Evaluating Dynamic Signage for Emergency Evacuation using an Immersive Video Environment

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DECLARATION

I declare that this thesis entitled “Evaluating Dynamic Signage for Emergency Evacuation using an Immersive Video Environment “is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature:

Name: **Roya Olyazadeh**

Place: **Muenster, Germany**

Date: **28 February 2013**

To my beloved mother and father

تقدیم به پدر و مادر عزیزم

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ABSTRACT

There are numerous reasons to evacuate a building in case of emergency; generally evacuation runs in case of constraints as fire, earthquake, indoor air pollution incidents, terrorist attacks and so on. There was a fire tragedy reported on January 28, 2013 in a night club in Brazil that many victims confused the exit sign with that for the toilet sign, where 50 bodies were found dead in toilet. It is reported that the victims lost their sense of direction due to the smoke [1]. Consequently the traditional static emergency signs are no longer effective especially in a complex building. They are not intelligent to decide how many people are using different exit, where the fire is and how much it may spread or how the evacuee will decide and think while they are in panic. They are several attempts to simulate the evacuation area and create a better model to dynamically lead the evacuee to exit. However creating such system is difficult because the prediction of behaviors in emergency incidents, modeling and examination in the real scenario are the biggest problems. Evacuation exercise are expensive and time consuming, as a result Virtual Environment (VEs) might be the feasible solution to create the emergency scenario and to study the physical, cognitive, and perceptual capabilities of the evacuees, letting them to experience and feel the emergency incident that are impossible to apply in the real world. This project presents the use of VE, called Immersive Video Environment (IVE) [2] to investigate and evaluate the possible dynamic signage inside a building to guide the evacuees to safety and exit. IVE system contains three screens with 140 degree from each other using 3 back projected wall at the same time. In this study dynamic signs inform the evacuee by following the exit signs cause of fire emergency and move towards the exit. Generally the user of VE is disoriented or discomforted due to navigation (Travel) part. As a result, following factors are evaluated by using some pre-defined questionnaire such as Simulator Sickness Questionnaire and NASA TLX:

1. The pre-movement time or response time to the dynamic signs.
2. Panic behavior or Decision making
3. Comfort of the system due to navigation part.
4. Performance of IVE
5. Realism of the simulation

8 scenarios have been managed for this experiment in which each of them last around 30 to 40 seconds for a trip from start point to the exit door. In the entire scenario, the exit signs will be varied. The test participants were 10 people (5 Female, 5 Male) who come from different countries not specially Germany. There were great considerable results of decision making in this study for example, there were several errors for the fire sign during the experiment besides the response time for the fire sign were highly more than the other designs. From the evaluator recognition, it is said that their response has been influenced by the exit door or the design of sign. Generally the performance and the comfort of the system show interesting results in the emergency simulation and footage video for VE. There were a significant different in term of discomfort between men and women and the results of their response time had significant difference. By users rating, the realism of the simulation has been confirmed. For response time experiment, some errors and significant variation were observed during the individual test. The IVE can be used for future experiment investigation such as way finding. The proposed system shall help to yield more reliable information about human behavior and decision making in emergency egress and creating a model. Locations, timing, duration and speed, helping from dynamic signs can be considered as decision-making process subject to emergency evacuation.

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Chapter 1

Introduction

1.1 Introduction

There are numerous reasons to evacuate a building because of emergency. Generally evacuation runs in case of constraints as fire, earthquake, and indoor air pollution incidents (radioactive materials and toxic gases), terrorist attacks (sabotages, bombing) and so on. Occasionally it leads to the wrong exit and path and causes extra damages and fatalities. Everyone remembers the September 11, 2001. In this tragedy it was estimated between 13000 to 15000 persons successfully evacuated from the building [3] .The important factor is that how an evacuation system provides to solve the barriers successfully. There was a study of participants of September 11 at 2003 who mentioned the following factors while they were evacuating [3]:

1. Influence of decision making.
2. Knowledge of the location.
3. Information regarding what and where occurred and how to recognize it immediately.
4. Choosing and locating exit route.
5. Travel speed defined by age and gender [4].
6. Response time to the event (the pre movement and movement time).
7. Capacity of the route

In Addition a fire tragedy has been reported on January 28, 2013 in a night club in Brazil that 232 people are dead and more than 100 people injured. Many victims confused the exit sign with that for the toilet sign, where 50 bodies were found dead in the toilet. It is reported that the victims lost their sense of direction due to smoke [1]. As it can be understood the current evacuation systems like Alarm emergency systems and static emergency sign (Figure 1-1) are not adequate and most of them are developed as static signage (They can be invisible due to smoke or inaccessible due to airlessness or huddle) so they are not flexible and dynamic. In addition they are not intelligent to decide how many people are using which exit, where the fire is and how much it might spread or how the evacuee shall decide and think while they are in panic situation. This may involve more costs for people who are not familiar with the building and it shall lead to the reduction in evacuation process and blockings in the exits.

This project presents the use of virtual environment (VE), called immersive video [2] to investigate and evaluate the possible dynamic signage inside a building (like hospitals, museums and airports) to guide the evacuees to safety and exit.

Figure 1-1 Example of static sign for emergency egress

1.2 Related work

The traditional static emergency signs are no longer effective especially in a complex building such as Airport, hospital and etc. Recently such static systems are transformed to dynamic evacuation systems. They are so many attempts to simulate the evacuation area and create a better model to dynamically lead the people to exit. Karas Ismail Rakip [5] developed a 3D interactive human navigation for an indoor air pollution disaster. It is described that an optimum evacuation system consists of alarm devices, sensors and detector, evacuation lights and an indoor navigation system to help the people to exit [5].

Most of the models for evacuation are used Cellular Automata (CA) [6] [7] [8]. CA model is used in simulation because its operation process is very simple and it contains the models for individual movements. Varas [6] used a bi-dimensional cellular automata model to simulate an evacuation process from a classroom with full capacity. Evacuation times with and without obstacles were compared. In this model a personal tendency in each pedestrian to follow crowds were ignored.

Inhye Park [7] applied CA model to compute movement of evacuees with various velocities and connect with indoor positioning techniques RFID technology and present movement of individual evacuees for the 3D topological analysis. The problem of CA is that obstacle was fixed in integer number of cells.

Helbing [9] exercised a continuous pedestrian model based on Moleculardynamic, which is, about the possible mechanisms beyond escape panic. By simulating number of 90 pedestrians who are trying to escape a smoky room by certain desired speed and direction, he found an optimal strategy for escape from a smoked room, involving a mixture of individualistic behavior and collective `herding' instinct. This model did not consider few characteristics like falling people while escaping.

Isobe [10] implemented a simulation of the evacuation of a room without visibility by an extended lattice gas model where the empirically observed behavior, adding more exits does not improve the situation in the expected way. Christakos [11] applied an ad hoc network to find the best path to an exit in a situation where paths may be blocked.

RescueMe [12] employed using image-based localization such as IQEngine. Two models used in this system: one without any evacuation model just by path-finding algorithm and the other one by using the Rescueme Algorthim. The simulated people were randomly evacuated to the shortest-path exit door which adapted the shortest amount of time as well. Moreover LifeBelt [8] is based on Cellular Automata technique. This system is implemented as a Silent Directional Guidance for Crowd Evacuation. Application in a real site scenario, Linz station is one of the benefits of Lifebelt. In this model the decisions are made based on: Nearest exit (NE), Familiarity of the Exit, Exit population (EP), Exit capacity (EC) and Time to reach the Exit (TEA). LifeBelt progresses evacuation efficiency by more than 34.5 %.

Furthermore, several researchers developed models considering these three specific factors: Sound (Alarm), Tactile (Vibration) and Visualization (Light). Directional Sound Evacuation (DSE) [13] was examined with 75 individual participants in a road tunnel filled with smoke and visibility of 1 meter; the success rate was 87%. Lifebelt [8] and Activebelt [14] are the samples of tactile system for evacuation. They provide the directional guidance based on a variety of sensed measures including relative exit area dynamics [8].

All the works are mentioned above, have their advantages and disadvantages. Recently Ubiquitous Computing [15] or ubicomp systems are in the main area of computer science especially when physical objects are related with computers or mobile devices. Mark Weiser [15]was the first who proposed the idea of ubicomp. The main two characteristics of ubicomp are physical integration and spontaneous interoperation. This cannot be called ad hoc because ad hoc are autonomous systems and they cannot achieve spontaneous interoperation [15]. The GAUDI [16] system and the Rotating Compass [17] are examples of ubicomp which are designed to guide the people inside the complex building by using the dynamic signage [18]. Rotating compass [17] can be referred to visualization system where a public display demonstrates a compass with a rotating needle.

1.3 Problem statement

According to the National Fire Protection Association [19]the fire at Düsseldorf airport killed 17 people and 62 injured. The following elements reported as the result of the fire [19]:

- Lack of adequate communications
- Insufficient radio frequencies available for fire ground operations

- Lack of awareness of the building layout
- Lack of indoor geo-information
- Lack of dynamic information
- No fire fighter accountability system
- Insufficient command staff to manage the incident

Accordingly, if there were an adequate evacuation system, majority of people could survive from this disaster. So recently evacuation topic is changed to an active research. Safety is the critical issue in all and the purpose is guidance of the people who are in the danger to the exit. They have to evacuate the building in the shortest time with shortest path without confronting any obstacle or blocked route. Besides the invisibility, smoked area and huddle should be considered. However creating such system is difficult because the prediction of behaviors in emergency incidents, modeling and examination in the real scenario are the biggest problems. Evacuation exercises are expensive and time consuming. As a result VEs can be the possible solution to create the emergency scenario and to study the physical, cognitive, and perceptual capabilities of the evacuees, letting them to experience and feel the emergency incident that are impossible to run in the real world. This work shall improve the usability interaction of an Immersive VE in an emergency evacuation and preliminary result of decision making for a dynamic signs.

1.4 Aims and Objective

The basic idea for this study is to use a public display system that uses contextual information to dynamically direct people to safety. The main idea shall improve the presentations of dynamic directional signs for quick and safe emergency evacuation. It is expected to accomplish the following objectives:

1. Collect information regarding the dynamic signage.
2. Create the virtual environment of emergency evacuation by using immersive video.
3. Study on the performance and effectiveness of the VE.
4. Study the behaviors of the people in of emergency egress.
5. Discuss the results for a suggestion of evacuation model based on them.

1.5 Research Methodology

To be able to provide a dynamic navigation evacuation system, a virtual environment (VE) need to be considered to simulate the environment and study on the human behavior and decision making through the emergency egress. VE gives useful and usable result because it is impossible to create a real environment for disaster and emergency. In this research it is expected to simulate the evacuation area by using the

Immersive video system [2]. The immersive video (Figure 1-2) is achieved by capturing the images and sounds in the wide field of view between 140 to 360 degrees. Two major components of immersive video system:

1. Wizard: the wizard controls the sequence of video clips
2. Sensor information: by using XML files to store the sensor information about every clip.

Figure 1-2 Immersive Video environment (IVE) [2]

The steps of the proposed methodology are described as follows:

1. To investigate travel demand and fundamental needs
2. To prepare the study area, shooting the video and apply to IVE.
3. To study on performance of interaction techniques such as time, accuracy, usefulness and ease of comfort (task completion time, convenience, accuracy, and realism)
4. To evaluate the result by statistical analysis and study on human behavior and decision making.
5. To come up with a model for evacuation system based on the results

Figure 1-3 indicates the flowchart of this research methodology.

1.6 Thesis outline

The thesis is in six chapters as detailed below:

Chapter one: It introduces the research topic, the background of the study, problem statement, research objective, scope and methodology.

Chapter two: This chapter covers literature review which is to explore methodology for emergency evacuation and dynamic signs in a Virtual Environment.

Chapter three: This chapter provides the methodology of this study. The steps include; Evacuee demand, preparation, interaction and output.

Chapter four: This chapter discusses implementations and preparation of this research. The steps contain; how to create the environment of emergency in IVE and how to overlay the exit signs inside the video.

Chapter five: This chapter presents the evaluation part and usability test for the study.

