The Influence of Herding on Departure Choice in Case of an Evacuation
Design and Analysis of a Serious Gaming Experimental Set-up

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The Influence of Herding on Departure Choice in Case of an Evacuation

Design and Analysis of a Serious Gaming Experimental Set-up

Mignon van den Berg

Delft University of Technology, 2016

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The Influence of Herding on Departure Choice in Case of an Evacuation

Design and Analysis of a Serious Gaming Experimental Set-up

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"...we are far less rational in our decision making... Our irrational behaviors are neither random nor senseless: they are systematic and predictable. We all make the same types of mistakes over and over, because of the basic wiring of our brains."

- Dan Ariely

Preface

Before I started this PhD research I always had the impression that doing a PhD was a very lonely existence. But I found out that this definitely does not have to be the case! That is why I would like to thank everyone who I worked with, who helped and supported me during this PhD.

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Mignon van den Berg, December 2016

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Chapter 1

Introduction

Natural and man-made disasters, such as earthquakes, floods and terrorist attacks, have an enormous impact on people's lives, leading to many deaths, injuries and trauma's. In case of disasters where people have the possibility of safely evacuating, choices need to be made, such as the choice to stay at home or leave home, comply to evacuation instructions, use their car or use collective transportation means. These choices also have an impact on the possible number of casualties, which cause personal tragedies and cost societies a significant amount of money.

Insight into factors influencing evacuation choices is essential for modelling and prediction of evacuation choice behaviour. When it is possible to better model and predict people's evacuation choice behaviour, better evacuation management strategies - to evacuate an area that is struck by a disaster - can be developed. Societies can benefit from these strategies because they will influence people's perception of the situation and therefore change their choice behaviour. This will then cause less casualties.

1.1 Research on evacuation behaviour

To understand human evacuation behaviour from a psychological point of view, Leach (1994) described that generalised human behaviour could be observed before, during and after the impact of a disaster. Before the disaster, people are in denial and inactive. During the impact phase, a classification of people can be made into three groups: the first group of people undertakes action and remains calm and rational, the second and largest group reacts in a semi-automatic manner and the third group responds uncontrolled and inappropriate. After the impact, there is a need for people to express their emotions.

Extensive research from the field of transport is available on travel choice behaviour that occurs during evacuations from disasters (research on e.g. deciding to evacuate or not, choosing a preferred route or mode of transport). Which disaster is focussed on differs per country due to the occurrence of a certain type of disaster in that country.

For example, in Australia there has been a focus on choice behaviour in case of bush fires (Handmer and Tibbits, 2005; Alsnih et al., 2005), whereas in the United States there is a focus on choice behaviour in case of hurricanes (Litman, 2006; Lindell et al., 2005). Over the past decade choice behaviour in case of tsunamis also receives more attention due to the tsunamis in Southeast Asia in 2004 and Japan in 2011 (Charnkol and Tanaboriboon, 2006; Urata and Hato, 2012).

In the Netherlands, there is a focus on floods, due to different threats and actual floods in the past century. In 1953 a large part of the province of Zeeland was flooded. A more recent example is the evacuation of 250.000 people from the area called the Culemborger- and Tielerwaard on January 31 in 1995. This was due to the threat of the Waaldijk breaking (Canon van Culemborg, 1995). In the Netherlands there has been a national exercise on flood evacuation (De Jong and Helsloot, 2010).

In case of a disaster, people might copy the behaviour of others. Ariely (2008) considers this to be herding behaviour and defines it as seeing other people doing something (e.g. leaving) and believing that what they are doing is a good alternative, resulting in doing the same thing.

Herding is also a well-known phenomenon with animals. It exists because individual animals derive anti-predator or foraging benefits from it (Hamilton, 1970; Bertram, 1978; Alexander, 1974; Rubenstein, 1978; Gueron et al., 1996). In case of people, as discussed in Helbing et al. (2000), individualism allows people to detect a good solution (e.g. in case of an evacuation from a building, to detect the exits), while herding might guarantee the imitation of successful alternatives. It can therefore be a useful survival mechanism. However, the effect of herding on evacuation choices is unknown.

To better model and predict people's evacuation choice behaviour, including e.g. the decision to evacuate or not but also mode and route choice, the influence of factors on this choice behaviour needs to be quantified. This could be done by empirical research. Existing data collection techniques for empirical research can roughly be divided in two groups: stated preference (SP) and revealed preference (RP).

With SP, people are confronted with a hypothetical situation and are asked what they would do (e.g. evacuate or not, choose a preferred route or mode of transport). A major disadvantage of SP is that it is uncertain whether people respond like they would in reality (Train, 2003).

With RP, one option is to ask people who experienced an actual evacuation what they did. However, the researchers only know the available choice situation from what people remember, which makes it hard to exactly reconstruct the actual situations that people were in. Another option is to directly observe what people are doing but the disadvantage is that the researchers are limited to available choice situations (Train, 2003). Since natural disasters are unpredictable and quite extreme, real time data collection is often difficult and could be dangerous.

In the literature review in Chapter 2, it will become clear that especially the effect of herding, as briefly introduced above, is one of the aspects that needs further research. It is extremely difficult to study the effect of herding using classic SP and RP techniques as described above. Therefore, this explorative research focusses on studying the effect of herding on evacuation decisions using a new technique which claims to overcome limitations of existing techniques.

The remainder of this chapter further introduces this thesis. In the next section the research objective and questions are defined, followed by the research approach in Section 1.3. Section 1.4 shows the context of this research. Section 1.5 discusses the scientific, methodological, theoretical and practical contributions of this thesis. The outline of this thesis is presented Section 1.6.

1.2 Research objective and questions

To better understand evacuation choice behaviour, the influence of factors on this choice behaviour needs to be quantified. This thesis focusses on aspects of evacuation behaviour that could not have been considered due to disadvantages of existing data collection techniques. Therefore, the main objective of this thesis is twofold:

1. **To develop, apply and assess a new experimental set-up[1] to study evacuation choice behaviour.**

2. **To quantify the effect of herding on evacuation choice behaviour.**

This main objective is very broad. To reach the objective seven research questions have been formulated. These questions are presented and discussed below. The first two research questions are asked to find out which gaps can be identified from literature by performing a state-of-the-art.

1. Which factors, related to both the characteristics of the individual and characteristics of the situation this individual is in, influence evacuation choices?
By presenting and discussing an overview of what is known about factors influencing evacuation choice behaviour, it will be shown which factor(s) need(s) further research. Examples of factors related to the individual him- or herself include e.g. age, gender and household situation this person is in. Examples of characteristics related to the situation include e.g. type of disaster and distance to the disaster. To present the overview in a structured way, a conceptual framework is developed, in which similar or related aspects are grouped.

[1] In this thesis the experimental set-up is considered to be the full experiment people participate in, including all phases of a set-up from beginning (arrival at the experiment) to end (departure from the experiment) and including different scenarios.

2. What is the scientific knowledge about how people make evacuation choices?
When it is clear which decision strategies people use when they make their evacuation choices, evacuation choice behaviour can be better modelled and predicted. The conceptual framework including the aspects influencing evacuation choice behaviour will also include the decision strategies.

Questions 3 and 4 are asked to determine which limitations of existing data collection techniques need to be overcome and which requirements have to be set before developing the experimental set-up.

3. What are the advantages and disadvantages of existing data collection techniques for empirical research on evacuation choice behaviour?
Since existing data collection techniques have disadvantages, an overview of advantages and disadvantages will show which disadvantages should be dealt with to develop new behavioural insights. This should make it possible to focus on those factor(s) that need(s) further research (see answer to question 1).

4. What are the requirements for developing the experimental set-up?
On the basis of the answers to the first three questions, the requirements for the experimental set-up for data collection on evacuation choice behaviour are determined. These requirements should make it possible to design an experimental set-up which makes it possible to develop new behavioural insights on evacuation choice behaviour.

Questions 5 and 6 focus on the results of data that will be collected with the developed experimental set-up. Question 7 focusses on the validity of the results.

5. Which results of the experiments with the experimental set-up show similar and different results when comparing them with existing research?
To develop new behavioural insights on evacuation choice behaviour, it has to be clear which aspects of evacuation choice behaviour influence the participants in the experiments with the experimental set-up. It is needed to find out whether these results are similar to or whether they differ from results from existing research. Therefore, the results will be compared to results from existing research and possible explanations on similarities and differences will be discussed.

6. What are new behavioural insights from the results of experiments with the experimental set-up?
After discussing the results, it has to be clear which conclusions can actually be drawn with respect to new behavioural insights found with the developed experimental set-up. The answer to this question considers which new aspects of evacuation choice behaviour are quantified in this research by estimating choice models with the data collected with the experimental set-up.

7. How valid are the results conducted with the experimental set-up?
To find out how valid the results are, both the experimental set-up and the results themselves will be critically assessed on their validity.

To reach the main objective and answer the research questions, the research approach of this thesis will be discussed in Section 1.3.

1.3 Research approach

This section describes the approach that is followed to reach the main objective and to answer the research questions. Figure 1.1 shows the approach that is followed during this research.

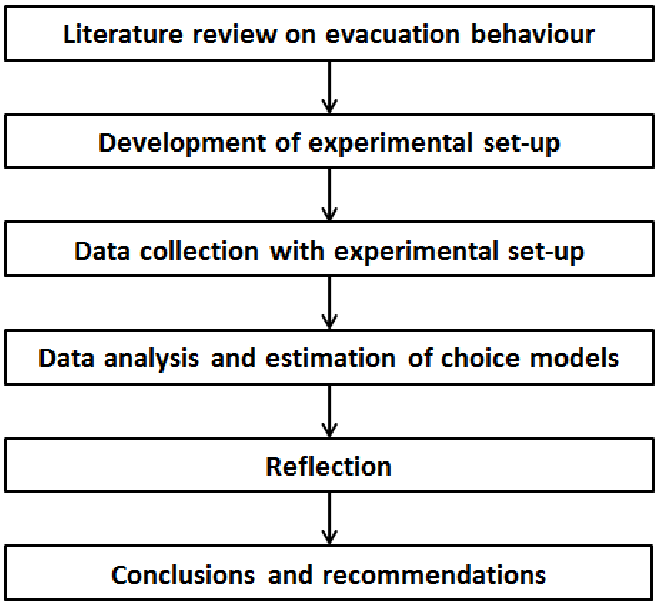

Figure 1.1: Research approach

To answer research questions 1 and 2, a **literature review** is performed on evacuation behaviour, resulting in a conceptual framework. This framework provides a structured overview of what is known from existing research and shows which aspect(s) need(s) attention.

The next step is the **development of the experimental set-up**. In this step research questions 3 and 4 are answered. To answer research question 3, existing data collection techniques are compared and discussed, more into detail than in the introduction of this chapter. The advantages and disadvantages of existing data collection techniques, together with the aspect(s) that need(s) further attention (see research questions 1 and 2), are used to answer research question 4.

Based on the requirements of the experimental set-up (research question 4), a 3D multi-user virtual or serious gaming environment, called Everscape, is developed. This is done in cooperation with the National Institute of Informatics (in Tokyo, Japan). Everscape consists of a virtual island, where an avatar is appointed to each user (or participant). With this avatar, users can walk and drive around on this island. They can also see each other's avatars and what they are doing. Beforehand, users know they will go to this island to see a concert but during this concert there is an earthquake and they have to evacuate for a tsunami.

Since experiments with the experimental set-up, and especially the data collection instrument Everscape, have to lead to valid results, Everscape is built, tested and improved. The result is the final experimental set-up, which is a combination of Everscape and a questionnaire, including testing several scenarios with a focus on herding behaviour.

After the experimental set-up is developed, a **data collection** with this set-up is conducted. To answer research questions 5 and 6, the **data of these experiments are analysed and choice models are estimated** to quantify the effect of herding on evacuation choice behaviour.

To answer research question 7, a **reflection** is performed on the validity of the experimental set-up (with a focus on the tool Everscape) that is used for the data collection and the results that are found in the analysis and with the estimation of the choice models. At the end, the **conclusions and recommendations** are considered.

1.4 Context of research

This research is part of the VICI program 'Travel Behaviour and Traffic Operations in case of Exceptional Events'. The main objective of this program is:

'To develop behavioural theories, conceptual and mathematical models to predict the transportation system response to exceptional events described in terms of the uncertain spatio-temporal cascade of effects and the impacts of mitigating actions taken by network managers on the planning and on the operational level.'(Hoogendoorn, 2008)

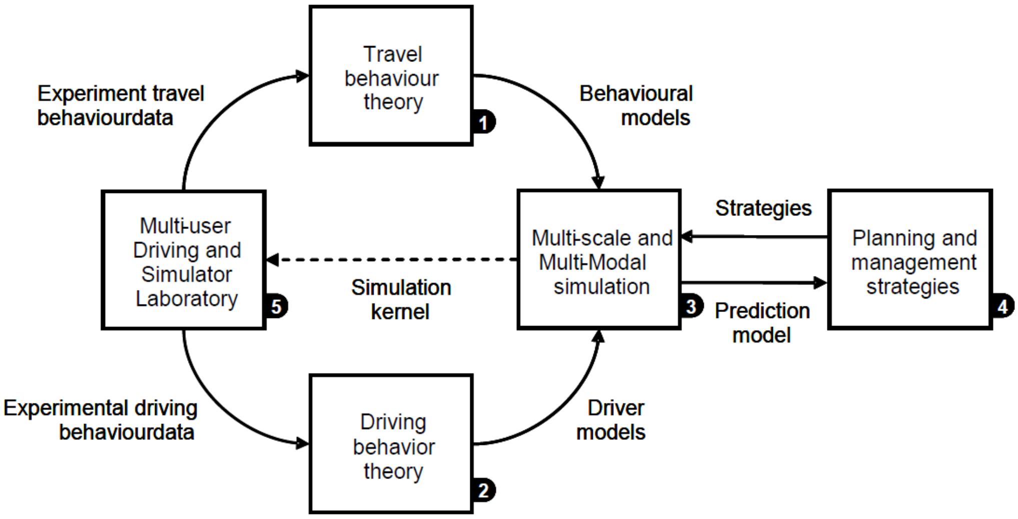

Figure 1.2: Research topics VICI project (Hoogendoorn, 2008)

Figure 1.2 shows the sub-projects that are part of this VICI project, including their relations. This thesis focusses on sub-project 1 'Travel behaviour theory' and thus the focus is on developing behavioural theories or new insights. As discussed in the previous sections of this chapter, the objective is to quantify the effect of herding on evacuation choice behaviour.

1.5 Thesis contributions

The contributions of this thesis have scientific, methodological, theoretical and practical relevance. These contributions are separately discussed in this section with references to the different chapters in this thesis. The scientific contributions are presented in 1.5.1 and the methodological contributions in 1.5.2. The theoretical contributions are presented in 1.5.3 and the practical contributions in 1.5.4.

1.5.1 Scientific contributions

The scientific contributions of this thesis are discussed in this sub section.

This thesis presents a literature review on human evacuation behaviour and structures this behaviour with a conceptual framework that consists of four main elements: information (including e.g. disaster characteristics and instructions), personal context (including e.g. socio-economic characteristics and direct surroundings), choice options and human evacuation behaviour (consisting of the perception of the situation, the decision mechanism and the actual choices).

The conceptual framework is considered to be the first scientific contribution and it is used as a guideline throughout this thesis. It is used during the development of the experimental set-up and it is used to structure the analysis of the results.

The second scientific contribution concerns the experimental set-up. This thesis shows that data collected with the developed experimental set-up is suitable and shows potential for empirical research on evacuation choice behaviour. This contribution is twofold.

1. Results of the experiments conducted with the experimental set-up are consistent with literature on evacuation behaviour and thus support the framework.
2. The experimental set-up makes it possible to conduct a large scale data collection through which new aspects of evacuation choice behaviour are quantified.

The experimental set-up in this thesis is specifically developed to focus on one of the gaps from literature and thus one of the aspects from the framework: the effect of herding on evacuation behaviour. With the descriptive analysis of data collected with the experimental set-up and estimation of choice models with the data, it is shown that the experimental set-up is suitable for quantifying herding behaviour. Because the Everscape data includes not only where each participant was, but also this person's viewing directions, it makes it possible to consider the actions of other people and the effect of these actions on evacuation behaviour. Therefore, this thesis takes an important step into quantifying the effect of herding behaviour on departure choice.

1.5.2 Methodological contributions

The developed experimental set-up is of methodological relevance for data collection on travel choice behaviour in case of an evacuation. This is explained further in this sub section.

The new experimental set-up consists of a combination between a virtual environment (Everscape) and a questionnaire, which makes it possible to combine data from two different sources. Since it is based on the main advantages of existing data collection techniques, it makes it possible to provide new behavioural insights.

The main conclusion from this is that the experiment is considered to be an enriched stated preference method because it offers the combination of an experiment with the virtual environment and a questionnaire. Like Levinson et al. (2004), the virtual environment might be considered as a virtual experience SP (VESP). In line with this, the questionnaire is considered to be a virtual experience RP (VERP).

Compared to standard SP surveys, Everscape allows for mimicking a more realistic situation which people are part of. This makes it easier for them to identify with the situation. Since participants are all part of the same virtual environment, they are aware of each other's existence because they can see each other and what they are doing at all times. An other advantage is that these actions of other people are recorded with Everscape. As a result, interaction and emergent behaviour can be studied. This is why it was possible to focus on herding behaviour.

Compared to existing RP methods, of every individual participant a full trajectory, his path over time, is available. For each event (e.g. start earthquake, start tsunami, departure time train, departure time helicopter), it is known when exactly it happens, which allows for determining at every time step the exact situation each participant was in. In combination with the results from the questionnaire, more detailed information is available with respect to the available aspects and aspects people say they have considered for the choices they made. This has shown to be useful for estimating the choice models with a focus on the effect of herding on departure choice.

1.5.3 Theoretical contributions

The theoretical contributions are explained in this sub section.

The data collected with the experimental set-up with Everscape make it possible to provide new knowledge on people's evacuation choice behaviour. The main theoretical contribution of this thesis is that a first step is made in quantifying herding behaviour in case of an unexpected and (potentially) stressful situation.

In this thesis, it is shown that when people are in a stressful situation, they are inclined to follow others. Seeing people leave influences the decision to leave. The more people someone sees leaving, the more inclined this person is to leave. Especially seeing people leave the last few seconds before the decision is made influences this decision.

Furthermore, a segmentation is made related to information. When people have less information about the situation they are more likely to follow others than when they have information and instructions on what to do. The importance of information is therefore demonstrated.

1.5.4 Practical relevance

The final contributions are discussed in this sub section and are related to practical relevance.

From a practical side, a better understanding of evacuation choice behaviour is useful for developing evacuation management strategies that make sure people's evacuation choices lead to less casualties. This results in natural disasters causing less personal tragedies and costing societies less money.

New insights are developed on the effect of herding behaviour on the decision to evacuate, especially a difference in herding behaviour became clear when people have no information versus when they have received instructions and information. Therefore, it is concluded that with this thesis, a step is taken towards improving evacuation management strategies because these insights can be used when developing these strategies.

When people have no or limited information they consider other people around them as a source of information. This is difficult to manage by those who are responsible for evacuation strategies in case of for example a natural disaster. Therefore, it is relevant for practice to control large scale evacuations by providing people with correct and clear information. Then, people know what to do and they are less likely to not let their actions depend on the actions of others.

1.6 Thesis outline

To reach the main objective, this thesis is split in 4 parts and 7 chapters, see Figure 1.3.

Part I: Conceptual framework for evacuation choice behaviour
In Chapter 2, a literature review is presented on factors influencing evacuation choice behaviour in case of natural disasters. This chapter also presents what we know about how people make choices in these kind of situations. The result of Part I is a conceptual framework that structures existing research and through which gaps in literature become clear. It especially becomes clear that the effect of herding on evacuation decisions has not been quantified. In this part *research questions 1 and 2* will be answered.

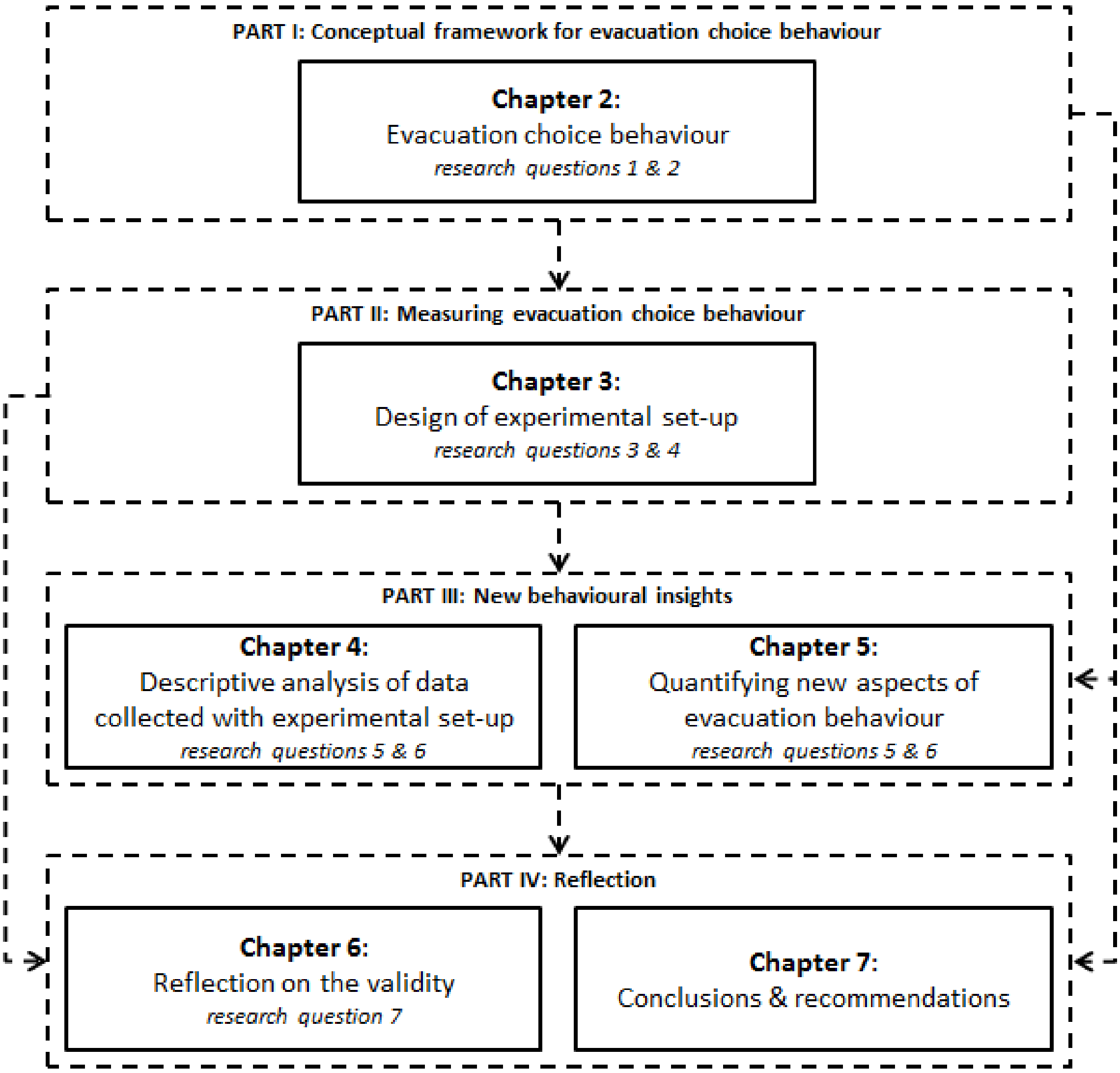

Figure 1.3: Thesis outline

Part II: Measuring evacuation choice behaviour

Part II focusses on developing the experimental set-up that makes it possible to quantify the effect of herding on evacuation decisions.

Chapter 3 will first present advantages and disadvantages of existing data collection techniques, so *research question 3* will be answered. Then, this chapter will present what kind of technique is considered to be promising for developing new behavioural insights in case of an evacuation from a natural disaster. It also explains the requirements - which answers *research question 4* - for a new data collection tool, followed by the development of the tool.

Since it is a new tool, pilot experiments have been conducted to test the tool and design the experimental set-up. The results and conclusions from the pilot experiments and the experimental set-up that was designed based on these results and conclusions are also described in Chapter 3.

Part III: New behavioural insights

Part III focusses on new behavioural insights and is split in two chapters.

Chapter 4 presents the descriptive analysis of the data collected with the experimental set-up as described in Chapter 3. It shows an overview of the available data from the experiments and presents characteristics of the participants. It also discusses what the participants actually did during the Everscape part of the experiments and what the participants said about this behaviour in the questionnaire afterwards.

The effect of herding on evacuation decisions is quantified by estimating choice models with a specifically designed choice set based on the data collected with the experimental set-up. How this is done and the results of these estimated choice models are discussed in Chapter 5. Chapters 4 and 5 will be used to answer *research questions 5 and 6*.

Part IV: Reflection

Based on Parts I, II and III, Chapter 6 focusses on reflecting on the experimental set-up and results with a focus on critically assessing the validity. In this chapter, *research question 7* will be answered.

Chapter 7 ends with the conclusions and recommendations (both for future research directions and for practice) on developing behavioural theories and developing the experimental set-up for data collection on evacuation choice behaviour.

Chapter 2

Conceptual framework of evacuation choice behaviour

As discussed in Chapter 1, to model and predict people's evacuation choice behaviour, factors influencing this choice behaviour need to be quantified. However, a comprehensive overview of factors that have been studied and those that still need to be studied is lacking. Therefore, the aim of this chapter is to provide an overview of factors influencing evacuation choice behaviour and structure the current state of the art into a conceptual framework. This will be used to find out which factor(s) need(s) further research.

To gain more insight into evacuation choice behaviour, Section 2.1 starts with an introduction to evacuation travel behaviour. Since insight into evacuation behaviour is important for modelling and prediction of this behaviour, Section 2.2 provides a general introduction to travel behaviour modelling and activity-based modelling.

Section 2.3 presents a conceptual framework of evacuation choice behaviour of an individual. The aspects of the framework are discussed more into detail and supported by references in Section 2.4. Since more people are involved in the evacuation from a natural disaster, Sections 2.5 and 2.6 present the conceptual framework including the interactions of multiple people who are involved. Section 2.7 discusses some possible decision strategies on how people make their evacuation choices. The conclusions are presented in Section 2.8.

2.1 Evacuation behaviour

To introduce evacuation behaviour, this section starts with explaining the difference between daily travel behaviour and evacuation travel behaviour in 2.1.1. Then, the main elements of evacuation behaviour are introduced in 2.1.2 as a guideline for explaining evacuation behaviour more into detail in the rest of this chapter.

2.1.1 Daily travel behaviour versus evacuation travel behaviour

This section will introduce evacuation travel behaviour by comparing daily travel behaviour and evacuation behaviour.

Daily travel behaviour depends on habit and routine (Schönfelder and Axhausen, 2010). Since there is experience with these situations, the costs (e.g. time costs) are more or less known. To avoid costs for the potentially new information or additional acquisition of information for a new situation, known alternatives are reapplied.

Daily mobility patterns differ between people according to a traveller's particular social context and access to mobility tools (Schönfelder and Axhausen, 2010). For example, a mother who has no access to a car takes her son to soccer by bicycle every Wednesday afternoon.

Evacuation from a natural disaster does not occur on a daily basis. The behaviour that occurs in case of an evacuation is therefore expected to differ from day to day behaviour. Since people are confronted with different decision situations from what they are used to in daily travel behaviour, there is no habit or routine. The available mobility tools may limit or improve the possibility of evacuating. The social context, especially a persons household (Murray-Tuite and Mahmassani, 2003), has an impact on the mobility patterns during natural disasters.

