	2.898	3	.408
N of Valid Cases	60		

It is possible to notice that the significance is greater than 5%. Thus, it is not possible reject the null hypothesis and furthermore it is not possible to state that the results show a statistical valid pattern between participants' master hand and their exit choice.

4. Discussion

The results of the experiments and participants' answers have been presented and summarized in the results section. A discussion of the obtained results is presented in the following chapter. The discussion is primarily focused on the results concerning the total time needed to evacuate, the total travelled distance and the averaged distance from the tunnel walls.

Table 5 summarizes the mean values for the three studied dependent variables. It was noticed that scenario 2 and 3 present smaller values compared to the control test. Thus, it is possible to observe that there is a reduction on the total time needed to evacuate, on the total travelled distance and on the averaged distance from the lateral walls. Furthermore, scenarios 2 and 3 present similar values for the three categories. The averaged time required to evacuate in scenario 2 is 283.08 seconds while for third scenario is 285.19. Thus, the difference between the two groups is about 2 seconds and it can be considered negligible. Furthermore, the difference between the averaged travelled distance and the lateral distance from the tunnel walls between scenario 2 and 3 is about 1%. Also in this case, it is possible to state that the differences between the two scenarios are small and negligible.

It is worth noticing that 92.5% of participants performing scenario 2 and 3 saw the way-guidance installation inside the tunnel. By collecting the questionnaire answers and checking participants' coordinates inside the tunnel, it was possible to observe that 82.5% of participants understood the purpose of the installations. Furthermore, the majority of participants (87.5%) declared having seen green lights located on the sidewalk of the tunnel and 94.5% of the previous percentage declared that the colour was suitable for installations' purpose. This result confirms the studies conducted by Nilsson (Nilsson, 2009), in which it was found out that the use of green lights is more suitable for emergency situations and they are usually associated with positive aspects. By collecting the information obtained from the questionnaire, it was also possible to observe that 77.5% of participants declared to have been supported in their choice of evacuation path by the way-guidance installations. Thus, it has been possible to observe that the proposed way-guidance installations had positive effects on participants' exit choice and evacuation path.

As mentioned before, a normality test has been carried out in order to check if the random variables can be plotted according to normal distribution. Due to the fact that some results given by the Kolmogorov-Smirnov test (shown in Table 7) are greater than the threshold value, it has been decided to treat the results as non-normally distributed. Thus, non-parametric tests have been used. The Chi-square test has been used in order to verify if any set of relationship was present inside the model. In particular, it was decided to analyse if any relationship between three independent variables and the three dependent variables was present. In this analysis, the three independent variables were, namely, (1) any previous experience in evacuation drills, (2) any previous experience with virtual realities and (3) the frequency of taking trains in the past year. Tables 10, 11, 12 and 13 present the results from the cross-tabulation analysis. Also in this case, the significances of each case were found to exceed the adopted value of the confidence interval. Thus, it is possible to state that no significant set of relationships between the random variables is present.

A second non-parametric test (ANOVA tests) was made, in order to check if any combination of independent variables could influence the dependent variables. The results are shown in Appendix

C. The presence of way-guidance installation, previous experience in evacuation drills and previous experience in VR, had no significant effects on the three dependent variables, i.e. the total time needed to evacuate, the total travelled distance and the averaged distance for the later walls. The confidence interval has been set to 95%. Table 21 summarizes the significance values obtained from the ANOVA tests.

Table 21 - ANOVA tests results

Tests of Between-Subjects Effects			
Source	Significance (sig.)		
	Dependent variable		
	Time	Area	Lateral Distance
Lights	.518	.464	.052
Experience In Evacuation	.681	.565	.932
Experience VR	.190	.196	.813
Frequency	.910	.954	.916
Lights * Experience In Evacuation	.956	.773	.750
Lights * Experience VR	.623	.953	.535
Lights * Frequency	.746	.870	.097
Experience In Evacuation * Experience VR	.893	.919	.523
Experience In Evacuation * Frequency	.895	.771	.365
Experience VR * Frequency	.312	.452	.851
Lights * Experience In Evacuation * Experience VR	.0	.0	.
Lights * Experience In Evacuation * Frequency	.0	.0	.
Lights * Experience VR * Frequency	.371	.495	.952
Experience In Evacuation * Experience VR * Frequency	.0	.0	.0
Lights * Experience In Evacuation * Experience VR * Frequency	.0	.0	.0

The results obtained by the statistical analysis reveals that the set of experiments doesn't present any significant difference between the results of the control group and the results obtained in the other two remaining scenarios. This statement refers and deals with the three dependent variables that have been analysed, namely, (1) time needed to reach an emergency door, (2) total travelled distance and (3) the averaged lateral distance from the walls.

4.1 Limitations

The statistical analysis revealed that no significant difference has been found between the results of the three scenarios. This can be explained by two factors. Primarily, the design settings had significant effects on the results. In particular, the head-mounted display used during the experiments played an important role. The limited resolution of the display affected the behaviour of some participants.

For instance, participant 50 stated:

> "*The virtual reality helmet had a small amount of latency ("lag"). I think this really kept me aware to the fact that it was not real*".

This concept was also remarked by participant 58 who stated:

> "*More peripheral vision would be good. The graphics must be improved!*"

Due to these limitations, it is argued that some participants behaved as in a non-real situation, affecting the results. Due to the fact that the experiments consisted only in a visual performance, participants were aware of carrying out a simulation with reduced sensations. As stated by participants 28 and 58

> "*If the smell of smoke could be added it would increase the realism*" and "*Some sort of physical sensations could be incorporated, such as heat, or smell or the feeling of wind*".

Thus, some participants were aware of taking part of a simulation and they didn't behave as they would have done in a real situation.

The second parameter which had strong influences on the statistical analysis is the sample size of the experiments. Performing studies with a small number of participants can have as many advantages as drawbacks. Having a small sample size can lead to an easier enrolment of participants, to a faster review of records and to an easier study of the questionnaires answers. Therefore, the strength of having such a small sample size is that analysis can be addressed in a short lapse of time. For instance, the presented set of experiments has been carried out in only two weeks. On the other hand, the main disadvantage in analysing the results obtained by small samples, regards the confidence intervals and p-values or significances. In the presented study, the collected data is used to make evaluations with 95% of confidence interval. Thus, it can be said that the results obtained by small samples studies must be read carefully, due to the fact that they do not normally produce consistent or precise evaluations.