Chapter six: This chapter discusses the results and analysis of this study from which necessary conclusion and recommendation will be made. Finally conclusions and recommendation for future study are discussed

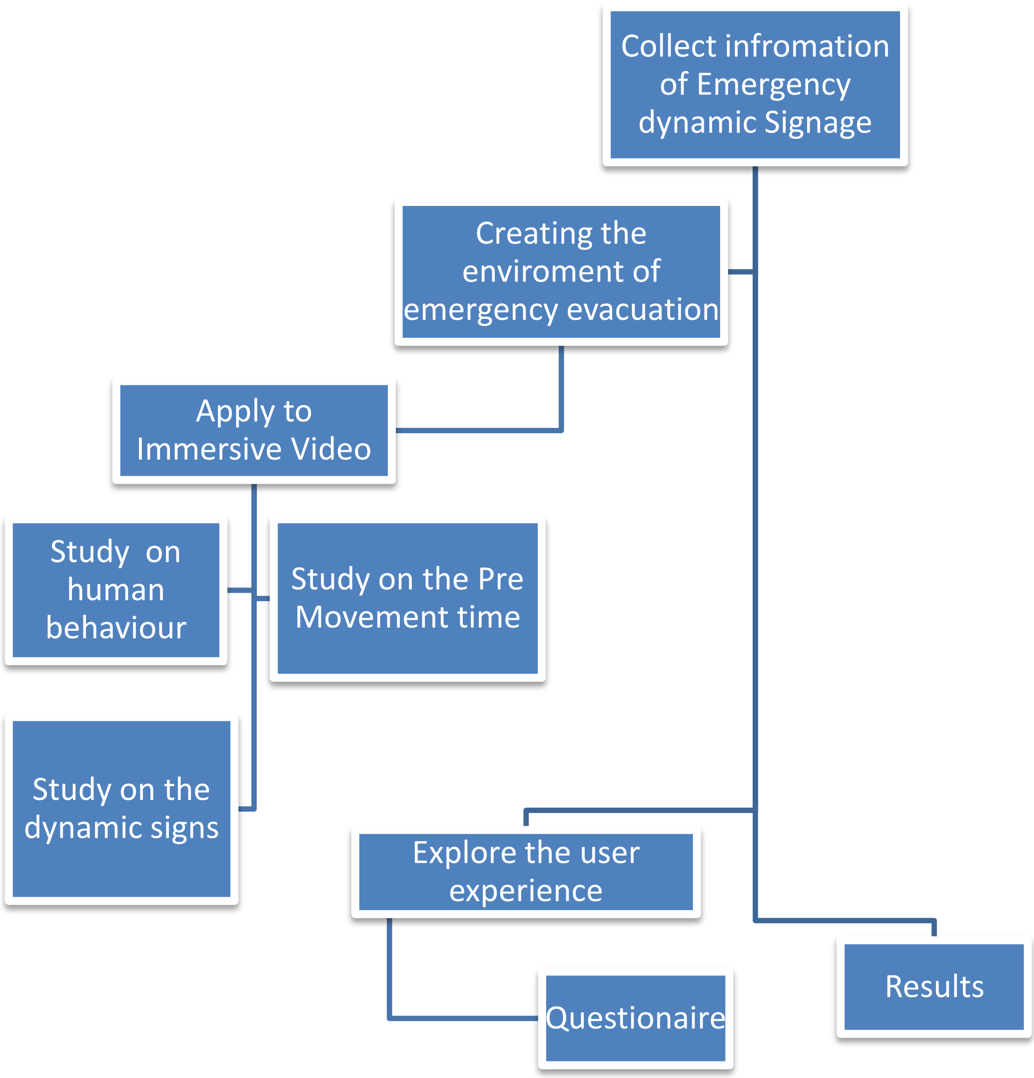

Figure 1-3 The diagram of the proposed methodology

Chapter 2

Literature Review

2.1 Introduction

This chapter focuses on all related works about dynamic signage evacuation systems, different models and testing environments. The first part 2.2 explains about the experimental works on evacuation systems based on different models. Part 2.3 investigates how static and dynamic signs are currently used in case of emergency egress and the last two parts will focus on Virtual environment, its usage for simulation a scenario and the possible evaluation methods

2.2 Emergency Evacuation Systems

As mentioned in chapter one, there are numerous works related to evacuation and emergency situations. The model and the factor that they considered in their studies can be seen in Table 2-1 Evacuation models. These models might be categorized as follows:

1. Cellular Automata (CA) [7] [6] [8].
2. Molecular dynamic [9].
3. Latice gas [10].
4. Ad hoc network [11].
5. Ubicomp [17] [16]
6. Shortest path algorithms [12]

There are some other models which are mentioned in [20] such as Fluid-dynamic, Fukui-Ishibashi, Gipps-Marksjös and etc. These models typically try to solve pedestrian dynamics and dynamics evacuations by finding three parameters: flow, density and velocity. Additionally other works consider some factors and analyze the results by comparing different situations. For example Helbing [9] tested Molecular Dynamic model in a smoky room. This model suggests that neither individualistic (find exit accidentally) nor herding behavior (following crowd and block direction) performs well.

Christakos [11] applied ad hoc network for an evacuation scenario for simply pedestrian simulator based on Helbing [9]'s escape panic simulator and the results shows improvement in escape time. Life Belt [8] examined CA model by comparing the following factors in Crowd dynamic: Time to reach to an Exit Area (TEA), Exit Population (EP) and Exit Capacity (EC). In this work, jamming at certain exits, while empty other exits were considered and it reduces the time for successful evacuation.

Work by	Model	Factor	Case Study	Considrations
Inhye Park [7]	CA	Various velocities,	Movement with IPS RFID	Obstacle can be fixed in integer number of cells
Varas [6]	CA	Obstacle, Single door vs double, Evacuation time	Classroom with full capacity	Ignore of personal tendency to follow crowds
Helbing [9]	Molecular Dynamic	Escape panic	Smokey room by certain desired speed and direction	Not consider falling people while escaping, Not complex strategies and interactions .
Isobe [10]	Lattice Gas	Observation of behavior, poor visibility	Room without visibility	More exits does not improve the system
Rescue Me [12]	Randomly, Rescue Me algorithms and Shortest path	shortest-path exit, People are randomly distributed, shortest amount of time 3D	Image-based localization such as IQEngine by WIFI IPS and Bluetooth	Ignore the Behavior of evacuee! It provides high positioning accuracy.
Christakos [11]	Ad Hoc network	Block area	Find the best path	Escape time is improved
Lifebelt [8]	CA	Crowd behavior , Silent Directional Guidance	Linz station for a crowd simulation	It reduces the time for successful evacuation.
Directional Sound Evacuation [13]		Sound Speed	Road tunnel filled with smoke	Bus and car are considered but not motorist
GAUDI [16]	Ubicomp	dynamic signage Accuracy of positioning	Inside the complex building	Small number of users, only one floor
Rotating Compass [17	Ubicomp	Tactile sense Public display	Single room with 14 participants	In Webpage not in Public place
Massink [21]	Stochastic (Bio-PEPA egress)	Dynamic selection, evacuee behaviour, Movement time	Inside a building	It decreases evacuation time which get blurred in the average numbers provided by fluid flow analysis.

Table 2-1 Evacuation models

RescueMe [12] is a novel system based on indoor mobile AR (Augmented-Reality) applications for an emergency situation. The user follows the AR indicator arrows to safety (Figure 2-1). IQEngine service has been used as an image based map and found the shortest exit path by AR in the smart phones. This model attempts the improvement of sthe exit time by applying different shortest path algorithms. The last three works [16], [17], [21] deals with direction and sign. Rotating Compass [17] tests different directions in a mobile navigation system combined with a public display. It develops the presentations of static directional signs by an animated public display. GAUDI (Grid of

Autonomous Displays) [16] consists arbitrary number of autonomous wireless displays and a navigation server. It is automatically assigned the dynamic signs with the current location of the user.

Figure 2-1 RescueMe [12] AR application in 3D and 2D views

2.3 Dynamic Signage vs. Static

The term of evacuation dynamic has to be understood on different level such as: physical, physiological, psychological, and social [20]. This work tests particularly physical and psychological level in a VE to determine the differences between static and dynamic signs. In this study dynamic signs inform the evacuee by following the exit signs in case of fire emergency and move towards the exit. Directional signage systems such as [16], [17], [21] are designed to support users in different environment.

GAUDI [16] is a pervasive navigation system. It contains a set of dynamic signs to be used by untrained users and to be adapted to their location automatically. Rotating compass [17] can be referred to visualization system where a public display demonstrates a compass with a rotating needle. Smart Signs [21] offers personalized context-aware guidance to maintain way finding activities in indoor environment. [22] , [23] simulated a dynamic evacuation systems, besides they considered dynamic signals and signs in their studies. In work [23] bi-color LED in relative position for four kinds of signs has been used (Figure 2-2).

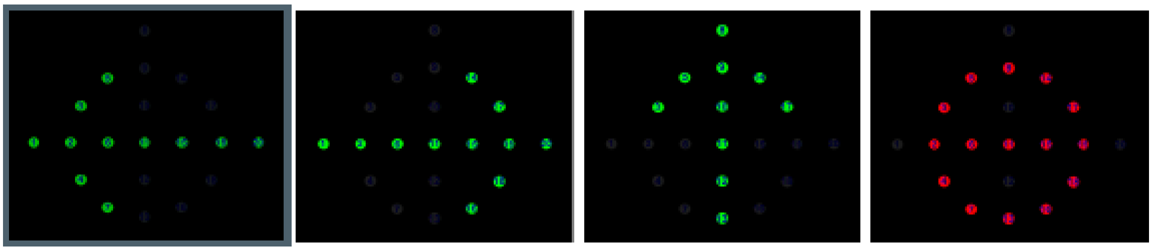

Figure 2-2 All the four different signs with Green-Red LEDs [23]

Dynamic signs shall follow the design of static sign. Emergency signs contain elements that evacuee should locate and identify the exit door. Exit signs show a long way over the past years. The English word "EXIT" is derived from the Latin word which means "To go out" [24]. They shall be visible from any direction and the size of the signs are dependent to structure of building approximately 12” long, 8” high. Mainly, the emergency signs follow two types of sign (Figure 2-3): Exit sign and the running man sign. The running man symbol was designed by Japanese named Yukio Ota at international contest in 1985 [25]. In European Union, Australia, New Zealand, China and Japan, Emergency exit signs have green lettering or mostly the running man sign (Red is used to show prohibited area like fire region). The running man sign has two pros: Firstly it is a pictogram so it can be understood even by people who don’t speak the same language of that country indeed it is green that is the color of safety. In the other hand the Emergency signs have either red or green lettering but typically red color in United States and Canada [24]. There might be a discussion which color (Green or Red) is more visible in smoky area. Emergency signs must have higher luminosity for smoke conditions and lower luminosity for free conditions [26].

Figure 2-3 Type of Exit signs

There are several studies for visibility of exit signs in emergency in both static and dynamic signage. Neil [27] found out the color differences and luminance contrast between different letter colors and background colors. The results were substantially the same. Quellette [28] studied about the interaction of the various combinations text and backgrounds (White, Green and Red) of exit signs between ambient illumination and smoke density. The result was that the difference between the tests is significantly small consequently the signs with white background require more luminance than those with darker backgrounds.

Rubini [29] compared the green and white background in different smoke area. It is pointed that visibility of a sign depends on relative contrast to the background and can be express by Weber contrast as:

$$C_w = \frac{L_T - L_s}{L_s} \quad (1)$$

Where LT is the luminance of the object and Ls is the luminance of the background.

Wright [30] compared different kind of dynamic sigs like LED or electroluminescent. Two of these signs are comprised of green colored background with white exit symbol and green LEDs forming symbols respectively. The study tries to distinguish the difference between the maximum viewing distance in a smoke area and the results shows there were no significant differences in all 15 tests. Collins [26] studied on electroluminescent signs and he pointed out that signs with illuminated letters and opaque backgrounds in some cases are more visible than panel-faced signs. Figure 2-4 illustrates some available signs in Germany where this research is applied.

Figure 2-4 Exit signs in Germany

2.4 Virtual Reality (VR)

During the past several years, Virtual Environment (VE) has gained extensive attention through the human computer interaction (HCI) community. Virtual Reality (VR), Virtual World or Virtual Environment (VE) dedicates to different technologies like Video game, Immersive displays, Web3D, and different area such as psychotherapy, location based scientific visualization and entertainment. VEs determine a computersynthesized world in which the user will be able to easily navigate from one location to another one and interact with objects and perform various activities [31]. The word "Navigation" has been used in term of the process of defining a path to travel through any environment. Navigation refers as exploration, walking, flying, motion, travel or way-finding in different VEs [31, 32, 33, 34]. Generally the user of VE is disoriented or discomfort due to navigation part. Two type of navigation or travel can be distinguished: Active and passive. In active, the user can interact with interface while in passive the navigation is predefined. Most common VEs have used head-mounted display (HMD) or CAVE systems. Figure 2-5 shows an example of Immersive VE called immersive projection technology (IPT) [35].

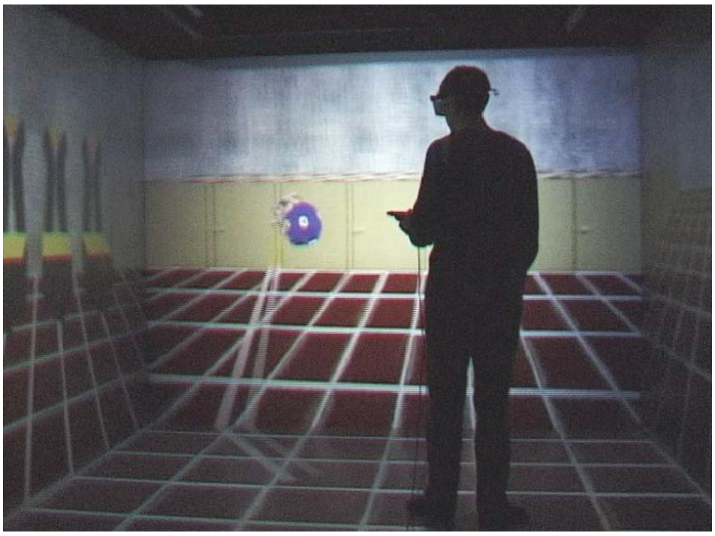

Figure 2-5 IPT user in selection and manipulation task [35]

2.5 Usability Evaluation

Virtual Environment (VR) is a new type of Human Computer Interaction (HCI) technique. Usability evaluation methods are one of the key factors in VR since they promise to obtain an enhanced system, higher performance and comfort for users. "Usability can be broadly defined as "ease of use" plus "usefulness", including such quantifiable characteristics as learn-ability, speed and accuracy of user task performance, user error rate, and subjective user satisfaction" [36]. There are different ways to test the usability of the VE. One of them is called "Think Load". In some VEs, voice recognition is used to render the Think load protocol. The common technique engages to address a tracking camera to record the synchronized video from user and interface which both are visible by evaluator. There are various usability evaluations available; following are some example [36]:

Cognitive walk through: This method is applied to understand usability of a system for the first time (Novice user).

Formative: It is used to assess usability problem and design ability that it is mostly based on qualitative result.