When a natural disaster is announced, some people might want to secure their property before leaving home (Litman, 2006; Lindell et al., 2005), whereas others even return home or move towards the disaster area to save family members and pets or protect valuable properties (Handmer and Tibbits, 2005). During an evacuation, people therefore make a plan of activities they want to perform based on the people and possessions they want to protect.

The choices people make are also affected by other factors prior to and during the evacuation (from for example a bush fire, flood or hurricane), including external factors such as characteristics of the disaster (e.g. the severity of the hurricane), availability and quality of information (via authorities and media), as well as the behaviour of people nearby (Alsnih et al., 2005; Murray-Tuite and Mahmassani, 2003; Leach, 1994). These external factors are dynamic, e.g. the distance from the disaster or information on which area might or will be affected changes over time. These dynamic factors are likely to influence the travel choices people make prior to and during an evacuation (Fu and Wilmot, 2004).

Concluding, for modelling travel choice behaviour prior to and during evacuations realistically, the dynamics of the evacuation need attention with respect to factors affecting travel choice behaviour and changes in travel choice behaviour.

2.1.2 Main elements of evacuation behaviour

As was mentioned in 2.1.1, in case of an evacuation from a natural disaster, people are confronted with different decision situations from what they are used to in daily travel behaviour. Some factors affecting evacuation behaviour have briefly been mentioned. However, there are many more. To structure available literature on factors influencing evacuation behaviour, this chapter will present and discuss a conceptual framework to organise the evacuation behaviour process. But first, the basis of the framework is discussed in this section by presenting the main elements of the conceptual framework. Later on in this chapter, the aspects are discussed more into detail including references to literature.

To structure available literature, factors influencing evacuation behaviour are grouped into 'information', 'personal context', 'choice options' and 'human evacuation behaviour', see Figure 2.1.

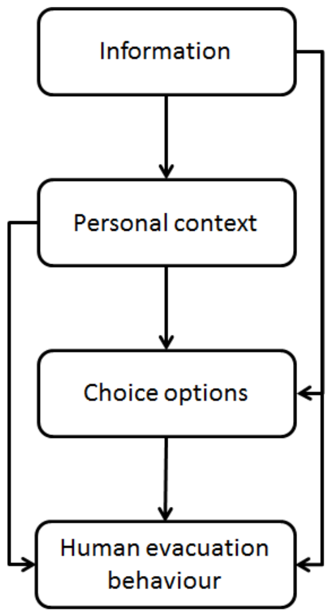

Figure 2.1: Main elements evacuation behaviour

The first element is 'information'. With respect to information in case of a natural disaster, people may receive information related to the disaster or event itself. For example, the type of disaster that is coming their way (e.g. a flood) and the time it might take before the area they are in will be affected (e.g. is flooded). The information might also be related to the traffic situation (e.g. whether congestion occurs due to many people evacuating).

As shown by for example (Dash and Morrow, 2001), people tend to actively seek for information (usually from mass media) before assessing their personal risk. This information can include characteristics of the disaster itself but also information concerning the traffic situation. Based on this, they make their independent evacuation decisions.

Two types of information sources exist: official and unofficial sources. Examples of official sources are television and radio. Family members and neighbours are examples of unofficial sources. Both of these might make people decide to for example stay where they are or evacuate (Alsnih et al., 2005; Whitehead et al., 2000; Baker, 1991; Leach, 1994).

Information itself and also how the information is presented influences how people respond to warnings and evacuation orders. To the author's knowledge this was confirmed in applied research related to the field of Transport by De Jong and Helsloot (2010) and Dash and Gladwin (2007). Therefore, for authorities wanting to guide and control an evacuation, it is important to know which information to give and how to present it to people.

The second element in Figure 2.1 is 'personal context'. These are the aspects that depend on the person. Besides the people and possessions a person wants to protect (see 2.1.1), several researches have shown that the socio-economic characteristics (e.g. age, gender) of a person also influence the travel choices he makes (Carnegie and Deka, 2010) in case of an evacuation from a natural disaster.

The third element in Figure 2.1 are the 'choice options'. As was mentioned in 2.1.1, in case of a natural disaster, people are confronted with different decision situations from what they are used to in daily travel behaviour. Choice options may be limited, e.g. people might not have access to a car and roads might be blocked.

The 'information', 'personal context' and 'choice options' influence the perception a person has of the situation but also the way he makes his decisions and therefore the actual choices that are made. In short, they influence 'human evacuation behaviour'.

In this chapter a conceptual framework will be presented to provide an overview on factors influencing evacuation choice behaviour. Before presenting and discussing this conceptual framework, Section 2.2 will first give a general introduction to travel behaviour modelling.

2.2 Travel behaviour modelling

Correct modelling and prediction of evacuation choice behaviour is needed to develop evacuation management strategies for evacuating an area that is struck by a disaster.

Since insight into evacuation choice behaviour is needed for correct modelling and prediction of evacuation choice behaviour, this section provides a very general introduction to travel behaviour modelling in 2.2.1 and activity-based modelling in 2.2.2.

2.2.1 General introduction to travel behaviour modelling

When people travel, they have to make travel choices. In the field of travel behaviour modelling, it is these travel choices that need to be modelled.

There are five travel choices to be made: activity choice, destination choice, mode choice, departure time choice and route choice. These choices can be made sequential (all choices are made separately) and simultaneously (e.g. a combination of destination and mode choice) (De Dios Ortúzar and Willumsen, 2011).

Travel choice behaviour differs according to the purpose of a trip or tour (a chain of trips), meaning travel behaviour differs according to the activity or activities to be done (De Dios Ortúzar and Willumsen, 2011). Trip purposes such as working, shopping and recreation can be seen as separate markets with their own laws. The importance of travel time differs for these different trip purposes. For example, travel time might be very important for someone who travels to work (because this person has to start at a specific time) while this may be a less important factor when going shopping. In shopping, prices might be more important (e.g. going to a cheaper supermarket instead of a more expensive one, even though it takes a few minutes cycling extra). In case of an evacuation, getting out of an area as quickly as possible might be the only important choice at a certain moment. Therefore, in planning practice different choice models are used for different travel purposes.

Disaggregated and aggregated models exist (De Dios Ortúzar and Willumsen, 2011). Disaggregated models are used to find out which factors influence individual trip making. They are used to find out which factors significantly influence individual travel choices. Aggregate models model the behaviour of larger groups of travellers, consisting of members whose behaviour is assumed to be comparable. With aggregate models, the average values of these groups are used. Compared to disaggregate models, they are less accurate but easier in use.

Evacuation models are usually applied to consider the impact of a certain disaster or to provide insight into the effectiveness of certain evacuation instructions. The evacuation models usually predict the travel demand based on the trips from origin (usually home or work) to destination (outside of the disaster area) (Pel et al., 2012).

2.2.2 Activity-based modelling

Based on the personal context people are in, they perform activities (e.g. taking children to daycare before going to work). One way to create activity patterns that reflect how people plan and organise their activities is with activity-based models (Henson and Goulias, 2006). Bowman and Ben-Akiva (2000) summarised activity-based modelling into two basic ideas. First, travel demand is derived from the demand for activities. When the utility for a certain activity is higher than the utility to stay at home, people choose to perform that activity (e.g. food has to be bought for dinner tonight). Second, humans face spatial-temporal constraints, limiting the number of feasible alternatives. One constraint is that people return home for rest and personal care.

In case of a natural disaster, the members of a household also perform activities. They usually assemble first and then evacuate as a single unit (Heat et al., 2001), meaning the travel choices a person makes in case of a natural disaster are therefore all related to the activities he performs.

A first attempt to model household travel behaviour during emergency situations with activity-based modelling can be found in Murray-Tuite and Mahmassani (2003). They refer to their model as a model for household trip-chain sequencing, considering the activities due to household interactions and resulting in a chain of trips. With their model they simulate picking up of household members. Prior to the evacuation two aspects are set: the meeting locations of the household members and which drivers will pick up which household members.

With respect to this research, they show that it is possible to model the activities that a household performs during an emergency situation but Murray-Tuite and Mahmassani (2003) also state that further research is needed. For example, communication and traffic information provision may allow the drivers of a household to switch pick-ups and to reroute en-route. Besides that, they do not consider modelling of the actual decision making process, which will be discussed in Section 2.7.

This section provided an introduction to research on travel behaviour modelling in case of an evacuation from a natural disaster. The next section presents and discusses the conceptual framework for evacuation choice behaviour.

2.3 Conceptual framework for evacuation behaviour

This section will present a conceptual framework for evacuation choice behaviour. All aspects of this framework will be discussed into detail in Section 2.4 with relevant references to literature.

The conceptual framework, presented in Figure 2.2, is divided in the same main elements as discussed in the previous section: information, personal context, the choice options people have and human evacuation behaviour. It represents travel choice behaviour of a single person.

The top of the framework concerns information. The situation (i.e. evacuation from a natural disaster) influences different factors related to information provision (e.g.

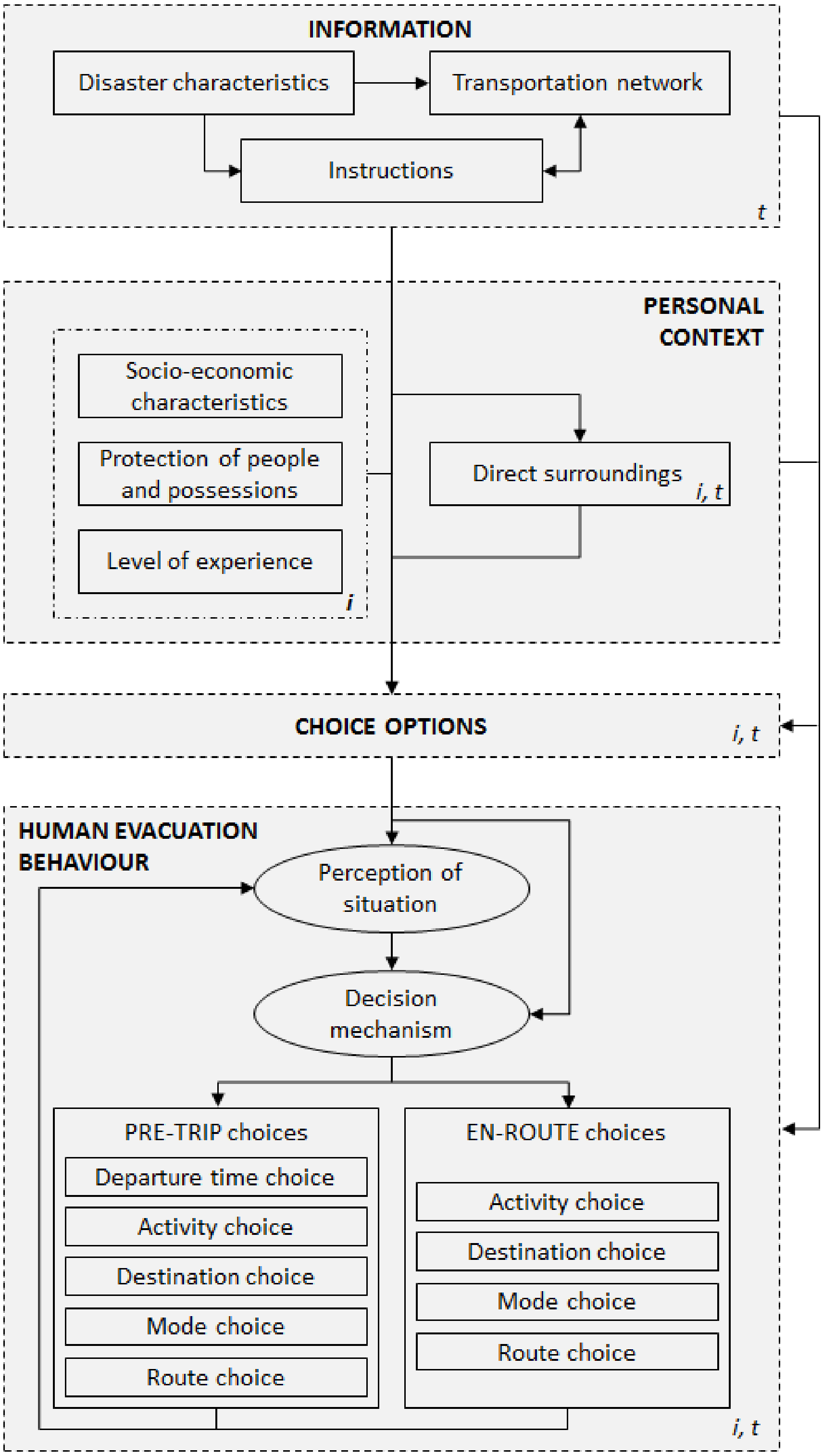

Figure 2.2: Conceptual framework representing travel choice behaviour of a single individual in case of an evacuation from a natural disaster

from authorities or media), including information on the disaster (e.g. the severity), information concerning the transportation network (e.g. congestion due to many people evacuating towards the same direction) and instructions (e.g. evacuate). The instructions also influence the transportation network (e.g. authorities blocking roads to make it impossible for people to move towards a certain area).

This framework represents the choice behaviour of a single person, this person's socio-economic characteristics, the people and possessions he wants to protect and his level of experience with evacuations from a natural disaster. These aspects differ per individual. Furthermore, each person sees or hears things (e.g. the behaviour of other people) in his direct surroundings. What happens in the direct surroundings of a person is also influenced by the information from the disaster characteristics, the transportation network and provided instructions.

To make travel choices, choice options must be physically available. These options depend on the transportation network (e.g. available roads) as well as on personal context (e.g. access to a car).

Information, personal context and the choice options influence the perception a person has of the situation but also the way he makes his decisions (decision mechanism). The resulting decisions are the pre-trip and en-route travel choices, shown at the bottom of the framework. For clarity sake, the choices have been put in two boxes. It must be noted that, it is unclear whether all these choices are made before people evacuate or whether people decide to leave and make the other choices along the way.

Feedback loops are included in the framework because the travel choices (pre-trip and en-route) made by an individual together with new information may make this individual change his perception of the situation. For example, a person has decided to evacuate but first wants to pick up his children from school as fast as possible, meaning this person is in a hurry. Together with that, this person is confronted with new information, which may also lead to a different perception, which may then result in new choices (e.g. changing the route to the school because some streets are congested).

For all elements in Figure 2.2, the conceptual framework presents if the element depends on the individual (*i*), changes over time (*t*) or depends on the individual and changes over time (*i,t*). What can be seen is that information concerning the disaster characteristics, the transportation network and instructions changes over time but is the same for all individuals. The personal context depends on the individual. The socio-economic characteristics, the people and possessions a person wants to protect, and the level of experience do not change over time, that is for the same natural disaster. The element representing what someone sees and hears in his direct surroundings does change over time. The objective choice set and the elements representing human evacuation behaviour depend on the individual and may change over time. Besides *i* and *t*, location is also of importance (e.g. the information characteristics all depend on the location: areas that will be affected by the disaster, location of congestion in the transportation network).

All elements of this conceptual framework are separately discussed and supported by references to literature.

2.4 Detailed discussion on the conceptual framework

This section explains the elements of the conceptual framework more into detail based on a literature review. Sub section 2.4.1 discusses the upper part of the framework, the information. The personal context is explained in Sub section 2.4.2. Sub section 2.4.3 discusses the choice options that a person has. Human evacuation behaviour is discussed in Sub section 2.4.4.

2.4.1 Information

This sub section discusses the information a person receives (e.g. from authorities or media) regarding disaster characteristics, the transportation network and instructions. These elements are dynamic. They are shown in the upper part of Figure 2.2.

Disaster characteristics
The first aspect discussed is the influence of characteristics of the disaster on travel choice behaviour.

From research on bush fires, floods and hurricanes it has become clear that information on the distance to the disaster and time it will (or might) take for the disaster to strike the area are of importance.

With regard to bush fires, Alsnih et al. (2005) found that the distance to the fire, wind speeds and wind direction influence the decision to evacuate. As expected, a decision maker will more likely decide to evacuate when the distance to the fire is smaller, the wind speeds are higher and the wind direction is unfavourable. In case of a flood, it is the severity which influences the decision to evacuate (Heat et al., 2001). This is also the case for hurricanes: the more intense the storm is, the more likely people will decide to evacuate (Dow and Cutter, 2000; Whitehead et al., 2000). For hurricanes people also consider the predicted path to determine their personal risk (Dash and Gladwin, 2007).

Concluding, bush fires, floods and hurricanes have similar and different characteristics which all influence the decision to evacuate.

Transportation network
The next aspect concerns the characteristics of the transportation network which influence travel choice behaviour. Information with regard to the transportation network deals with the available travel options people have and the state of these travel options.

Concerns about the traffic situation and not being able to return home after an evacuation have been shown to result in people not evacuating (Dow and Cutter, 2000; Dash and Morrow, 2001). For example, drivers have shown to communicate their frustration with the traffic to state and emergency management officials and radio stations, which were broadcasting the problems. People who had not started to evacuate heard about these problems and decided not to evacuate.

Disaster characteristics and instructions both influence the transportation network. Due to bad weather (e.g. resulting in trees falling down) or instructions taken by authorities, roads might be blocked. The transportation network is also influenced by the travel choices people make. Congestion might occur due to people evacuating from an area and moving in the same direction, resulting in uncertain delays.

Concluding, the transportation network is of great importance due to available travel options (e.g. routes). Due to a natural disaster roads might become blocked, limiting the number of travel options.

Instructions
The third aspect is instructions. These instructions result from authorities wanting to guide and control an evacuation, meaning they are related to their evacuation strategies.

Instructions from the authorities concerning the evacuation are influenced by characteristics of the disaster (e.g. the severity is so high that people are not safe if they stay in their homes) as well as by the transportation network (e.g. certain roads might be blocked because they have been flooded or due to trees that have fallen down).

Concerning evacuation instructions or orders, three types exist: voluntary evacuation, recommended evacuation and mandatory evacuation. Several researches have shown that a mandatory evacuation order is most effective for evacuating as many people as possible (Whitehead et al., 2000; Hek, 2011).

Information people receive influences their perception of a situation, see also 2.4.4, which influences response to instructions. Especially the credibility of the information influences response. A low credibility seems to have an effect on (not) starting the evacuation on a person's own initiative (De Jong and Helsloot, 2010). Information is considered less credible when the government and experts are contradicting each other. Other reasons for not complying to evacuation instructions are the traffic situation causing inconvenience (e.g. delays) or the risk that people receive from information on a storm's expected track (Dash and Morrow, 2001). People are more likely to comply to for example evacuation instructions when the message is directed to them personally (Baker, 1991).

As discussed by Leach (1994), it could have been expected that people are just in denial and are being inactive before they themselves experience the actual impact of the disaster. However, the results discussed above show that authorities can guide and control an evacuation before the actual impact. On the other hand, the information they provide and how they present it is of importance and may lead to inactivity instead of activity (evacuation).

2.4.2 Personal context

This sub section explains the next main block of the framework, the aspects that are related to a single person. These aspects include the socio-economic characteristics, the people and possessions this person wants to protect, the level of experience this person has with evacuations from natural disasters and the direct surroundings of this person.

Socio-economic characteristics
The first aspect related to personal context concerns the socio-economic characteristics. These socio-economic characteristics influence decision makers through risk assessment (Dash and Gladwin, 2007).

From an overview presented by Carnegie and Deka (2010), socio-economic characteristics have been shown to influence evacuation decisions. However, Carnegie and Deka (2010) have shown that in one research age and gender have an impact on the decision to evacuate while in another research they do not affect the decision to evacuate. Variations clearly occur, which may depend on the set-up of the research itself and also on correlations between aspects.

Concerning age and gender influencing evacuation decisions, the following has mainly resulted from research (Alsnih et al., 2005; Elliot and Pais, 2006; Wilmot and Mei, 2004). Younger people and women will evacuate sooner than older people and men. This might be because older people have lived in their homes for many years and do not want to leave their possessions behind but this might also be because older people are less mobile. Whitehead et al. (2000) also found that gender plays a role in destination choice, as women are less likely to go to a shelter (instead of friends) than men.

Furthermore, during the evacuation from hurricane Katrina, both ethnicity and social economic status influenced evacuation decisions (Elliot and Pais, 2006). For example, those who were most likely to remain in New Orleans throughout the disaster were low-income African-Americans. Not only the decision to evacuate but also other decisions, such as destination choice, are influenced by socio-economic characteristics. According to Whitehead et al. (2000), Caucasian households and those with a higher education level are less likely to go to either a hotel/motel or a shelter. Instead they prefer to stay with friends.

Concluding, many researches have shown the impact of socio-economic characteristics on evacuation decisions. However, differences between researches have been found.

Protection of people and possessions
The next aspect concerning personal context are the people and possessions that people want to protect.

During a natural disaster, a person's social situation (especially a person's household (Murray-Tuite and Mahmassani, 2003)) has an impact on the mobility patterns. Before evacuating, not all members of a household might be at home and therefore people might want to pick up loved ones or valuable properties before travelling to the safe area. This may even result in people moving towards the danger instead of away from it.

Specifically children and pets have been shown to influence evacuation outcomes (Carter et al., 1983; Gladwin and Peacock, 1997). Children may motivate evacuation because parents want to protect them (Dash and Gladwin, 2007; Dow and Cutter, 2000). It has been found that fewer households with children failed to evacuate than households without children. Besides that, more households with pets than households without pets failed to evacuate (Heat et al., 2001). Why more households that owned pets failed to evacuate was explained by the fact that these households owned multiple pets, they owned outdoor pets or they did not have the resources to evacuate their pets. Concerning destination choice, pet owners also prefer to stay with friends (Whitehead et al., 2000). This might be because pets are not allowed in a hotel/motel or a shelter.

The number of household members as well as the age of the household members also influences behaviour. For instance, during the tsunami warning phase, the response was lower for families with more members (Charnkol and Tanaboriboon, 2006) than with fewer. This might be because it was harder to assemble and evacuate as a single unit within the available time. The number of children also decreased the probability of quickly responding to the tsunami warning. This does not confirm what has been found by Dash and Gladwin (2007) and Dow and Cutter (2000), where children seem to motivate evacuation. Concerning the tsunami a causal relation is expected between the number of children in a household and available evacuation resources.

Besides evacuating to a safe area, it is also possible that household members decide not to evacuate or they even want to return home to protect their belongings (Handmer and Tibbits, 2005).

Concluding, as with the socio-economic characteristics, different results have been found in different researches. This might be due to the type of disaster or household composition and available evacuation resources but also due to differences in set-up of the researches. Besides that, correlations are expected between socio-economic characteristics and the aspect discussed in this paragraph (e.g. low income families having more children and due to their low income they do not have the resources to evacuate).

Level of experience
The next aspect is level of experience a person has with natural disasters.

Alsnih et al. (2005) found that residents who have experienced bush fires are less likely to evacuate than those who have not experienced bush fires. Charnkol and Tanaboriboon (2006) showed that people who have experienced a tsunami or people who have family members who have experienced a tsunami evacuated faster. Therefore, level of experience with a natural disaster influences evacuation decisions. However, it may increase or decrease the level of evacuation participation. This is also confirmed by Dow and Cutter (2000).

Since the level of experience with a natural disaster does not change during the same natural disaster, it is considered to be a static factor for the same person and the disaster at hand. However, the next time the same person experiences the same type of disaster, the level of experience has changed. Note that, the level of experience discussed here is related to experience with the natural disaster itself and not to the evacuation specifically.

Concluding, it was shown that the level of experience with a natural disaster may increase or decrease the level of evacuation participation. It seems that the type of disaster influences this participation: experience with bush fires decreases the level of participation and experience with tsunami's increases the level of participation.

Direct surroundings
The final aspect concerning personal context is what people see and hear in their direct surroundings.

Besides information through official channels (such as authorities or media), people can also receive information through unofficial channels, including relatives, neighbours and other social ties (e.g. friends and co-workers) (Lindell et al., 2005). People's decisions are also influenced by information they receive from what happens in their direct surroundings (what they see and hear).

According to Alsnih et al. (2005), one of the reasons for households to not evacuate is due to the perception of their neighbours not evacuating. However, Baker (1991) explains that neighbours are often leaving or staying for the same reasons, such as risk and actions taken by public officials for that neighbourhood. But seeing neighbours evacuate might be the last incentive to decide to evacuate, resulting in herding behaviour.

Different researchers have discussed herding. Herding is described as, seeing other people doing something (e.g. leaving) and believing that what they are doing is a good alternative, resulting in doing the same thing (Ariely, 2008). In case of an evacuation from a natural disaster, people experience stress, which causes choice behaviour to be more impulsive than rational. Prechter (2001) stated that herding behaviour results from impulsive mental activity in individuals responding to signals from the behaviour of others. It might therefore be questionable whether it is conscious (see also Parker and Prechter (2005), where it becomes clear that between and within different fields theories of herding might be considered as conscious or unconscious).

Deutsch and Gerard (1955) describe this herding behaviour as informational social influence. Because of time pressure and being in an ambiguous situation it is likely that an individual does not have the abilities to come up with a quick and appropriate response on his own. Therefore, he needs additional information and looks for this in others, meaning the individual will see others as a source of information to guide his own behaviour.

As discussed in Helbing et al. (2000) individualism allows people to detect a good solution (e.g. in case of an evacuation from a building, to detect the exits), while herding might guarantee the imitation of successful alternatives. Herding might also lead to the imitation of unsuccessful alternatives (e.g. when people move towards an unsafe area and they are being followed). Helbing et al. (2000) conclude that optimal behaviour in escape situations is a suitable mixture of individual and herding behaviour.

Concluding, travel choice behaviour of other people in a person's direct surroundings might influence his own travel choice behaviour, which might be a good thing, especially when successful alternatives are imitated. However, no research was found where herding behaviour was quantified based on empirical data. This might be because quantifying herding behaviour is difficult due to its impulsive nature.

2.4.3 Choice options

The third block of the framework consists of the choice options. In order to choose between alternatives (e.g. decide to evacuate or not, when to evacuate, take the car or use collective transportation means), choice options must be available.

Not everyone has the same alternatives to choose from. The choice options a person has depend both on the transportation network (e.g. available routes) and on his own options (e.g. access to a car).

The choice options can be divided in an objective and a subjective choice set. The physical environment a person is in includes e.g. the built-up surroundings, the network infrastructure (Bovy and Stern, 1990). This physical environment forms the basis for the objective choice set. The objective choice set consists of the alternatives which are physically available to a person. These include the availability of transport modes, routes and destinations on the transport network.

This objective choice set during an evacuation from a natural disaster is influenced by the transportation network and the socio-economic characteristics of a person. With respect to the transportation network it concerns the availability of for example routes, destinations and public transport services. The socio-economic characteristics of a person include for example if someone has a driving license and owns a car.

The image a person has of the actual situation is somewhat distorted as his perception (see 2.4.4) of relevant alternatives is somewhat incomplete and inaccurate (Bovy and Stern, 1990), resulting in the subjective choice set. This subjective choice set is the choice set a person is considering, is aware of. These choice options are input for the decision mechanism (see 2.4.4). Note that, this is in case of a non disaster (and also no evacuation) situation. When a disaster occurs and people have to evacuate, they are more likely to have a much more incomplete and wrong idea on the possible alternatives.

Concluding, it is expected that in case of an evacuation from a natural disaster, a person does not consider all physically available alternatives. In order to evacuate, a person needs to make more decisions (e.g. when to leave, where to go, which route to take) of which some might have only one or a few options to choose from and some might have more options to choose from. For this research, the choice options a person actually considers are important.