Nevertheless, in Table 5 it is possible to notice that there is a reduction for the dependent variables of scenario 2 and 3. It might be worth to notice that there is a reduction of about 5% regarding the total time need to evacuate. It is interesting to notice that the reduction of time between the groups is achieved with a fixed walking speed. Even though each participant could move with the same walking speed, it was possible to notice a difference in times between the groups having a way-guidance installation and the control group. Instead, the difference increases up to 9% regarding the total travelled distance. Moreover, the difference regarding the distance from the lateral walls between the control group and the other two scenarios is about 24%. Therefore, participants performing scenarios with the way-guidance installations had faster egress times with shorter travelled distances and they tended to stay closer the way-guidance installation. Thus, it can be stated that the presence of the way-guidance installations creates a positive trend and reduces the averaged values of the three analysed dependent variables. Although the statistical analysis revealed that there are not significant differences between the observed groups, the results gave promising values. This means that the limitations of the used device and some characteristics of the experimental design might have influenced the results.

5. Conclusions

Emergency signage and way-guidance systems cover an important role during the evacuation process (International Symposium on Human Behaviour in Fire, 2009). In order to have a successful egress it is important to provide enough information and guidance signs to direct evacuees. Although experiments have been carried out in the past, there is no certainty if way-guidance systems are effective in practice. Thus, it is important to understand if occupants can uptake the correct information given by the emergency way-guidance installations. In the current study, a series of experiments have been conducted in a virtual environment in order to evaluate a new way-guidance installation for railway tunnels. A total of 60 people participated to the experiments. Participants were divided into three groups in order to test two proposed way-guidance installations and compare the results with the control test group.

Descriptive statistics showed evidences of positive effects generated by the analysed way-guidance installations. Moreover, Table 5 shows small differences between the results of the categories in which the way-guidance installations were inserted, i.e. scenario 2 and 3. As mentioned previously, the difference among the two scenarios is less than 1% regarding the total time needed to evacuate, the total travelled distance and the averaged distance from the tunnel walls. Thus, it can be stated that the way-guidance installations inserted in scenario 2 and 3 present the same positive results.

It has been possible to observe that the present study presents a trend of improved safety. The results obtained by scenario 2 and 3 revealed a reduction of 9% regarding the total travelled distance inside the tunnel. Furthermore, the administered questionnaire revealed that the analysed way-guidance installations received positive feedbacks. In particular, 92.5% of participants noticed the way-guidance installation on the sidewalk of the tunnel and 82.5% recognized and understood its purpose. Additionally, 77.5% of participants declared having been influenced by the way-guidance installations on their evacuation path. The positive trend given by the way-guidance installations can be also seen in a reduction of the total time needed to evacuate. The difference within the control group is about 5%. It is worth noticing that this reduction has been found by keeping the walking speed of participants constant to 1.2 m/s. The experiments also revealed that the presence of the way-guidance installations led participants to stay closer to the tunnel walls.

No significant statistical difference between the control group and the result obtained by participants having a way-guidance installation inserted in their experiments was observed. This may be linked to some characteristics of the experimental design. In particular, the sample size and the resolutions of the head-mounted display played an important role. Furthermore, the experiments were based only on a visual experience with limited sensations. This limitation might have affected participants' results, in which it was possible to observe non-real behaviours. It might be worth remarking that new high-definition head-mounted displays have been released recently (Oculus VR Inc., 2014). Thus, it might be worth reproduce the same set of experiments in order to verify if the poor resolution of the adopted VR played a significant role.

Given these limitations, the results of this study must be read carefully and it is not possible to make strong conclusions regarding the effectiveness of the way-guidance installations.

Nevertheless, descriptive statistics show a positive trend derived from the use of the way-finding aid system. Further experimental studies must be carried out (both in virtual reality and real settings). It might be more reasonable to conduct the same study in a virtual environment by presenting better VR settings and a bigger sample size, in order to verify the presence of a positive trend and to further study the causes of the differences in the behaviours.

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Appendix A – Questionnaire

For participants belonging to the control group, questions from number 20 to 30 were automatically skipped.

Tunnel Safety Questionnaire - Test 2

General Information

In the first page we ask you to fill-in general information about yourself. All the personal information given in this survey will be treated anonymously according to the description given in the informed-consent document. This questionnaire takes around 5 minutes. The questions are both free text questions, i.e., open questions, and checkbox questions, i.e., multiple choice questions. We ask that you take your time and answer the questions to the best of your ability. If you feel that you cannot answer a question on your own or you don't understand the question, please ask to the researcher any question.

*Required

1. **1 - Which is your nationality?** *

   ____

2. **2 - What is your gender?** *

   Mark only one oval.

   ⬭ Male

   ⬭ Female

3. **3 - What is your age?** *

   Insert your age in numbers (e.g. 18)

   ____

4. **4 - Which is your Profession?** *

   ____

5. **5 - Are you affected by color blindness?** *

   Mark only one oval.

   ⬭ Yes

   ⬭ No *Skip to question 7.*

6. **6 - Which type of color-blindness do you have?**

   Mark only one oval.

   ⬭ Total color blindness

   ⬭ Red-Green

   ⬭ Blue-Yellow

   ⬭ Other: ____________________

7. **7 - Have you worked or do you currently work in the fire safety field?** *

Mark only one oval.

- ◯ Yes
- ◯ No *Skip to question 9.*

8. **7a - What is/was your job in this field?**

____

Background Information

9. **8 - Which of the following options best represents your frequency of taking a train/metro (approximately)?** *

Mark only one oval.

- ◯ Every Day
- ◯ Once a week
- ◯ Once a month
- ◯ Once a year

10. **9 - Have you ever personally experienced an evacuation (a real evacuation or a fire drill)?** *

Mark only one oval.

- ◯ Yes
- ◯ No *Skip to question 12.*

11. **9a - Where have you experienced the evacuation (example: your home, office, university, tunnels)?**

____

____

____

____

____

12. **10 - Have you ever personally evacuated from a tunnel?** *

Mark only one oval.

- ◯ Yes
- ◯ No *Skip to question 14.*

13. **10a - If yes, from which kind of tunnel?**

Mark only one oval.

- Road Tunnel
- Railway Tunnel
- Subway/Metro Tunnel
- Other: ____________________

14. **11 - Have you experience with Virtual Environments (for instance do you play videogames)?** *

Mark only one oval.

- Yes
- No *Skip to question 16.*

15. **11a - Which type of experience do you have with a Virtual Environment?**

Mark only one oval.

- I play video games
- I have participated in other research studies in Virtual Reality
- Other: ____________________

Experiment Information

16. **12 - What was the first clue or the first sign that supported your decision to evacuate (you can select more than one answer)?** *

Tick all that apply.

- [ ] Sirens
- [ ] Presence of smoke
- [ ] Voice Message
- [ ] Other: ____________________

17. **13 - What was the first thing you saw when you exited from the train?** *

____

____

____

____

____

18. **14 - Why have you chosen a certain direction to evacuate (right or left)? (if there was no reason write “no reason”)** *

....