Heuristic or Guideline-based [37]**:** This method is applying a set of design guideline for the users; it is difficult to predict. This test is addressed for the expert user (Task Descriptions Sequences & Dependencies)

Questionnaire: The test can be run by set of defined questionnaire. This is more convenient way to evaluate the users. Nowadays there are different types of evaluation and workload questionnaire are available. Next part will explain some of the examples.

Interview: Interview may let the evaluator gather more information than questionnaire even some factor which they were not considered in the test and later it shows that it has big influence on the results.

Summative: This is way of statistical comparison of different interface design (qualitative and quantitative)

Testbed [38]**:** This test is introduced by Bowman and it is composed of Heuristic and Quantitative performance.

Sequential evaluation [39]**:** It is collected of formative, Summative and Heuristic (Both Design and evaluation).

Figure 2-6 presents the test bed and sequential evaluation approach [36].

The questionnaire appears in the fact that evaluator is trying to measure different kind of factors likely such performance, presence, comfort, ease of use, etc. So based on these factors there are different type of questionnaire. Following describe briefly the most common questionnaires in VE.

Questionnaire to test the comfort of the user:

Simulator sickness Questionnaire (SSQ) [40]**:** It is the most famous questionnaire to define the motion sickness developed by Robert Kennedy. This part is explained more in section 5.5.2.

Questionnaire to test presence:

Presence Questionnaire: PQ has designed to measure presence in VEs. The factors that is contributed to measure presence are: Control, Sensory, Distraction and Realism factors [41]

Immersive Tendency Questionnaire (ITP): Immersion is a necessary factor to experience the presence. The three components of these questionnaires are involvement and game (Tendency to play video games) [41].

Questionnaire to test performance:

NASA Task Load Index (TLX) [42]**:** The NASA TLX applies six dimensions to evaluate workload: mental demand, physical demand, temporal demand, performance, effort, and frustration. More information can be found on 5.5.4.

VRUSE [43]**:** It is based on the attitude and perception of its users, indeed system performance on presence is included. The rates change from 1 to 10 in terms of never to always, cluttered to uncluttered, impossible to easy confusing to clear VRUSE include the total 100 questions and it is not appropriate to delete the questions but it is possible to remove the total section from questionnaire. Following factors are assign for VRUSE: 1) Functionality 2) User Input 3) System Output (Display) 4) User Guidance and Help 5) Consistency 6) Flexibility 7) Simulation Fidelity 8) Error Correction/Handling and Robustness 9) Sense of Immersion/Presence 10) Overall System Usability.

Software Usability Measurement Inventory (SUMI) [43]**:** SUMI produces six scaled scores: Efficiency, Aspect, Helpfulness, Control and Learn-ability in three different levels (Agree, Undecided and Disagree).

Subjective Workload Assessment Technique (SWAT) [44]**:** SWAT applies three levels (low, medium and high) to produce a single rating scale workload. It is considered that TLX has better scale for measuring the mental factor than SWAT.

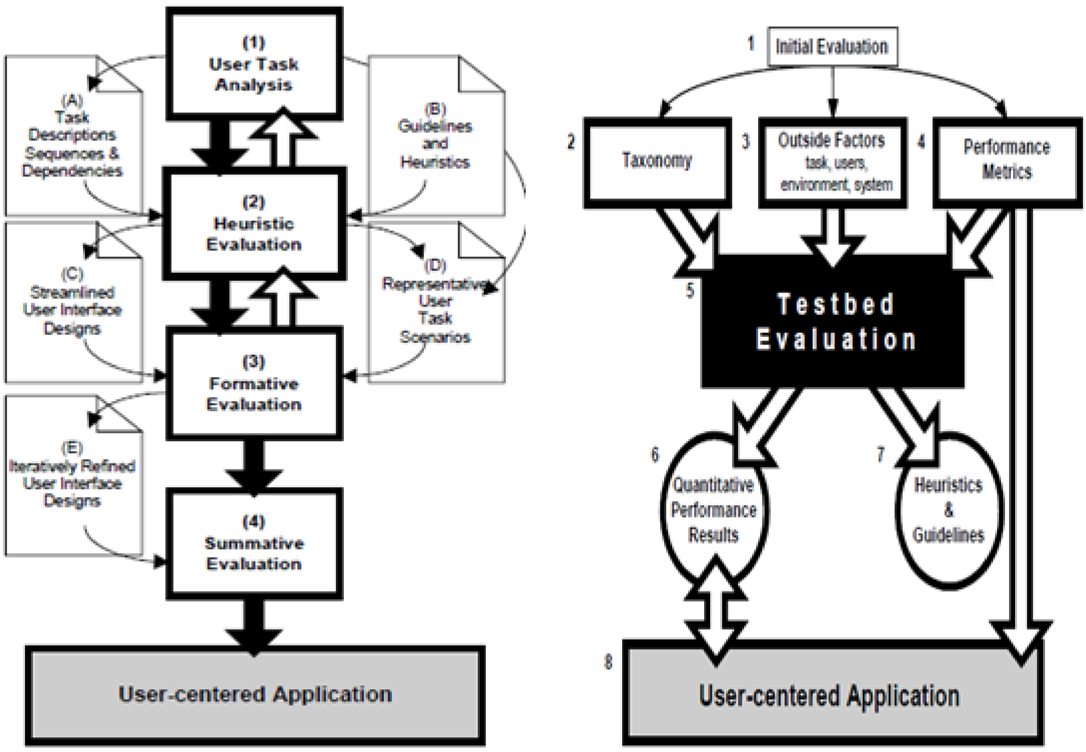

Figure 2-6 Sequential evaluation and Testbed [36]

Chapter 3

Methodology

3.1 Introduction

This chapter specifies the methodology for this study. Bowman [38] and Tan [45] proposed their methods to apply to Virtual Environment (VE). In this study their methods has been used to create the simulation of dynamic evacuation signs in an Immersive Virtual Environment by using Immersive Video. Part 3.2 describes the evacuee demands for an emergency incident; besides part 3.3 and 3.4 will express that how it is implemented in VE. Finally part 3.5 and 3.6 explains the performance and evaluation test study. Evaluation test study also described in chapter two and five widely with all the possible statistical analysis. Figure 3-1 represents the steps of the proposed methodology; they can also be described as follows:

1. To investigate travel demand and fundamental needs
2. To prepare the study area, shooting the video and apply to IVE.
3. To study on performance of interaction techniques such as time, accuracy, usefulness and ease of comfort (task completion time, convenience, accuracy, and realism)
4. To evaluate the result by statistical analysis and study on human behavior and decision making.
5. To come up with a model for evacuation system based on the results

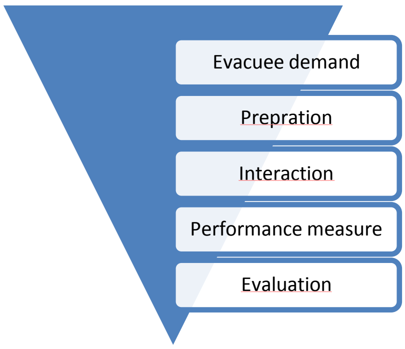

Figure 3-1 Steps of methodology

3.2 Evacuee demand or task characteristics

The first step towards the methodology of this work gains the possible characteristic demands for Evacuee. Some factors from literature review are concluded into this study such as escape panic, poor visibility or smoky area, response time, speed. Figure 3.2 shows the factors that are considered in this study.

The first part of evacuee demand is personal characteristics. This part mostly is connected to the situational conditions such as travel, time and poor visibility. Nevertheless it can be expressed as decision making in panic situation. In [20] , Panic describes as an irrational behavior which the people compete to dwelling to exit. Panic is an unexpected event and due to that it is not possible to model it and to test it quantitatively. The best option is to call it as decision making instead of escape panic. Speed of the traveler changes due to their age, the location (Corridor or Stairs) and the situation of them. If they are in a relaxed situation, the observed free velocity is around 0.6 m/s and for normal and nervous conditions are around 1 m/s a and 1.5 m/s respectively [9].In addition, one study [4] mentioned that the maximum walk speed for male is 1.6 m/s and for female is about 1.4 m/s . Upward walking speed is depended to the age, sex and length of the stairs and is around 0.391 to 1.16 m/s [20]. Accuracy is ignored here but the test runs with the running velocity situation. Concerning the egress time, 5 classes are distinguished: 1) detection time, 2) awareness time, 3) decision time, 4) reaction time, and 5) movement time. Generally, the first four classes called the pre-movement time (response time). This pre-movement time is going to be tested by how and when the users react while the dynamic signs are changed. These results shall be helpful afterward to model the evacuation and decision making analysis.

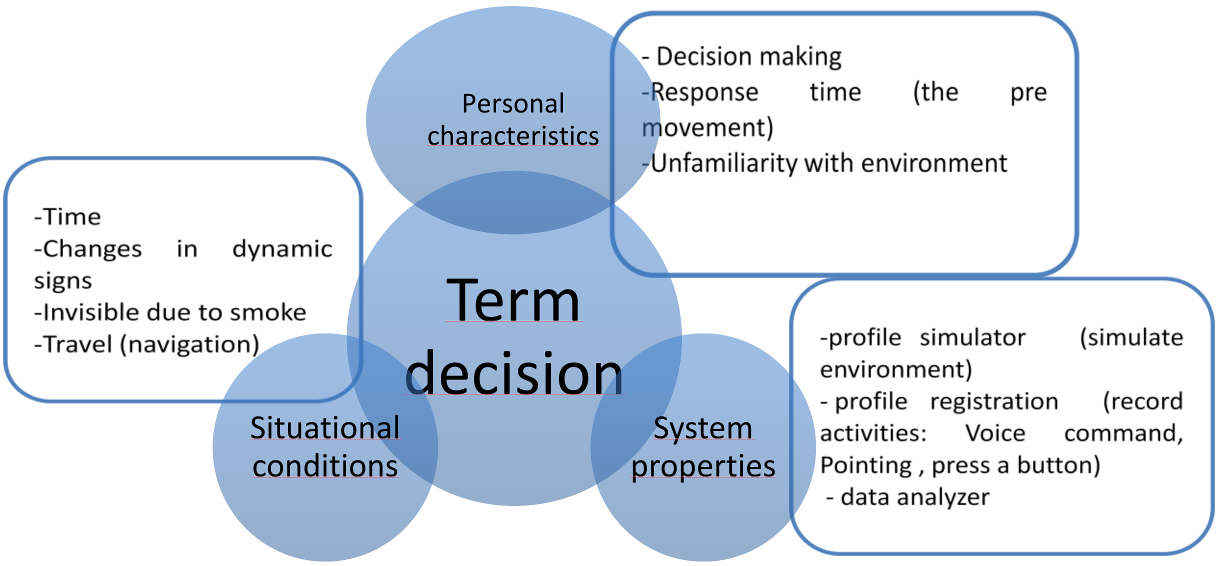

Figure 3-2 Evacuee Demand

Figure 3-2 explains the task characteristics are separated to 3 different categories: personal characteristics, situational characteristics and system properties. The above paragraph talked about the first two classes. System properties are divided to three parts: profile simulator, profile registration and data analyzer [45]. Profile simulator represents the virtual environment and dynamic virtual objects inside it (in this study dynamic signs). Profile registration records all the activities and behavior of the users; this is completed by a tracking camera or a voice command. More descriptions are explained in Interaction part (3.4) called Selection. The last element of the system is data analyzer that works to evaluate the quality and quantity of data collection. This also called as Evaluation process that is the last step of VE (part 3.6 and result).

3.3 Planning and preparation

Planning plays an important role in this subject to complete the experiment. Figure 3-3 gives you an idea about the steps in planning and preparation section. As this study focuses on Immersive Video, the first part prepares the environment for the video shooting. This is accomplished by answering these questions: Where is the place? How is it possible to apply footage video? Where are exit doors located? How can the evacuee reach them (Corridors and stairs)? The next steps are to find the suitable camera for shooting the video and pretest the recorded video to see if it is realistic. Later on the tasks are defined and the acceptable task should be shifted to the respective scenario.

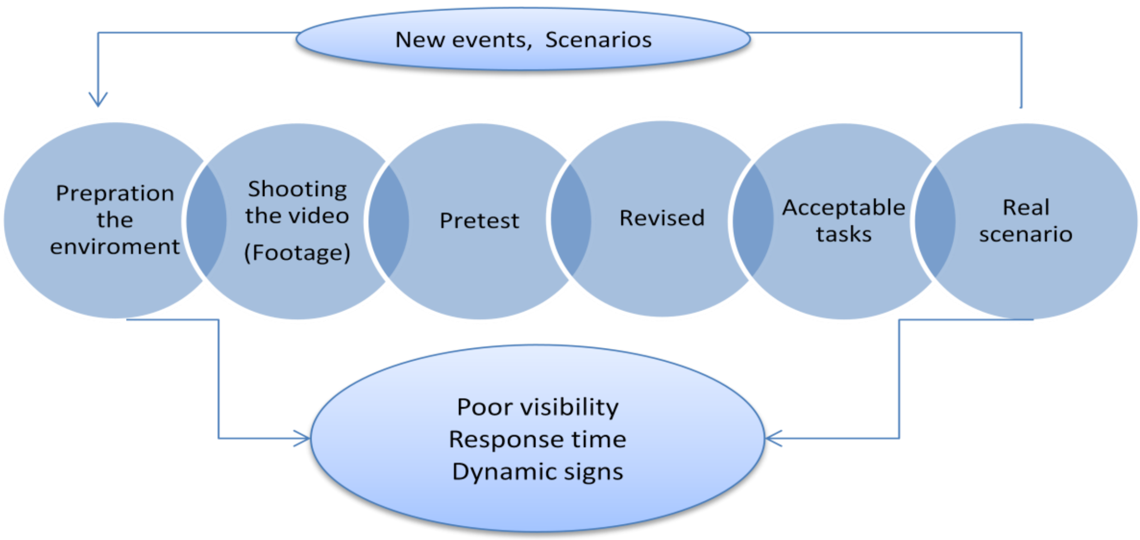

Figure 3-3 Planning and preparation

3.4 Interaction

Interaction refers to how the participants or users interact with the system. According to the methodology of Bowman [38], Interaction Technique (IT) contains three major processes: Navigation, Selection and Manipulation (Figure 3-4). In this work, navigation which is called travel or motion as well; it is how the user directs automatically to the exit. Moreover the velocity and direction will be adapted automatically. Indeed selection is how the user reacts with dynamic signs and environment. The user indicates to the signs by pointing to the left or right. Finally the manipulation is how the system acts while it is running. The main object in this step is how to change the exit signs inside the IVE in a specific time, position and size. Normally the selection and the manipulation are connected somehow together. In this study case, manipulation is implemented before selection.