2.4.4 Human evacuation behaviour

This sub section discusses the aspects that are part of human evacuation behaviour, the bottom part of the framework. But before discussing these aspects, a general introduction is given on typical human behaviour before, during and after a disaster.

After this general introduction, the actual aspects are discussed. First, the perception of the situation is discussed, followed by shortly mentioning the decision mechanism, which depends on the perception of the situation and the available choice options. After that, the pre-trip and en-route travel choices are discussed. The feedback mechanism is discussed at the end of this section.

Typical human behaviour before, during and after a disaster
Concerning human behaviour before, during and after a disaster, Leach (1994) distinguishes between the pre-impact phase (consisting of a threat and warning stage), the impact phase, the recoil phase and the rescue phase, see Figure 2.3. These phases can be perceived by all individuals but the duration of the phases differs per event. Human behaviour is assumed to be consistent per phase, independent of the event. This will be explained below.

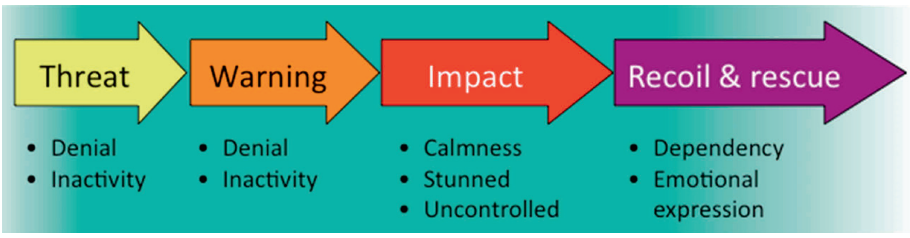

Figure 2.3: Typical human behaviour in different phases that occur in emergency conditions (Leach, 1994; Hoogendoorn et al., 2009)

The pre-impact phase is the phase before the actual impact which might take hours or even days during which many external factors may change over time. It is assumed that this pre-impact phase is related to the event status an individual is experiencing. The location this individual is at is not, or at least not yet, affected, which makes it still possible for this individual to evacuate (e.g. roads are not flooded).

The pre-impact phase is split into two stages, the threat stage and warning stage. During the threat stage, a disaster is predicted but it is not yet compelling (Vorst, 2010), e.g. the water level is rising but it cannot yet be characterised as a flood, there is a bushfire coming but it is still far away, or a strong wind is present but it is not yet a hurricane. During this phase, evacuation is still a possibility. In the warning stage, the danger is convincing and evacuation is necessary (e.g. the first flooding is a fact, the wind is hurricane-like). However, during the threat and warning stage, denial and inactivity are commonly observed.

During the impact phase, the disaster is a fact and evacuation is inevitable but difficult. Three types of behaviour are distinguished during this phase: most people are stunned and not able to think effectively. However, some people stay calm and collected, make decisions and act while other people show uncontrolled behaviour. Finally, during the recoil and the rescue phase, people show a dependency on others and a need for emotional expression.

Perception of the situation
The first aspect discussed is the perception people have of the situation. It is influenced by the information, personal context and the choice options.

Risk perception is highly subjective (Plous, 1993) and is one of the key factors in understanding the evacuation decision-making process (Dash and Gladwin, 2007). Every individual processes information through his own social lenses, depending on his particular cultural context. As a result, the same information may be interpreted differently by different people. Not only the type of risk but also the way a particular risk is presented influences the perception and also the value people place on preventive behaviour.

Concluding, in order to make a decision people first have a perception of a situation, which is then input for the decision mechanism. This perception is therefore important for understanding and predicting the demand pattern in case of an evacuation from a natural disaster. However, quantifying the perception people have of a situation is difficult because it is highly subjective.

Decision mechanism
The second aspect discussed is the decision mechanism, which depends on the decision strategy a person uses to make his decisions.

The decision mechanism in the framework refers to the actual choice making which leads to human evacuation behaviour. The decision mechanism is influenced by the perception a person has of the situation and the choice options a person chooses his alternative(s) from. How people make their choices depends on the decision strategy they use. Some possible decision strategies are presented in Section 2.7.

The decision mechanism is essential for understanding and predicting the demand pattern in case of an evacuation from a natural disaster.

Pre-trip and en-route choices
The third aspect are the pre-trip and en-route choices. They are located at the bottom of the framework.

The perception of the situation influences the plan of activities people want to perform hence their pre-trip and en-route travel choices. At the bottom of Figure 2.2 two boxes are shown with pre-trip and en-route travel choices. The pre-trip choices concern the choices people (can) make before they start with their activities. When they have started, when they are en-route, the choices are called en-route choices.

Departure time choice is not part of the en-route choices because people have already departed. En-route mode choice is included but it is very unlikely people just transfer from car to bus during an evacuation. However, it might happen that people are stuck in traffic and they need to leave their car behind and start walking.

The framework might suggest that all choices are made together before the evacuation. However, it is unknown whether all the choices are made before the evacuation or only some are made before and the others are made during the evacuation.

Feedback Mechanism
The final aspect is the feedback mechanism, which depends on the feedback loops in the framework.

For evacuation modelling it is essential to include reactive traveller behaviour due to the time-varying information concerning the disaster itself, the traffic situation, instructions and what people see and hear in their direct surroundings (Pel et al., 2012).

This varying information may lead to reconsideration of earlier made choices. Therefore, a feedback loop is shown in the framework between the travel choices and the perception a person has of the situation. This loop is essential for modelling realistic evacuation behaviour.

Concluding, based on the framework, the focus will be on human evacuation behaviour, including the elements involved (e.g. decision mechanism, actual travel choices). It is important to be able to understand and predict the activity patterns and changes due to dynamics over time.

2.5 Interaction behaviour in case of evacuations

A conceptual framework for individual evacuation choice behaviour is presented and discussed. However, in reality, when there is a natural disaster many people need to evacuate. Therefore, this section presents the conceptual framework including choice behaviour of all people in case of a natural disaster.

The conceptual framework presented in Figure 2.4, shows the same elements as the conceptual framework in Figure 2.2, while including travel choice behaviour of more individuals. This means that the elements concerning the information (disaster characteristics, transportation network and instructions) are the same for these individuals. Note that, a location element is not included but information people receive might depend on where they are.

The personal context, the choice options and human evacuation behaviour are different for each individual, therefore these elements are separately included in the combined

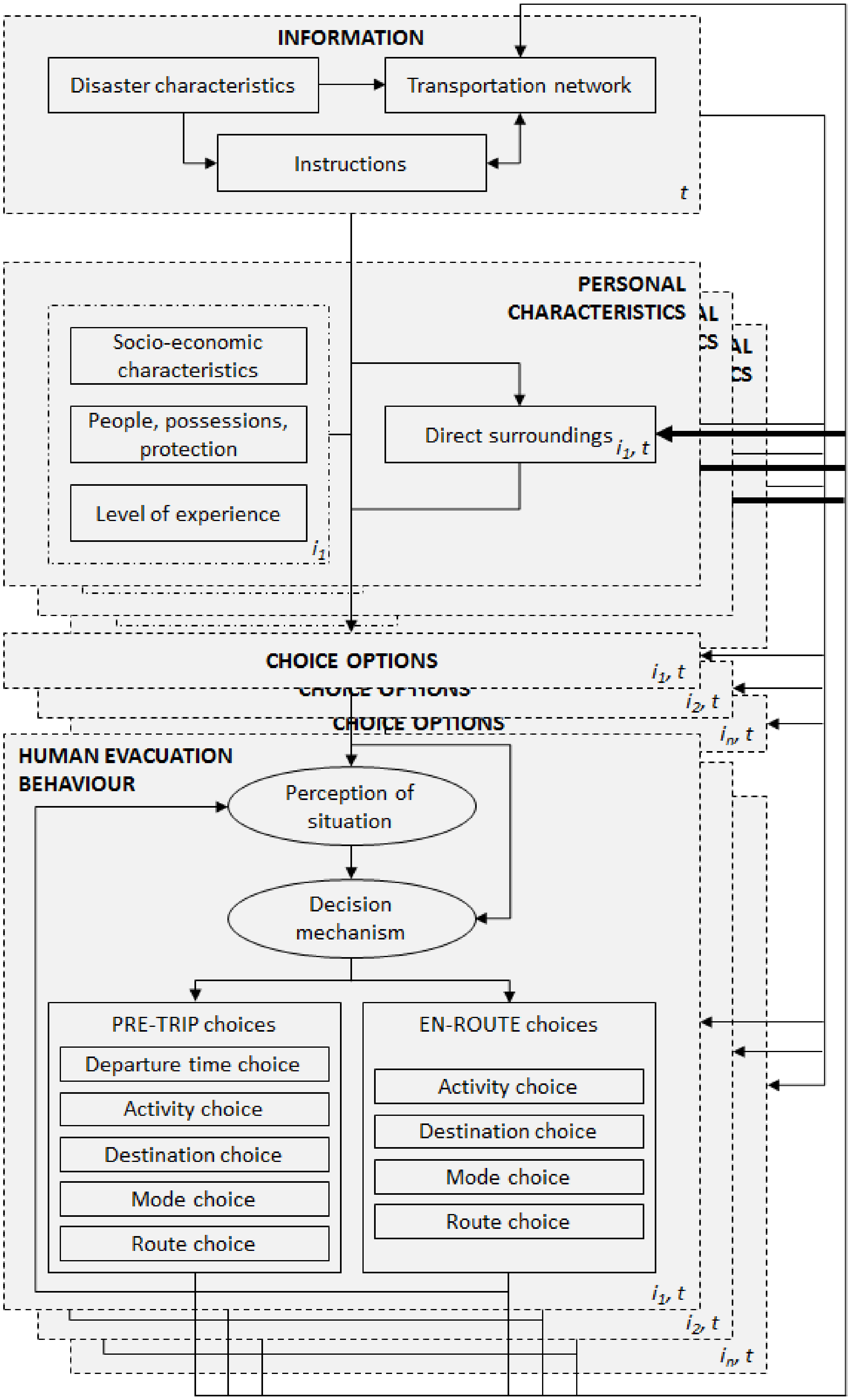

Figure 2.4: Conceptual framework representing the whole system of travel choice behaviour in case of an evacuation from a natural disaster

conceptual framework. For simplicity sake this figure shows three individuals: i_1, i_2, and i_n. Each layer of personal context, choice options and human evacuation behaviour represents these elements for one and the same person.

Travel choice behaviour of one individual does not have enough impact on the whole system, meaning on the whole transportation network. However, travel choice behaviour of more individuals does influence the situation on the transportation network. This is represented by a feedback loop from all travel choices back to the transportation network.

Which decision strategy is used or which strategies are used by each individual does not become clear from this framework. However, it might be expected, as will be discussed in Section 2.7, that different people might use a different strategy in a different situation (e.g. concerning daily travel behaviour versus travel behaviour during natural disasters, but also concerning travel choice behaviour pre-trip versus travel choice behaviour en-route).

Concerning activity-based modelling, the framework shows the impact of the travel choices of all individuals influencing the transportation network, which can have its own impact (again) on new decisions that are made.

Compared to Figure 2.2, the framework in Figure 2.4 also includes a thick arrow representing the actual herding or interaction behaviour. This arrow is explained further in the next section.

2.6 Herding behaviour in case of evacuations

The conceptual framework presented in this section is considered as the framework representing the whole system of travel choice behaviour in case of an evacuation from a natural disaster. One aspect, the actual interaction behaviour is represented by the thick arrows. These arrows show that the choices that are made are used as input for the direct surroundings and therefore they are also input for the choice options and human evacuation behaviour. These arrows have not been explained above. They will be discussed in this sub section.

The choices that are input for the direct surroundings concern the choices that might lead to herding behaviour. Herding behaviour was already introduced in 2.4.2 as part of the direct surroundings. It involves the behaviour of other people, hence it involves interaction behaviour, and is discussed further on the basis of typical human evacuation behaviour.

Based on typical human evacuation behaviour, as described in 2.4.4, Leach (1994) also stated that during the impact phase the following classification of people can be made based on their psycho-behavioural responses:

1. 10-15% of the people undertake action and remain calm and rational (they are able to quickly collect their thoughts, their awareness of the situation is intact),
2. around 75% of the people react in a semi-automatic manner (they are stunned and bewildered, they may suffer 'tunnel vision') and
3. 10-15% of the people respond uncontrolled and inappropriate (i.e. weeping, confusion, screaming and paralysing anxiety).

As shown in this chapter, literature was found on different aspects influencing evacuation choice behaviour (e.g. the effect of age and gender on the decision to evacuate). No literature was found where the effect of herding on evacuation choices was quantified on the basis of empirical data. It is unknown what causes people to be part of one of the three groups. It is therefore concluded that the effect of herding on evacuation decisions needs further research.

2.7 Possible decision strategies in case of evacuations

This section discusses options on how people make choices in case of evacuations from natural disasters. By no means is this a complete overview but it will provide a general idea on how people might make their choices. At the end of this section decision strategies for evacuation choice behaviour are discussed.

2.7.1 Trade-off between effort and accuracy

First, a basic idea on a trade-of that people make in decision making is discussed.

Payne et al. (1993) discuss that each strategy is based on a trade-off between accuracy and effort. An example of a high accuracy / high effort decision strategy is expected utility theory (EUT). In expected utility theory decision makers are assumed to have complete information about the probabilities and consequences attached to each choice alternative, they understand all information, they are able to calculate the advantages and disadvantages of each choice alternative, compare the calculations and choose for the alternative with the highest expected utility. In reality, information is often incomplete or uncertain, the perceptions that people have are highly subjective, memory is fraught with biases, consequences of choices may be misunderstood and not all possible alternatives are compared (Plous, 1993).

A low accuracy / low effort decision strategy has been proposed by Simon (1955). He proposed that people rather 'satisfice' than optimise when making decisions. With this decision strategy the first alternative that is evaluated as acceptable, according to some minimum aspiration level, is chosen. Due to a time limit during an evacuation from a natural disaster this may be needed.

The two examples discussed above are each others opposites in terms of accuracy and effort. What can be concluded from this is that, when there are no limitations, meaning people are not limited in their abilities, a high accuracy / high effort decision strategy sounds plausible. However, in reality people are faced with limitations in for example their abilities.

A method which goes more into the limitations of people concerning decision making is explained below. It is called the theory of bounded rationality. After that, two other more elaborated concepts are discussed: prospect theory and regret theory. With these concepts, the value of all choice alternatives is not known in advance (Bogers, 2009). The main ideas that resulted from the decision strategies presented are discussed at the end of this section.

2.7.2 Bounded rationality

The choices people make, according to bounded rationality, depend on some consistent overall goal and properties of the external world but these choices are bounded due to the knowledge that decision makers do and do not have of the world and their ability or inability to evoke that knowledge when it is relevant. Rationality is bounded because abilities are limited (Simon, 2000).

According to bounded rationality, decision makers in the real world have to cope with a number of constraints (Frör, 2008), such as:

- limited information availability,
- limited time to acquire information and
- limited computational capabilities.

During natural disasters the available information may be limited. For example, the path of a hurricane is predicted with a certain probability but it still might change or the exact delay that people experience during the evacuation is uncertain.

Due to limited computational capabilities simplified decision strategies are used. The strategies may be based on past experience or people accept a result which they consider as satisfactory instead of only accepting the maximum achievable.

2.7.3 Prospect theory

Prospect theory has first been proposed by Kahneman and Tversky (1979). They replace utility by value, which is based on gains and losses (deviations from a reference point), see Figure 2.5.

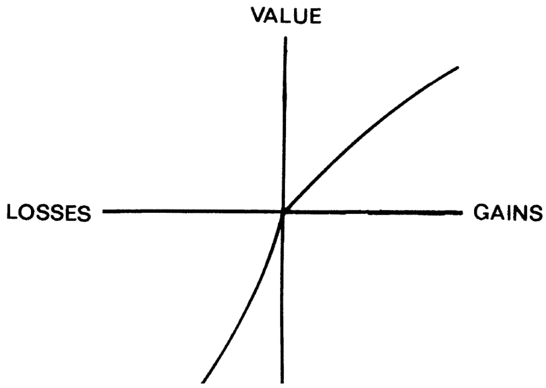

Figure 2.5: Prospect theory - Value function for gains and losses (Kahneman and Tversky, 1979)

As is shown in Figure 2.5, both gains and losses are represented by a value function, which is steeper for losses than for gains, meaning that the value for losses weights heavier. This results in a four-fold pattern of risk attitudes which is confirmed by Tversky and Kahneman (1992). Concerning gains, people are risk-seeking for small probabilities and risk-averse for medium or high probabilities. Concerning losses, people are risk-averse for small probabilities and people are risk-seeking for medium or high probabilities.

2.7.4 Regret theory

Regret theory has been proposed by Bell (1982) and Loomes and Sugden (1982) as an alternative theory of rational choice under uncertainty. Regret theory is based on two fundamental assumptions (Plous, 1993):

- People experience sensations that are called regret and rejoicing.
- In decision making under uncertainty, people try to anticipate and take account of those sensations.

Compared to prospect theory where decision makers evaluate their alternatives relative to a reference point, in regret theory decision makers compare the quality of their decisions to what might have happened if they had made a different choice. This theory has been introduced to the field of transport by Chorus (2007).

2.7.5 Evacuation behaviour strategies

This section presented some decision strategies that might be considered. In case of an evacuation from a natural disaster there are important limitations that most likely play a role.

People do not have full information of the situation and what they should or could do and the time to acquire information is limited. Due to time pressure, people might have to accept a satisfactory option instead of the maximum achievable option. Based on this, bounded rationality seems reasonable in case of an evacuation from a natural disaster.

However, every person and every situation is different which might mean that a different strategy is used. When considering Leach (1994), who explains that three types of behaviour are distinguished this might be explained (see 2.6). Those who stay calm and collected probably use a different strategy (e.g. they are capable of making a quick trade-off between some options) than those who show a dependency on others (e.g. they are most likely not able to have a clear idea of possible options). When people are in a different situation, they might also use a different strategy. For example, those who are having experience with a situation respond differently (see 2.4.2). Concluding, there is not one clear evacuation decision strategy expected to be used by all people and no empirical evidence was found on how people actually make their choices.

2.8 Conclusions

As described in Chapter 1, to understand people's evacuation choice behaviour, the influence of factors on choice behaviour needs to be quantified. Research questions 1 and 2 are related to this and are answered in this chapter.

To answer ***research question 1***, two conceptual frameworks for travel choice behaviour of both an individual as well as all people having to evacuate from a natural disaster were presented. These frameworks provide a structured overview of what is known from existing literature.

It became clear that substantial research has been undertaken on the influence of factors on evacuation choice behaviour. These factors are split into the following groups: information, personal context, choice options and human evacuation behaviour. However, there are some interesting remarks to be made.

- Differences in results have been found on the influence of factors on evacuation choice behaviour. These differences might be caused by:
  - The differences between different types of disasters and the available information about the disasters.
  - The set-up of the research that was conducted (e.g. how and which data was collected).
  - Causal relations between the many influencing factors are to be expected.
- No literature was found on quantifying the effect of herding on evacuation decisions based on empirical data.

- The perception people have of a situation is difficult to quantify because it is highly subjective.

To answer ***research question 2***, a brief and general overview of possible decision strategies was presented in Section 2.7. Based on the psycho-behavioural responses, people are split into three groups: the first group undertakes action, the second group reacts semi-automatic and the third group responds uncontrolled and inappropriate. Based on this, these groups use different decision strategies. It is concluded that empirical evidence is lacking on how people make their choices in case of an evacuation from a natural disaster. Based on the three types of psycho-behavioural responses, especially the effect of herding on evacuation behaviour needs to be quantified on the basis of empirical research.

The conceptual frameworks presented in this chapter will be used as a guideline throughout this thesis. They are used when developing the experimental set-up in Chapter 3, when presenting the descriptive analysis of data collected with this experimental set-up in Chapter 4, when estimating choice models with the data to quantify herding behaviour in Chapter 5, when critically assessing the experimental set-up and results in Chapter 6 and when discussing the conclusions and recommendations in Chapter 7.

In this chapter it became clear that especially herding behaviour needs further research. Since empirical research needs to be done to quantify the influence of factors on evacuation choice behaviour, Chapter 3 will discuss the advantages and disadvantages of existing data collection techniques. This will be done to find out which disadvantages need to be solved in order to quantify herding behaviour. Based on this, requirements are set to focus on herding behaviour and the experimental set-up for this research is developed.

Chapter 3

Design of experimental set-up

In the previous chapter a conceptual framework for evacuation choice behaviour was presented. In the end, it was stated that empirical research could to be done to quantify factors influencing this evacuation choice behaviour. Especially the effect of herding behaviour in case of an evacuation from a natural disaster is unknown. The aim of this chapter is to present and discuss the development of a new experimental set-up for research on evacuation choice behaviour in case of a natural disaster, specifically with a focus on herding behaviour.

To gain more insight into the properties of existing data collection techniques, Section 3.1 discusses advantages and disadvantages of existing techniques and shows that virtual environments are suitable for empirical research on quantifying herding behaviour in case of an evacuation from a natural disaster.

Based on this and the conclusions of Chapter 2, Section 3.2 presents the requirements for a new experimental set-up with a focus on herding. Section 3.3 discusses the design of the virtual environment Everscape. Three pilot experiments have been conducted with Everscape. The results of the pilot experiments are discussed in Section 3.4. Based on these pilot experiments the experimental set-up for this research is designed. This set-up, which consists of an introduction, the experiment with Everscape (including different herding scenarios) and a questionnaire, is presented in Section 3.5. The conclusions of this chapter are discussed in Section 3.6.

This chapter is based on edited versions of:

- *Van den Berg, M., Doirado, E., Van Lint, J.W.C., Nakasone, A., Hoogendoorn, S.P., Prendinger, H. and Van Nes, R. (2012). Application of a 3D multi-user virtual environment for research on travel choice behaviour. The case of a tsunami. In M. Roorda and E. Miller (Eds.), International conference on travel behaviour research, pp. 103-125*
- *Doirado, E., Van den Berg, M., Van Lint, J.W.C., Hoogendoorn, S.P. and Prendinger, H. (2012). Everscape: The Making of a Disaster Evacuation Experience. Presented at CHI12, May 5–10, 2012, Austin, Texas, USA*

3.1 Measuring evacuation choice behaviour

Before designing the experimental set-up, this section starts with discussing advantages and disadvantages of existing data collection techniques in 3.1.1. This needs to be done to find out which issues need to be solved in order to quantify herding behaviour. Based on this, the best technique that will be used for quantifying herding behaviour will be discussed more into detail in 3.1.2. Since a new experimental set-up will be developed, the importance of validity and controllability will be shortly explained in 3.1.3.

3.1.1 Existing data collection techniques

To determine the advantages and disadvantages of existing data collection techniques in a structured way, these techniques are roughly divided in Stated Preference (SP) and Revealed Preference (RP) techniques.

With SP, people are confronted with a hypothetical situation and are asked to state their response (e.g. their preferred route or mode of transport). The main advantage is that the researchers can include the aspects they want to consider. However, there are doubts about whether people respond like they would in reality (Train, 2003), especially in case of unique and uncommon events such as natural disasters.

With RP, the actual behaviour is considered. One option to do this is for example to directly observe the behaviour (with e.g. camera's) but researchers are limited to available choice situations (Train, 2003) and when these situations occur they cannot be controlled by the researchers. Since natural disasters are unpredictable and quite extreme, real time data collection is difficult, dangerous and there is limited or no time to prepare.

Another option to consider the actual behaviour is to afterwards ask what people did. Then, the researchers only know the available choice situation from what people remember. In case of a stressful situation, such as a natural disaster, it has been found that many people do not and perhaps cannot provide highly accurate summaries of how they coped with the situation (Smith et al., 1999). This makes it hard to exactly reconstruct the actual situations people were in, especially at the time when they made their decisions.

For research on quantifying herding behaviour in case of an evacuation from a natural disaster, it is important that researchers:

- can design and control experiments to meet the requirements stemming from their research questions,
- can observe actual behaviour that occurs in real life,

- can reconstruct the actual situations people were in,
- can safely conduct experiments when they want and
- have enough time to prepare.

By no means is this list of aspects considered to be a complete list for researchers. They are based on the disadvantages of SP and RP techniques that are discussed above and they are used to structure the different data collection techniques. Table 3.1 summarises how the different data collection techniques meet these aspects for research with a focus on evacuation choice behaviour and more specifically herding behaviour kept in mind.

Table 3.1: Overview of advantages and disadvantages of existing data collection techniques

It is important that the researchers...	**response to hypothetical situation (SP)**	**directly observe behaviour (RP)**	**ask what people did afterwards (RP)**
can design and control experiments to meet the requirements stemming from their research questions	+	-	-
can observe actual behaviour that occurs in real life	-	+	+
can reconstruct actual situations people were in	-	+	-
can safely conduct experiments when they want	+	-	+
have enough time to prepare	+	-	+

To 'exploit advantages of each type of data and to overcome their disadvantages', data from different sources can be combined (Ben-Akiva et al., 1994). This is kept in mind during the development of the experimental set-up by considering a combination of data from different sources.

Conducting experiments in a real life situation like a natural disaster is dangerous and there is limited or no time to prepare for such an experiment. It is expected that the best option for creating a situation that matches a real life natural disaster is with a virtual environment. Other advantages of such an environment are that the researchers can design and control experiments how they want and they can reconstruct the situation people were in. Therefore, this thesis will focus on a virtual environment as a data collection tool for research on evacuation choice behaviour, especially with a focus on herding behaviour. Before discussing the requirements for the experimental set-up, virtual environments are discussed more into detail below.

3.1.2 Virtual environments

Virtual environments have shown their usefulness in other fields, especially for educational or training purposes (Wideman et al., 2007; Smith, 2009; Thompson et al., 2010). In the field of evacuation behaviour, as discussed in Shendarkar et al. (2006), virtual environments can be used to mimic real world scenarios that are too difficult to conduct in live exercises, e.g. allowing to conduct experiments with disaster scenarios. A key concern, however, relates to limitations in behavioural (internal) validity: do respondents exhibit behaviour (e.g. make travel choices) in a virtual environment that is representative for their behaviour in real life situations. This is one of the important issues that will be considered in this thesis.

Kobes et al. (2010) have compared the behavioural responses from a real world experiment and a virtual experiment, both related to an evacuation from a fire in a hotel. Different scenarios were tested with differences in conditions (e.g. the influence of smoke, the location of exit signs). The responses (quantified by taking percentages of evacuees choosing for different exits) showed similarities and differences, depending on the scenario that was tested. With relative-validation analysis the authors concluded that the environment was a valid research tool. This is an encouraging result that supports the use of a virtual environment for experimental research on evacuation choice behaviour. However, one important element missing in this study is usefulness of such tools for research on herding in case of an evacuation. This thesis will consider this.

Because a virtual environment can meet most of the aspects mentioned in 3.1.1, it was decided for this research to mimic an evacuation scenario in a virtual environment. However, no more literature was found to prove the validity of the behavioural data from virtual environments, especially when considering herding behaviour. Before discussing the requirements of the experimental set-up, the next section therefore introduces the importance of validity and controllability. The validity of the data from the experimental set-up designed in this chapter and the results presented in Chapters 4 and 5, is thoroughly assessed in Chapter 6.

3.1.3 The importance of validity and controllability

Since the experimental set-up is specifically developed for this research, validity and controllability are important. This section briefly explains the importance of validity and controllability before presenting the requirements for and developing the experimental set-up.

Validity is important because the experimental set-up has to measure what it is supposed to measure. For this research it has to measure evacuation behaviour and more specifically herding behaviour. Therefore, the experience of the virtual environment has to be realistic.

With respect to ***controllability***, as also explained in Hoogendoorn (2012), it is important for researchers to possess a high degree of experimental control. This will reduce the risk of confounding variables.