....

....

....

....

19. **14a - Are you left-handed or right-handed?** *

Mark only one oval.

- ◯ Left-handed
- ◯ Right-handed

20. **15 - Have you noticed something unusual on the sidewalk?** *

Mark only one oval.

- ◯ Yes
- ◯ No *Skip to question 22.*

21. **15a - What have you seen on the sidewalk of the tunnel?**

....

....

....

....

....

22. **16 - Have you noticed the lights located on the floor?** *

Mark only one oval.

- ◯ Yes
- ◯ No *Skip to question 29.*

23. **17a - In your opinion, which was the purpose of the lights?** *

....

....

....

....

....

24. **18 - In your opinion, which of the following options best represents the purpose of the lights?** *
Mark only one oval.

- ⬭ To illuminate the tunnel
- ⬭ To indicate the exits
- ⬭ For a decorative purpose
- ⬭ Other: ______________________

25. **19 - What was the color of the lights?** *

____

26. **20 - Was the color appropriate for its purpose?** *
Mark only one oval.

- ⬭ Yes *Skip to question 28.*
- ⬭ No

27. **20a - If you think that the color was not suitable, which color do you recommend to use in the future?**

____

28. **21 - Did the lights support your choice of the evacuation path?** *
Mark only one oval.

- ⬭ Yes
- ⬭ No

29. **22 - From a scale from 1 to 5, where 1 means very low and 5 means very high, how did the lights influence your decision on the direction of evacuation?** *
1 = The lights didn't affected my decision; 5 = The lights influenced my decision
Mark only one oval.

	1	2	3	4	5	
very low	⬭	⬭	⬭	⬭	⬭	very high

30. **23 - From a scale from 1 to 5, where 1 means poorly and 5 means strongly, how did the lights support your decision to evacuate?** *
1 = The lights didn't support my decision; 5 = The lights strongly supported my decision
Mark only one oval.

	1	2	3	4	5	
poorly	⬭	⬭	⬭	⬭	⬭	strongly

Final Remarks

31. **24 - From 1 to 5 (where 1 means very poor and 5 means good) how would you rate the realism of the test?** *
Mark only one oval.

	1	2	3	4	5	
poor	◯	◯	◯	◯	◯	good

32. **25 - In your opinion, what can be improved in the experiment?**

....

....

....

....

....