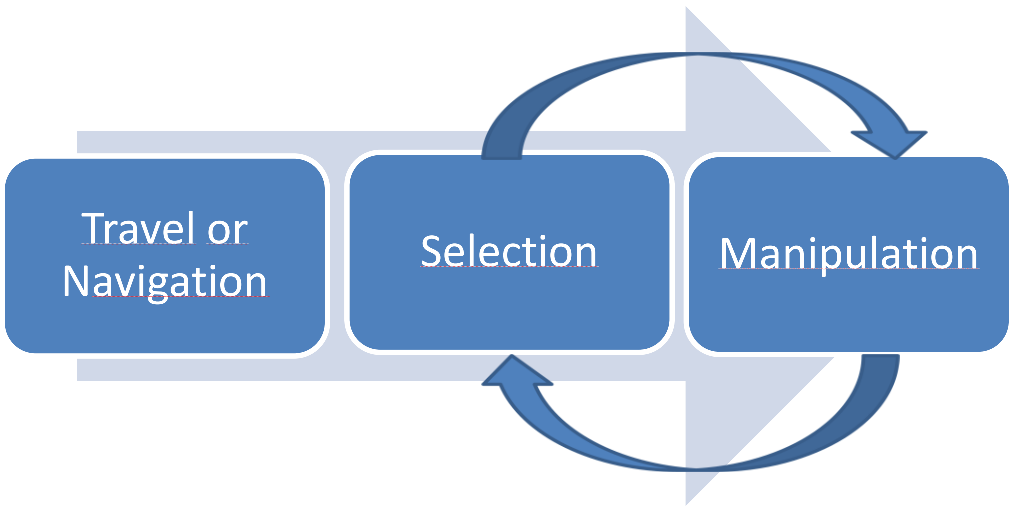

Figure 3-4 Interaction

3.5 Performance measure

The methodology is assigned to obtain information about performance in IVE task. "Performance may be roughly defined as the effectiveness in accomplishing a particular task." [46]. This part is highly related to the task characteristics. Bowman [38] pointed out that performance is speed or task completion time, accuracy, ease of use and ease of comfort. In VE, presence (Involvement and Immersion) and realism might be also a valuable measure [47, 41] . "A VE that produces a greater sense of immersion will produce higher levels of presence [41]". Some of them are easy to measure and they are quantitative and the others are depended to decision making and human behavior thus they are called qualitative. As mentioned before accuracy is not a significant case in this study in case of metric like speed or distance. There are two main ways to measure the performance: Primary and secondary measure workload. In this research, performance is introduced as follows:

6. The pre-movement time or response time to the dynamic signs.
7. Comfort of the system
8. Performance of IVE
9. Realism of the simulation
10. Panic behavior or Decision making

The next part and chapter 5 will explain how it is possible to measure these factors.

3.6 Evaluation

The last step of this methodology is evaluation of the system. So based on the result, it is possible to suggest special model for the evacuation. The effectiveness of virtual environments (VEs) has often been linked to the sense of presence reported by their users. The evaluation of dynamic signage IVE is divided to 4 parts:

1. Tracking camera to record the video from both participant and graphical view. It is planned to trace the evacuee behavior and their response time to the dynamic signs
2. NASA TLX questionnaire to define the performance of the IVE
3. SSQ questionnaire to discover the comfort of the system specially motion sickness.
4. Likert scale questionnaire that there are some predefined questions which use the Likert scale to understand the overall effectiveness and realism of the dynamic signs evacuation simulation on the users.

Chapter 4

Design and Implementation

4.1 Introduction

In this chapter the design and implementation of the IVE components for a dynamic evacuation signage are described. Filming the video to simulate the user's experience as a virtual environment for emergency egress is one of the component of this research. System properties of IVE are explained in part 4.2. Section 4.3 focuses on the preparation of the test plan, location and dynamic signs. Section 4.4 and 4.5 will talk about the editing and overlays. The purpose of these tasks is then to show how, under these assumed conditions, a successful system can be constructed for a Virtual Environment to feel the reality of emergency exit.

4.2 System properties

IVE system contains three screens with 140 degree from each other using 3 projectors at the same time. Generally the IVE System composed of the following:

- 3 digital cameras (CANON; right, center and left camera), Figure 4-1.
- 3 back projected wall that creates wide screen (140 degree),
- Figure 4-2
- Software (VLC player)
- Adobe Pro (To edit, synchronize of video clips and overlay of exit signs)

Figure 4-1 Digital cameras

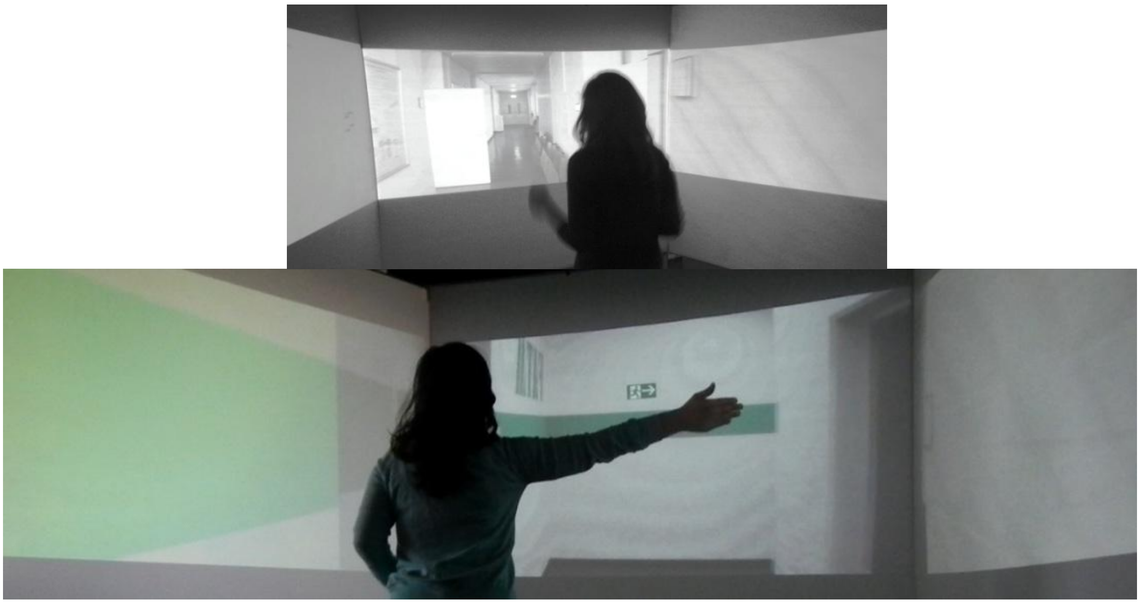

Figure 4-2 View of IVE

4.3 Preparation

The first step of implementation is selection of the location that emergency egress can be applied. The geometry of the building, size of the corridors and door locations are important issues. It is intended to choose a building that it has the following characteristics:

1. There are several exit ways from one floor which dynamic evacuation system can be applied to it.
2. The corridors are not tiny that moving platform can move easily.
3. The exit signs are visible while shooting the video.
4. The corridors are different that the user shall not feel the same in the tasks.
5. There are no people while shooting the video (human factor like crowd is not interested in this study).
6. The building and corridor should be new for the participants, this is a key to enable evacuee to evacuate an unfamiliar building rapidly and securely in an emergency condition.

From the above discussion, the final place has been chosen which has all of these qualities. Figure 4-3 demonstrates the plan of the floor, Exit doors and corridors.

Place: 3rd floor of Psychology building in University of Muenster.

Figure 4-3 Plan of the selected area (3rd Floor)

4.4 Video shooting and editing

The video shooting has been completed in 3rd floor of psychology building in Muenster, Germany. The corridors and the three possible ways to exit can be observed in the map floor (Figure 4-3). A moving platform has been applied to move the cameras for footage video and the normal walking speed has been concerned for video recording. There were six points that video shooting has been started there. It has been taken from beginning of each corridor to the end of that. There was also one video clip for turning around while the people change their way and go back to find a new way to exit. Accordingly there will be seven clips from corridors and turning point. Afterward the clips from three cameras (right, center and left) are synchronized in Adobe Premiere pro 5. The size of new clip must be 5700 * 1080 pixels to be matched to the IVE system. This will make the video files so huge, around 3 to 4 GB for just one minute video clip. As a result the IVE system could handle to play the short video with huge size and this cannot be run in a normal PC. Since the video shooting has been recorded in the normal walking speed, it is important to use the tool in Adobe pro which it can change the speed to double and decrease the duration of the clips to half. Consequently the running speed is adapted to the evacuation trip. One of the key components that it should be applied to the synchronized clips, is stabilization. This feature tries to remove jiggle from footage video and help the users do not experience disoriented by IVE. This is also one of the video effects that can be made by Adobe Premiere Pro or Adobe after effect (version 5.5 or more). Subsequently, the scenarios for the evacuation are defined. 8 scenarios has been produced that each of them starts from one point and end to the exit door. More information about these scenarios can be explored in section 5.2. It is important to merge the available clips in a specific way that it could be possible to use the dynamic signs inside the task. Since there are just 7 video clips and they have to be merged to create a real evacuation scenarios, The mirror effect (Horizontal flip) has been applied to some of them while it helps the user not to feel the same situation as previous task. The final tasks after adapting the running speed are around 30 to 40 seconds per trip. Other information about the experimental design is available in section5.3. Following Figure 4-4 indicates the steps to prepare the final task.

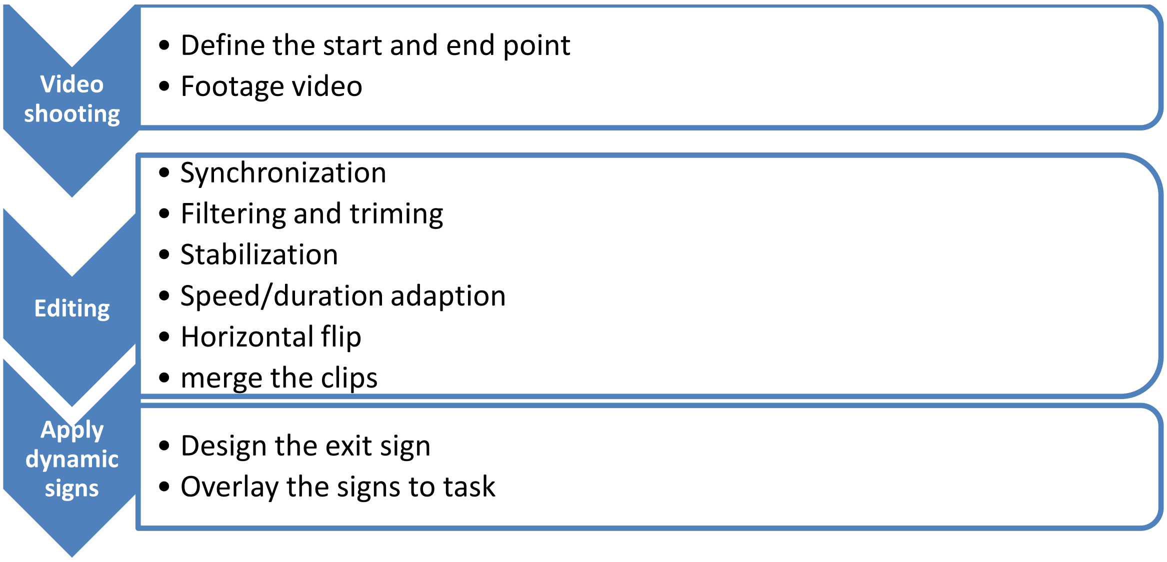

Figure 4-4 Steps in designs and Implementation

4.5 Design and Overlay the dynamic signs

After generating the tasks from the clips, it is time to design the exit signs. As it is mentioned before, this part is called manipulation. These signs follow the German standard. Figure 4-5 illustrates all the possible signs which are helpful in this special simulation of emergency exit. They are called from 1 to 6 consequently and later they are known by these numbers. These signs were added to the proposed tasks and in several specific cases they are changed for example from right to left or from exit to fire (Sign 6 to Sign5). Figure 4-6 and Figure 4-7 confirm the exit signs in this IVE simulation. It was also planned to add smoke and fume to the task that the users feel more reality. These effects can be applied easily in Adobe After Effect 6. The final video with smoke was around 20 GB just for 30 seconds and it was not possible to render in the IVE system. The video has to be compressed by one of the available video editing to the smaller version and the final result drove the less quality. Finally the smoke effect has been removed from the final task while in future possible solution might be found for that.