The aspects of validity and controllability will be considered during the development of the experimental set-up in this chapter but also after the results are presented. The experimental set-up and results will be critically assessed on their validity and controllability in Chapter 6.

3.2 Requirements for experimental set-up

Before designing the experimental set-up, requirements for the experimental set-up are determined in this section. The requirements are based on:

1. the focus of this research being set on quantifying herding behaviour in case of an evacuation from a natural disaster (see Chapter 2),
2. using a virtual environment that is able to meet the aspects mentioned in 3.1.1 and
3. the validity of the experimental set-up, when using a virtual environment (see 3.1.2).

Requirements could have been differentiated into constraints, functional and non-functional requirements but it was decided to structure them in a comprehensive overview of categories based on different aspects of the research itself. The following categories are differentiated: setting the stage, travel choice behaviour in case of an evacuation, quantifying herding behaviour, representative sample of the population should be able to participate and validity of the experimental set-up.

Category 1: setting the stage
Since the focus is on evacuation from a natural disaster, a natural disaster has to be simulated within the virtual environment. In case of such a disaster, people experience a sense of emergency (caused by the perception of a threat). Therefore, this sense of emergency needs to be mimicked as well. See requirements 1 and 2 in Table 3.2.

Category 2: travel choice behaviour in case of an evacuation
During a natural disaster, people make travel choices to evacuate. Therefore, the scenario should make it possible for people to make these travel choices (e.g. departure choice, mode choice). The travel options that people consider differ in risk level and travel time. Therefore, the mode and route options people can choose from need to differ in risk level (e.g. differences in whether and when routes are affected by the disaster) and travel time. See requirements 3 and 4 in Table 3.2.

Table 3.2: Requirements experimental set-up

	Requirement	**Based on**
1	A natural disaster scenario needs to be simulated in the virtual environment.	Setting the stage.
2	A feeling of emergency needs to be invoked.	Setting the stage.
3	The following travel choices have to be included: departure time (stay or leave), mode, route and destination choice.	Travel choice behaviour in case of an evacuation.
4	The travel modes/routes have to differ in risk level and travel time.	Travel choice behaviour in case of an evacuation.
5	Participants have to be able to see each other and each other's actions.	Quantifying herding behaviour.
6	At the time the disaster starts, all participants have to be in the same area where they can see each other and each other's actions.	Quantifying herding behaviour.
7	The recorded data should include viewing directions.	Quantifying herding behaviour.
8	The virtual environment has to be simple and logical to use.	Representative sample of the population should be able to participate.
9	The experience with the virtual environment should be realistic.	Validity of the experimental set-up.
10	Evacuation choice behaviour of participants should match results from literature.	Validity of the experimental set-up.

Category 3: to quantify herding behaviour
In Chapter 2, it became clear that people are influenced by what they see and hear in their direct surroundings and especially by the behaviour of other people. Therefore, people who participate in an experiment with the experimental set-up need to be able to see each other and each other's actions. This is essential to observe herding behaviour. To especially focus on this aspect, all participants should be within the same area where they can see each other at the moment the disaster starts. To quantify herding behaviour, recorded data should include what people see. Therefore, viewing directions have to be included. See requirements 5, 6 and 7 in Table 3.2.

Category 4: representative sample of the population should be able to participate
Not all participants have experience with virtual environments but to make sure a representative sample of the population can participate, usage of the virtual environment should be simple and logical. See requirement 8 in Table 3.2.

Category 5: validity of the experimental set-up
With respect to the validity of the experimental set-up, the experience should be realistic and results should match results from existing literature on evacuation choice behaviour. Socio-economic characteristics such as age and gender but also information need to be found as influencing factors on evacuation choices made by the participants in Everscape. See requirements 9 and 10 in Table 3.2.

The requirements for the experimental set-up, summarised in Table 3.2, have been determined and form the basis for the development of the set-up, which is discussed in the following three sections.

3.3 Development of virtual environment 'Everscape'

The development of the experimental set-up consisted of two main parts: the development of the virtual environment 'Everscape' and the development of the experimental set-up which uses Everscape and focusses on herding. Figure 3.1 schematically shows the development process of the experimental set-up.

Decisions made with respect to Everscape at the start of the project are explained in 3.3.1. After these decisions were made, Everscape was built and tested during a prototyping process. This process is discussed in 3.3.2.

Pilot experiments conducted with Everscape will be discussed in Section 3.4. Based on this, the experimental set-up was designed. This set-up will be discussed in Section 3.5.

3.3.1 Creating the basis for Everscape

Everscape, created in Unity3D (Unity3D, 2012), is a 3D multi-user virtual environment. It is the result of a collaboration between the National Institute of Informatics

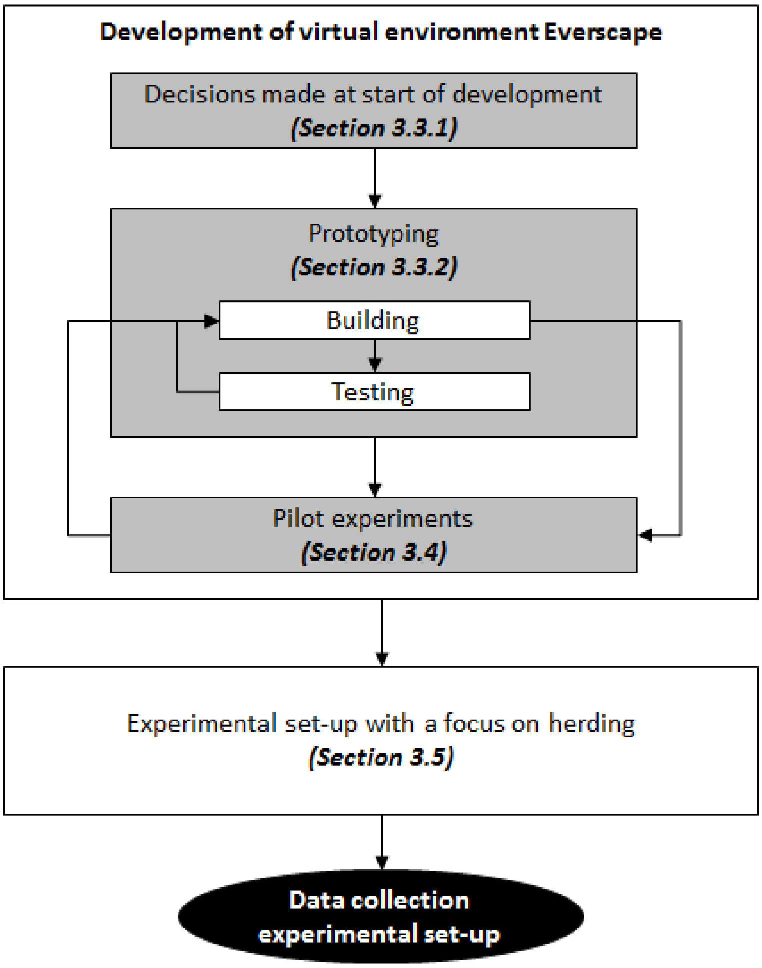

Figure 3.1: Development process experimental set-up

(Japan) and Delft University of Technology (the Netherlands). The functional design was developed in Delft and Everscape was built in Japan. To design Everscape, the researchers in Japan and Delft closely worked together with a graphic designer. The graphic designer used the storyboarding technique to create the user-experience and identify design flaws. This technique made it possible for the designer and researchers to easily communicate about the different aspects and make decisions with respect to the scenario.

Before developing Everscape, choices related to the scenario of Everscape and invoking a sense of emergency were made. These choices are explained below.

Choices related to the Everscape scenario

The chosen disaster is an **earthquake**, followed by a **tsunami**. One of the reasons why this disaster is chosen is that the design started around the time of the big earthquake and tsunami in Japan in 2011. Besides that, the combination of an earthquake and tsunami makes sense because an earthquake is already an emergency trigger for people to evacuate. In combination with the chosen location, an island, an earthquake and tsunami is also logical. It is furthermore believed that this scenario could be represented sufficiently realistically within the environment, especially in combination with the emergency feeling, which is discussed later in this section.

A **non-existing island** is created because all participants will then have the same amount of knowledge and level of experience with the location. But it is also decided for practical reasons because it is quicker and easier than an existing situation.

To influence the mindset of the participants, they need to have an activity goal to visit the island. Besides that, they all have to be at the same location when the disaster starts because then they can see each other and each other's actions. Therefore, the goal of the participants is to **visit the island to see a concert by the sea**. Figure 3.2 gives an impression of the concert area that is created.

In Everscape, participants are able to make different travel choices. **Departure choice** is related to the decision to evacuate or not and if decided to evacuate, when to evacuate. Several moments are included to trigger the evacuation choice moment. As explained in Chapter 2, evacuation choice behaviour is influenced by different aspects, among which characteristics of the disaster and information through media. These are both implemented and explained below, when discussing the emergency feeling.

With respect to **mode choice**, it is decided to include three modes. Two fast modes, car and train, and one slow mode of transport, walking. **Route choice** is included for car. These routes are different in risk level and travel time. There is one shorter route with a, possibly dangerous, bridge and a longer route through the mountains. See Figures 3.3 and 3.4 for an impression of the car options and Figure 3.5 for the train option. Information on the two car routes is provided on traffic signs, see Figure 3.8.

With respect to **destination choice**, it is decided to let people evacuate the island by helicopter. This is chosen because participants will also arrive on the island by helicopter. Also included is the possibility of surviving on top of the mountain.

Figure 3.2: Impression of Everscape

Figure 3.3: Short route via bridge

Figure 3.4: Long route through mountains

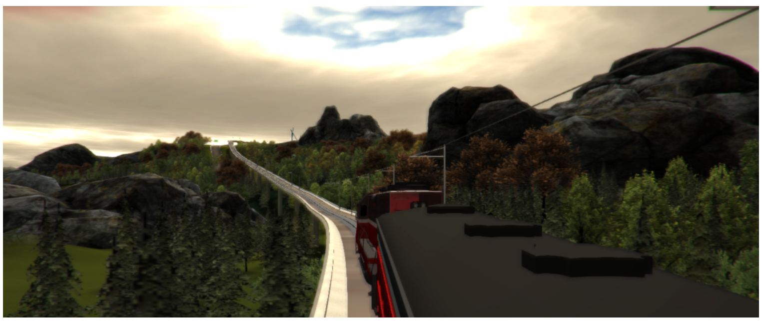

Figure 3.5: Train connection

To create a realistic scenario that mimicked a natural disaster scenario, a feeling of emergency has to be invoked. How this is done is explained below.

Choices related to the emergency feeling
In case of a tsunami, people in a (soon to be) affected area experience a feeling of emergency to move out of the area. To create this feeling, it is decided to include a number of possible triggers:

- The first trigger is related to the disaster, so the earthquake. The earthquake is simulated by making the ground shake, adding a rumbling sound and crashing of parts of the concert stage (see Figure 3.6).
- Adding information through media, a news item, to inform the participants about the upcoming tsunami and tell them they will have to evacuate to survive. See Figure 3.7 for the information that is presented during the news item.
- After the news item, the expected arrival time of the tsunami is shown in a corner of the screen, also indicating the departure time of the helicopter. The departure time of the train is also shown on the screen (see Figure 3.8).
- Alarm sounds are added to the concert area to influence the sense of emergency even more.
- Earthquake after-shocks are added because that also happens in reality.
- The weather gradually becomes frightening. It will start with some rain and towards the end result in a thunderstorm.

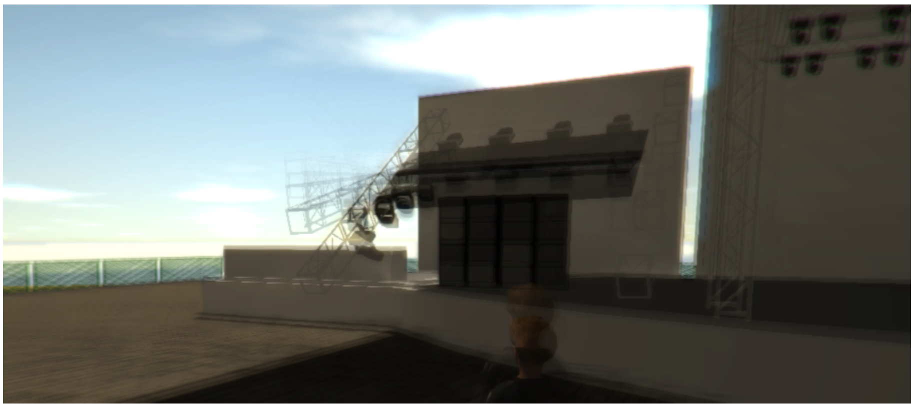

Figure 3.6: Parts of the concert stage crashing during the earthquake

3.3.2 Prototyping Everscape

After the basis for Everscape was set in 3.3.1, the actual building of Everscape started. This was done by prototyping and it consisted of five iterations of building and testing

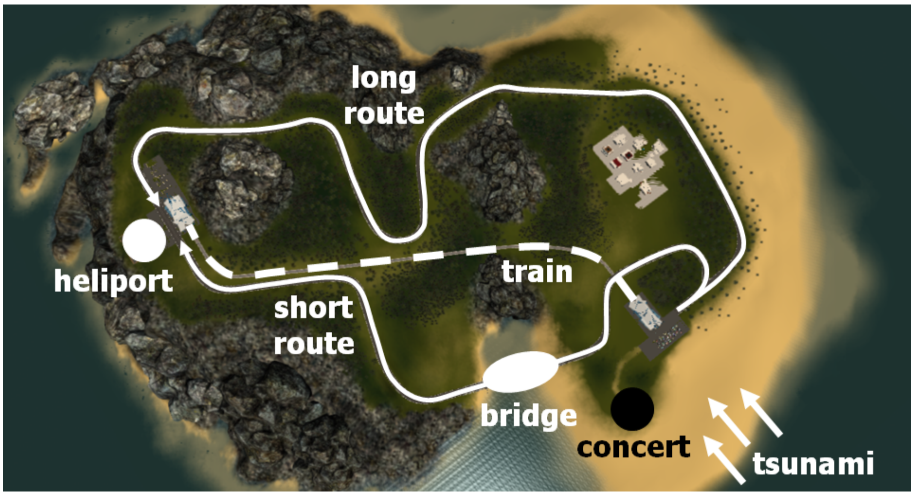

Figure 3.7: Information presented during news item

Figure 3.8: Information expected arrival time of tsunami and departure of helicopter

with actual people. These iterations are described in this section. With each iteration a description is given of what was built, tested and concluded.

ITERATION 1:

I. What was built: In this iteration, the designer and researchers in Japan used the DiVE (Distributes Virtual Environment) developed at the National Institute of Informatics to create the on-line world in Unity3D. Based on the industry's state of the art, a first version of the avatar control scheme was implemented together with the island and its main elements.

II. What was tested and why: To gain insight into the participants (who were considered to be the end-users) and how they experienced the controls (for walking), the first version of Everscape was tested in Delft with a number of people individually. These people had to play the simulation only once due to the surprise factor of the earthquake.

III. What was concluded: The controls for moving forward, backward and turning left and right used the standard gaming controls (W, A, S, D). However, these appeared to be too difficult and therefore had to be simplified to only using the four arrow-keys of the keyboard throughout the whole simulation.

ITERATION 2:

I. What was built: In the second iteration the different transport modes were implemented. The earthquake now triggered the tsunami.

II. What was tested and why: The people in Delft who tested this version started at the concert area and had to evacuate by car or train. The controls were tested again. Besides walking, also car driving and taking the train were tested to see whether people were able to use the controls for these modes.

III. What was concluded: In this iteration car driving was too difficult because of the sensitive steering. Besides that, the viewpoint was too detached from the cars which made people less part of the actual situation, hence the experience of a sense of emergency got lost. Since the focus of the research was on travel behaviour and not on how to control a car in such an environment, car driving was simplified by adding a steering assistant that automatically made the car realign with the road tangent.

ITERATION 3:

I. What was built: In the third iteration, special effects were added (e.g. collapsing of the bridge, helicopter flying away).

II. What was tested and why: The controls were tested again to see whether they improved.

III. What was concluded: After another test with several participants, the car driving still seemed too difficult. Based on this, it was decided to let people experience the full scenario in an experiment. The full scenario meant that people would arrive on the island by helicopter and take a car to drive to the concert. This way the participants would have some time to adapt to the controls of the car and also get familiar with the topology of the island. Since people usually evacuate via familiar routes (Graham and Roberts, 2000; Sandberg, 1997), this also makes it possible to find out if participants choose travel options (mode and route) they are familiar with.

In this iteration it was also decided to provide participants with this information during the briefing at the start of the experiment. This meant that participant needed information on why they would go to the island (to see a concert), how they would arrive on the island (by helicopter), how they would travel to the concert (by car) and how they would have to use the controls.

ITERATION 4:

I. What was built: The multi-user aspect was included.

II. What was tested and why: To gain insight into what an experiment with Everscape would be like and find out which aspects needed to be improved a test experiment was conducted with 21 people, all students or researchers from the National Institute of Informatics.

III. What was concluded: The results of the test experiment were promising. It suggested that the pace of the overall simulation was adequate. Besides that, the situation was clear and engaging for the participants. It was concluded that more interaction between participants would make the situation more realistic. Therefore, a chat message was included, see Figure 3.9 where a chat box is included at the lower left corner of the screen.

ITERATION 5:

Since the emphasis was on delivering a complete natural disaster experience, the final iteration included finishing of different elements. The news item was added, as well as the introduction and ending parts. The introduction consisted of the experience of flying to the island by helicopter and the ending consisted of the helicopter taking off (see Figure 3.10) and the end credits. No extra tests were needed.

3.3.3 Virtual experiment with Everscape

To gain insight into the virtual experiment with Everscape, a description is given of the full scenario in Everscape that resulted from building and testing the scenario that was developed in 3.3.1 and 3.3.2.

In Everscape, people arrive on the island by helicopter and take a car to drive to the concert. Figure 3.2 shows a snapshot of the concert area, where all participants initially

Figure 3.9: Screen including chat box at the lower left corner of the screen

Figure 3.10: Helicopter flying away at the end

gather. After a time period, participants who have not yet arrived at the concert area are teleported to this area, after which unexpectedly for the participants an earthquake is triggered.

During this earthquake, the ground starts to shake, a part of the concert stage collapses and there is an earthquake sound. After the earthquake, a news item is presented to the participants, informing them that there is a tsunami coming and that they have to evacuate from the island by helicopter.

They will have to travel back to the helicopter themselves. They can do this by taking the car or the train. By car they can choose between a short (beach) route with a, possibly dangerous, bridge or a longer route through the mountains. A train offers a direct connection to the helicopter. See Figure 3.7 for a map of the island, including the direction where the tsunami comes from.

The short route is affected first by the tsunami and therefore people who choose the short route have to be quick. Besides that, the bridge will collapse after four participants have passed so those who are not among those four to pass the bridge might see a collapsed bridge in front of them or drive into the water. The long route does not have an unreliable obstacle but it will take more time to travel to the helicopter. The train offers a direct connection to the helicopter and it has a limited capacity. A timer, indicating the departure time of the train, is shown.

To invoke a sense of urgency during the evacuation, the weather will become severe, with heavy rain and some wind. Besides that, the expected arrival time of the tsunami is shown in a corner of the screen, also indicating the departure time of the helicopter. Those who are not on time in the helicopter will 'not survive'.

The next section discusses the first pilot experiments conducted with the version of Everscape that was developed in this section.

3.4 Pilot experiments

Since Everscape was a new virtual environment for empirical research on the effect of herding in case of an evacuation from a natural disaster, pilot experiments have been conducted. The objective of the pilot experiments is twofold:

1. The experience should be realistic and results on evacuation choice behaviour should be similar to results from literature.

A realistic experience is needed to establish the validity of Everscape. The more realistic the experience in Everscape, the more similar the behaviour is compared to the behaviour in a real life situation. Realism is aspired by the choices made concerning the Everscape scenario and invoking the emergency feeling that occurs in case of an earthquake and tsunami (see 3.3.1).

2. It should be possible to reconstruct the situation.
To maximise the added value, all relevant data to describe the situation and the behaviour of the participants has to be recorded. This makes it possible to afterwards reconstruct different situations participants were in, which is used to find out which aspects of the situation influenced the participants behaviour. To do this, data is needed over time on what happens and what people do.

3.4.1 Experimental set-up pilot experiments

The process of pilot experiments consisted of two iterations. The first iteration consisted of the first two pilot experiments conducted on January 24, 2012 at TRB. The third pilot experiment was conducted on March 14, 2012 at a Dutch conference called PLATOS and this pilot experiment is part of the second iteration.

During the pilot experiments between 15 and 40 people participated, of which more than 90% are professionals in the field of traffic and transport. These experts were visitors of the previously mentioned conferences. Participants during the TRB conference were invited beforehand through mailings and they have registered themselves on-line. The participants at the PLATOS conference were randomly selected upon arrival at the conference.

ITERATION 1: Everscape v1.0
The pilot experiments with Everscape consisted of three parts: the virtual experiment with Everscape, a questionnaire and a discussion with the participants afterwards. These parts are discussed below.

Virtual experiment with Everscape
Before the virtual experiment started, participants were given a general introduction, explaining that they were going to see a concert on an island. A helicopter would take them to the island, where an avatar was appointed to them. From this point on, they could clearly see the avatars of the other participants on the same island and they would have to take a car and drive to the concert, where they would have to wait for the others. Those who were late for the concert were 'teleported' to the concert area just before the concert started.

The participants were given headphones to make sure they were disconnected from the outside world and they were really part of the experiment. They were urged to follow the instructions on screen and act as they would do in reality. After the introduction the virtual experiments started. For a thorough explanation of the virtual experiment, see 3.3.3.

Questionnaire and discussion with the participants
To compare the results from the pilot experiments to results from literature, a questionnaire was added to focus on the choices they made during the experiment, some background information about themselves (e.g. age, gender), their experience

with natural disasters and what their opinion was about the experiment (e.g. what is good, what could be improved). The last part of the questionnaire was meant as a starter for the discussion afterwards.

The main goal of the discussions was to learn about the opinions of the professionals and also to discuss what could be improved. Useful input was received at the first two pilot experiments at TRB, therefore, Everscape version 1.0 was improved to Everscape version 1.1 for the pilot experiment at PLATOS.

ITERATION 2: Everscape v1.1
During the discussions with the participants at the TRB sessions, it became clear Everscape's realism could easily be improved by changing three aspects. Two of these were related to the news item and one was related to a message that was given on screen.

The first aspect concerns the news item, which was shown directly after the earthquake and full screen for all participants. It was decided to let the news item start later and to not show the news item full screen. This was therefore adjusted for the experiment at PLATOS. At PLATOS, people could see the news item on the screens at the concert stage.

The second aspect is related to leaving the concert area during the news item. People were not able to walk away from the concert area before the news item had ended. However, some of them wanted to leave earlier. The sound should then decrease for people who are further away from the concert stage. Since this would make the experiment more realistic, it was adjusted for the PLATOS experiment.

At the TRB sessions, there was an extra message at the exit of the concert area which told people to choose between car and train. Because this was not realistic and people said that 'it abruptly took them out of the experiment', it was removed for the experiment at PLATOS.

3.4.2 Main findings of the pilot experiments

The objectives of the pilot experiments are discussed below. Appendix A presents the extended results, synthesis and conclusions of the pilot experiments.

The experience should be realistic and results on evacuation choice behaviour should be similar to results from literature
The first requirement was that the experience should be realistic. This requirement is discussed on the basis of observed behaviour, the results of the questionnaires and the opinions of the professionals.

Compared to a standard SP survey most of the participants believe such a method for data collection adds value because they experienced the situation as realistic and they were more part of the experience itself, meaning they could easily identify with the situation.

It should be stressed that before and during the experiment the terms ‘gaming’ or ‘serious gaming’ were not used; before the experiment participants were urged to act as they would do in reality. However, one participant stated in the questionnaire that he considered the experiment as a ‘game’, which is a point of attention because this might mean that this person does not respond like he would do in reality. From the data it is assumed that 87% of the people seriously participated, because they stated their main goal was to survive by helicopter. It should be noted that there might always be people who consider the experiment as a game. Therefore, assessing the validity of the tool and the results is very important. This will be done in Chapter 6.

It should also be emphasised that the experience of such situations in a virtual environment is obviously very different from experiences of such situations in reality. What matters is whether the virtual experiment is valid (enough) to test hypotheses about the particular behavioural response of interest (in this case: go/no go and mode/route choice). Everscape must hence be considered a virtual experience SP (VESP) (Levinson et al., 2004) research method. In line with this, the questionnaire is considered to be a virtual experience RP (VERP), because it considers what people actually did and why they did this during the experiment with the VESP.

For the behavioural results to be acceptable, they are compared to those found in literature. Because the participants were mainly professionals in the field of traffic and transport, no statistically viable and reliable behavioural conclusions can be drawn with respect to what they did. Some general notes can be made with respect to the results from the data analysis and the opinions of the participants.

- With the new data collection method evacuation choice behaviour is considered, specifically in case of an earthquake and tsunami. The earthquake suddenly struck the island when the participants were at the concert. It was shown that both disaster characteristics and information presented during the news item influence people’s decision to get out of the concert area. This is consistent with results from literature (Carnegie and Deka, 2010; De Jong and Helsloot, 2010; Leach, 1994).
- Most participants indicated they first decided to get out of the concert area and along the way (e.g. while running out of the concert area, when they were at the parking area) they chose their mode/route. During the earthquake, parts of the concert stage were collapsing and around half of the people already passed the exit of the concert area. This is a logical response because the concert area clearly is unsafe. Such responses are consistent with typical flight behaviour that occurs when people experience a dangerous situation such as a natural disaster. When a person is in a dangerous situation, a chemical process activates the sympathetic nervous system to cause the known flight-or-fight response (Leach, 1994). This chemical process is also related to a sense of urgency that people feel. In case of the pilot experiments, about half of the people indicated they felt this sense of urgency.

- Most people (82%) indicated their mode/route choice was a conscious decision, which is also consistent with Leach (1994). When most of the participants made this decision (which was along the way), they had already gained awareness of what was happening, due to having experienced the earthquake and from what they saw and/or heard from the news item.
- The participants were asked what they would do next time when they are in the same situation. What they indicated resembles what they actually did during the experiment, which is consistent with existing literature. What has been described by Schönfelder and Axhausen (2010) is that when there is experience with situations, the costs (in this case for 'surviving') are more or less known. To avoid costs for potentially new information or additional acquisition of information for a new situation (e.g. because people do not know how successful other alternatives are), known alternatives are reapplied. Since most people survived, it is to be expected that they will not change their choice next time.
- Concerning the behaviour of other people, household evacuation behaviour occurred. Most of the participants participated individually but from the observations during the experiment it became clear that people who participate together might do the same thing. This is consistent with earlier research where it is stated that households evacuate as single unit (Heat et al., 2001; Murray-Tuite and Mahmassani, 2003).
- Consistent with the work from Mahmassani and Liu (1999), people are able to simultaneously interact with each other in the virtual environment. At all pilot experiments, people indicated that their behaviour was influenced by other people. A striking example is the participant at TRB who missed the earthquake and news item but just followed the other participants because for him they were all suddenly running away from the concert area. This is a typical example of herding behaviour. No disaster characteristics or information were presented to this participant but because the other participants were running away, this participant assumed this was the right thing to do and imitated the behaviour. This is consistent with results from Helbing et al. (2000).

It should be possible to reconstruct the situation

The second requirement for the data collection is that it should be possible to reconstruct the situation. With the new data collection method it is possible to log detailed information of the situation over time. The data allow for checking at every time step where people were, what the situation was and if what the participants said they did, in the questionnaire afterwards, is what they actually did.