Appendix B – FDS input File

```
&HEAD CHID='Tunnel half-height', TITLE='Tunnel smoke development 2' /
&MESH IJK= 2304, 30, 36, XB= 0.0, 450, 0.0, 5.6, 0.0, 6.6 /
//2(n)*3(m)*5(l) correct
dx = 0.199
Total number of cells = 2'488'320
the enclosure is x=400, y= 5.6, z= 6.6
mesh = 0.198*0.187*0.183 m fine case
Total cells = 2488320//
&TIME T_END= 300 /
&DUMP NFRAMES= 300 /
&MISC  TMPA= 20
       HUMIDITY=     70
       SURF_DEFAULT='No_material_defined'
       RADIATION=    .TRUE.
       BNDF_DEFAULT=.FALSE.                    /
&SURF  ID='No_material_defined' , MATL_ID='Matl_concrete', THICKNESS=          0.2       /

&MATL ID='Matl_concrete', DENSITY=2300          , SPECIFIC_HEAT=0.88, EMISSIVITY=0.5,
CONDUCTIVITY=1.4     /

----------TUNNEL GEOMETRY-------------------------------------------------------------------------------
&OBST  XB= 0.0, 450, 0.0, 1.3, 0.0, 1.4, SURF_IDS='WALL','INERT','INERT', COLOR='BANANA'/ BLOCK A 1
&OBST  XB= 0.0, 450, 1.3, 4.3, 0.0, 0.66, SURF_IDS='WALL','INERT','INERT', COLOR='GRAY'/ BLOCK B 2
&OBST  XB= 0.0, 450, 4.3, 5.6, 0.0, 1.4, SURF_IDS='WALL','INERT','INERT', COLOR='BANANA'/ BLOCK C 3
&OBST  XB= 0.0, 450, 5.4, 5.6, 1.4, 4.8, SURF_IDS='WALL','INERT','INERT', COLOR='GRAY'/ BLOCK D 4
&OBST  XB= 0.0, 450, 0.0, 0.2, 1.4, 4.8, SURF_IDS='WALL','INERT','INERT', COLOR='INVISIBLE'/ BLOCK E 5
&OBST  XB= 0.0, 450, 0.0, 1.2, 4.8, 6.66, SURF_IDS='WALL','INERT','INERT', COLOR='INVISIBLE'/BLOCK F 6
&OBST  XB= 0.0, 450, 1.3, 4.3, 6.61, 6.66, SURF_IDS='WALL','INERT','INERT', COLOR='INVISIBLE'/ BLOCK 7
&OBST  XB= 0.0, 450, 4.3, 5.6, 4.8, 6.66, SURF_IDS='WALL','INERT','INERT', COLOR='GRAY'/ BLOCK H8

------TRAIN------------------------------------------------------------------------------------------------------------------
&OBST XB= 170, 240, 1.46, 1.47, 0.86, 5, SURF_IDS='TRAIN',  'INERT','INERT'/ TRAIN DIMENSIONS 9
&OBST XB= 170, 240, 3.9, 4.0, 0.86, 5, SURF_IDS='TRAIN',  'INERT','INERT'/                     10
&OBST XB= 170, 171, 1.46, 4.0, 0.86, 5, SURF_IDS='TRAIN',  'INERT','INERT'/                    11
&OBST XB= 239, 240, 1.46, 4.0, 0.86, 5, SURF_IDS='TRAIN',  'INERT','INERT'/                    12
&OBST XB= 170, 240, 1.46, 4.0, 4.9, 5, SURF_IDS='TRAIN',  'INERT','INERT', COLOR='INVISIBLE'/   roof 13
&OBST XB= 170, 240, 1.46, 4.0, 0.86, 1, SURF_IDS='TRAIN',  'INERT','INERT', COLOR='SIENNA'/    floor 14
&OBST XB= 180, 180.5, 2.3, 2.4, 5, 6, SURF_IDS='TRAIN',  COLOR='BROWN'/ 'INERT','INERT'/ pantograph
&OBST XB= 178, 182, 2.1, 2.2, 6, 6.3, SURF_IDS='TRAIN', COLOR='BROWN' /'INERT','INERT'/
&OBST XB= 178, 182, 2.5, 2.6, 6, 6.3, SURF_IDS='TRAIN', COLOR='BROWN'/'INERT','INERT'/

------TRAIN NOSE LEFT--------------------------------------------------------------------------------------------------------
&OBST XB= 166, 170, 1.46, 4.0, 0.86, 1.5, SURF_IDS='TRAIN',  'INERT','INERT', SAWTOOTH=.FALSE./
&OBST XB= 166.5, 170, 1.46, 4.0, 1.5, 2, SURF_IDS='TRAIN',  'INERT','INERT', SAWTOOTH=.FALSE./
&OBST XB= 167, 170, 1.46, 4.0, 2, 2.5,  SURF_IDS='TRAIN',  'INERT','INERT', SAWTOOTH=.FALSE./
&OBST XB= 167.5, 170, 1.46, 4.0, 2.5, 3,  SURF_IDS='TRAIN',  'INERT','INERT', SAWTOOTH=.FALSE./
&OBST XB= 168, 170, 1.46, 4.0, 3, 3.5,  SURF_IDS='TRAIN',  'INERT','INERT', SAWTOOTH=.FALSE./
&OBST XB= 168.5, 170, 1.46, 4.0, 3.5, 4,  SURF_IDS='TRAIN',  'INERT','INERT', SAWTOOTH=.FALSE./
&OBST XB= 169, 170, 1.46, 4.0, 4, 4.5,  SURF_IDS='TRAIN',  'INERT','INERT', SAWTOOTH=.FALSE./
&OBST XB= 169.5, 170, 1.46, 4.0, 4.5, 5,  SURF_IDS='TRAIN',  'INERT','INERT', SAWTOOTH=.FALSE./

------TRAIN NOSE RIGHT------------------------------------------------------------------------------------------------------
&OBST XB= 240, 244, 1.46, 4.0, 1.5, 0.86,  SURF_IDS='TRAIN',  'INERT','INERT', SAWTOOTH=.FALSE./
&OBST XB= 240, 243.5, 1.46, 4.0, 2, 1.5,  SURF_IDS='TRAIN',  'INERT','INERT', SAWTOOTH=.FALSE./
&OBST XB= 240, 243, 1.46, 4.0, 2.5, 2,   SURF_IDS='TRAIN',  'INERT','INERT', SAWTOOTH=.FALSE./
&OBST XB= 240, 242.5, 1.46, 4.0, 3, 2.5,   SURF_IDS='TRAIN',  'INERT','INERT', SAWTOOTH=.FALSE./
&OBST XB= 240, 242, 1.46, 4.0, 3.5, 3,   SURF_IDS='TRAIN',  'INERT','INERT', SAWTOOTH=.FALSE./
&OBST XB= 240, 241.5, 1.46, 4.0, 4, 3.5,   SURF_IDS='TRAIN',  'INERT','INERT', SAWTOOTH=.FALSE./
&OBST XB= 240, 241, 1.46, 4.0, 4.5, 4,   SURF_IDS='TRAIN',  'INERT','INERT', SAWTOOTH=.FALSE./
```

```
&OBST XB= 240, 240.5, 1.46, 4.0, 5, 4.5,   SURF_IDS='TRAIN',  'INERT','INERT', SAWTOOTH=.FALSE./

--------TRAIN WINDOWS-----------------------------------------------------------------------------------------------
&OBST XB= 171, 172, 1.47, 1.47, 2, 4,  COLOR='CYAN',/ DEVC_ID='Activation_75s'/     15
&OBST XB= 175, 177, 1.47, 1.47, 2, 4,  COLOR='CYAN',/ DEVC_ID='Activation_75s'/     16
/&OBST  XB= 180, 182, 1.47, 1.47, 2, 4,  COLOR='CYAN',/ DEVC_ID='Activation_75s'/
&OBST  XB= 185, 187, 1.47, 1.47, 2, 4,  COLOR='CYAN',/ DEVC_ID='Activation_75s' /     17
&OBST  XB= 190, 192, 1.47, 1.47, 2, 4,  COLOR='CYAN',/ DEVC_ID='Activation_75s' /     19
&OBST  XB= 195, 197, 1.47, 1.47, 2, 4,  COLOR='CYAN', /DEVC_ID='Activation_75s'/     20
/&OBST  XB= 200, 202, 1.47, 1.47, 2, 4,  COLOR='CYAN', /DEVC_ID='Activation_75s'/     21
&OBST  XB= 205, 207, 1.47, 1.47, 2, 4,  COLOR='CYAN',/ DEVC_ID='Activation_75s'/     22
&OBST  XB= 210, 212, 1.47, 1.47, 2, 4,  COLOR='CYAN', /DEVC_ID='Activation_75s' /     23
&OBST  XB= 215, 217, 1.47, 1.47, 2, 4,  COLOR='CYAN', /DEVC_ID='Activation_75s' /     24
/&OBST  XB= 220, 222, 1.47, 1.47, 2, 4,  COLOR='CYAN',/ DEVC_ID='Activation_75s' /     25
&OBST  XB= 225, 227, 1.47, 1.47, 2, 4,  COLOR='CYAN',/ DEVC_ID='Activation_75s' /