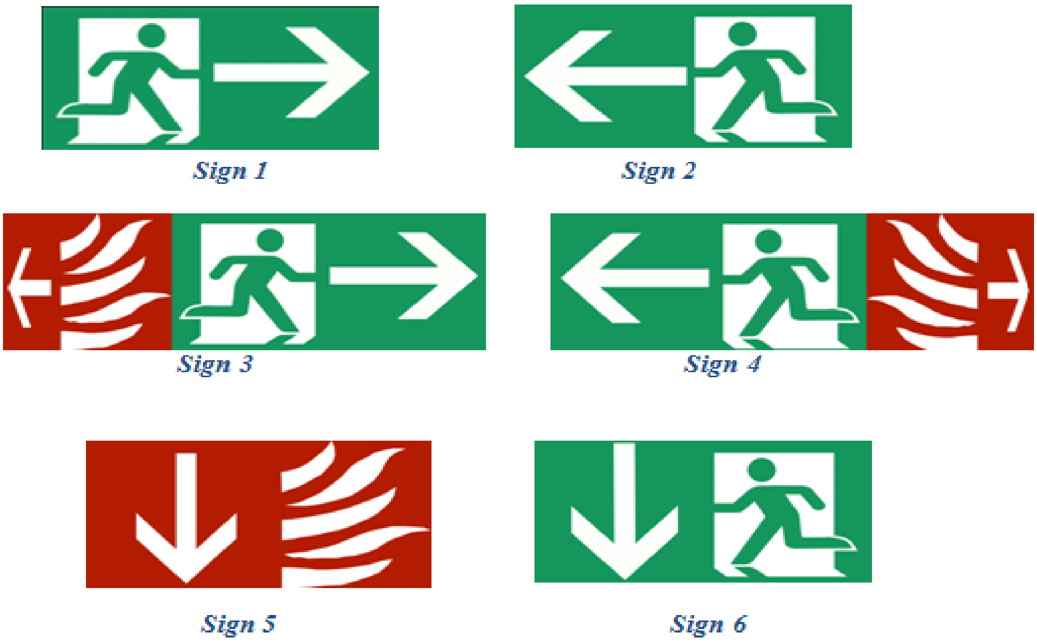

Figure 4-5 Exit signs for IVE evacuation

Figure 4-6 Exit sign 4 inside one of the available task

Figure 4-7 Fire sign 5 inside one of the available task

Chapter 5

Experimental plan

5.1 Introduction

This chapter represents a review of the experimental design, instruction guideline and available workload subjective assessments (SSQ and NASA TLX). These methods are presented here in this chapter. Additionally results and analysis will be discussed in the next chapter. The chapter starts with a preliminary description of experimental design of the whole work such as goal, tasks, rotation material and expected outcomes. There are various publications regarding the evaluation analysis methods. In this research the most common and important of them has been chosen. The latter is an introduction to selected test and guideline.

5.2 Experimental Design

Design of experiment (DOE) or experimental design is the procedure that defines how information will be gathered in the experiment. The principle of DOE explains: How many factors the design will have? How to control the conditions? Did the manipulation truly work? Which kind of materials can be used? And etc. The steps for this research are as follows:

Goal:

- Identify how people react with IVE in evacuating the building.
- Discover the response time when they realize the changes in the sign.
- Identify the effort, performance and comfort of the IVE.

Task:

- Design 6 signs which follow the German standard (The running man symbol)
- Plan 8 different scenarios which they last around 35 seconds from one point to the exit door. The tasks design in different level from easy to difficult.
- Repeat the changes in these signs for these scenarios.

Rotation:

- Randomized experiment
- Randomized experiment makes sure that repeating the scenarios for all participants will not affect the results.

Participant ID	Tasks							
1	1	2	3	4	5	6	7	8
2	8	7	6	5	4	3	2	1
3	4	5	6	7	8	3	2	1
4	4	3	2	1	5	6	7	8
5	6	7	8	1	2	3	4	5
6	2	4	6	8	1	3	5	7
7	1	3	5	7	8	6	4	2
8	3	6	5	8	1	7	2	4
9	7	8	1	6	3	5	4	2
10	4	3	6	5	2	1	7	8

Table 5-1 Sequence of the tasks for each participant

Procedure:

- The participants arrive to the lab, read the instruction and sign it.
- Tracking camera starts to record.
- They are asked to stand and act like when they are running.
- They start the test (6 minutes).
- Stop the video camera to record.
- Hand out the questionnaires (SSQ, Likert Scale questionnaires and NASA TLX around 15 minutes)

Materials:

- IVE system
- Tracking camera (Nikon)
- Printed version of questionnaires.

Potentially interesting outcomes:

- Response time in two different exit signs.
- The behavior of the participants when they see a sign changes.
- Comfort of the system by SSQ.
- Performance of the users in IVE by NASA TLX questionnaire.
- Realism of the system by Likert scale questionnaire.

5.3 Scenario of the test (Tasks)

8 scenarios have been managed for this experiment in which each of them last around 30 to 40 seconds for a trip from start point to the exit door. In the entire scenario, the exit signs will be varied. They are some differences between them. They are planned from easy to difficult level. The signs will be changed just one time in a task for the easiest level and two to three times for the difficult one (Table 5-1). The task will be selected randomized by the evaluator and users don't interact with the interface

Task	Difficulty	Sign 1	Sign 2	Sign 3	Sign 4	Sign 5	Sign 6
1	Medium	2 Changed	2 Used	-	-	-	Used
2	Easy	Changed	Used	-	-	-	-
3	Easy	-	-	Changed	Used	-	-
4	Easy	-	-	Used	Changed	-	-
5	Medium	-	-	Changed	Used	Used	Changed
6	Difficult	-	-	Used Changed	Changed Used	Used	Changed
7	Difficult	Changed	Used	-	-	Used	Changed
8	Medium	Used Changed	Changed Used				

Table 5-2 Available signs in each task

5.4 Participants

The test participants were 10 people (5 Female, 5 Male) who come from different nationalities not specially Germany. Most of the participants do not speak German while they leave in Germany for a while. They all are educated in different background and participants ages ranges from 21 to 30 year (M=27).

5.5 Selected tests and guideline

5.5.1 Instruction (Guideline)

As an experimental plan, it is really important that how the system and the tasks will be informed to the participants. The followings should be considered in all Guidelines or instruction parts. The instruction of this experiment is illustrated in APPENDIX A1: Instruction.

1. The participation is free and the user can choose to either stay or leave.
2. The user can withdraw from the experiment any time he wants.
3. The purpose of the study.
4. The procedure of the test.
5. All the information from the user is for scientific purposes and is not going to be used for any other kind of reasons.

5.5.2 Simulator Sickness Questionnaire (SSQ)

Generally the user of VE is disoriented or discomfort due to navigation (Travel) part. As a result, in this test, SSQ used to test the motion sickness of the current VE system. It is the first time which footage video is applied to this IVE and it could be helpful to find out the discomfort of participants while they are dealing with the test.

Kennedy et al [40] embedded the Simulator Sickness Questionnaire (SSQ). The SSQ uses a questionnaire to measure the three weights: Nausea, Oculomotor and Disorientation in a virtual environment (Table 5-3; the users report the degree of 16 symptoms (APPENDIX A3: SSQ) from none, slight, moderate to severe [48]. The total SSQ score is achieved by multiplying the weights to the scale scores. More information about how to calculate the final result can be seen in [49]. In this study it is intended just to use the post questionnaire for the SSQ. Young [50] described that people who were just exposed to a post questionnaire after VE were less likely to report motion sickness than who were delivered the both pre and post questionnaire. Nevertheless, the SSQ can be significantly biased by demand characteristics and also caused more distortion due to illness of the participants [50].

5.5.3 Likert Scale Questionnaire

"Likert scale is a bipolar scaling method, measuring either positive or negative response to a statement. A typical test item in a Likert scale is a statement, the respondent is asked to indicate their degree of agreement with the statement (Strongly agree to strongly disagree). Traditionally a five-point scale is used, however many psychometricians advocate using a seven or nine point scale. Likert scales may be subject to distortion from several causes." [51]. As it is mentioned before, Likert scale questionnaire has been applied to this study to figure out the realism of the system. The questions can be observed in APPENDIX A4: Likert Scale Questionnaire.

	Weight		
SSQ Symptom	*Nausea*	*Oculomotor*	*Disorientation*
General discomfort	1	1	0
Fatigue	0	1	0
Headache	0	1	0
Eyestrain	0	1	0
Difficulty focusing	0	1	1
Increased salivation	1	0	0
Sweating	1	0	0
Nausea	1	0	1
Difficulty concentrating	1	1	0
Fullness of head	0	0	1
Blurred vision	0	1	1
Dizzy (eyes open)	0	0	1
Dizzy (eyes closed)	0	0	1
Vertigo	0	0	1
Stomach awareness	1	0	0
Burping	1	0	0

Table 5-3 Total weight for SSQ Symptoms [49]

5.5.4 NASA Task Load Index

The NASA TLX is a multidimensional rating workload that uses six dimensions based on weighted average of rating to assess the performance of system. These six subscales are: Mental Demand, Physical Demand, Temporal Demand, Performance, Effort and Frustration [42]. One of the drawbacks is the time to complete questionnaire however NASA TLX rating can be obtained and analyzed quickly. Literature review pointed out that there is another workload assessment called SWAP. One study [44] found out that NASA TLX is better based on mental activity than SWAP. NASA TLX is one of the most common and effective workload for the performance of the system. APPENDIX A2: NASA TLX explains the rating scales and scoring instruction [52]. There was a discussion about that Performance should have a high number associated with good performance and a low number with poor performance. However in NASA TLX scale, good performance is connected with the low numbers since the lower score is defined for the better performance of the system. Besides it is achieved that there is no significant difference between paper, computerized and verbal test in NASA TLX [52]. So in this study the paper evaluation has been performed.

Chapter 6

Results and discussion

6.1 Introduction

This chapter indicates the results in six sections. The first part explains the result of human behavior from tracking camera and their response time. The second part focuses on SSQ test result. Third part clarifies the performance of the system by NASA task. Then it is talked about the realism of the system. Finally an overall result and comparison between time response, comfort and performance of the users has been discussed.

6.2 Decision making and response time

In this part, the result of the response to the dynamic signs has been discussed. The result of the tracking camera indicates the following outcomes as human decision making:

1. In a few cases (2 out of 10), the participant confused between right and left, but finally they have chosen the correct way.
2. Mostly the error appeared for the Fire signs (8 out of 15). The user could not recognize the changes of the exit sign (sign 6) to the fire sign (Sign 5) when they saw the exit door (Figure 6-1).
3. Some of the users (4 out of 10)decided not to act like walking or running however the result shows after some tasks, they (3 out of 4) started to move their bodies while they experience the running simulation in IVE. In a simple way it can be said that the users felt the evacuation is running.
4. A few number of the users (3 out of 10) pointed out to the left or right after the simulation turned to another corridor (late movement). It can be explained the pre movement time to shift to other clips was not enough for some users (Figure 6-2).
5. Occasionally (2 out of 10) they had confusion that there are two ways to exit (For the Sign 1 and 2).

6. Sometimes they responded to the dynamic signs by sounds (like wow the sign changed, oh no, was it changed? etc) instead of pointing especially when they recognized the changes a bit late.
7. Learning the situation is not affecting their reaction to dynamic signs and even sometimes they realized the changes in signs later in the last tasks than the beginning (It has been seen in 3 users). This is the result of mentally being tired or bored. The total time of the test is around 5 minutes so it can be concluded the human cannot decide quickly and correctly in rush situation after some minuets.
8. The evacuation success was around 80% (15 errors during the 8 tasks of 10 participants). So the future work will recommend for the full success.
9. The summery of the results can be seen in http://youtu.be/4E-bO5nsDTo:

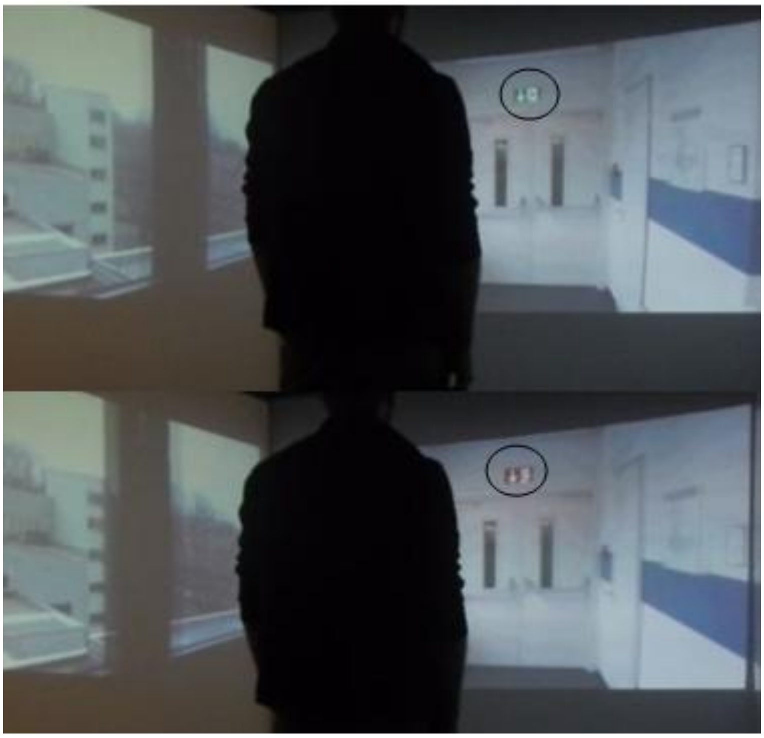

Figure 6-1 No respond for fire sign when there is an exit door

The second aim of using tracking camera was to calculate their response time to the dynamic signs. Appendix A5 demonstrates the movement time for all the participants in all different kind of tasks. In several cases there was an error to see the sign. This movement time is measured from the time that sign changes to the time they start to move their hands or in some specific cases when they react by saying something. Figure 6-3 illustrates one user when he saw the sign; he started to move his hand then he pointed out to the direction.