Due to the combination of the virtual experiment and the questionnaire, it is possible to reconstruct the situation each participant was in over time, meaning it is possible to determine which factors (w.r.t. disaster characteristics, information and behaviour of other people) were available and which of these factors might be considered by each participant. Because of this, it is believed that the new data collection method forms a major contribution for modelling and prediction of evacuation choice behaviour.

3.4.3 Conclusions pilot experiments

In this section the results from three pilot experiments with Everscape were presented. The main conclusion is that Everscape allows for mimicking a more realistic situation which people are part of, making it easier for them to identify with the situation. An important characteristic of the method is that since participants are all part of the same virtual environment, they are aware of each other's existence because they can see each other and what they are doing at all times. As a result, interaction behaviour can be studied, including herding behaviour.

Compared to existing RP methods, of every individual participant a full trajectory, his path over time, is available. Besides that, for each event it is exactly known (e.g. start earthquake, start tsunami, departure time train, departure time helicopter), when it happens. This allows for determining at every time step the exact situation each participant was in. In combination with the results from the questionnaire, more detailed information is available with respect to the available factors and factors participants have considered for the choices they made. This is essential for modelling of choice behaviour. It is therefore concluded that Everscape can be used for data collection on herding behaviour in case of an evacuation from a natural disaster.

Based on this, an experimental set-up was designed for the actual data collection. This experimental set-up is presented in the next section.

3.5 Set-up of Everscape experiments with a focus on herding

Based on the results from the pilot experiments discussed in Section 3.4, the experimental set-up that was developed in Delft, focusses on herding behaviour by including different herding scenarios. This section will discuss the experimental set-up.

Before discussing the experimental set-up, how possible participants were approached and how they registered for an experiment is discussed in 3.5.1. The experimental set-up consisted of three parts: an introduction, the virtual experiment with Everscape and the questionnaire. These aspects are discussed in 3.5.2, 3.5.3 and 3.5.4. Since the focus was on herding behaviour in case of an evacuation, 3.5.5 discusses how this aspect was considered by including different herding scenarios.

3.5.1 Participants

This section describes how possible participants were recruited and how they registered for the experiments.

To draw statistical viable conclusions, a representative mix of age and gender were needed. Therefore, a thorough plan was made to recruit the participants.

Announcements were made at the website of Delft University of Technology, the website of the Faculty of Civil Engineering and Geosciences, via the news paper of Delft University of Technology (Delta), a local news paper (Delft op Zondag), a local radio station (Omroep West) and on social media (LinkedIn, Facebook and Twitter).

Information presented in the announcements stated that participants were needed to test a new type of experiment for research on travel choice behaviour. Nothing was said about natural disasters or evacuations. The announcements also stated that participants received a €25 gift cheque.

Since the experiments were conducted with Dutch people, the questionnaire was in Dutch to make sure language would not be a barrier. Therefore, participants had to speak Dutch. Because the experiment was on computers, participants had to have some computer experience as well.

People could register for the experiment on-line, where they also chose a session day and time slot.

The minimum age was set to 12. Participants younger than 18 received a letter beforehand which had to be signed by their parents or care takers. This letter stated they were allowed to participate.

Before an experiment, participants received a confirmation e-mail providing general information on the day, time and location.

Upon arrival at the experiment, participants took part in an experiment which consisted of three parts: an introduction to the experiment, the experiment with Everscape and a questionnaire. These three parts are discussed below.

3.5.2 Part 1: Introduction to experiment

When people arrived at the experiment, they were welcomed at the entrance and they received a short instruction.

Each participant sat down behind a computer. Behind each computer they found a set of documents. The first document included the participant id, which each participant had to use throughout the whole experiment. It also included a brief description which stated that the participant voluntarily participated and agreed for the researchers to use the data anonymously. It explained to the participant that he or she could stop with the experiment at any time during the experiment. Each participant had to sign this form and hand it in before the experiment started. An instruction on how to use the controls was also provided at each computer, including a headphone that they were supposed to use during the virtual experiment.

When all participants had handed-in their signed form, the experiment started. First, an introduction (or briefing) was given to the participants, explaining them that they would take part in a new type of experiment which was split in a virtual part and a questionnaire (both parts are explained below). For the full text that was given to the participants during the introduction, see Appendix B.

In the virtual part they would visit an island to see a concert. They would arrive on the island by helicopter and had to drive to the concert by car. A short demonstration was given on the arrival at the island and how people could control the avatar and car.

After the demonstration was given, the actual experiment started.

3.5.3 Part 2: Experiment with Everscape

At the start of the virtual experiment, people were urged to put on their headphones, otherwise they would miss the concert. The virtual experiment was the same as explained in 3.4.1.

During the virtual experiment, one person was managing the experiment. This was the same person who gave the introduction as explained in the previous section. There was one person sitting behind the main computer, checking whether all participants were at the island, able to control the avatar, able to drive to the concert and to check if all went well. This person would start the earthquake after a signal given by the person who was managing the experiment. There were two extra people walking around to help people get started and help participants who were experiencing problems.

During the experiments it became clear a maximum number of participants had to be set otherwise Everscape could not work properly. This maximum number was set to 38. Since many more people registered for the experiments, it was decided to split all experiments and conduct double the amount of originally planned experiments.

This resulted in giving a general introduction to all participants, then splitting the group in two smaller groups. The first group started with the virtual experiment. The second group had to wait outside of the room (while enjoying a cup of coffee or tea). After the first group had started the questionnaire (which in total was between 5 and 10 minutes later), the second group entered the room again and started the virtual experiment. Since the first group was still busy with the second part of the experiment when the first group entered the room, no exchange of information was possible.

3.5.4 Part 3: Questionnaire

After the virtual experiment, all participants filled in a questionnaire. Like with the pilot experiments, the questionnaire included questions concerning socio-economic characteristics (e.g. age, gender, education level, type of work or whether they were still in school) of the participants but also questions concerning the virtual experiment (e.g. what they did and why, possible stress levels they experienced and contact with other participants during the virtual experiment). Participants were also asked about their real life experiences with natural disasters and evacuations from natural disasters.

3.5.5 Herding scenarios

Since the focus of the experiments was on herding behaviour in case of an evacuation, four different scenarios were designed to find out how the behaviour of other people influences evacuation choice behaviour. The scenarios involved extra participants who were familiar with the experiment and had the task to leave (or not leave), take a car or take the train at a certain time. These extra participants are called spooks. This sub section will describe the herding scenarios.

The focus of the herding scenarios was to find out how the behaviour of other people influences departure choice, so the decision to stay or leave. The focus was set on departure choice because in Everscape, at the moment of departure from the concert area participants would be able to see most of the other participants and their actions. After leaving the concert area, the participants were more spread out over the island and thus less likely to see other participants and their actions.

The herding scenarios were created with the following aspects kept in mind:

1. The effect of herding on departure choice.
2. The effect of herding with and without a feeling of emergency. This was possible by making people leave before and after the start of the earthquake.
3. If and how the effect of herding can lead to ineffective behaviour as an extra check to find out whether people were really following or just accidentally leaving right after each other.

Table 3.3 provides an overview of the herding scenarios with spooks. The column to the right shows to which from the above presented aspects the scenario is related.

Scenario A was the reference scenario and did not involve extra participants with a spook instruction. Scenarios B, C and D were the scenarios with the spooks.

In Scenario B the spooks were instructed to leave the concert area before the earthquake started. Then, they had to go back to the concert area during the earthquake

Table 3.3: Herding scenarios

	Spook instruction [name of scenario]	**Related to aspect 1, 2 and/or 3**
A	No spooks [no spooks]	Reference scenario
B	Leave the concert area before the earthquake, go back during the earthquake, leave during the news and take the train (in short, follow participant01) [leave return leave]	1, 2, 3
C	As soon as you notice the earthquake, leave the concert area and take the car (route you can choose yourself) [leave continue]	1
D	Stay at the concert area [stay]	1, 3

and leave the concert area again during the news item to take the train. This scenario was included to have a scenario where people were leaving without being confronted with disaster characteristics. The turning around behaviour was included to confuse the real participants. Since this instruction was quite complicated, they also received the instruction to stick together as a group and follow Participant01. Sticking together as a group was also included in the instruction to make sure their behaviour would be more obvious and therefore seen. To make sure they were seen by the others, they had to gather near the concert stage at the spook area, see Figure 3.11. This would mean that most of the participants, who were the visitors of the concert, would see them running away. In the instruction e-mail, the spooks received a map of the island and Figures 3.11 and 3.12.

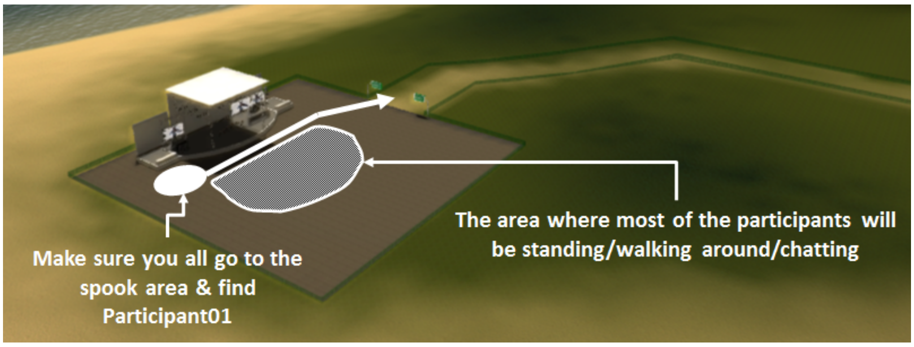

Figure 3.11: Spook instruction Scenario B

With Scenario C the participants had to leave the concert area as soon as they noticed the earthquake. They were also instructed to take a car. The route they could choose themselves.

With Scenario D, the spooks had to stay at the concert area. This meant they would ‘not survive’.

All spooks were asked to make sure the real participants would see what they were doing. Besides that, they were not allowed to talk about their behaviour and

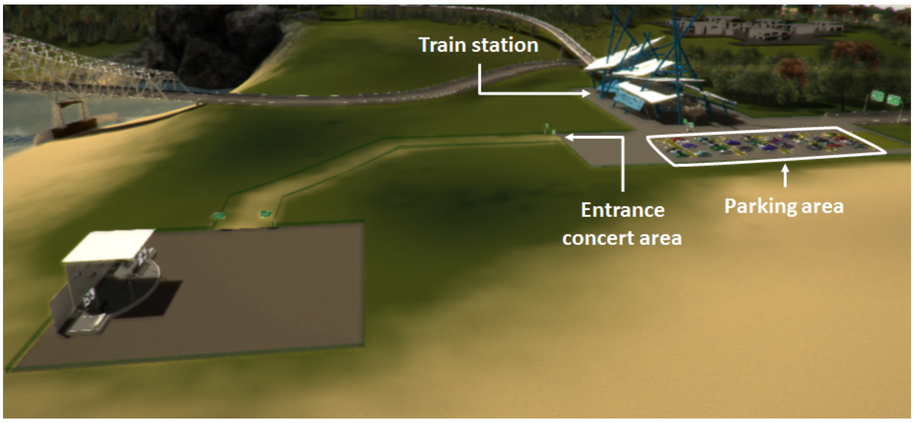

Figure 3.12: Spook explanation of parking and train station area

instructions in the chat and they had to act as normal participants (e.g. arrive at the experiment together with the participants, sign their form).

3.5.6 Available data and observable characteristics

Before discussing the conclusions of this chapter in Section 3.6, this section shortly shows which data are available after each experiment. An overview of the observable characteristics, including their links to Chapter 2, is also presented.

Available data
After each experiment there are two datasets. The first dataset includes data from the virtual experiment with Everscape. The second dataset includes data from the questionnaire.

Like with the pilot experiments, the behaviour of each participant was closely monitored during the virtual experiment: the data were collected at a 1.0 [s] time and at a 0.1 [m] position resolution along with viewing directions (resolution of 1°). Furthermore, the following data from the events that occurred were logged:

- starting time of the earthquake,
- timing of the tsunami,
- departure time of the train,
- departure time of the helicopter and
- when a participant got in / out of a car, the train or the helicopter.

The questionnaire was made with Google Docs[1], which resulted in an online dataset with the answers sorted per participant. Since each participant received a participant

[1] docs.google.com

id, which they had to fill in before the virtual experiment and at the start of the questionnaire, both datasets were easily combined.

Observable characteristics

Based on the conceptual framework presented in Chapter 2 and the experimental set-up presented in this chapter, Table 3.4 presents an overview of the observable characteristics that are used for the data analysis.

Table 3.4: Overview of observable characteristics

	Characteristic	**Explanation**	**Results from**
1	Departure, mode, route and destination choice.	These travel choices are important in case of an evacuation, see sub section 2.2.1.	Everscape
2	Socio-economic characteristics: age and gender.	From literature it is known that age and gender might influence evacuation decisions, see sub section 2.4.2. They are considered in this research to find out if the results are consistent with literature.	Questionnaire
3	Information via news item.	In sub section 2.4.1, research was presented on the effect of information and instructions. This aspect is included to find out if the results are consistent with literature.	Everscape
4	Stress experienced before and due to the disaster.	To find out if typical human behaviour occurs during the experiments, as is the case in emergency conditions, see sub section 2.4.4, the effect of stress experienced during the experiments is considered.	Questionnaire
5	Computer and gaming experience.	These aspects are added to find out if they influence the behaviour of the participants and find out if they cause a bias.	Questionnaire
6	Per participant, at every time step his location and viewing direction are known.	Herding is defined by Ariely (2008) as seeing other people doing something (e.g. leaving) and believing that what they are doing is a good alternative, resulting in doing the same thing. Two options are considered. The first is to find out if and how herding can be influenced by different scenarios. The second is to quantify the effect of herding with seeing other people's actions. For a detailed description of the herding data, see Section 5.1.	Everscape

The first group of characteristics are the actual choices that are made in case of an evacuation from a disaster. From Everscape it is known (if and) when a participant departed from the concert area. From this, it is possible to derive when someone started to leave (see Chapter 5 how this is done). Mode (car, train, walking) and route (e.g. short beach route, long route via mountains) also result from Everscape. With respect to destination choice, the data from Everscape show if people went to the helicopter or the top of the mountains or any other place on the island (or even the see).

The second, third and fourth group of characteristics concern the socio-economic characteristics (age and gender), information via the news item and stress experienced during the experiment. These three groups of aspects result from the questionnaire and are considered to find out if they are consistent with results from literature.

The fifth group of characteristics, computer and gaming experience, also result from the questionnaire and are considered to find out if they cause a bias in the behaviour of the participants in the experiments.

The sixth and final group of characteristics concerns the herding behaviour and result from Everscape. Two options are included. The first is herding via scenarios (this is known from the experimental set-up) and the second is herding via seeing the actions of other people. However, this needs to be derived from the Everscape data (see Chapter 5 how this is done). This is possible because of every participant, at every time step, his location and viewing direction is known.

3.6 Conclusions

In Chapters 1 and 2, the focus of this research was set on quantifying herding behaviour in case of an evacuation from a natural disaster. This chapter first determined the requirements for developing an experimental set-up to quantify this behaviour. Then, the development of the experimental set-up was discussed.

The experimental set-up consists of three parts: an introduction to the experiment, a virtual experiment with Everscape and a questionnaire. The introduction to the experiment starts at the moment participants arrive at the experiment and lasts until they start the virtual experiment with Everscape.

The full introduction is kept the same during all experiments that are conducted to make sure this will not cause differences in results. During the virtual experiment with Everscape participants will visit an island to see a concert. During the concert an earthquake affects the island and participants have to evacuate the island because a tsunami is coming their way. After the virtual experiment with Everscape, participants fill in a questionnaire including questions concerning e.g. their age and gender but also what they did during the virtual experiment and why.

The presented experimental set-up in 3.5 is used for the main data collection for this research. The descriptive analysis of this data collection will be presented in the next chapter. After that, Chapter 5, focusses on estimated choice models to quantify herding behaviour. Since it is unclear how well the actual behaviour in the virtual environment Everscape resembles the behaviour in reality, the validity of the experimental set-up (and specifically the tool Everscape) is critically assessed in Chapter 6.

Chapter 4

Descriptive data analysis of Everscape experiments

Chapter 3 presented the development of the experimental set-up for the data collection to quantify herding in case of a natural disaster. In total, 14 experiments were conducted with this experimental set-up. Before quantifying herding with the data from the experiments in Chapter 5, this chapter will present and discuss the descriptive data analysis of the Everscape experiments.

This analysis is needed to explore which behaviour supports results from literature, hence supports the conceptual framework presented in Chapter 2. The results will also be used as a starter for quantifying herding in Chapter 5.

To discuss the results in a structured way, Section 4.1 first presents an overview of the experiments. The characteristics of the participants are shown in Section 4.2. Based on the analysis in Sections 4.1 and 4.2, the approach for the rest of this chapter is determined and further explained in Section 4.3.

The travel choices made by the participants in the experiments are considered. Section 4.4 shows the results with respect to the decision to evacuate. The results on mode and route choice are presented in Section 4.5. Insights from the questionnaire on what participants said they did during the virtual experiment with Everscape are discussed in Section 4.6 to consider how the participant's mindset was. The conclusions of this chapter are presented in Section 4.7.

4.1 Overview experiments and number of participants

Before discussing the results, this section introduces the Everscape experiments that were conducted with the set-up that was developed in Chapter 3. This will be done by presenting an overview of the conducted experiments to gain an idea of how many experiments were conducted, which scenarios were tested and how many participants took part in the experiments. To get an idea of the type of participants, they are presented in Section 4.2.

A general overview of the experiments is presented in Table 4.1. In total, 14 experiments were conducted. Experiments I, II and IV were different from the rest in population and experience level of the participants. Experiments I and II were conducted with students only[1], the rest of the experiments were organised and conducted with a mixed population. Most of the participants from experiment III did an extra run, resulting in experiment number IV. The second column presents the adjusted experiment number that will be used throughout the analysis. It includes an (a) and (b) for experiments III and IV.

Table 4.1: Overview experiments

Exp. nr.	**Exp.**	**Date**	**Scenario type**	**Number of participants**	**Number of spooks**
I[a]	1	21-11-2013	A (no spooks)	37	0
II[a]	2	28-11-2013	C (leave continue)	31	7
III	3a	01-02-2014	A (no spooks)	33	0
IV[b]	3b	01-02-2014	A (no spooks)	27	0
V	4	08-02-2014	C (leave continue)	18	4
VI	5	08-02-2014	C (leave continue)	19	7
VII	6	08-02-2014	D (stay)	21	4
VIII	7	08-02-2014	D (stay)	22	5
IX	8	11-02-2014	B (leave return leave)	31	4
X	9	11-02-2014	B (leave return leave)	29	7
XI	10	12-02-2014	A (no spooks)	27	0
XII	11	12-02-2014	A (no spooks)	29	0
XIII	12	18-02-2014	B (leave return leave)	25	6
XIV	13	18-02-2014	B (leave return leave)	29	5
				378	**49**

[a] Experiment conducted with students only.
[b] Most of the same participants of experiment 3 did a second run.

To make sure the experience level is consistent over all participants, the focus is on those experiments involving participants with no experience. Therefore, experiment

[1]The first two experiments were conducted with students only to find out whether the experimental set-up worked. When this was the case, the actual experiments were organised with a mixed population. Since the student experiments went well, the data are also used in the analysis.

3b will not be considered in this chapter. Differences in results between experiments 3a and 3b will be considered in Chapter 6 when discussing the validity of the results. This chapter will focus on the results of experiments 1, 2, 3a, 4, 5, 6, 7, 8, 9, 10, 11, 12 and 13.

Columns 3 and 4 in Table 4.1 show when each experiment was conducted and which scenario was conducted. The student experiments (1 and 2) were conducted in November 2013. The other experiments in Februari 2014. Scenario A [no spooks], the base case, was conducted five times, Scenario B [leave return leave] four times, Scenario C [leave continue] three times and Scenario D [stay] was conducted twice[2]. The names of the scenarios are shown between brackets, for an overview of the herding scenarios see Table 3.3. Columns 5 and 6 in Table 4.1 show how many participants and how many spooks participated per experiment. It should be noted that the spooks themselves are not considered in the analysis; only the actual participants.

Before discussing what the participants did during the experiments, Section 4.2 will focus on the population that participated in the experiments to get an idea of the type of people and some of their experiences with the experiments.

4.2 Participants in the Everscape experiments

This section will focus on three aspects: how **age and gender** were represented among the participants (see 4.2.1), how much **stress** they experienced during the experiments (see 4.2.2) and how much **computer and gaming experience** participants have (see 4.2.3).

Age and gender are considered to find out how age and gender are represented among the participants. Stress, computer and gaming experience are considered to get a first idea on these aspects because they are expected to influence the results that are discussed later on in this chapter and in Chapter 5. Based on the analysis in the previous section and in this section, the approach for the rest of this chapter is determined and further explained in Section 4.3.

4.2.1 Age and gender of the participants

As discussed in Chapter 3, the goal was to make sure a more representative sample of the population would participate in the actual experiments compared to the pilot experiments where only experts participated. Because of the focus on herding, it was decided that it was more important to have as many participants as possible than having a representative population.

[2]The number of times the different scenarios were conducted differs due to a technical issue of limiting the number of participants per group and splitting up the groups into smaller groups. Since some timeslots were easier to fill, these groups were bigger and had to be split.

This sub section will show how age and gender were represented among the participants. Results on these aspects are also available from literature, see Chapter 2, making the results later on in this chapter and in Chapter 5 comparable. This sub section first presents the age of the participants, followed by gender.

Table 4.2 presents the averages and standard deviations of age for the student experiments (1 and 2), the other experiments (3a, 4 until 13) and all these experiments together.

Table 4.2: Age of the participants

Experiments	**Average**	**St. dev.**	**Youngest**	**Oldest**
Experiment 1 & 2 (only students)	21,56	2,24	17	29
Experiment 3a, 4 - 13	33,88	17,67	12	78
All experiments	31,49	16,72	12	78

The youngest participants were 12 years old. There were 12 of them. There was one participant of 78 years old.

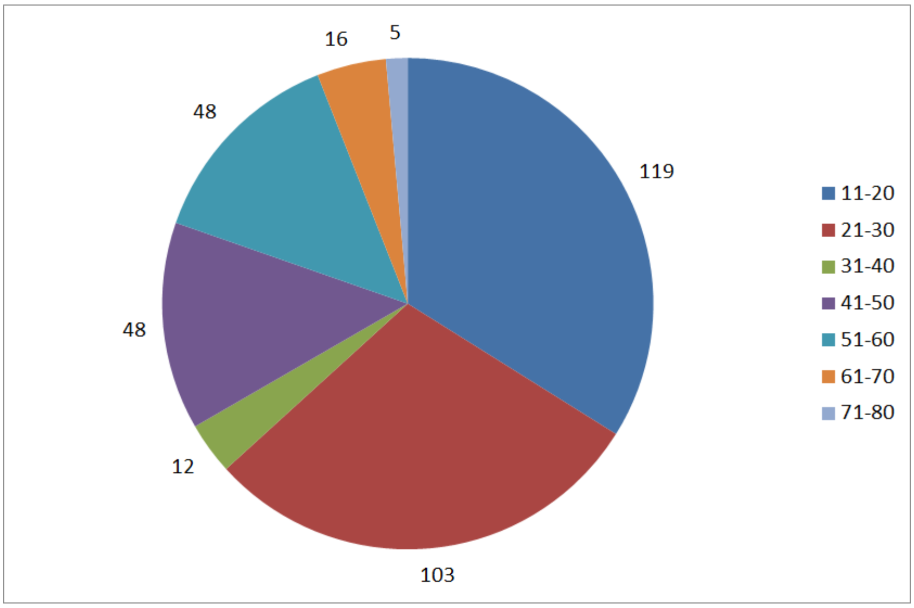

Figure 4.1: Age of the particpants

Figure 4.1 shows a pie chart of the age of the participants per 10 years. The numbers in the figure indicate the number of participants within the age group. Most of the participants were at most 30 years of age. People within their fourties and fifties were equally represented with 48 participants. People between 30 and 40, between 60 and 70 and between 70 and 80 were much less represented among the participants; 12, 16 and 5 participants respectively.

It is concluded that the average age of the participants is relatively low but considering the representation of the different age groups, people within their forties and fifties

Table 4.3: Gender of the participants

Experiments	Male	Female
Experiment 1 & 2 (only students)	36 (52,9%)	32 (47,1%)
Experiment 3a - 8b	160 (51,6%)	150 (48,4%)
All	196 (51,9%)	182 (48,1%)

were also reasonably represented. For the other age groups (31-40, 61-70 and 71-80) there were less participants.

With respect to gender, Table 4.3 shows how many men and women participated in the student experiments (1 and 2), the other experiments (3a, 4 until 13) and all these experiments together. As can be seen in the table, the shares of men and women are nearly 50% over all experiments.

4.2.2 Stress experienced by the participants

Literature states that, in case of a natural disaster, stress influences people's behaviour such that it becomes more impulsive than rational, which means that especially things that happen in people's direct surroundings influence their choice behaviour, see Section 2.4.2. The stress levels participants experienced are considered to be a useful indication for realism of the experiment.

To gain insight into the stress levels participants experienced, this section discusses results from the questionnaire where participants stated how much stress they experienced before the disaster and due to (or during) the disaster. Participants could indicate this on a scale of 1 (no stress) to 10 (very much stress). Table 4.4 presents the averages and standard deviations.

Table 4.4: Stress levels experienced by the participants

	Before the disaster	Due to the disaster
Average	2,05	5,42
St. dev.	1,57	2,53
Minimum	1	1
Maximum	9	10

Participants experienced on average very little stress before the disaster. Those who experienced a little more stress before the disaster (i.e. level 4 and higher) might have experienced this because of the situation they were in. They were taking part in an experiment on a computer with a group of participants who they did not know. For some participants this whole situation might have caused some stress (or excitement), which was also visible in the room: they showed eager behaviour already at the start of the experiment, they were sitting on the edge of their seat or they were very concentrated, almost as if they were sitting inside their computer.