&OBST  XB= 230, 232, 1.47, 1.47, 2, 4,  COLOR='CYAN',/ DEVC_ID='Activation_75s' /     27
/&OBST  XB= 235, 237, 1.47, 1.47, 2, 4,  COLOR='CYAN', /DEVC_ID='Activation_75s'/
&OBST  XB= 239, 239.8, 1.47, 1.47, 2, 4,  COLOR='CYAN',/ DEVC_ID='Activation_75s',/
&HOLE XB= 171, 172, 1.46, 1.47, 2, 4 /
&HOLE XB= 175, 177, 1.46, 1.47, 2, 4 /
&HOLE XB= 180, 182, 1.46, 1.47, 2, 4 /
&HOLE XB= 185, 187, 1.46, 1.47, 2, 4 /
&HOLE XB= 190, 192, 1.476, 1.47, 2, 4 /
&HOLE XB= 195, 197, 1.46, 1.47, 2, 4 /
&HOLE XB= 200, 202, 1.46, 1.47, 2, 4 /
&HOLE XB= 205, 207, 1.46, 1.47, 2, 4 /
&HOLE XB= 210, 212, 1.46, 1.47, 2, 4 /
&HOLE XB= 215, 217, 1.46, 1.47, 2, 4 /
&HOLE XB= 220, 222, 1.46, 1.47, 2, 4 /
&HOLE XB= 225, 227, 1.46, 1.47, 2, 4 /
&HOLE XB= 230, 232, 1.46, 1.47, 2, 4 /
&HOLE XB= 235, 237, 1.46, 1.47, 2, 4 /
&HOLE XB= 239, 249.8, 1.46, 1.47, 2, 4 /

---------TRAIN DOORS-----------------------------------------------------------------------------------------------
&OBST  XB= 180, 182, 1.27, 1.47, 1.5, 4,  COLOR='BLUE', DEVC_ID='Activation_75s'/
&OBST  XB= 200, 202, 1.47, 1.47, 1.5, 4,  COLOR='BLUE', DEVC_ID='Activation_75s'/
&OBST  XB= 220, 222, 1.47, 1.47, 1.5, 4,  COLOR='BLUE', DEVC_ID='Activation_75s'/
&OBST  XB= 235, 237, 1.47, 1.47, 1.5, 4,  COLOR='BLUE', DEVC_ID='Activation_75s'/
/&HOLE XB= 180, 182, 1.27, 1.47, 1.5, 4 /
&HOLE XB= 200, 202, 1.47, 1.47, 1.5, 4 /
&HOLE XB= 220, 222, 1.47, 1.47, 1.5, 4 /
&HOLE XB= 235, 237, 1.47, 1.47, 1.5, 4 /
&DEVC ID='Activation_75s', XYZ= 0, 0, 0, QUANTITY='TIME', SETPOINT=30, INITIAL_STATE=.TRUE. /

-----SEATS-------Front WALL from smokeview------------------------------------------------------------------
&OBST  XB= 172, 172.5, 1.50, 2.5, 0.86, 1.80,SURF_ID='Polyurethane_foam' / BACK
&OBST  XB= 172.5, 173, 1.5, 2.5, 0.86, 1.4,    SURF_ID='Polyurethane_foam' / SEAT
&OBST  XB= 174, 174.5, 1.50, 2.5, 0.86, 1.80,SURF_ID='Polyurethane_foam' / BACK
&OBST  XB= 174.5, 175, 1.5, 2.5, 0.86, 1.4,    SURF_ID='Polyurethane_foam' / SEAT
&OBST  XB= 177, 177.5, 1.50, 2.5, 0.86, 1.80,SURF_ID='Polyurethane_foam' / BACK
&OBST  XB= 177.5, 178, 1.5, 2.5, 0.86, 1.4,    SURF_ID='Polyurethane_foam' / SEAT
&OBST  XB= 182, 182.5, 1.50, 2.5, 0.86, 1.80,SURF_ID='Polyurethane_foam' / BACK
&OBST  XB= 182.5, 183, 1.5, 2.5, 0.86, 1.4,    SURF_ID='Polyurethane_foam' / SEAT
&OBST  XB= 185, 185.5, 1.50, 2.5, 0.86, 1.80,SURF_ID='Polyurethane_foam' / BACK
&OBST  XB= 185.5, 186, 1.5, 2.5, 0.86, 1.4,    SURF_ID='Polyurethane_foam' / SEAT
&OBST  XB= 188, 188.5, 1.50, 2.5, 0.86, 1.80,SURF_ID='Polyurethane_foam' / BACK
&OBST  XB= 188.5, 189, 1.5, 2.5, 0.86, 1.4,    SURF_ID='Polyurethane_foam' / SEAT
&OBST  XB= 215, 215.5, 1.50, 2.5, 0.86, 1.80,SURF_ID='Polyurethane_foam' / BACK
&OBST  XB= 215.5, 216, 1.5, 2.5, 0.86, 1.4,    SURF_ID='Polyurethane_foam' / SEAT
&OBST  XB= 218, 218.5, 1.50, 2.5, 0.86, 1.80,SURF_ID='Polyurethane_foam' / BACK
&OBST  XB= 218.5, 219, 1.5, 2.5, 0.86, 1.4,    SURF_ID='Polyurethane_foam' / SEAT
```

```
&OBST  XB= 224, 224.5, 1.50, 2.5, 0.86, 1.80,SURF_ID='Polyurethane_foam' / BACK
&OBST  XB= 224.5, 225, 1.5, 2.5, 0.86, 1.4,    SURF_ID='Polyurethane_foam' / SEAT
&OBST  XB= 227, 227.5, 1.50, 2.5, 0.86, 1.80,SURF_ID='Polyurethane_foam' / BACK
&OBST  XB= 227.5, 228, 1.5, 2.5, 0.86, 1.4,    SURF_ID='Polyurethane_foam' / SEAT
&OBST  XB= 230, 230.5, 1.50, 2.5, 0.86, 1.80,SURF_ID='Polyurethane_foam' / BACK
&OBST  XB= 230.5, 231, 1.5, 2.5, 0.86, 1.4,    SURF_ID='Polyurethane_foam' / SEAT
&OBST  XB= 233, 233.5, 1.50, 2.5, 0.86, 1.80,SURF_ID='Polyurethane_foam' / BACK
&OBST  XB= 233.5, 234, 1.5, 2.5, 0.86, 1.4,    SURF_ID='Polyurethane_foam' / SEAT
&SURF  ID='Polyurethane_foam'
          COLOR='ORANGE RED'
          ADIABATIC=.TRUE.                    /

-----SEATS-------BACK WALL from smokeview----------------------------------------------------------------------
&OBST  XB= 172, 172.5, 3, 4, 0.86, 1.80,       SURF_ID='Polyurethane_foam' / BACK
&OBST  XB= 172.5, 173, 3, 4, 0.86, 1.4,        SURF_ID='Polyurethane_foam' / SEAT
&OBST  XB= 174, 174.5, 3, 4, 0.86, 1.80,       SURF_ID='Polyurethane_foam' / BACK
&OBST  XB= 174.5, 175, 3, 4, 0.86, 1.4,        SURF_ID='Polyurethane_foam' / SEAT
&OBST  XB= 177, 177.5, 3, 4, 0.86, 1.80,       SURF_ID='Polyurethane_foam' / BACK
&OBST  XB= 177.5, 178, 3, 4, 0.86, 1.4,        SURF_ID='Polyurethane_foam' / SEAT
&OBST  XB= 183, 183.5, 3, 4, 0.86, 1.80,       SURF_ID='Polyurethane_foam' / BACK
&OBST  XB= 183.5, 184, 3, 4, 0.86, 1.4,        SURF_ID='Polyurethane_foam' / SEAT
&OBST  XB= 186, 186.5, 3, 4, 0.86, 1.80,       SURF_ID='Polyurethane_foam' / BACK
&OBST  XB= 186.5, 187, 3, 4, 0.86, 1.4,        SURF_ID='Polyurethane_foam' / SEAT
&OBST  XB= 189, 189.5, 3, 4, 0.86, 1.80,       SURF_ID='Polyurethane_foam' / BACK
&OBST  XB= 189.5, 190, 3, 4, 0.86, 1.4,        SURF_ID='Polyurethane_foam' / SEAT
&OBST  XB= 192, 192.5, 3, 4, 0.86, 1.80,       SURF_ID='Polyurethane_foam' / BACK
&OBST  XB= 192.5, 193, 3, 4, 0.86, 1.4,        SURF_ID='Polyurethane_foam' / SEAT
&OBST  XB= 195, 195.5, 3, 4, 0.86, 1.80,       SURF_ID='Polyurethane_foam' / BACK
&OBST  XB= 195.5, 196, 3, 4, 0.86, 1.4,        SURF_ID='Polyurethane_foam' / SEAT
&OBST  XB= 198, 198.5, 3, 4, 0.86, 1.80,       SURF_ID='Polyurethane_foam' / BACK
&OBST  XB= 198.5, 199, 3, 4, 0.86, 1.4,        SURF_ID='Polyurethane_foam' / SEAT
&OBST  XB= 224, 224.5, 3, 4, 0.86, 1.80,       SURF_ID='Polyurethane_foam' / BACK
&OBST  XB= 224.5, 225, 3, 4, 0.86, 1.4,        SURF_ID='Polyurethane_foam' / SEAT
&OBST  XB= 227, 227.5, 3, 4, 0.86, 1.80,       SURF_ID='Polyurethane_foam' / BACK
&OBST  XB= 227.5, 228, 3, 4, 0.86, 1.4,        SURF_ID='Polyurethane_foam' / SEAT