Figure 6-2 Movement for the sign after they turned to new corridor

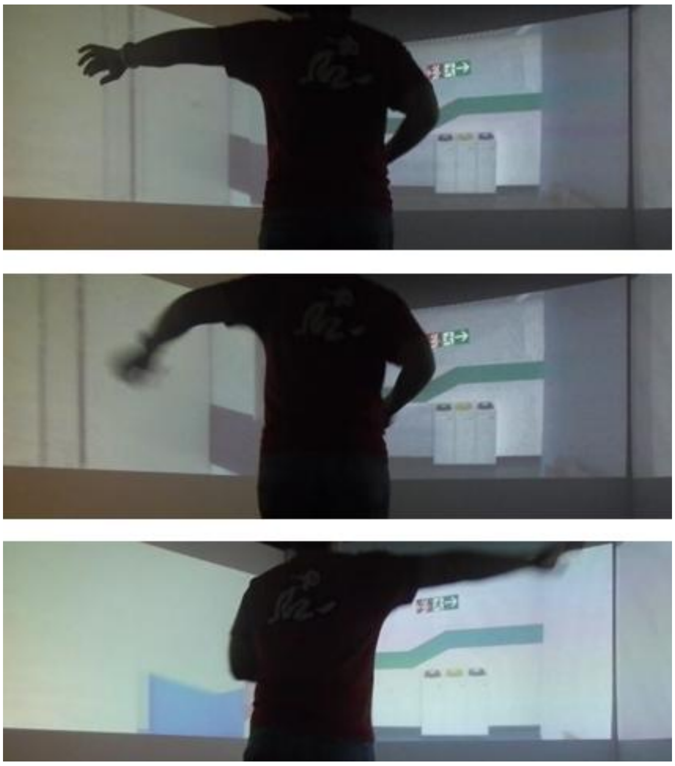

Figure 6-3 Calculation of pre movement time

The average for response time (Pre Movement time) is 0.92 seconds. This result varies to 0.82 seconds for men and 0.98 seconds for women. The average time for the first design (signs 1-2) is significantly same with the average time for the second design (signs 3-4); 0.84 and 0.85 seconds respectively. Nevertheless the average time for the fire sign design (5-6) is 1.18 seconds. This indicates that the exit door influenced the participant to react later. Figure 6-4 presents the line chart for the total number of errors per participant in the test and Figure 6-5indicates the scatter plot for number of errors to their response time. It can be concluded from the trend line that errors is not affecting to their response. In the other hand the maximum response time is not related to maximum errors. The task difficulty has been defined for the entire task. The task is named hard if the signs change more than two times in a trip and the time difference for change and turning to another corridor is less than 3 seconds. Figure 6-6 shows that response time is not related to task difficulty nevertheless the number of errors appear more while the task become harder. ASdditional statistical analysis can be run for this part later.

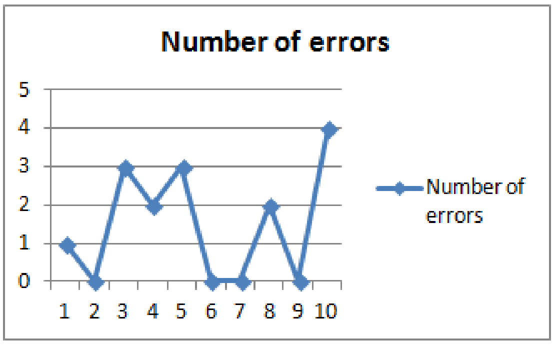

Figure 6-4 Number of errors per participant

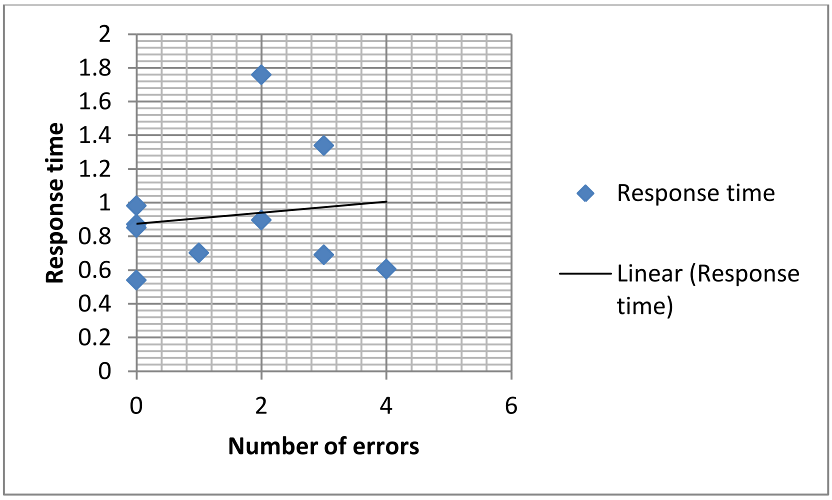

Figure 6-5 Scatter plot indicates response time to the number of errors

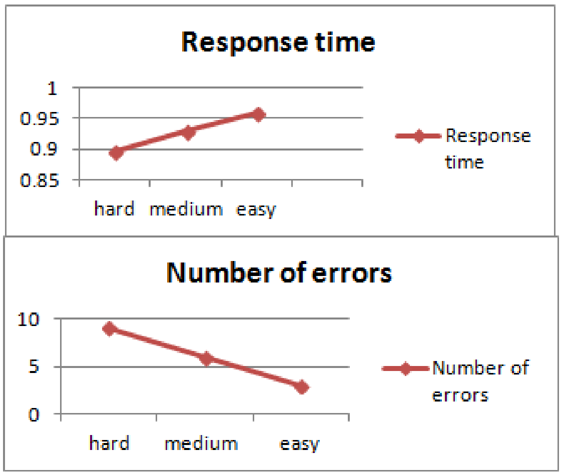

Figure 6-6 Task difficulty level to response time and number of errors

The response time for each task (Male: M=0.98, Female M=0.82) with t test, there is a significant difference for groups of male and female (t (14) = 2.85, p = 0.01, Cohen's d=0.55).

6.3 SSQ result (Comfort)

The result of the SSQ test indicates that the participants believe more disorientation than the two other scales. In this experiment, 3/7 symptoms associated in Oculomotor weight, significantly enhance: eyestrain, difficulty concentrating and blurred vision. Whereas 4/7 symptoms connected to nausea were absent: increased salivation, nausea, stomach awareness and burping. Figure 6-7demonstrates a bar chart of SSQ test result.

In this study, males have significantly greater stability than females and they all reported less motion sickness or in better explanation better comfort. This can be related that men have better physical strength than women. Figure 6-8 shows that overall SSQ for men accounted less than women. The Disorientation score for females were considerably higher than males. In contrast, males stated higher Nausea discomfort score than females. The overall SSQ (Male: M=17.95, Female M=32.91) with a t test, there is statically significant effect for groups of male and female (t (8) = 1.50, p = 0.1, Cohen's d=0.63 90%confidence). In the other hand, men were significantly more comfort than women.

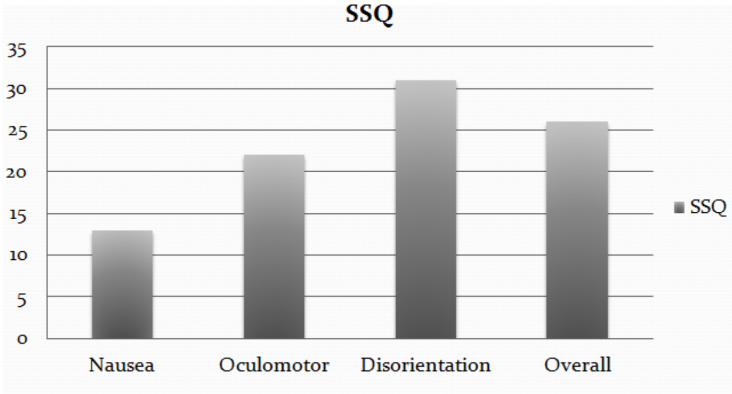

Figure 6-7 SSQ test result

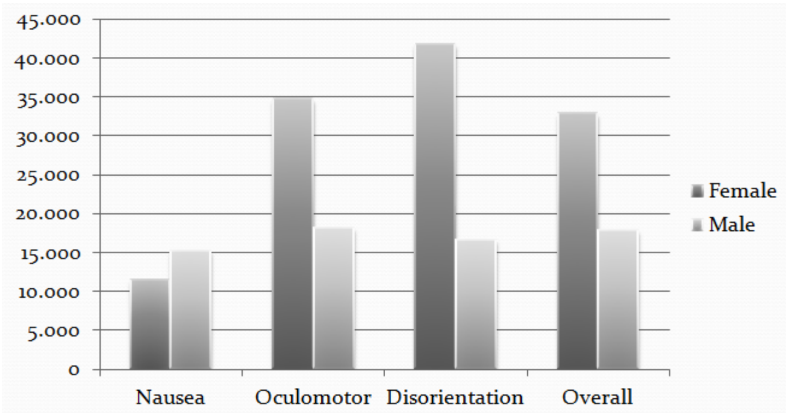

Figure 6-8 SSQ for Female and Male

6.4 NASA TLX result (Performance)

It can be observed from Figure 6-9 that temporal and mental scales in NASA TLX test have the highest scores. These mean that time pressure in test and perceptual activity (e.g., thinking, calculating, looking, searching, etc) were highly graded. Generally in VE, this might be a disadvantage of the system whereas in this study, it was planned that the participant feel rush and hurry besides the test was managed to test their mental activity when they are in rush. The users reported roughly no frustration in the system. Therefore they were not irritated from the jiggle in footage video that has been tried to remove by stabilization effect as well as high velocity in the task. Particularly none of the subscales of NASA TLX were highly correlated (the result is shown in APPENDIX A5: Results: NASA result). Figure 6-10 represents the trend line of overall score for each participant. The maximum and minimum scores are observed in 6 and 8 respectively that both are reported by men.

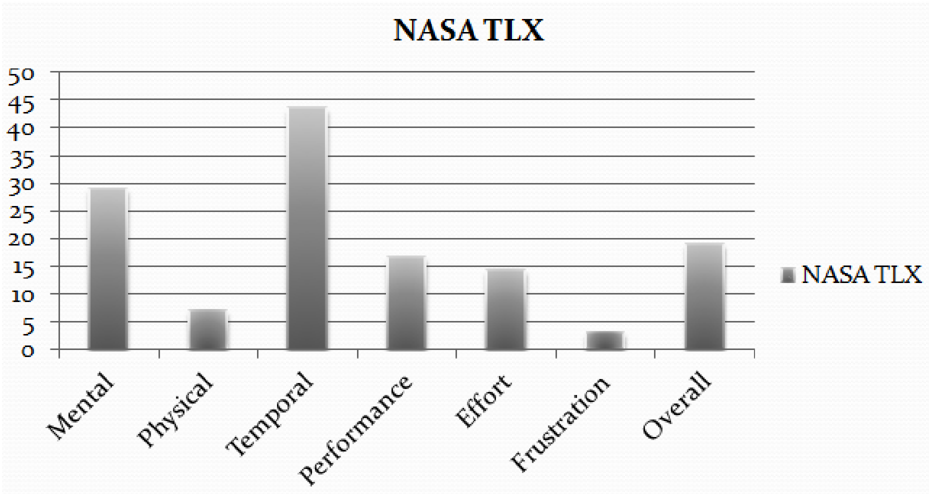

Figure 6-9   NASA TLX result

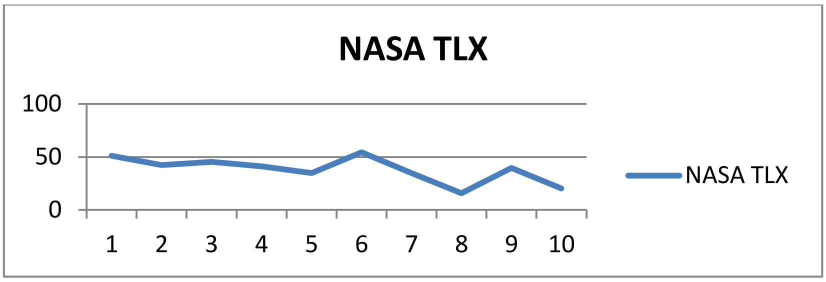

Figure 6-10 NASA TLX for each participant

6.5 Likert Scale Questionnaire result

It was planned to prepare a specific questionnaire apart from NASA and SSQ. The aim of this questionnaire is to identify the realism of evacuation simulation in IVE. Totally 8 questions were initially written in technical terms (APPENDIX A4: Likert Scale Questionnaire) and the likert scale has been applied for the answers to address cross correlation between the different questions. Figure 6-11 shows the mean and standard deviation for these 8 questions. The following results can be concluded:

1. They could see the signs clearly.
2. They were happy with the idea of dynamic signage.
3. They were evacuating the building and the simulation looks real for them.
4. They understood differences in the task and they were happy with the design.
5. They thought that they have recognized the changes in sign in the exact time.
6. Mostly they did not feel rush or panic.
7. Mostly they recommend that they prefer the sound signs synchronized with Graphic signs in the environment to recognize the situation clearly

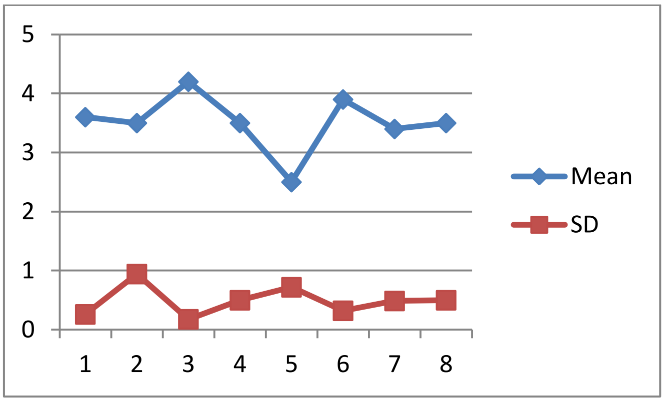

Figure 6-11 Mean and SD for likert scale for 8 questions

As might be expected from

Table 6-1, a relatively medium correlation was found between questions (4, 7), (5, 8), (1, 8) and (4, 8). So we can say that

- The users who could see the signs in current time, they were happy with the design.
- The users were happy with the idea of dynamic evacuation indeed they think that the simulation looks real.
- The users felt that they are evacuating a building and in their opinion the simulation looks real.
- The users who could see the signs in current time, they think that the simulation looks real.
-

Column1	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
Q1	1.000							
Q2	0.000	1.000						
Q3	-0.102	0.000	1.000					
Q4	0.304	-0.404	0.373	1.000				
Q5	0.253	0.202	-0.310	0.277	1.000			
Q6	-0.152	0.705	-0.371	-0.138	0.345	1.000		
Q7	0.492	0.164	0.452	0.674	0.374	0.112	1.000	
Q8	0.609	-0.243	-0.373	0.556	0.647	0.138	0.449	1.000

Table 6-1 Correlation between likert scale questions

Apparently this is the final conclusion of this questionnaire: The users were agreed with realism of the evacuation simulation in IVE, they were satisfied with the design and the idea of dynamic signs although they did not feel any panic and rush.