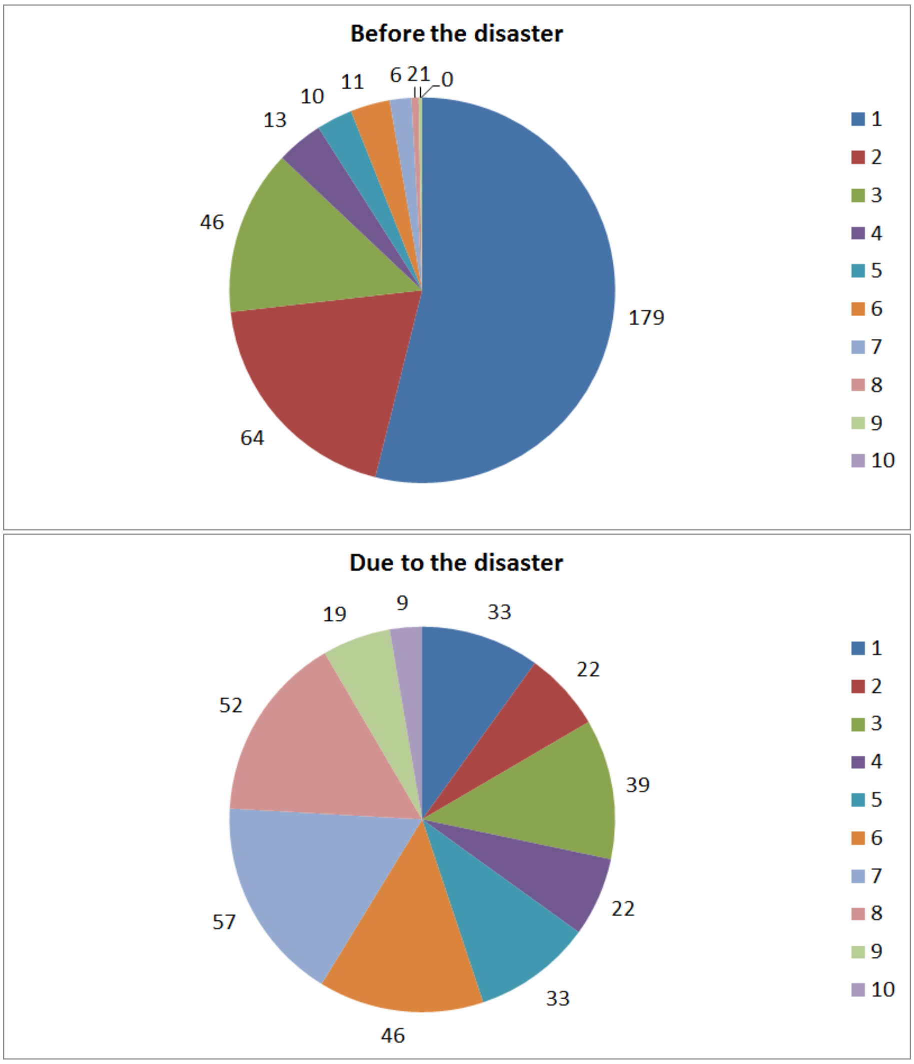

Figure 4.2: Stress levels experienced by the participants

The stress level participants experienced due to the disaster was much higher and there was more variance in the stress level they experienced due to the disaster. This is also shown in Figure 4.2. Experiencing more stress due to the disaster is logical because in real life people also experience more stress when a disaster occurs (see 2.4.2). More variance in stress due to the disaster also makes sense because different people react differently to stress and also experience stress in a different way based on for example their experiences.

Concluding, with respect to realism of the experiment, evidence is provided that participants stated they experienced more stress due to the disaster than before the disaster. If this actually is due to the disaster or due to different triggers that were added to influence the emergency feeling (see 3.3.1) or due to the task they were executing remains unknown. Because participants were asked about the stress they experienced due to the disaster, this is how it is called in this thesis.

4.2.3 Computer and gaming experience of the participants

Since the experiment was conducted with a virtual environment on a computer, it was expected that computer and/or gaming experience influence(s) what participants did, hence there might be a bias. Computer and gaming experience of the participants are considered in this sub section. Participants indicated their level of experience in the questionnaire.

One requirement to participate was that participants would have at least some computer experience. Table 4.5 shows the levels of computer experience.

Table 4.5: Computer experience of the participants

	Number	**Percentage**
Daily	313	89,2%
Weekly	16	4,6%
Monthly	2	0,6%
Unknown	20	5,7%
Total	**351**	**100%**

Most of the participants use computers on a daily basis. A small share of the participants uses computers on a weekly basis and only 2 participants use computers on a monthly basis. Of 20 participants their computer experience is unknown due to technical problems with uploading the questionnaire.

Since most of the participants use computers on a daily basis, no conclusions can be drawn on the effect of computer experience on the participant's actions. Participants with 'unknown' computer experience have been considered throughout the analysis to find out whether they experienced any computer problems or acted considerably different from the other participants but that was not the case.

Compared to computer experience, there were much more differences in gaming experience, see Figure 4.3. Almost half of the participants plays computer games on a regular basis (daily, weekly, monthly). Around one third of the participants has no gaming experience or tried it only once. De rest plays computer games less than once a month. Together with gaming experience levels of 'never' and 'tried it but not my cup of tea' these participants are considered to be part of the little or no gaming experience group. Based on this division, around half of the participants are considered to be (quite) experienced gamers.

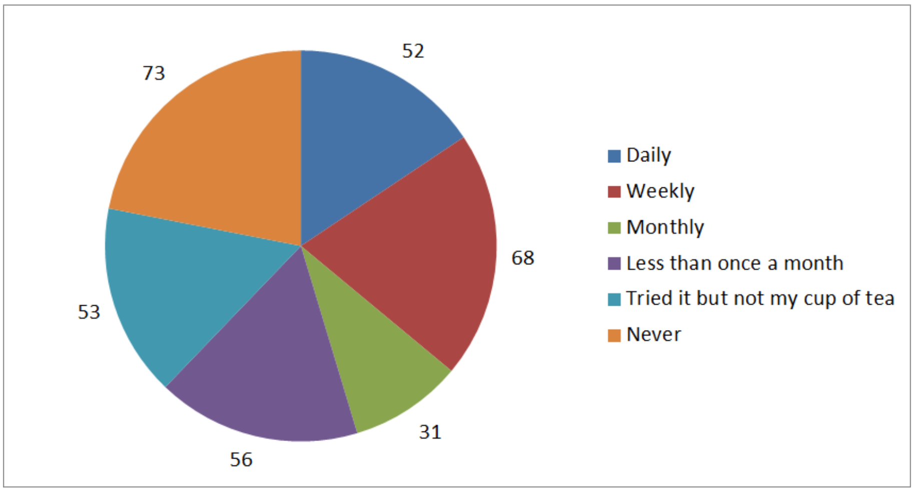

Figure 4.3: Gaming experience of the participants

Concluding, since most of the participants use computers on a daily basis, the effect of computer experience will not be considered in the rest of the analysis. Gaming experience will be considered because there were differences and it might be expected that participants with more gaming experience acted differently from participants with limited or no gaming experience. It should be noted that in the questionnaire, participants were asked how much gaming experience they have and not what type of gaming experience they have (e.g. card games or games where they would be walking around with an avatar). To find out whether gaming experience influenced the results, two aspects in relation to gaming experience are shown below: gaming experience and age, gaming experience and stress.

Gaming experience and age

It is expected that younger people play computer games more often, which might have caused differences in what younger and older participants did. The relation between age and gaming experience is shown in Figure 4.4. The figure suggests that younger participants play computer games more often. Most of the age groups have participants in all gaming experience levels, except for the age groups with relatively few participants, so the groups of 31-40 and 71-80.

An ANOVA test was performed to find out whether these differences were statistically significant. The ANOVA test resulted in a significance level of 0.000, which is below 0.05. Therefore, there is a statistically significant difference in the mean

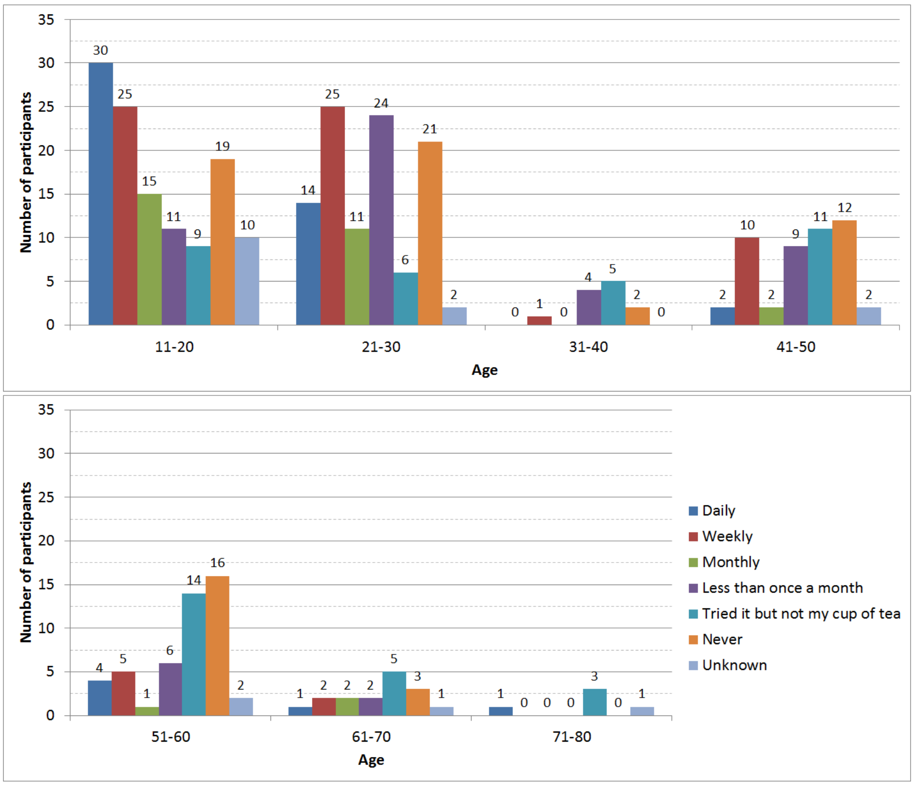

Figure 4.4: Relation between gaming experience and age

which confirms that younger participants have more gaming experience. Correlations between gaming experience and age have separately been checked as well and confirmed that they exist at a significance level of 0.01, which means that gaming experience and age are highly correlated.

Gaming experience and stress

Since it is expected that gaming experience influences what participants did, it is also expected that gaming experience influences the stress levels experienced by the participants. It is expected that participants with more gaming experience, experienced lower stress levels.

*Table 4.6: Relation between stress levels **before** the disaster and gaming experience*

	Daily	**Weekly**	**Monthly**	**Less than once a month**	**Tried it but not my cup of tea**	**Never**
Average	1,69	1,62	2,10	2,07	2,91	2,04
St. dev.	1,36	1,06	1,15	1,57	2,14	1,42
Minimum	1	1	1	1	1	1
Maximum	8	7	6	7	9	6

Table 4.6 shows that the experienced stress levels are the lowest for participants with a ‘daily’ and a ‘weekly’ gaming experience level. The highest stress level is found for

*Table 4.7: Relation between stress levels **due to** the disaster and gaming experience*

	Daily	**Weekly**	**Monthly**	**Less than once a month**	**Tried it but not my cup of tea**	**Never**
Average	4,39	5,09	6,10	5,34	5,83	5,92
St. dev.	2,80	2,36	2,60	2,40	2,37	2,49
Minimum	1	1	1	1	1	1
Maximum	10	10	10	10	10	10

participants who have tried computer games but considered it to be 'not their cup of tea'.

The experienced stress levels due to the disaster, see Table 4.7, are lowest for participants with 'daily' gaming experience. It is considerably higher for those who play computer games less than 'weekly'.

ANOVA tests have been performed to find out whether there are statistically significant differences for gaming experience and stress experienced before the disaster and due to the disaster. The differences in stress before and due to the disaster were also checked.

With respect to gaming experience and stress before and due to the disaster, the ANOVA test resulted in significance levels of 0.000 and 0.006, which are below 0.05. For gaming experience and the difference in stress before and due to the disaster, the ANOVA test resulted in a significance level of 0.056 which is close to 0.05.

Based on the ANOVA results it is concluded that there is a statistically significant difference in the mean which confirms that gaming experience influenced stress that the participants experienced before and due to the disaster. Correlations between gaming experience and stress have also been separately checked and they exist at a significance level of 0.01. This means that gaming experience and stress are highly correlated.

It is expected that the results on gaming experience influenced the actions of the participants during the experiments. For now, no conclusions with respect to these aspects are drawn. During the rest of the analysis, these aspects are kept in mind when differences occur in what participants did. For example, when participants with more gaming experience and lower stress levels evacuated from the concert area much earlier than participants with less or no gaming experience and higher experienced stress levels. Gaming experience versus age and gaming experience versus stress will then be used to possibly clarify differences in what participants did or indicate the involvement of the participants in the Everscape experiments.

4.3 Approach for descriptive data analysis

To discuss the descriptive analysis in a structured way, the aspects considered in this section are also used as a guideline throughout the whole chapter. The conceptual framework of Chapter 2 is used as a basis, see Figure 4.5 for the main elements of the framework.

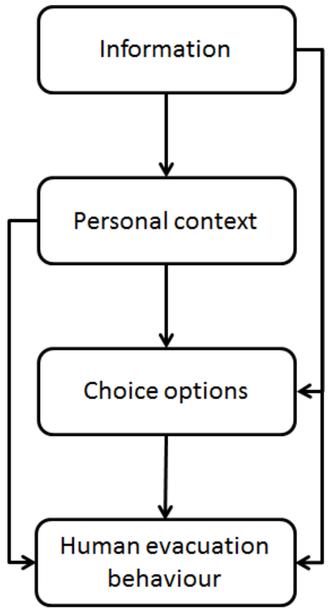

Figure 4.5: Main elements evacuation behaviour

All aspects that will be discussed are expected to influence human evacuation behaviour, hence they support or do not support the **conceptual framework** that was presented in Chapter 2. Aspects related to information and personal context will be considered. The first aspect involves the relation between personal context, the socio-economic characteristics age and gender, but also information participants received via the news item.

The second aspect relates to **realism of the experience** in the Everscape experiments, which is important for the validity discussion in Chapter 6. In reality, people experience stress when a natural disaster occurs. Stress that participants experienced during the experiments is considered. Gaming experience is also considered because it is expected that participants with more gaming experience have acted differently and experienced less stress. It is important to consider what participants said about their own actions in the questionnaire because this could imply their mindset and how seriously they participated (or whether they were considering the experiment as a game).

The last aspect is meant as a starter for **quantifying herding**. Chapter 5 will discuss herding more into detail but this chapter will already consider the effect of herding scenarios.

Sections 4.4 and 4.5 consider the travel choices of the participants. This involves the relation between the travel choices the participants made and their age, gender and information they received via the news item. Also discussed are stress levels that participants experienced before and due to the disaster and their gaming experience, all in relation to their travel choices. The final aspect in relation to the travel choices that is discussed is the effect of herding scenarios.

What participants said about their own actions (e.g. what they did, why they did this, what their goal was) is discussed in Section 4.6 to find out what the mindset of the participants was. Each of the sections will start with explaining its relevance before actually discussing the results. The conclusions of this chapter are presented in Section 4.7.

4.4 Departure choice analysis

The previous two sections presented an overview of the experiments and characteristics of the participants. This section and Section 4.5 will discuss the travel choices the participants made during the experiments. In this section the results on departure choice analysis, leaving the concert area, are presented and discussed.

Chapter 2 discussed typical human evacuation behaviour before, during and after a disaster. Leach (1994) distinguishes between the pre-impact phase, the impact phase, the recoil phase and the rescue phase and explained that these phases can be perceived by all individuals. To discuss the results in a structured way, the results are related to different phases that occurred during the experiments. Not all of Leach's phases were part of the Everscape scenario.

The impact phase is the phase where the actual disaster occurs. In Everscape, two moments can be considered as impact phase: the earthquake and the tsunami reaching the island. The pre-impact phase is the phase during which people can still evacuate safely, which in Everscape is until the tsunami reaches the island. The tsunami is the actual disaster participants needed to evacuate from and is considered as the impact phase.

In Everscape, the pre-impact phase consists of the time before and during the earthquake, the time between the earthquake and news item and the time during the news item. Even some time after the news item is part of this phase because there is still time available until the tsunami reaches the island.

An extra phase, the 'no disaster' phase is added. This is the phase before the earthquake. During this phase there are no signs of a possible disaster that might occur. It is included in the analysis because it gives the opportunity to consider herding without a disaster.

In short, the experiment is divided in the following phases:

- before the earthquake (in short, before EQ),
- during the earthquake (in short, during EQ),
- between the earthquake and news item (in short, between EQ&NI),
- during the news item (in short, during NI) and
- after the news item (in short, after NI), which at the end of the experiment becomes the actual impact phase.

This division is related to possible triggers over time that are part of the Everscape scenario. Before considering the relation between departure choice and other aspects, Table 4.8 shows a general overview of the departures of the participants.

In total, 14 experiments have been conducted, with on average 27 participants per experiment. There were 351 participants and 384 departures in total. Of the participants, 318 left the concert area once and 33 left the concert area twice, meaning they returned in the meantime. Since in one of the herding scenarios the spooks left twice, participants who left twice will be considered in sub section 4.4.5.

Table 4.8: Departure choice (excl. experiment 3b)

Number of experiments	13
Average number of participants per experiment	27
Number of participants in total	351
Number of departures	384
Number of participants departing once	318
Number of participants departing twice	33

Figure 4.6 shows the departures over time per experiment. The duration of the phases in Everscape was exactly the same for all experiments. The data has been processed such that for all experiments time on the horizontal axis is the same. The earthquake started at 80s, it ended at 125s, the news item started at 130s and ended at 172s. Most of the departures were during the earthquake (154) and during the news item (203), which makes sense because the earthquake and news item were the main triggers to influence the participants. With respect to the departures during the earthquake, there seems to be a reaction time before the participants started to leave because most of them left after the earthquake was going on for a while (about 15 seconds).

In total for all experiments, some of the participants (11) left before the earthquake, between the earthquake and news item (3) and after the news item (13). The time for participants to leave between the earthquake and news item was very short. That was probably why only three of them were able to leave within that time frame. For participants who left before the earthquake, it is unknown why they left this early but maybe they did not like the concert or had a feeling something was going to happen.

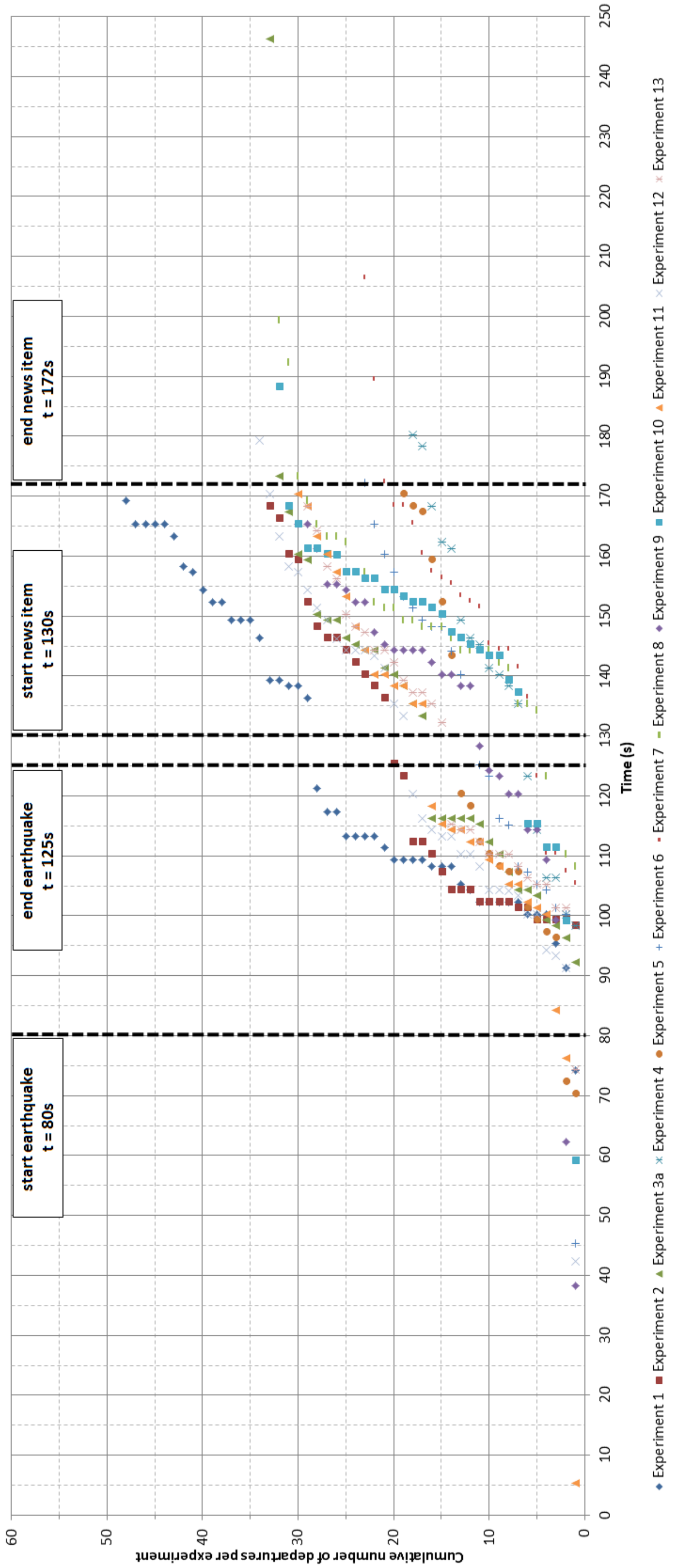

Figure 4.6: Cumulative number of departures over time per experiment

Other reasons might have been that they just wanted to know what would happen or they had some prior knowledge. Reasons for participants to leave after the news item are also unknown but this might have been because they were confused about the situation, they first wanted to have as much information as possible or they had some problems with controlling the avatar. One other possibility might have been because they had prior knowledge and wanted to find out what would happen. Note that one of the requirements to participate was that participants could only take part in one experiment. Some participants might have accidentally slipped through the selection process.

To know more about their actual prior knowledge, they were asked about this knowledge in the questionnaire. There were three questions in the questionnaire asking about their prior knowledge: did you know that an earthquake was going to happen, did you know you had to evacuate and did you see this version or an earlier version of Everscape? Table 4.9 shows the answers. There were 15 participants who knew that there was going to be an earthquake, 20 participants knew they had to evacuate and 10 participants had seen an earlier version. Of 18 participants, the answers are unknown because of technical problems when uploading the questionnaire.

Table 4.9: Prior knowledge of the participants

I...	**Yes**	**No**	**Unknown**
knew an earthquake was going to happen	15 (4,3%)	318 (90,6%)	18 (5,1%)
knew I had to evacuate	20 (5,7%)	313 (89,2%)	18 (5,1%)
have seen a version of Everscape before	10 (2,8%)	323 (92,0%)	18 (5,1%)

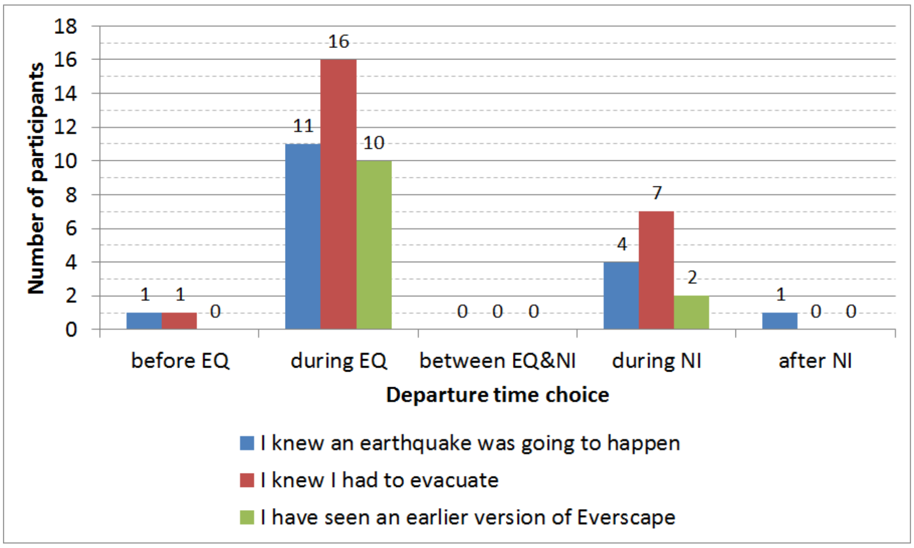

Figure 4.7: Departures per phase for participants with prior knowledge

Figure 4.7 shows the departures per phase for the participants with prior knowledge. Most of the participants with prior knowledge left during the earthquake. Two participants even left before the earthquake. Those who had seen an earlier version seemed to have waited until the earthquake struck the island.

These are the general results for departure choice. Below, the results are presented and discussed on how departure choice in the Everscape experiments might have been influenced by or is related to other characteristics. As explained in 4.3, three aspects will be considered: the relation with socio-economic characteristics, realism of the experiment and the effect of herding scenarios.

4.4.1 Departure choice and socio-economic characteristics

This sub section discusses how age and gender of the participants are related to departure choice. This is done to find out whether the results support the conceptual framework presented in Chapter 2, see Figure 4.8 for the part of the framework that includes the personal context. As can be seen in the figure, the socio-economic characteristics age and gender are part of the personal context that belong to one person.

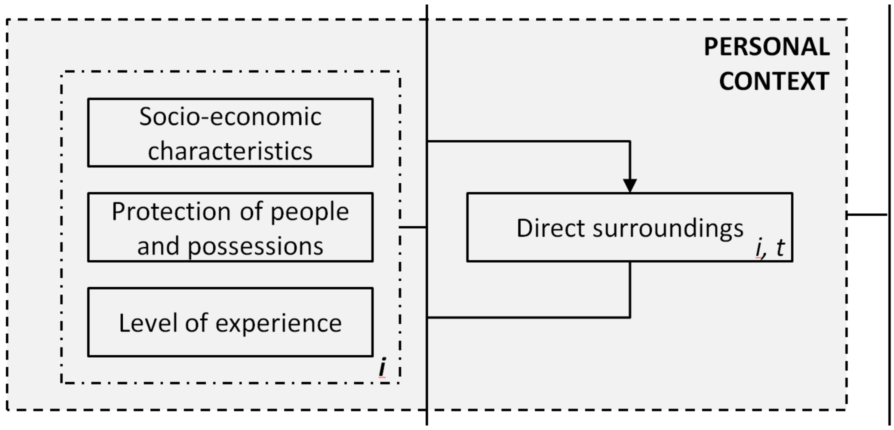

Figure 4.8: Conceptual framework - personal context

Age of the participants
What can be seen in Table 4.10 and Figure 4.9 is that until the age of 71, most of the participants left during the news item. Compared to the age-groups 41-50 and 51-60, the age-groups of 11-20 and 21-30 have a higher share of participants who already left during the earthquake. This is supported by literature where younger people are inclined to leave earlier than older people, see 2.4.2.

A $\tilde{\chi}^2$ test was performed to find out whether there is a statistically significant difference. Since the significance level of this test was 0.001, it is concluded that there is a statistically significant association between age and departure choice, meaning age influenced departure choice.

Gender of the participants
It was shown in 2.4.2 that women are inclined to leave earlier than men. The Everscape results shown in Figure 4.10 do not confirm this effect. The results for men and women are similar.