&OBST  XB= 230, 230.5, 3, 4, 0.86, 1.80,       SURF_ID='Polyurethane_foam' / BACK
&OBST  XB= 230.5, 231, 3, 4, 0.86, 1.4,        SURF_ID='Polyurethane_foam' / SEAT
&OBST  XB= 233, 233.5, 3, 4, 0.86, 1.80,       SURF_ID='Polyurethane_foam' / BACK
&OBST  XB= 233.5, 234, 3, 4, 0.86, 1.4,        SURF_ID='Polyurethane_foam' / SEAT
--------------------------------------------------------------------------------------------------------------------------------
&SURF ID                        = 'WALL'
     MATL_ID                   = 'CONCRETE'
     COLOR                    = 'GRAY'
     THICKNESS                 =  0.2 /
&SURF ID = 'WALL', ADIABATIC=.FALSE.            /
&MATL ID                                    = 'CONCRETE'
          EMISSIVITY = 0.8
          DENSITY = 2300.
          CONDUCTIVITY = 0.8
          SPECIFIC_HEAT = 1.0 /
&REAC              ID='polyurethane',
                   SOOT_YIELD=0.1875,
                   CO_YIELD=0.02775,
                   C=1.0, H=1.75, O=0.25, N=0.065,
                   HEAT_OF_COMBUSTION=25300.,
                   IDEAL=.TRUE.,
                   MASS_EXTINCTION_COEFFICIENT=8700,
                   VISIBILITY_FACTOR=3 /

------------------------- FIRE -------------------------------------------------------------------------------------
&OBST XB= 190, 220, 1.46, 4.0, 2, 2.1, SURF_IDS='BURNER', 'INERT','INERT', COLOR='RED' /
//76.2 m2 OF BURNING AREA OF THE TRAIN//
```

```
&SURF ID='BURNER', HRRPUA=262, TAU_Q=-652.33 /
//20 MW FIRE //
&SURF ID                    = 'TRAIN'
        MATL_ID        = 'STEEL'
        COLOR          = 'SILVER'
        THICKNESS       =  0.1 /
&MATL ID                    = 'STEEL'
        EMISSIVITY= 0.95
        DENSITY= 7850.
        CONDUCTIVITY= 45.8
        SPECIFIC_HEAT= 0.46 /
&SURF ID='TRAIN', ADIABATIC=.FALSE.            /

-----VISIBILITY------------------------------------------------------------------------------------------------------------------------
&DEVC XYZ=320, 2.8, 1.8, QUANTITY='VISIBILITY', ID='Visibility'/
&DEVC ID='Visibility inside the train', XYZ=350, 2.8, 1.8,QUANTITY='VISIBILITY',SPEC_ID='SOOT'/
&DEVC ID='Visibility  X=-30m', XYZ=320, 2.8, 1.8,QUANTITY='VISIBILITY',SPEC_ID='SOOT'/
&DEVC ID='Visibility x=-50', XYZ=300, 2.8, 1.8,QUANTITY='VISIBILITY',SPEC_ID='SOOT'/
&DEVC ID='Visibility x=-100', XYZ=250, 2.8, 1.8,QUANTITY='VISIBILITY',SPEC_ID='SOOT'/
&DEVC ID='Visibility x=+30', XYZ=380, 2.8, 1.8,QUANTITY='VISIBILITY',SPEC_ID='SOOT'/
&DEVC ID='Visibility x=+50', XYZ=400, 2.8, 1.8,QUANTITY='VISIBILITY',SPEC_ID='SOOT'/
&DEVC ID='Visibility x=+100', XYZ=450, 2.8, 1.8,QUANTITY='VISIBILITY',SPEC_ID='SOOT'/
&DEVC ID='Layer Height', XB= 0, 450, 1.2, 1.2, 1. 3, QUANTITY='LAYER HEIGHT'/
&SLCF PBZ=3.2, QUANTITY='VISIBILITY', VECTOR=.TRUE./
&SLCF PBZ=2.0, QUANTITY='VISIBILITY', VECTOR=.TRUE./
&SLCF PBY=2.8, QUANTITY='VISIBILITY', VECTOR=.TRUE./

-----------TEMPERATURES-------------------------------------------------------------------------------------
&SLCF PBY=2.8, QUANTITY='TEMPERATURE',VECTOR=.TRUE./
&SLCF PBZ=3, QUANTITY='TEMPERATURE',VECTOR=.TRUE./
&BNDF QUANTITY='WALL TEMPERATURE'                /
&BNDF QUANTITY='INCIDENT HEAT FLUX'              /
&DEVC XB=170, 170, 2, 2, 0, 6.6,    QUANTITY="LAYER HEIGHT", ID='Layer Height'            /
&DEVC XB=170, 170, 2, 2, 0, 6.6,    QUANTITY="UPPER TEMPERATURE",  ID='Layer Temperature'    /
&DEVC XYZ=320, 2.8, 1.8             QUANTITY="OPTICAL DENSITY",         ID='Optical density -30'/
&DEVC XYZ=300, 2.8, 1.8             QUANTITY="OPTICAL DENSITY",         ID='Optical density -50'     /
&DEVC XYZ=250, 2.8, 1.8             QUANTITY="OPTICAL DENSITY",         ID='Optical density -100'    /
&DEVC XYZ=380, 2.8, 1.8             QUANTITY="OPTICAL DENSITY",         ID='Optical density +30'    /
&DEVC XYZ=400, 2.8, 1.8             QUANTITY="OPTICAL DENSITY",         ID='Optical density +50'    /
&DEVC XYZ=450, 2.8, 1.8             QUANTITY="OPTICAL DENSITY",         ID='Optical density +100'  /
&DEVC XYZ=320, 2.8, 1.8             QUANTITY="EXTINCTION COEFFICIENT",      ID='Extinction coeff. -30'/
&DEVC XYZ=300, 2.8, 1.8             QUANTITY="EXTINCTION COEFFICIENT",      ID='Extinction coeff. -50'/
&DEVC XYZ=250, 2.8, 1.8, QUANTITY="EXTINCTION COEFFICIENT",    ID='Extinction coeff. -100'/
&DEVC XYZ=380, 2.8, 1.8, QUANTITY="EXTINCTION COEFFICIENT",    ID='Extinction coeff. +30'/
&DEVC XYZ=400, 2.8, 1.8, QUANTITY="EXTINCTION COEFFICIENT",    ID='Extinction coeff. +50'/
&DEVC XYZ=450, 2.8, 1.8, QUANTITY="EXTINCTION COEFFICIENT",    ID='Extinction coeff. +100'/
&DEVC XYZ=170, 1, 3.5,  QUANTITY="EXTINCTION COEFFICIENT", ID='Extinction coeff. bench 1'/
&DEVC XYZ=180, 1, 3.5,  QUANTITY="EXTINCTION COEFFICIENT", ID='Extinction coeff. bench 2'/
&DEVC XYZ=190, 1, 3.5,  QUANTITY="EXTINCTION COEFFICIENT", ID='Extinction coeff. bench 3'/
&DEVC XYZ=200, 1, 3.5,  QUANTITY="EXTINCTION COEFFICIENT", ID='Extinction coeff. bench 4'/
&DEVC XYZ=210, 1, 3.5,  QUANTITY="EXTINCTION COEFFICIENT", ID='Extinction coeff. bench 5 right'/
&DEVC XYZ=220, 1, 3.5,  QUANTITY="EXTINCTION COEFFICIENT", ID='Extinction coeff. bench 6 right'/
&DEVC XYZ=230, 1, 3.5,  QUANTITY="EXTINCTION COEFFICIENT", ID='Extinction coeff. bench 7 right'/
&DEVC XYZ=240, 1, 3.5,  QUANTITY="EXTINCTION COEFFICIENT", ID='Extinction coeff. bench 8 right'/

------------VELOCITY------------------------------------------------------------------------------------------------------
&SLCF PBY=2.8, QUANTITY='VELOCITY',VECTOR=.TRUE./

------------PRESSURE------------------------------------------------------------------------------------------------------
&MISC RESTART=.TRUE.
&TAIL /
```