6.6 Overall result (relationship between Time, Comfort and performance)

In this part, it is important to find the relation between time, comfort and performance. As mentioned before SSQ questionnaire have been known to test the comfort of the users and NASA TLX has been assessed to discover the performance of the system. Therefore there are three variables available for each participant. One of them is response time and the two others are the overall scores from SSQ and NASA TLX results (Out of 100). The first step is to normalize these 3 variables. In Appendix A5 the final normalized data is accessible. Figure 6-12 demonstrates the trend lines for normalized data. No pattern can be seen (i.e., if one variable increase, other variable increase or decrease). For this situation (for time instances or comfort instances the performance is always high. So maybe time and comfort don’t affect performance highly. As a result for the next step regression analysis is desirable.

Table 6-2 clarifies the correlation between time, comfort and performance. Correlation does not imply causation. It means between two variables does not necessarily imply that one causes the other. The best way to explicate the relation between these three variables is to use the regression. The relation is explained if their time response has been affected by comfort and performance or not.

Correlation	Time	Comfort	Performance
Time	1		
Comfort	-0.488	1	
Performance	0.214	0.263	1

Table 6-2 Correlation between time, comfort and performance

In Figure 6-13 it can be seen that this linier regression model explains there is no relationship. The value of R-squared is the coefficient of determination indicating goodness-of-fit of the regression and the test fit perfect if this statistic is equal to one. In this regression the value is small which is not enough to predict the dependent variable. Therefore there is no sufficient amount of data or there are high variances in the participants

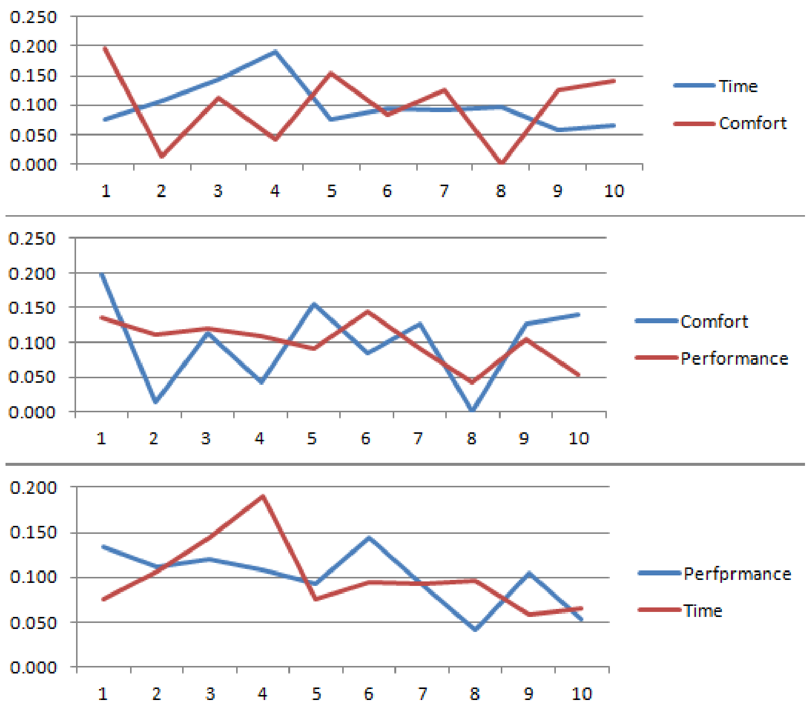

Figure 6-12 Trend lines for normalized data

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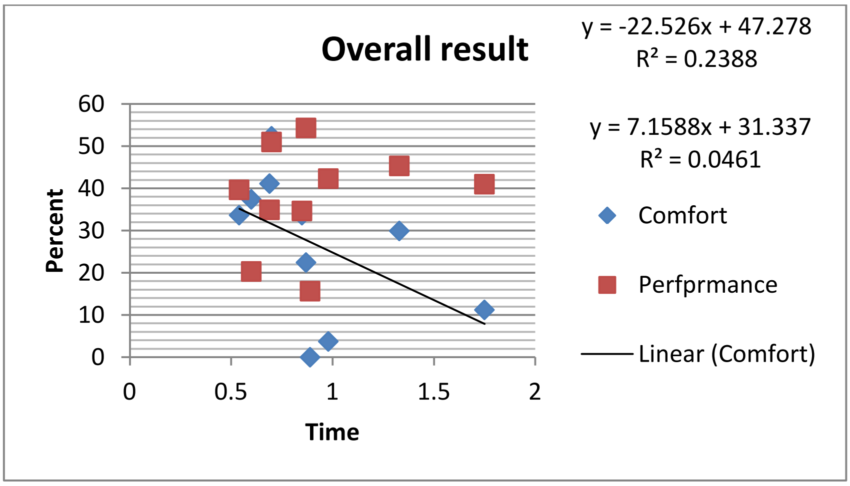

Figure 6-13 Scatter plot for Overall result (comfort and performance to time)

6.7 Discussion

In the test, two subjects had high variant response time in different tasks (from 0.5 to 4 seconds). It was planned to discard some of their results from the analysis but finally their results have been added because this simulation is prepared for emergency response. Since all the participants were in a healthy condition, it can be concluded being tired or being in rush affected their result and this can also be happened in a real scenario.

In section 3.2, the panic situation and decision making were discussed. Apparently, there were two different result from likert scale and NASA TLX questionnaire in the issue of being in rush or panic. In likert scale questions, most of the participants declared that they did not feel any rush or panic meanwhile some of them reported low level. In contrast, NASA TLX assessment indicated high temporal demand score. That means the participants felt time pressure and rapid pace. It might be a misunderstanding of the question for all participants. So the participant felt rush during the test but not panic.

- Rush means: A sudden forward motion, hurry, surging emotion
- Panic: A sudden overwhelming feeling of terror or anxiety, esp. one affecting a whole group of people.

In addition, there were so many errors for the fire sign during the experiment besides the response time for the fire sign were highly more than the other designs. From the evaluator recognition, it can be said that the exit door influence their response or the design were not clear enough. The errors are defined by the following phrase: The error appears when the user could not realize the changes in the sign and choose the wrong path (Point out to the wrong direction).

Chapter 7

Conclusion and Recommendation

7.1 Findings

This work presents the aspects of using an immersive virtual environment (IVE) for the study and measurement of human behavior and decision making in the context of emergency evacuation. The results of this study prove that the IVE can be an effective tool. The performance of this simulation was high in temporal and mental demand which it was the purpose of this research. Generally the performance and the comfort of the system show interesting results in the emergency simulation and footage video for VE. There were a significant different in term of discomfort between men and women and the results of their response time had significant difference. By users rating, the realism of the simulation has been confirmed. The IVE can be used for future experiment investigation such as way finding. For response time experiment, some errors and significant variation were observed during the individual test.

7.2 Limitations

It should be noted that in this research, the accuracy in term of distance and speed is neglected. However it is possible for a system to perform with low accuracy but still it can be effective. This study is limited to the statistical factors such as time, comfort and performance and the others like satisfaction ease of use and ease of learning is not considered. The exact extent of color deficiency and luminance contrast were also constant and not examined in the evaluation. The color background, color text and illumination were stable since in related work, it is referred that there are no significant different on them. It seems to be important to add the panic situation to evacuation simulation because all of the results are shown without this factor and this may change them. Besides there were some limitation in graphical interface, for instance the final video clip were not in high quality the same with the row videos, the size of the final video were huge and it generates small pauses during the experiment and due to footage video, dynamic signs had small jumps in some of the sequences. .

7.3 Recommendation and future work

In this research, dynamic evacuation signs were highlighted. From the user's recognition, it is understood that sound and smoke can be also influenced them to feel more reality or to realize the changed in the signs faster. So for next study it is recommended to add these factors to experience the result. From the evaluator experience, it is recognized that users gender and even nationality also influence to their time response so to have more accurate result, more user test will be suggested for further study.

In this work to evaluate the behavior and the pre movement time for the user, the tracking camera and normal manual calculation of their behaviors has been assessed. By merging of real and virtual elements, it helps the users to physically interact with the VE and they can be fully involved that uses the contexts of human activity and location in VEs. For future it is recommended such tools like Kinect Microsoft to be used. Kinect is a new technology from Microsoft which these days are mostly used for game or advertising. It is a cost effective tool and programming with Microsoft Kinect cannot be difficult while it will deliver more accurate and precise results. As

The statistical analysis for this study to discover the exact relationship between time, comfort and performance were not successful because there were not sufficient amount of data. Further statistical analysis can also be suggested when there are number of enough participants available.

7.4 Conclusion

This work presents the aspects of a virtual environment by using Immersive Video for the study of emergency evacuation and measurement of human behavior in the context of activity. The proposed system helps to yield more reliable information about human behavior and decision making in emergency egress and creating a model in VE. Locations, timing, duration and speed, helping from dynamic signs can be considered as decision-making process subject to emergency evacuation.

The main conclusions are:

- IVE is efficient system to create a real scenario and study the human behavior.

- The comfort and the performance of IVE were satisfied in this study.
- The evacuation success was around 80% (Section6.2).
- The response time to dynamic signs is 0.92 seconds that it is varied during the design and conditions for instance near the exit door is 1.18 seconds.
- There was significant difference in the term of comfort and response time between male and female.
- There were no differences in term of task difficulty for the time response while more mistakes are generated by the users.

It can be said, since the overall comfort of the IVE was satisfied (6.3) and the performance of the system (6.4) shows that the people felt rush and mentally working and thinking and they reported the realism of the system (6.5), so we can conclude that the results of 6.2 can be trust-able. Of course the panic situation did not apply to the system; however the evacuee failed several testes, responded late to the dynamic signs, confused the signs and had late response time after some tasks. As a result the real evacuation system should even consider all these patterns. For example if the signs are going to be changed near the exit door (From Exit to Danger), since most of the evacuee failed and run to the door, the system must be connected to the automatic sensors to lock that door or the system should guide them with the sounds to avoid them to pass that area (They reported they prefer sounds with signs to react faster). Definitely another study is suggested that Audio signage will present better result if it is combined with graphical signs.

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APPENDIX A1: Instruction

Name:........................

Date:..........................

Male or Female

Age:...........................

Instruction

Dynamic signs in emergency exit

The purpose of the present test is to exercise the effective of different dynamic signs under the emergency exit situation by using a virtual environment.

In the experiment, you will see six different of exit signs with red and green colors. Green shows you the way to exit and safe area however red means danger and prohibited area. The picture below shows a sample that how a sign can look like. The fire graphic shows the restricted area and the running man shows the exit. These signs will appear in the experiment while you feel that you are evacuating the building. You just need to follow them to the exit door.

In the first step, you will need to read the instruction carefully. Afterward the test starts. There will be 8 scenarios that each of them will take around 35 seconds. While the test runs, there will be a tracking camera behind you which it records your behavior and reaction to the signs. These records are going to use just for the scientific and academic purpose not any other reasons.

In all the clips you will experience the changes in signs, walking through the corridor. Each time that you see a sign changes, you can simply point out by your hand to the direction of the sign like right or left. It is asked that you also try to react that you are running so we can observe your behavior of emergency egress more clearly. Additionally if you see that the sign changes to the restricted area then you need to turn around so again you can point out by your hand and this time it does not matter if you point to the left or right. The tracking camera will record the time of changes in the sign and your response time.

Finally at the end of the test, you will be asked to answer some questions and share your experience of this virtual environment with us. Indeed there are some questions that you will rate them and we can make statistical analysis of them.

If you have any questions before the test starts, please do not hesitate to ask.

Thank you very much for your cooperation.