Table 4.10: Departure choice and age

	11-20	21-30	31-40	41-50	51-60	61-70	71-80	Total
Before earthquake	4	5	1	1	0	0	0	**11**
During earthquake	65	51	5	11	15	5	2	**154**
Between earthquake and news	0	2	0	1	0	0	0	**3**
During news	69	58	5	32	29	9	1	**203**
After news	1	0	1	3	4	2	2	**13**
Total	**139**	**116**	**12**	**48**	**48**	**16**	**5**	**384**

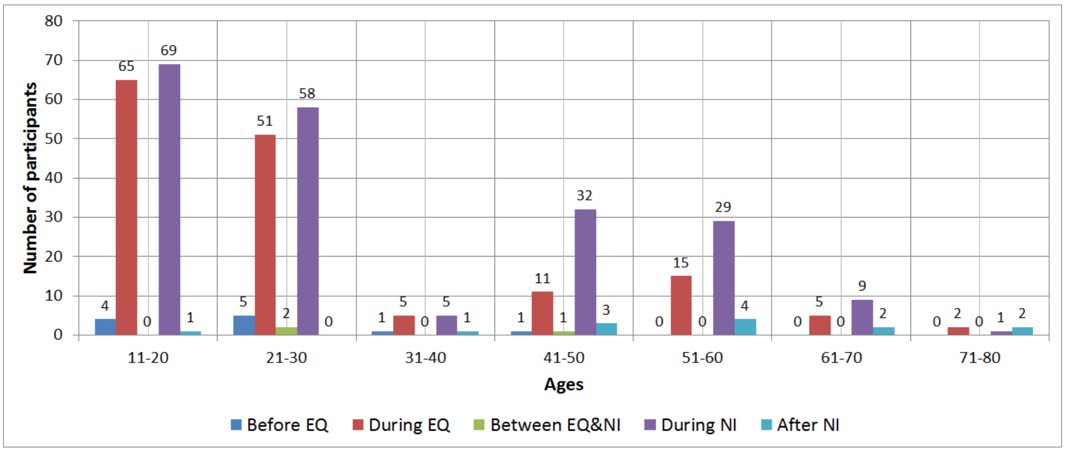

Figure 4.9: Departure choice and age

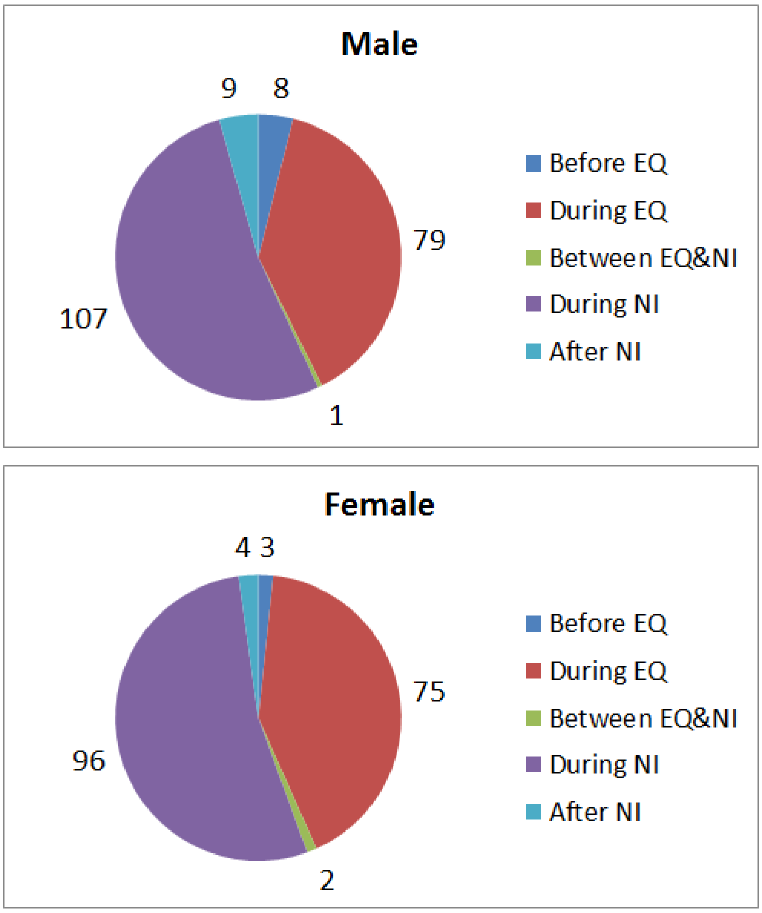

Figure 4.10: Departure choice and gender

A $\tilde{\chi}^2$ test was performed to find out whether there is a statistically significant difference. Since the significance level of this test was 0.843, it is concluded that there is no statistically significant association between gender and departure choice, meaning gender did not influence departure choice. Concluding, in the Everscape experiments women were not inclined to leave earlier than men.

4.4.2 Departure choice and information from news item

During the experiments, participants received information about the disaster and instructions on how to evacuate through a news item. This sub section presents the results on departure choice and the news item to find out whether the results support the conceptual framework in Chapter 2, see Figure 4.11 for the information part of the framework.

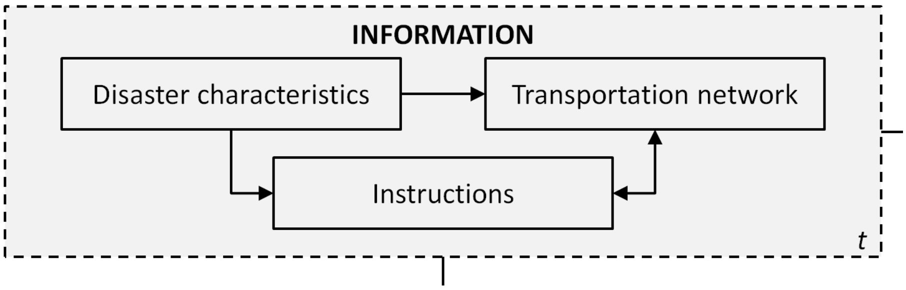

Figure 4.11: Conceptual framework - information

Table 4.11: Departure choice and information from news item

	Before the news	**After start of news**
Number of participants	168	216
Percentage of participants	44%	56%

Figure 4.6 and Table 4.10 already showed that most of the participants left during the earthquake and news item. Only a few of them left before the earthquake, between the earthquake and news item and after the news item. Table 4.11 shows that in total around half of the participants left before the start of the news item.

It is concluded that both the earthquake and news item were the main triggers that made participants leave. This is confirmed by the conceptual framework in Chapter 2, which showed that disaster characteristics and also instructions influence evacuation decisions.

4.4.3 Departure choice and stress

This sub section discusses the relation between departure choice and the answers from the questionnaire that considered the experienced stress levels before and due to the disaster. This is considered to find out how stress experienced by the participants influenced their actions.

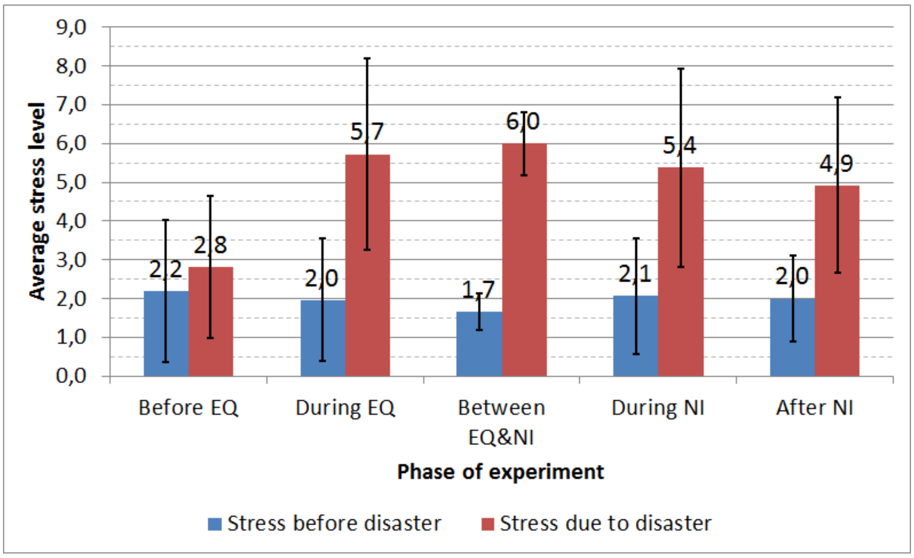

Figure 4.12: Departure choice and stress experienced by the participants

Figure 4.12 shows the average stress levels the participants experienced before and due to the disaster, both related to departure choice, and it includes the standard deviation. It shows that stress experienced before the disaster is quite similar over the different phases. The average stress level experienced by those who left between the earthquake and news item is a little lower. There were only three participants who left between the earthquake and news item, resulting in a small standard deviation. These are not enough participants to conclude anything about their experienced stress levels.

The stress level participants experienced due to the disaster is clearly higher when participants left during the earthquake or later. This is logical because then participants were already confronted with the disaster. There seems to be a decrease in average stress level for participants who left during the earthquake, during the news item and after the news item. Apparently, when participants had received more information, their stress levels decreased. This makes sense because information that people receive influences their perception of the situation, see 2.4.1, and in case of the Everscape experiment also their stress because the information explained the situation and what they should and could do.

ANOVA tests have been performed to find out whether the differences are statistically significant. In line with the ANOVA tests in 4.2.3, considered are stress levels experienced before the disaster, due to the disaster and the differences in stress before and due to the disaster. The ANOVA tests resulted in significance levels of 0.376, 0.331 and 0.119 respectively. These significance levels are all higher than 0.05, meaning stress did not influence departure choice.

4.4.4 Departure choice and gaming experience

In this sub section the results for departure choice and gaming experience are presented to find out whether there is a relation between these two that causes a bias in the results for departure choice.

Tables 4.12 and 4.13 show departure choice for the different levels of gaming experience. Table 4.12 shows the results for participants with regular gaming experience and Table 4.13 shows the results for little or no gaming experience.

Table 4.12: Departure choice and regular gaming experience of the participants

	Daily	**Weekly**	**Monthly**
Before earthquake	3	2	0
During earthquake	28	32	16
Between earthquake and news	0	0	0
During news	27	42	22
After news	0	2	0
Total	**58**	**78**	**38**

Table 4.13: Departure choice and little or no gaming experience of the participants

	Less than once a month	**Tried it but not my cup of tea**	**Never**
Before earthquake	1	3	1
During earthquake	26	18	29
Between earthquake and news	2	0	1
During news	28	29	40
After news	1	5	5
Total	**58**	**55**	**76**

Figure 4.13 is added to graphically display the results. It might seem that participants with more gaming experience left earlier during the experiments (so before and during the earthquake). The share of participants leaving later seems to be higher for lower gaming experience levels.

When only considering departures during the earthquake and news item, a gaming experience level of ‘less than once a month’ has almost the same percentages of participants leaving during these two phases.

A $\tilde{\chi}^2$ test was performed to find out whether there is a statistically significant difference. With this test all distributions were compared against the total. Since the significance level of this test was 0.444, it is concluded that there is no statistically significant association between gaming experience and departure choice, meaning gaming experience did not influence departure choice.

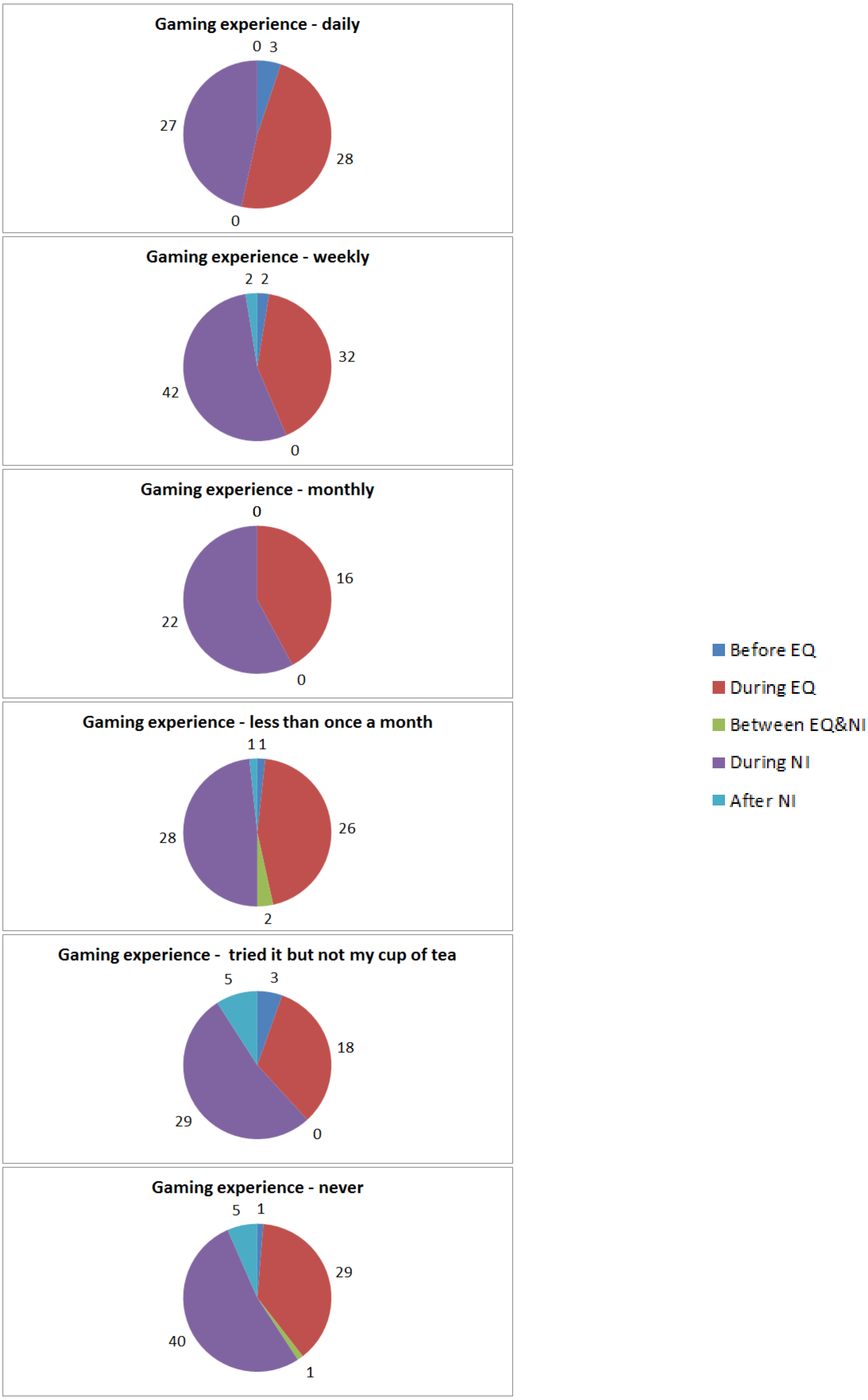

Figure 4.13: Departure choice and gaming experience

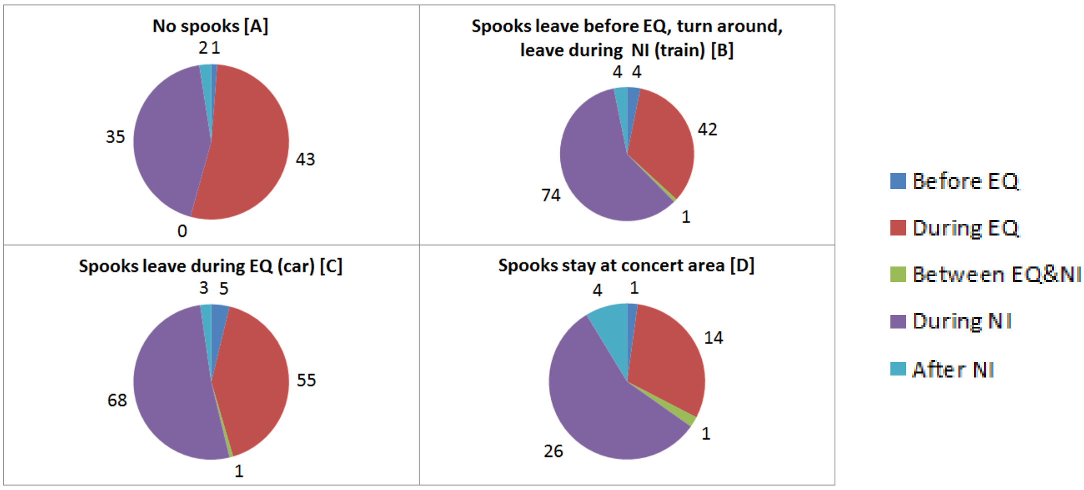

Figure 4.14: Departures per phase and herding scenarios

4.4.5 Departure choice and herding scenarios

This sub section presents the results for the effect of the herding scenarios on departure choice to find out whether (and how) they affected departure choice. Herding in the conceptual framework is part of the direct surroundings, see Figure 4.8.

Table 4.14: Departure choice and herding scenarios

Scenario	**No spooks** [A]	**Leave return leave** [B]	**Leave and continue** [C]	**Stay** [D]
Before earthquake	1 (1,2%)	4 (3,2%)	5 (3,8%)	1 (2,2%)
During earthquake	43 (53,1%)	42 (33,6%)	55 (41,7%)	14 (30,4%)
Between earthquake & news	0 (0,0%)	1 (0,8%)	1 (0,8%)	1 (2,2%)
During news	35 (43,2%)	74 (59,2%)	68 (51,5%)	26 (56,5%)
After news	2 (2,5%)	4 (3,2%)	3 (2,3%)	4 (8,7%)
Total	**81**	**125**	**132**	**46**

[A] No spooks.
[B] The spooks left before the earthquake, turned around during the earthquake, left during the news item and took the train.
[C] The spooks left during the earthquake and took a car.
[D] The spooks stayed at the concert area.

As explained in Section 3.5, four different scenarios were tested with and without spooks, who had specific tasks to influence the participants. A $\tilde{\chi}^2$ test was performed to find out whether there is a statistically significant difference. Since the significance level of this test was 0.013, it is concluded that there is a statistically significant association between the herding scenarios and departure choice, meaning the herding scenarios influenced departure choice. The question is whether the actions of the spooks were copied by the actual participants.

It is shown in Figure 4.14 that during the scenario without spooks, most of the participants already left before the start of the news item. In the scenarios with spooks, most participants left after the start of the news item, even in the scenario where the spooks did not leave the concert area (D), which suggests that the actions of the spooks were not copied (no participant stayed). This suggests no herding based on the actions of the spooks.

The difference between Scenarios B and C suggests herding. Compared to Scenario C, in Scenario B, fewer participants left during the earthquake. This seems logical because during Scenario C the spooks left during the earthquake and during Scenario B the spooks returned during the earthquake.

To consider herding a bit further, participants who left the concert area twice are now considered. In Scenario B, where the spooks left the concert area twice, it is expected that more participants (than in the other scenarios) left the concert area twice as well. To find out whether this was the case, Figure 4.15 shows the first and second departures of all participants. The figure shows that especially in Scenario A participants more often left two times, which also suggests that not the herding scenarios influenced herding when considering the number of departures per participant.

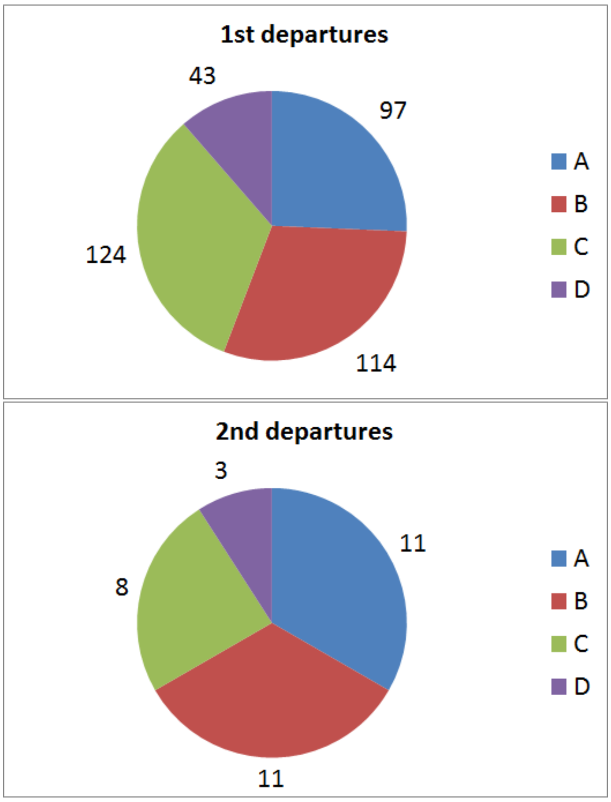

Figure 4.15: Scenarios and 1st & 2nd departure of ***all participants***

Figure 4.16 shows, for participants who left the concert area twice, the phases when they left the first and the second time. This suggests that participants went back to the concert area to get more information from the news item because most of the second departures were during the news item.

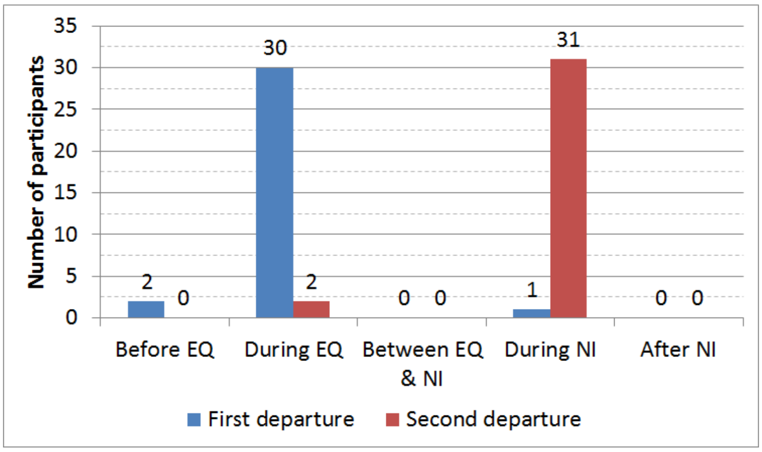

Figure 4.16: Departure choice 1st and 2nd departure of ***the participants who left twice***

Concluding, the herding scenarios influenced departure choice but they did not show the expected herding behaviour (i.e. the participants copying the behaviour of the spooks). Chapter 5 will focus more on herding by considering what participants actually saw.

4.5 Mode and route choice analysis

In this section the results for mode and route choice are presented and discussed. To gain an idea of the results on mode and route choice, Figure 4.17 shows which modes and routes were chosen by the participants.

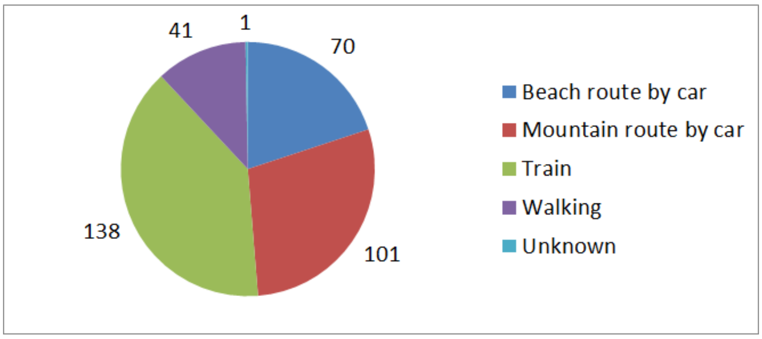

Figure 4.17: Mode and route choice

In total 171 participants took the car, of which 70 took the shorter beach route and 101 took the longer route through the mountains, 138 participants took the train and 41 participants went walking. One person experienced some technical issues. Due to this, it is unknown which mode and route this person chose.

These are the general results on mode and route choice. The rest of this section discusses the relation between mode and route choice and the other characteristics that were also discussed with respect to departure choice in the previous section. The socio-economic characteristics age and gender and the information the participants received via the news item are considered in 4.5.1 and 4.5.2 to find out whether the results support the conceptual framework in Chapter 2. Results on the experienced stress levels and gaming experience are presented in 4.5.3 and 4.5.4 to consider realism of the experiment. Finally, herding is considered by discussing the effect of the herding scenarios in 4.5.5.

4.5.1 Mode/route choice and socio-economic characteristics

This sub section discusses how the age and gender of the participants are related to mode and route choice behaviour to find out whether the results support the conceptual framework from Chapter 2. Figure 4.8 presented a part of the conceptual framework that showed the socio-economic characteristics as part of the personal context.

Age of the participants

Table 4.15 and Figure 4.18 show that especially younger participants (until 30 years old) more often took the train. When they took the car, they more often took the shorter beach route compared to participants between 41 and 60.

Table 4.15: Mode/route choice and age

	11-20	**21-30**	**31-40**	**41-50**	**51-60**	**61-70**	**71-80**	**Total**
Car - Beach route	26 21,8%	22 21,4%	2 16,7%	8 16,7%	6 12,5%	6 37,5%	0 0,0%	**70** 19,9%
Car - Mountain route	31 26,1%	28 27,2%	6 50,0%	12 25,0%	19 39,6%	3 18,8%	2 40,0%	**101** 28,8%
Train	52 43,7%	46 44,7%	4 33,3%	14 29,2%	17 35,4%	4 25,0%	1 20,0%	**138** 39,3%
Walking	10 8,4%	6 5,8%	0 0,0%	14 29,2%	6 12,5%	3 18,8%	2 40,0%	**41** 11,7%
Unknown	0 0,0%	1 1,0%	0 0,0%	0 0,0%	0 0,0%	0 0,0%	0 0,0%	**1** 0,3%
Total	119 100%	103 100%	12 100%	48 100%	48 100%	16 100%	5 100%	**351** 100%

No statistically significant conclusions could have been drawn due to too small sample sizes for route choice over the different age groups.

Gender of the participants

Table 4.16 and Figure 4.19 show that more men took a car and more women took the train and went walking. When both men and women took the car, most of them took the longer route through the mountains.

A $\tilde{\chi}^2$ test was performed to find out whether there is a statistically significant difference. The significance level of this test was 0.071. This is higher than 0.05

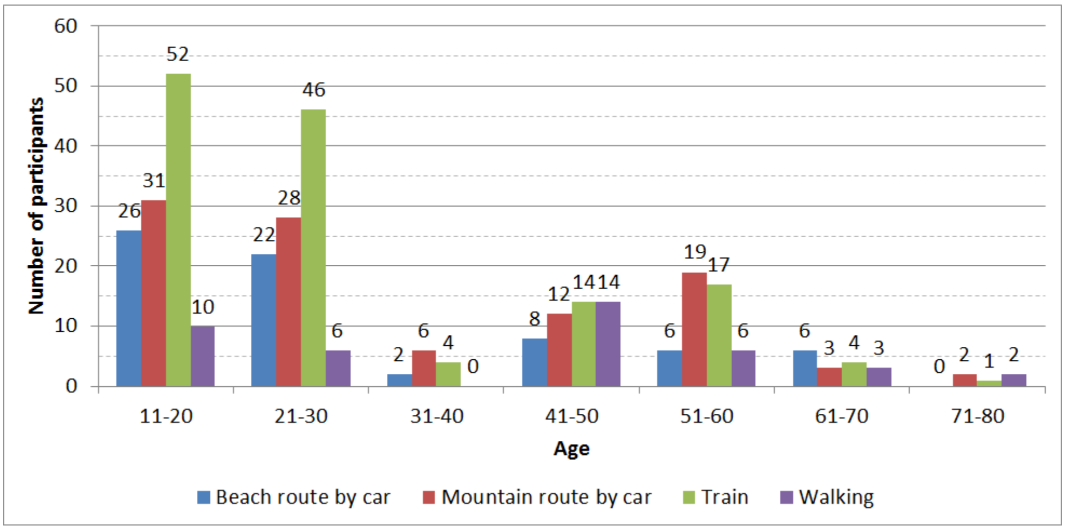

Figure 4.18: Mode/route choice and age

Table 4.16: Mode/route choice and gender

	Male	**Female**
Car - Beach route	42 (23,1%)	28 (16,6%)
Car - Mountain route	59 (32,4%)	42 (24,9%)
Train	64 (35,2%)	74 (43,8%)
Walking	17 (9,3%)	24 (14,2%)
Unknown	0 (0,0%)	1 (0,6%)

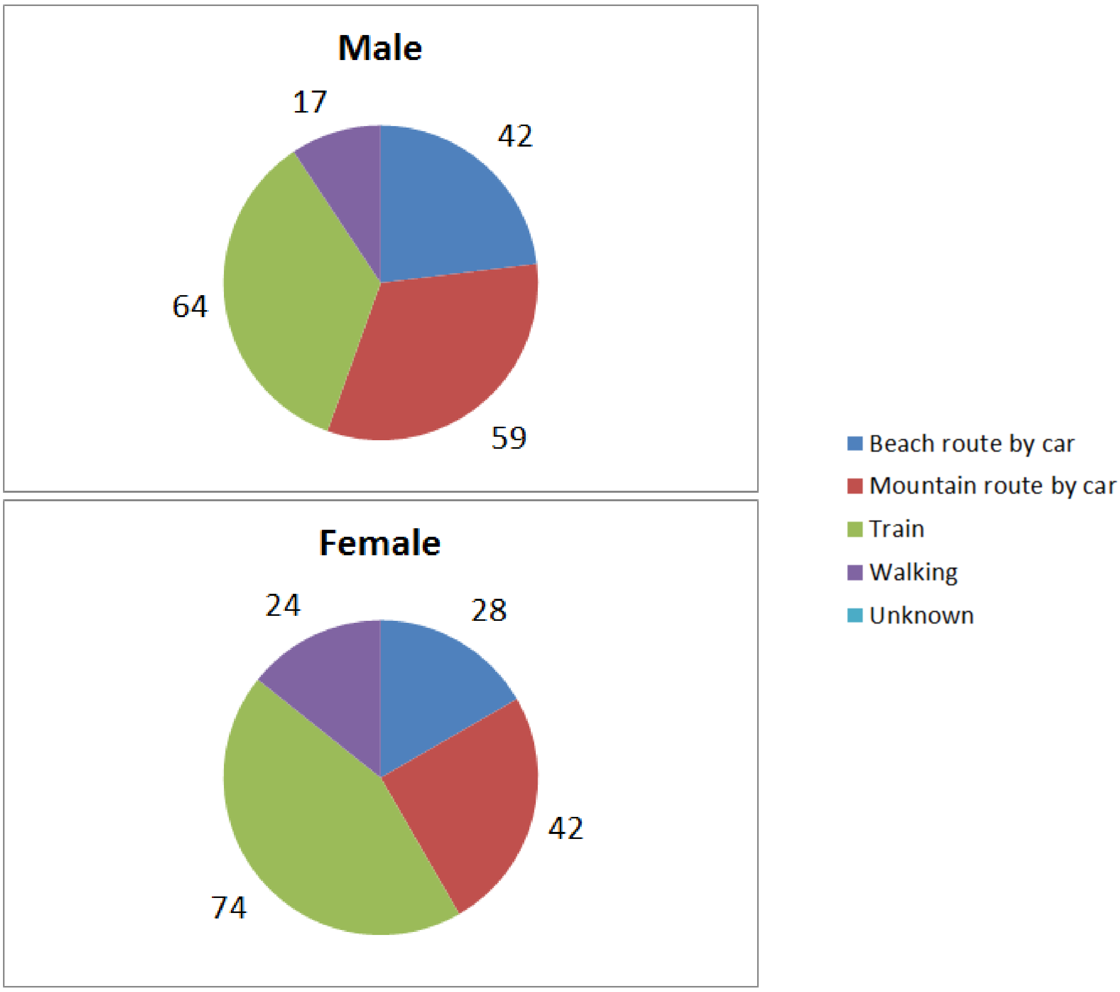

Figure 4.19: Mode/route choice and gender

but still below 0.10 (so 90%). Therefore, it is concluded that there is a statistically significant association between gender and route choice, meaning gender influenced route choice.