Appendix C – ANOVA tests

Between-Subjects Factors		
		N
Lights	No	20
	Yes	40
Experience In Evacuation	No	37
	Yes	23
Experience VR	No	20
	Yes	40
Frequency	Every Day	13
	Once a month	16
	Once a week	28
	Once a year	3

Table C2 – Results of the Between-Subject Test and Descriptive Statistics part I

Descriptive Statistics						
Dependent Variable: **Time**						
Lights	Experience In Evacuation	Experience VR	Frequency	Mean	Std. Deviation	N
No	No	No	Every Day	290	.	1
			Once a month	331.2	.	1
			Once a week	289.1	60.90996	5
			Total	295.2	52.20019	7
		Yes	Every Day	275.0	.	1
			Once a month	281.0	26.84177	2
			Once a week	353.7	55.11346	3
			Total	316.4	55.11975	6
		Total	Every Day	282.6	10.66317	2
			Once a month	297.7	34.63502	3
			Once a week	313.3	64.08998	8
			Total	305.0	52.42705	13
	Yes	No	Once a week	304.2	29.41564	2
			Total	304.2	29.41564	2
		Yes	Once a month	276.9	58.49095	4
			Once a year	275.0	.	1
			Total	276.5	50.66119	5
		Total	Once a month	276.9	58.49095	4
			Once a week	304.2	29.41564	2
			Once a year	275.0	.	1
			Total	284.4	45.13828	7
	Total	No	Every Day	290.1	.	1
			Once a month	331.2	.	1
			Once a week	293.4	51.68855	7
			Total	297.2	46.55380	9
		Yes	Every Day	275.0	.	1
			Once a month	278.2	46.91935	6
			Once a week	353.7	55.11346	3
			Once a year	275.0	.	1
			Total	298.2	54.58528	11
		Total	Every Day	282.6	10.66317	2
			Once a month	285.8	47.27685	7
			Once a week	311.5	57.49624	10
			Once a year	275.0	.	1
			Total	297.8	49.80951	20
Yes	No	No	Every Day	282.3	61.77285	2
			Once a month	314.3	27.57716	2
			Once a week	302.2	28.89745	4
			Once a year	381.6	.	1
			Total	309.3	41.86520	9
		Yes	Every Day	276.9	46.69685	3
			Once a month	285.2	67.28828	2
			Once a week	271.0	59.78518	9
			Once a year	249.0	.	1
			Total	272.6	52.39580	15

Table C2 – Results of the Between-Subject Test and Descriptive Statistics part II