Signature:

APPENDIX A2: NASA TLX

RATING SCALE DEFINITIONS

Title	Endpoints	Descriptions
MENTAL DEMAND	Low/High	How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting, or forgiving?
PHYSICAL DEMAND	Low/High	How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
TEMPORAL DEMAND	Low/High	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
PERFORMANCE	Good/Poor	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
EFFORT	Low/High	How hard did you have to work (mentally and physically) accomplish your level of performance?
FRUSTRATION LEVEL	Low/High	How insecure, discouraged, irritated, stressed, and annoyed versus secure, gratified, content, relaxed, and complacent did you feel during the task?

NASA Task Load Index

Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

Name:	Task:	Date:

Mental Demand How mentally demanding was the task?

Very LOW Very High

Physical Demand How physically demanding was the task?

Very LOW Very High

Temporal Demand How hurried or rushed was the pace of the task?

Very LOW Very High

Performance How successful were you in accomplishing what you were asked to do?

Very Good Very Poor

Effort How hard did you have to work to accomplish your level of performance?

Very LOW Very High

Frustration How insecure, discouraged, irritated, stressed, and annoyed wereyou?

Very LOW Very High

Effort or Performance	Temporal Demand or Frustration
Temporal Demand or Effort	Physical Demand or Frustration
Performance or Frustration	Physical Demand or Temporal Demand
Physical Demand or Performance	Temporal Demand or Mental Demand
Frustration or Effort	Performance or Mental Demand
Performance or Temporal Demand	Mental Demand or Effort
Mental Demand or Physical Demand	Effort or Physical Demand
Frustration or Mental Demand	

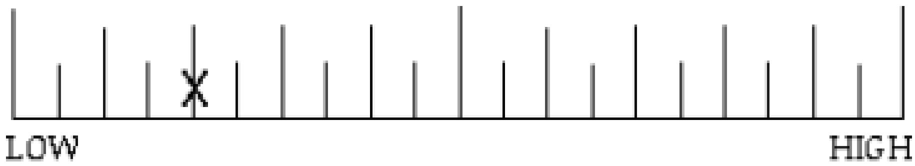
Scoring Instructions

1) In the tally column, record a mark for each time a participant chose a scale on the evaluation cards (e.g., each time the participant circled "Mental Demand" on a comparison card, the experimenter puts a mark on the "Mental Demand" row of the tally column).

2) Sum the number of tally marks for each scale in the tally column, and record the number of marks in the weight column. Weights cannot equal more than 5.

3) Sum all weights and record this number in the "Total Count" box. The total count must equal 15. If it does not equal 15, a miscalculation has occurred.

4) In the Raw Ratings column, record the responses from the Rating Sheet for each scale. The Rating Sheet provides a vertical line anchored at 0 and 100 and divided into intervals of 5 for each scale. To determine the number associated with a response, count the number of intervals from the left assuming that the left most bar is NOT counted, and multiply by 5 (e.g., if the participant marked an "X" on the fourth interval bar from the left, as below, the score would be 4 X 5 = 20).



If a participant marks between two interval bars, the value of the right bar is used (i.e., round up). The maximum Raw Rating for any one scale is 100.

5) Multiply the Raw Rating by the Weight for that scale. Record this number in the Adjusted Rating column.

6) Sum the Adjusted Ratings and record the total in the Sum "Adjusted Rating" box.

7) Divide the number in the Sum "Adjusted Rating" box by 15 to obtain the overall weighted workload score. Record the resulting quotient in the **WEIGHTED RATING** box.

APPENDIX A3: SSQ

Simulator Sickness Questionnaire(SSQ)

Please report the degree to which you experience each of the above symptoms.

General discomfort

None	Slight	Moderate	Severe

Fatigue

None	Slight	Moderate	Severe

Headache

None	Slight	Moderate	Severe

Eyestrain

None	Slight	Moderate	Severe

Difficulty focusing

None	Slight	Moderate	Severe

Increased salivation

None	Slight	Moderate	Severe

Sweating

None	Slight	Moderate	Severe

Nausea

None	Slight	Moderate	Severe

Difficulty concentrating

None	Slight	Moderate	Severe

Fullness of head

None	Slight	Moderate	Severe

Blurred vision

None	Slight	Moderate	Severe

Dizzy (eyes open)

None	Slight	Moderate	Severe

Dizzy (eyes closed)

None	Slight	Moderate	Severe

Vertigo

None	Slight	Moderate	Severe

Stomach awareness

None	Slight	Moderate	Severe

Burping

None	Slight	Moderate	Severe

APPENDIX A4: Likert Scale Questionnaire

Likert Scale questionaire

Please fill out this questionaire by choosing how far you agree.

If you felt that you are really evacuating the building.

Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree

If you felt any differences in the different scenes.

Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree

If you could see the signs clearly.

Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree

If you think you recognized the changes in the signs in the exact time.

Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree

If you felt rush or panic.

Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree

If you are happy with the idea of dynamic emergency signage in general.

Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree

If you are happy with the current design.

Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree

If you felt that the simulation felt real.

Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree

In general what you will recommend to improve the system.

APPENDIX A5: Results

Table A5- 1 Response time for each participant in each task

ID	Task 1		Task2	Task3	Task4	Task 5		Task6			Task7		Task8		AVG (M)
	L2R (1,2)	L2R (1,2)	L2R (1,2)	R2L (3,4)	L2R (3,4)	R2L (3,4)	Fire (5,6)	L2R (3,4)	Fire (5,6)	R2L (3,4)	Fire (5,6)	R2L (1,2)	L2R (1,2)	R2L (1,2)	
1	0.5	0.63	0.53	0.57	0.87	0.57	1	0.53	0.43	1.07	0.9	E	0.53	1	0.7
2	1.17	0.7	0.6	1.8	1.73	0.5	1.73	1.67	1.1	0.6	0.9	0.1	0.65	0.5	0.98
3	2.03	E	2.83	1.47	E	1.17	1.13	1.1	1.4	E	0.93	0.9	1.07	0.7	1.33
4	1.5	1.47	4.23	1.07	N	2	2.63	1.33	E	1.46	1.5	1.06	1.1	E	1.75
5	0.5	0.6	0.37	0.6	0.7	1.37	E	E	E	0.67	E	1.13	0.27	0.7	0.69
6	0.67	1.46	0.43	0.87	0.4	0.9	1.2	0.46	0.86	1.06	1.43	0.87	0.8	0.8	0.87
7	0.87	0.9	0.47	0.73	0.73	0.8	N	0.63	1.1	0.67	1.17	0.87	1.07	1.07	0.85
8	0.47	0.43	0.7	1.2	0.67	E	1.6	0.7	1.63	0.9	E	N	0.87	0.7	0.89
9	0.4	0.43	0.67	0.5	0.5	0.43	0.97	0.43	0.57	0.43	0.67	0.47	0.67	0.43	0.54
10	0.67	0.53	0.67	0.43	E	0.5	E	0.5	E	0.7	E	0.6	0.43	1	0.60
M	0.87	0.79	1.15	0.92	0.8	0.91	1.46	0.81	1.01	0.84	1.07	0.75	0.74	0.77	**0.92**

- Name of the signs referred to 4.5
- E means that the user could not see the change in the sign.
- N means they were blocking the view of tracking camera and it was not possible to track the time.
- M means Mean or Average

Table A5- 2 Response time in different task for male and female

Tasks	1	2	3	4	5	6	7	8
Male	1.003	1772.000	1068.000	1.300	1.285	0.987	0.861	0.782
Female	0.673	0.528	0.780	0.600	1.066	0.780	0.963	0.738

Table A5- 3 SSQ results for each participant

Symptoms	Participant ID									
	1	2	3	4	5	6	7	8	9	10
General Discomfort	1	0	0	0	1	0	1	0	1	1
Fatigue	1	0	0	0	2	1	0	0	0	0
Headache	1	0	0	0	2	0	0	0	0	1
Eyestrain	0	1	1	0	1	1	0	0	1	2
Difficulty focusing	1	0	0	0	2	0	1	0	0	0
Increased salivation	0	0	0	0	0	0	0	0	0	0
Sweating	1	0	0	0	0	1	0	0	0	0
Nausea	0	0	0	0	0	0	0	0	0	0
Difficulty concentrating	1	0	1	1	0	1	0	0	1	0
Fullness of head	1	0	0	1	0	1	0	0	0	1
Blurred vision	1	0	1	0	0	0	1	0	1	1
Dizzy (eyes Open)	0	0	1	0	0	0	0	0	1	2
Dizzy (eyes closed)	1	0	2	0	0	0	0	0	0	0
Vertigo	1	0	0	0	0	0	0	0	1	0
Stomach awareness	0	0	0	0	0	0	0	0	0	0
Burping	0	0	0	0	0	0	0	0	0	0

Table A5- 4 Weights for SSQ based on the rate of the participant

Symptoms	Rate	Weight		
		Nausea	Oculomotor	Disorientation
General Discomfort	5	5	5	0
Fatigue	4	0	4	0
Headache	4	0	4	0
Eyestrain	7	0	7	0
Difficulty focusing	4	0	4	4
Increased salivation	0	0	0	0
Sweating	2	2	0	0
Nausea	0	0	0	0

Difficulty concentrating	5	5	5	0
Fullness of head	4	0	0	4
Blurred vision	5	0	5	5
Dizzy (eyes Open)	4	0	0	4
Dizzy (eyes closed)	3	0	0	3
Vertigo	2	0	0	2
Stomach awareness	0	0	0	0
Burping	0	0	0	0
Sum		**12**	**34**	**23**
Overall		**11.448**	**25.772**	**30.624**

*Overall SSQ: 26.554

Table A5- 5 SSQ result for men and women

Participan ID	Nausea	Oculomotor	Disorientation	Overall SSQ
5	9.54	7.58	13.92	11.22
6	19.08	22.74	13.92	22.44
7	28.62	30.32	13.92	22.44
8	0.00	0.00	0.00	0.00
9	19.08	30.32	41.76	33.66
Male MEAN	14.31	15.16	10.44	14.03
1	28.62	45.48	69.60	52.36
2	0.00	7.58	0.00	3.74
3	9.54	22.74	55.68	29.92
4	9.54	60.64	27.84	41.14
10	9.54	37.90	55.68	37.40
Female MEAN	11.45	34.87	41.76	32.91

Table A5- 6 Likert scale Questionnaire results

Question:	Participant ID									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	3	4	3	4	3	4	4	4	4	3
2	4	4	4	2	4	4	5	3	3	2
3	5	4	4	4	4	4	4	5	4	4
4	4	3	2	4	3	3	4	4	4	4
5	3	3	1	3	3	3	3	1	3	2
6	4	4	4	3	4	4	5	3	4	4
7	4	4	2	3	3	3	4	4	4	3
8	3	4	2	4	3	4	4	3	4	4

Table A5- 7 Mean and Standard deviation for Likert scale questionnaire

	Q1	**Q2**	**Q3**	**Q4**	**Q5**	**Q6**	**Q7**	**Q8**
Mean	3.6	3.5	4.2	3.5	2.5	3.9	3.4	3.5
SD	0.26	0.944	0.177	0.5	0.72	0.322	0.488	0.5

Table A5- 8 NASA TLX scales for participants with their rated weight

Scale/Weight	*Participant ID*									
	1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***
Mental	50	55	45	40	25	50	50	15	30	30
	5	4	2	5	3	2	4	3	4	5
Physical	20	25	10	5	20	60	30	20	30	35
	0	2	1	4	1	2	1	2	1	1
Temporal	90	45	85	100	20	80	25	25	75	20
	4	5	5	3	2	5	2	1	4	3
Performance	30	45	20	45	45	15	20	20	25	5
	3	3	4	0	4	3	5	4	4	4
Effort	25	45	25	45	40	50	60	10	20	20
	2	0	0	2	5	3	2	4	1	2
Frustration	15	5	25	5	45	25	20	5	25	20
	1	1	3	1	0	0	1	1	1	0

Table A5- 9 NASA TLX calculation and results

Adjusted Rating	Participant ID											
	1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***	***Sum***	***Overall (of 100)***
Mental	250	220	90	200	75	100	200	45	120	150	1450	29
Physical	0	50	10	20	20	120	30	40	30	35	355	7.1
Temporal	360	225	425	300	40	400	50	25	300	60	2185	43.7
Performance	90	135	80	0	189	45	100	80	100	20	839	16.78
Effort	50	0	0	90	200	150	120	40	20	40	710	14.2
Frustration	15	5	75	5	0	0	20	5	25	0	150	3
Overall	51	42.33	45.333	41	34.93	54.33	34.66	15.66	39.66	20.33		**18.96**

Table A5- 10 Time, Comfort and performance for each user

Participant ID	**Time (S)**	**Comfort**	**Performance**
1	0.7	52.36	51
2	0.98	3.74	42.33
3	1.33	29.92	45.33
4	1.75	11.22	41
5	0.69	41.14	34.93
6	0.87	22.44	54.33
7	0.85	33.66	34.66
8	0.89	0	15.66
9	0.54	33.66	39.66
10	0.6	37.4	20.33

Table A5- 11 Correlation for subscales in NASA TLX

Correlation	Mental	Physical	Temporal	Performance	Effort	Frustration
Mental	1.00					
Physical	-0.26	1.00				
Temporal	0.20	0.13	1.00			
Performance	-0.15	-0.19	-0.29	1.00		
Effort	-0.20	0.29	-0.28	0.23	1.00	
Frustration	-0.13	-0.39	0.48	0.03	-0.46	1.00

Table A5- 12 Normalized data: Time, Comfort and performance for each user

ID	Time	Comfort	Performance
1	0.076	0.197	0.134
2	0.107	0.014	0.112
3	0.145	0.113	0.120
4	0.190	0.042	0.108
5	0.075	0.155	0.092
6	0.095	0.085	0.143
7	0.092	0.127	0.091
8	0.097	0.000	0.041
9	0.059	0.127	0.105
10	0.065	0.141	0.054