		Total	Every Day	279.1	45.30928	5
			Once a month	299.7	45.22605	4
			Once a week	280.6	53.07032	13
			Once a year	315.3	93.76236	2
			Total	286.4	51.08718	24
	Yes	No	Every Day	307.3	42.65268	2
			Total	307.3	42.65268	2
		Yes	Every Day	293.0	28.20970	4
			Once a month	277.5	76.08579	5
			Once a week	265.6	28.75417	5
			Total	277.7	48.45280	14
		Total	Every Day	297.7	29.93081	6
			Once a month	277.5	76.08579	5
			Once a week	265.6	28.75417	5
			Total	281.4	47.52023	16
	Total	No	Every Day	294.8	45.67325	4
			Once a month	314.3	27.57716	2
			Once a week	302.2	28.89745	4
			Once a year	381.6	.	1
			Total	308.9	39.80892	11
		Yes	Every Day	286.1	34.61512	7
			Once a month	279.7	68.02864	7
			Once a week	269.1	49.61060	14
			Once a year	249.0	.	1
			Total	275.0	49.69188	29
		Total	Every Day	289.3	36.93192	11
			Once a month	287.4	61.63194	9
			Once a week	276.4	47.22899	18
			Once a year	315.3	93.76236	2
			Total	284.4	49.13084	40
Total	No	No	Every Day	284.9	43.91153	3
			Once a month	319.9	21.80489	3
			Once a week	294.9	47.07492	9
			Once a year	381,6	.	1
			Total	303,1	45,56952	16
		Yes	Every Day	276.5	38.13973	4
			Once a month	283.1	41.89471	4
			Once a week	291.7	67.46824	12
			Once a year	249.0	.	1
			Total	285.1	55.60341	21
		Total	Every Day	280.1	37.28889	7
			Once a month	298.9	37.73188	7
			Once a week	293.1	58.24681	21
			Once a year	315.3	93.76236	2
			Total	292.9	51.62284	37
	Yes	No	Every Day	307.3	42.65268	2
			Once a week	304.2	29.41564	2
			Total	305.7	29.96813	4
		Yes	Every Day	293.0	28.20970	4
			Once a month	277.2	64.63434	9
			Once a week	265.6	28.75417	5
			Once a year	275.0	.	1
			Total	277.4	47.60434	19
		Total	Every Day	297.7	29.93081	6
			Once a month	277.2	64.63434	9
			Once a week	276.6	32.40174	7
			Once a year	275.0	.	1
			Total	282.3	45.79691	23
	Total	No	Every Day	293.9	39.60953	5
			Once a month	319.9	21.80489	3
			Once a week	296.6	43.28222	11
			Once a year	381.6	.	1
			Total	303.7	42.21753	20

Table C2 – Results of the Between-Subject Test and Descriptive Statistics part III

		Yes	Every Day	284.7	32.28542	8
			Once a month	279.0	56.84886	13
			Once a week	284.0	59.04649	17
			Once a year	262.0	18.38478	2
			Total	281.4	51.44709	40
		Total	Every Day	288.2	33.94737	13
			Once a month	286.7475	54.04231	16
			Once a week	288.9900	52.90684	28
			Once a year	301.9467	70.26417	3
			Total	288.8860	49.34801	60

Table C3 Test of Between-Subjects Effects Variable Time

Tests of Between-Subjects Effects					
Dependent Variable: **Time**					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	35679.310[a]	20	1783.9	.644	.853
Intercept	2228050.818	1	2228050	804.581	.000
Lights	1179,596	1	1179,5	,426	,518
Experience In Evacuation	474,421	1	474,4	,171	,681
Experience VR	4919,397	1	4919,3	1,776	,190
Frequency	1489,577	3	496,5	,179	,910
Lights * Experience In Evacuation	8,371	1	8,3	,003	,956
Lights * Experience VR	680,524	1	680,5	,246	,623
Lights * Frequency	1632.705	2	816.3	.295	.746
Experience In Evacuation * Experience VR	50.328	1	50.3	.018	.893
Experience In Evacuation * Frequency	618.454	2	309.2	.112	.895
Experience VR * Frequency	10212.854	3	3404.2	1.229	.312
Lights * Experience In Evacuation * ExperienceVR	.000	0	.	.	.
Lights * Experience In Evacuation * Frequency	.000	0	.	.	.
Lights * Experience VR * Frequency	5628.438	2	2814.2	1.016	.371
Experience In Evacuation * Experience VR * Frequency	.000	0	.	.	.
Lights * Experience In Evacuation * Experience VR * Frequency	.000	0	.	.	.
Error	107999.041	39	2769.2		
Total	5150985.611	60			
Corrected Total	143678.351	59			
a. R Squared = .248 (Adjusted R Squared = -.137)					

Table C4 Test of Between-Subjects Effects Variable Travelled Distance part I

Tests of Between-Subjects Effects					
Dependent Variable: **Area**					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	2050485785.378[a]	20	102524289.	.424	.979
Intercept	59655047646.514	1	59655047646	246.707	.000
Lights	132247092.192	1	132247092	.547	.464

Table C4 Test of Between-Subjects Effects Variable Travelled Distance part II

Experience In Evacuation	81283349.795	1	81283349	.336	.565
Experience VR	418895766.885	1	418895766	1.732	.196
Frequency	79345275.716	3	26448425	.109	.954
Lights * Experience In Evacuation	20449111.198	1	20449111	.085	.773
Lights * Experience VR	842445.823	1	842445	.003	.953
Lights * Frequency	67861107.003	2	33930553	.140	.870
Experience In Evacuation * Experience VR	2551155.902	1	2551155	.011	.919
Experience In Evacuation * Frequency	126612338.897	2	63306169	.262	.771
Experience VR * Frequency	649831827.601	3	216610609	.896	.452
Lights * Experience In Evacuation * Experience VR	.000	0	.	.	.
Lights * Experience In Evacuation * Frequency	.000	0	.	.	.
Lights * Experience VR * Frequency	346445833.995	2	173222916	.716	.495
Experience In Evacuation * Experience VR * Frequency	.000	0	.	.	.
Lights * Experience In Evacuation * Experience VR * Frequency	.000	0	.	.	.
Error	9430409604.012	39	241805374		
Total	142620201907.897	60			
Corrected Total	11480895389.390	59			
a. R Squared = .179 (Adjusted R Squared = -.243)					

Table C5 Test of Between-Subjects Effects Variable Lateral Distance part I

Tests of Between-Subjects Effects					
Dependent Variable: **Lateral Distance**					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	5.684[a]	20	.284	1.270	.255
Intercept	37.452	1	37.452	167.387	.000
Lights	.898	1	.898	4.015	.052
Experience In Evacuation	.002	1	.002	.007	.932
Experience VR	.013	1	.013	.057	.813
Frequency	.114	3	.038	.169	.916
Lights * Experience In Evacuation	.023	1	.023	.103	.750
Lights * Experience VR	.088	1	.088	.391	.535
Lights * Frequency	1.107	2	.553	2.473	.097
Experience In Evacuation * Experience VR	.093	1	.093	.416	.523
Experience In Evacuation * Frequency	.463	2	.231	1.034	.365
Experience VR * Frequency	.177	3	.059	.264	.851
Lights * Experience In Evacuation * Experience VR	.000	0	.	.	.
Lights * Experience In Evacuation * Frequency	.000	0	.	.	.
Lights * ExperienceVR * Frequency	.022	2	.011	.049	.952
Experience In Evacuation * Experience VR * Frequency	.000	0	.	.	.
Lights * Experience In Evacuation * Experience VR * Frequency	.000	0	.	.	.

Table C5 Test of Between-Subjects Effects Variable Lateral Distance part II

Error	8.726	39	.224		
Total	98.073	60			
Corrected Total	14.410	59			
a. R Squared = .394 (Adjusted R Squared = .084)					