Questions arise why participants have chosen the different modes and routes and whether they were aware of the risk levels of the different options. The shorter route had for example a higher risk level due to an unreliable bridge. It was also closest to where the tsunami would first reach the island. Did the participants know that the mountain route was located in a higher area and did they travel via this mountain route because it was safer? Were the participants aware of the actual travel times of the different options? From the pilot experiments it was already known that participants might not have chosen the beach route because the exit towards the beach route was not very clear and they might have just missed it.

Because it is unknown if participants were aware of the risks, no conclusions can be drawn with respect to the relation between the socio-economic characteristics and risks of the different modes/routes. From the questionnaire it is known why the participants have chosen their modes/routes. To find out if more can be concluded with respect to this, these questions are discussed below. Due to technical problems when uploading the questionnaire, from some participants only a part of the questionnaire or no questionnaire is available. Due to this the number of answers is much less than the number of participants who took a certain mode/route. These answers are considered to provide a useful indication of why participants chose a certain mode/route.

Why participants took the car

Table 4.17 shows the results for choosing the car and the beach or mountain route. It is shown that most of the participants took a car because they could control that themselves. Only one person took the car because the train was full and three participants indicated they followed someone.

The only answer the participants gave for choosing the shorter beach route (instead of the mountain route) was because it was the shortest, see Table 4.18.

Table 4.17: Why participants took the car

	Number of participants
Because I could control that myself	90
Because the train was full	1
Because I followed someone	3

It is remarkable to see that the reason why most participants took the mountain route was because they considered this to be the shortest route while it was actually the longest route. Two participants said this route was more beautiful which is a strange answer because if one wants to survive how important would one consider the looks of the scenery. One participant just followed someone, suggesting that herding in route choice exists. However, this one person is not enough to confirm herding in route choice. Three participants did not see the other route.

Table 4.18: Why participants took the beach route

	Number of participants
Because it is the shortest route	47
Because it is more beautiful	0
Because I followed someone	0
I did not see the other route	0

Table 4.19: Why participants took the mountain route

	Number of participants
Because it is the shortest route	52
Because it is more beautiful	2
Because I followed someone	1
I did not see the other route	3

Why participants took the train

To find out why participants chose the train, Table 4.20 shows the answer to this question. It can be seen that most of the participants took the train because it would obviously leave on time, no participants had problems with controlling the car which suggests that the attention that was paid to making the controls simple and logical were successful. Five participants chose the train because they followed someone, which suggests herding affected mode choice.

Table 4.20: Why participants took the train

	Number of participants
Because it would obviously leave on time	37
Because I had problems controlling the car	0
Because I followed someone	5

Why participants went walking

In total, 41 participants went walking. Unfortunately, no information from the questionnaire is available on why participants went running but some aspects can be checked from the trajectory data from Everscape. Table 4.21 shows aspects that were checked from the participants who went walking.

The table shows that from the 41 participants who went walking, 25 of them tried to get into the train and four participants were on their way to the train but the train had already left before they arrived. The trajectory data of the participants show that from the 41 participants who went walking, 24 started to follow the beach or the mountain route and 17 of them stayed at the train station or parking area. It seems that those were looking around for options. Concluding, from the participants who went walking, the data suggest that they were trying their best to move away from the concert area.

The main conclusion of this section is that reasons for choosing certain modes and

Table 4.21: Participants who went walking

	Number of participants
In total	41
Tried to get into the train	25
On his/her way to the train but too slow	4
Just started running via the beach or mountain route	24
Only walking around at the train station or parking area	17

routes give some insight in the perception that the participants had. The reasons they gave are consistent with the conceptual framework from Chapter 2. They took or at least tried to take the available options. It differs from a real life natural disaster because at the start, every participant had the same alternatives to choose from. During the experiment, some options became limited or even unavailable (e.g. the train was full or had left, there were no more cars available), which is the same as in real life. It should be noted that during the experiment, everyone could take the car, even participants who cannot drive a car in real life.

4.5.2 Mode/route choice and information from news item

This sub section presents the results on mode and route choice and information received through the news item to find out whether the results support the conceptual framework in Chapter 2. The news item included information about the disaster characteristics and instructions, which is consistent with Figure 4.11, showing the information part of the framework.

Table 4.22: Mode and route choice and information from news item

	Before start of news item	**After start of news item**
Car - Beach route	41 (24,7%)	29 (15,8%)
Car - Mountain route	54 (32,5%)	47 (25,5%)
Train	59 (35,5%)	79 (42,9%)
Walking	12 (7,2%)	29 (15,8%)

A $\tilde{\chi}^2$ test was performed to find out whether there is a statistically significant difference. Since the significance level of this test was 0.009. This means that there is a statistically significant association between having received information via the news and route choice, meaning the news item influenced route choice.

Table 4.22 and Figure 4.20 show that participants especially took the train more often after the start of the news item. This could be explained by the fact that everyone arrived at the concert by car and took this familiar option. If this is the actual reason for this is unknown. After the start of the news item, more participants went walking.

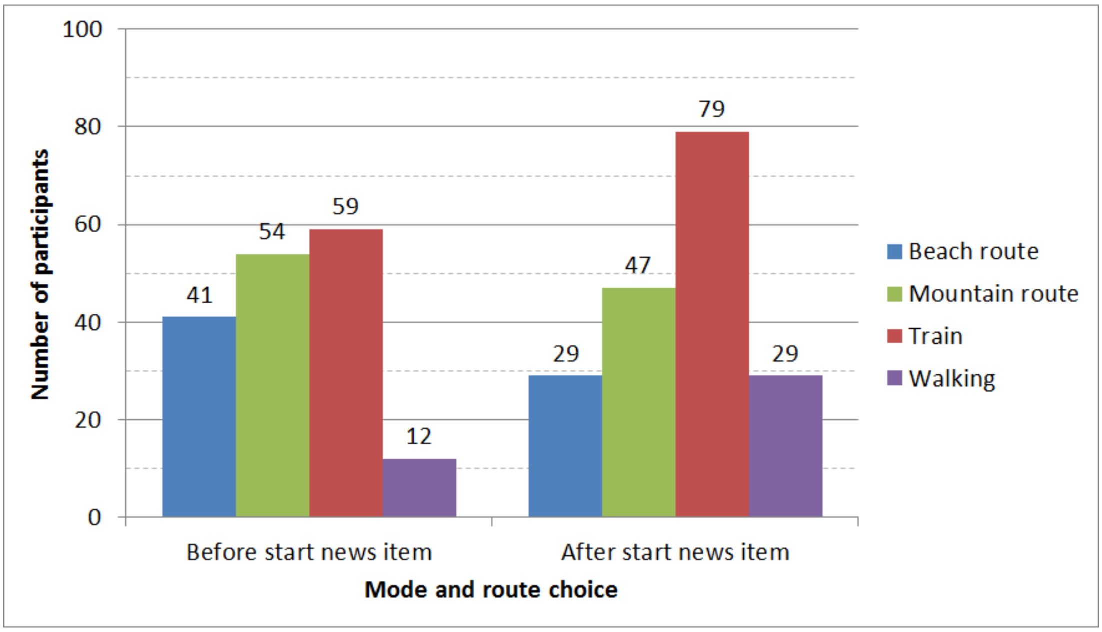

Figure 4.20: Mode and route choice and information from news item

This might be explained by the fact that later on during the experiment, the train might have been full or already left and there might not have been any more cars available.

All mode and route options (except for walking) were explicitly presented during the news item. It is important to consider what participants said themselves about information they received via the news item.

After leaving the concert area, participants were still able to hear the news item. To find out whether they heard and/or saw anything from the news item, they were asked about this in the questionnaire. Figure 4.21 shows that from the available answers, every participant at least saw or heard some aspects of the news item so all participants were still close enough to the concert stage to at least see or hear parts of it. It is assumed that everyone knew they had to evacuate.

The main conclusion from the information participants received via the news item is that they used this information. For example, it seems to have influenced participants in taking the train. This makes sense because this option was explicitly presented.

4.5.3 Mode/route choice and stress

This sub section discusses the relation between mode and route choice and stress levels participants experienced before and due to the disaster.

Figure 4.22 shows that the average stress participants experienced before the disaster is similar over all chosen modes and routes. Participants who took the shorter beach route by car experienced on average a little higher stress level than those who took the longer route by car through the mountains and took the train. This might be explained by the

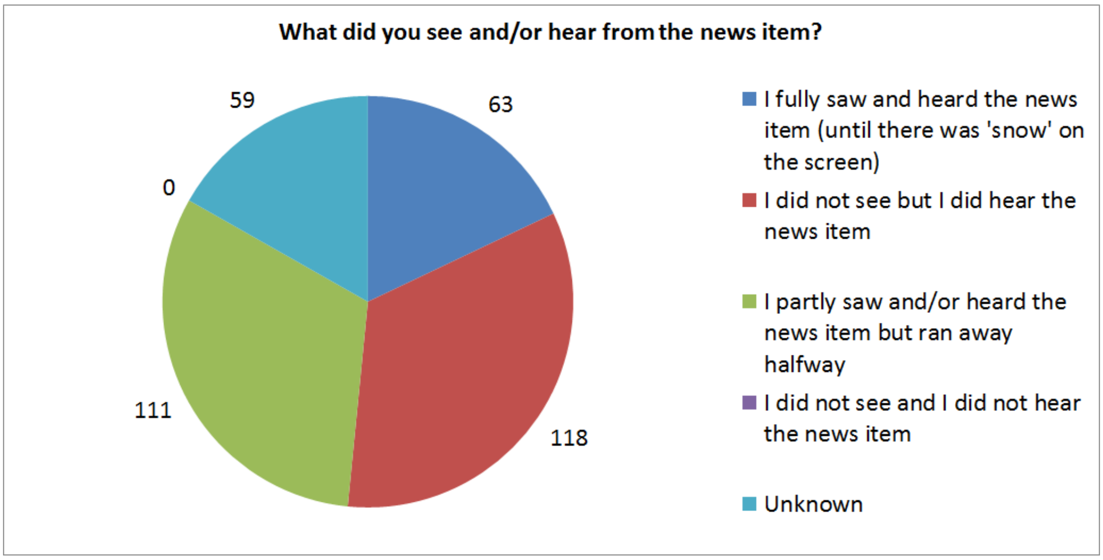

Figure 4.21: How participants said they received information from the news item

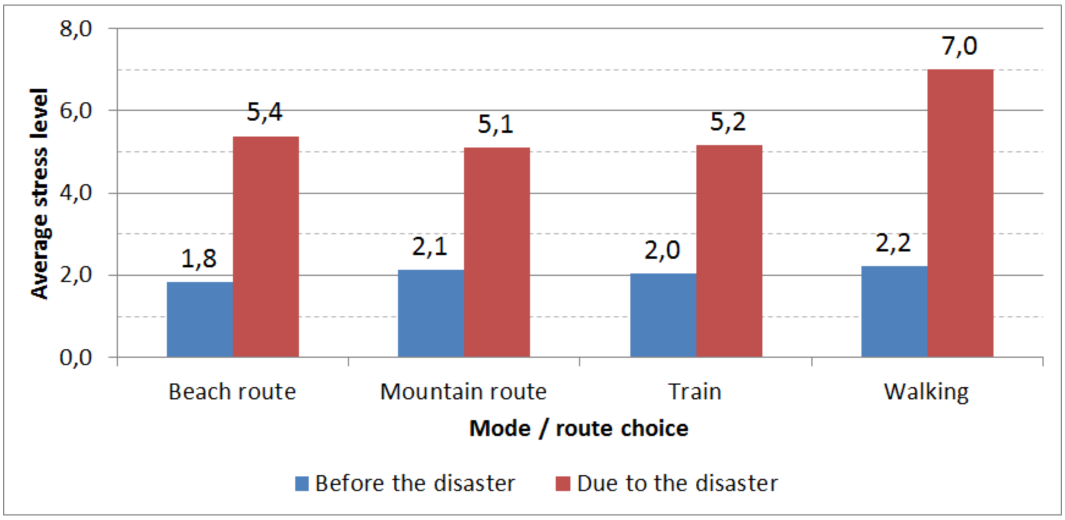

Figure 4.22: Mode/route choice and average stress experienced by the participants

fact that more participants who took the beach route drove into the water because the bridge had collapsed.

Those who went walking clearly experienced more stress due to the disaster. This makes sense because for those who went walking there was not enough time to get into the helicopter or on top of the mountain, hence there was not enough time to 'survive'.

ANOVA tests have been performed to find out whether the differences are statistically significant. In line with the ANOVA tests in 4.2.3 and 4.4.3, considered are stress levels experienced before the disaster, due to the disaster and the differences in stress before and due to the disaster. The ANOVA tests resulted in significance levels of 0.564, 0.000 and 0.001 respectively. The significance levels for stress due to the disaster and the difference in stress before and due to the disaster are lower than 0.05, meaning stress due to the disaster and the difference in stress before and due to the disaster influenced route choice.

4.5.4 Mode/route choice and gaming experience

In this sub section the results for mode and route choice and gaming experience are presented to find out whether gaming experience caused a bias.

Table 4.23: Mode/route choice and regular gaming experience of the participants

	Daily	**Weekly**	**Monthly**
Car - Beach route	11 (21,2%)	14 (20,6%)	11 (35,5%)
Car - Mountain route	18 (34,6%)	18 (26,5%)	6 (19,4%)
Train	20 (38,5%)	26 (38,2%)	12 (38,7%)
Walking	3 (5,8%)	10 (14,7%)	2 (6,5%)
Total	**52**	**68**	**31**

Table 4.24: Mode/route choice and little or no gaming experience of the participants

	Less than once a month	**Tried it but not my cup of tea**	**Never**
Car - Beach route	13 (23,2%)	10 (13,9%)	8 (15,1%)
Car - Mountain route	20 (35,7%)	17 (23,6%)	15 (28,3%)
Train	20 (35,7%)	32 (44,4%)	21 (39,6%)
Walking	3 (5,4%)	13 (18,1%)	9 (17,0%)
Total	**56**	**72**	**53**

Figure 4.23 and Tables 4.23 and 4.24 show that more participants took the train and went walking for the two lowest levels of gaming experience. Participants with weekly gaming experience responded quite similar with respect to mode choice. With the other gaming experience levels more than half of the participants took a car.

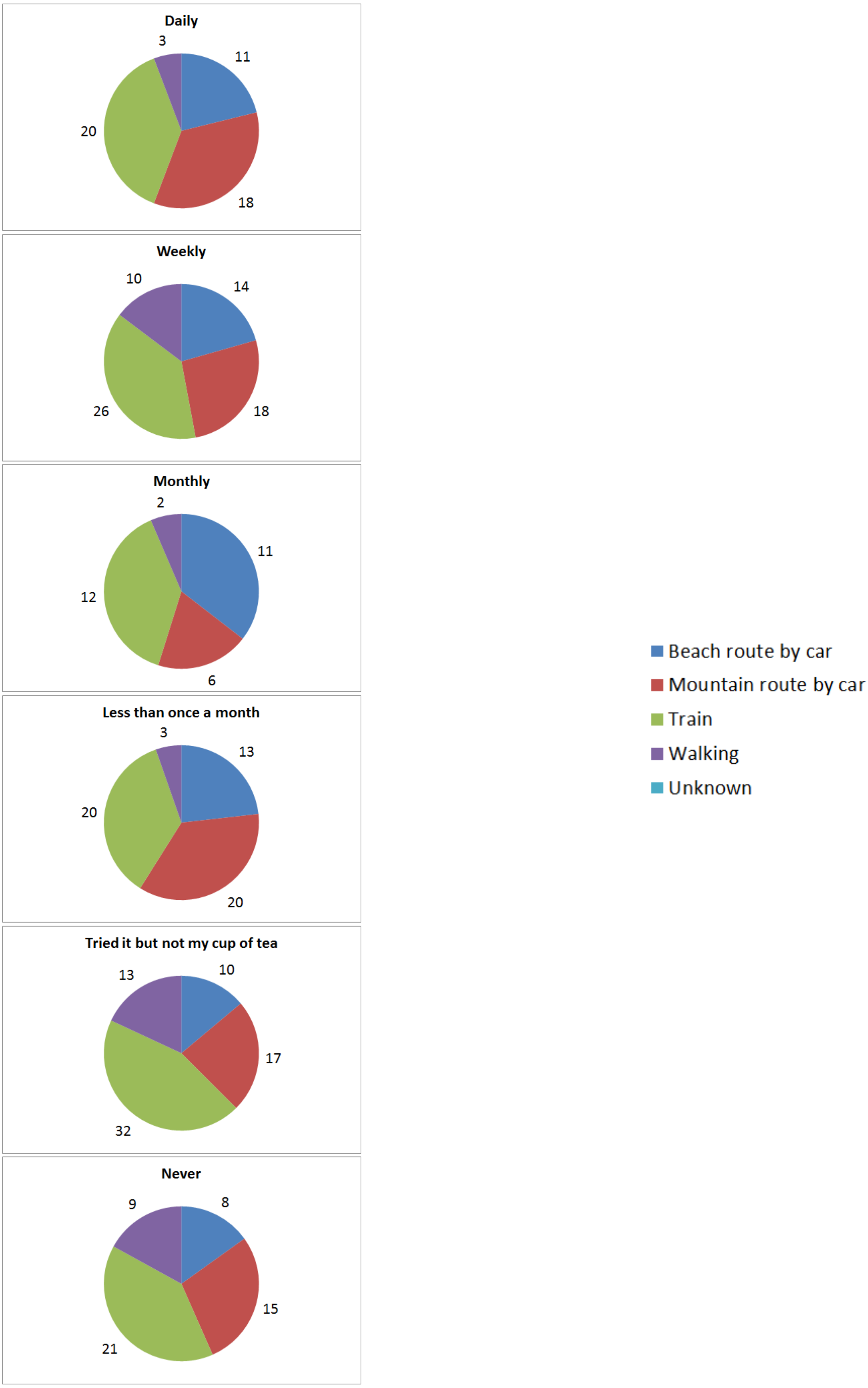

Figure 4.23: Mode/route choice and gaming experience

A $\tilde{\chi}^2$ test was performed to find out whether there is a statistically significant difference. Since the significance level of this test was 0.251. This means that there is no statistically significant association between gaming experience and route choice, meaning gaming experience did not influence route choice.

4.5.5 Mode/route choice and herding scenarios

This sub section presents herding results on mode and route choice by considering the effect of herding scenarios on mode and route choice. In the conceptual framework, herding is part of the direct surroundings, see Figure 4.8 which shows a selection of the framework that includes the personal context.

Table 4.25: Mode/route choice and herding scenarios

	A	B	C	D
Car - Beach route	15 (21,4%)	18 (15,8%)	28 (22,8%)	9 (20,9%)
Car - Mountain route	15 (21,4%)	32 (28,1%)	37 (30,1%)	17 (39,5%)
Train	30 (42,9%)	40 (35,1%)	53 (43,1%)	15 (34,9%)
Walking	10 (14,3%)	24 (21,1%)	5 (4,1%)	2 (4,7%)

[A] No spooks.
[B] The spooks left before the earthquake, turned around during the earthquake, left during the news item and took the train.
[C] The spooks left during the earthquake and took a car.
[D] The spooks stayed at the concert area.

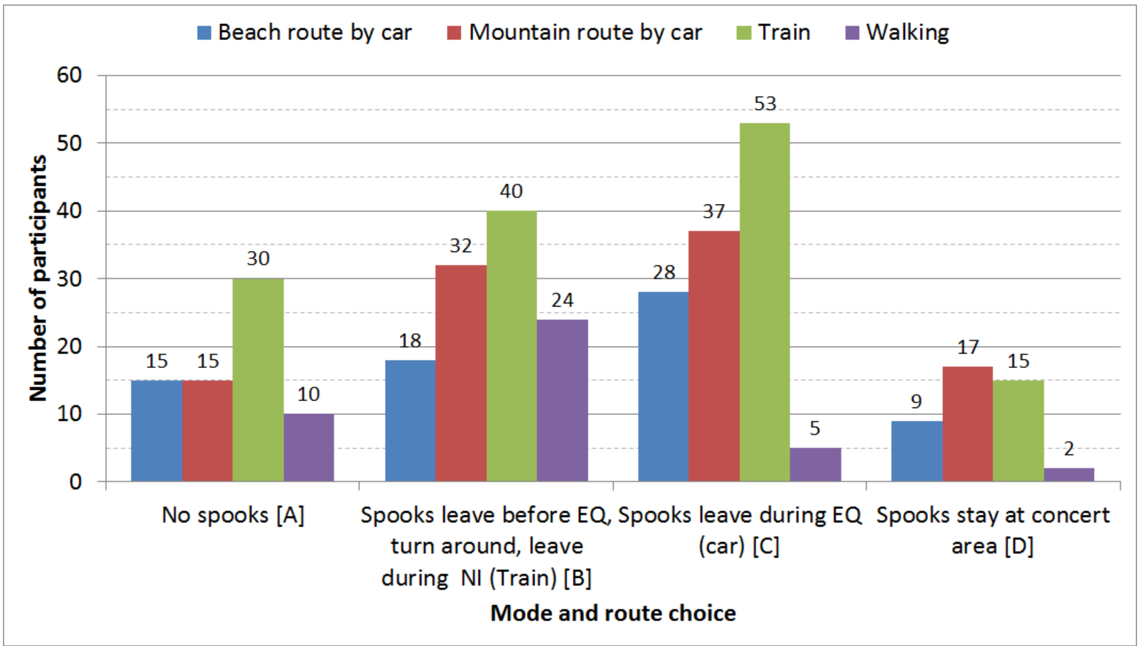

Figure 4.24: Mode/route choice and herding scenarios

Table 4.25 and Figure 4.24 show that with Scenario A the same amount of participants took the car and train. With the actual herding scenarios, which are Scenarios B, C and D, more participants took car than train, even in Scenario B where the spooks took the train. The train had a maximum capacity. Table 4.26 shows the number of participants that in each scenario tried to enter the train but could not get in because it was full.

Table 4.26: Participants receiving a train full message

	Number of participants
Scenario A (no spooks)	10
Scenario B (leave return leave)	19
Scenario C (leave continue)	4
Scenario D (stay)	0

The table suggests that especially in Scenario B, where the spooks took the train, more participants tried to enter a full train. A $\tilde{\chi}^2$ test was performed to find out whether there is a statistically significant difference. The significance level of this test was 0.006. This means that there is a statistically significant association between the herding scenarios and route choice, meaning they influenced route choice.

4.6 What participants said about their own actions in the questionnaire

This section presents the results from the questionnaire where participants explained what they did and why. These results are considered to find out why participants did what they did but especially to find out what their mindset was (i.e. did they participate seriously or did they experience it as a game). The mindset of the participants is important for judging realism of the experiment and considering the validity of the results in Chapter 6.

Considered in this section is what participants said they did before, during and after the earthquake and what their main goal was after leaving the concert area.

Before discussing the results, it should be noted that there are differences in the number of answers per question due to some technical problems with uploading the questionnaire. From some participants the full or a part of the questionnaire is missing.

4.6.1 Before, during and after the earthquake

This sub section discusses what participants said they did before, during and after the earthquake. Figure 4.25 shows the answers from the participants. Before the earthquake, most participants said they mainly looked at and listened to the concert or they walked around at the concert area. A smaller share of participants said they mainly talked to the other participants.

During and after the earthquake, participants also gave other options on what they were doing. Most of these options had to do with finding out what was happening and leaving the concert area.

Based on what participants said they were doing, it is concluded that they were acting seriously and not considering the experiment as a game. The trajectory data showed that they did not try things to find out what worked or did not work (i.e. run into the water, run to areas they were not supposed to go).

4.6.2 Main goal after leaving the concert area

This sub section presents the results with respect to the main goal of the participants. The main goal of most of the participants was to get to the helicopter as soon as possible, see Figure 4.26. Not one participant wanted to stay at the concert area. Besides participants having these goals, 11 participants stated they did not have a goal but all of the participants left the concert area, which was the most logical thing to do if they wanted to 'survive'.

Based on the results presented in this section, it is concluded that participants seriously participated because they were focussed on finding out what was happening and evacuating.

4.7 Conclusions

This chapter presented the results from the descriptive analysis of the data collected during the experiments. First, an overview of the experiments, including characteristics of the participants was presented. Second, the results on the travel choices made during the experiments were discussed. Finally, what participants said in the questionnaire about their actions during the experiments was shown.

There were three main aspects considered during the analysis: whether the results supported literature, hence the conceptual framework presented in Chapter 2, judging realism of the experiment and the effect of herding scenarios.

With respect to the results supporting the conceptual framework, it is concluded that in general the results are consistent with this framework. For example, socio-economic characteristics (age and gender) influenced departure choice and mode/route choice but also information that the participants received from the news item has influenced these choices.

In general, participants have shown that their mindset was how it was supposed to be because their main goal was to evacuate. The trajectory data confirmed this as well:

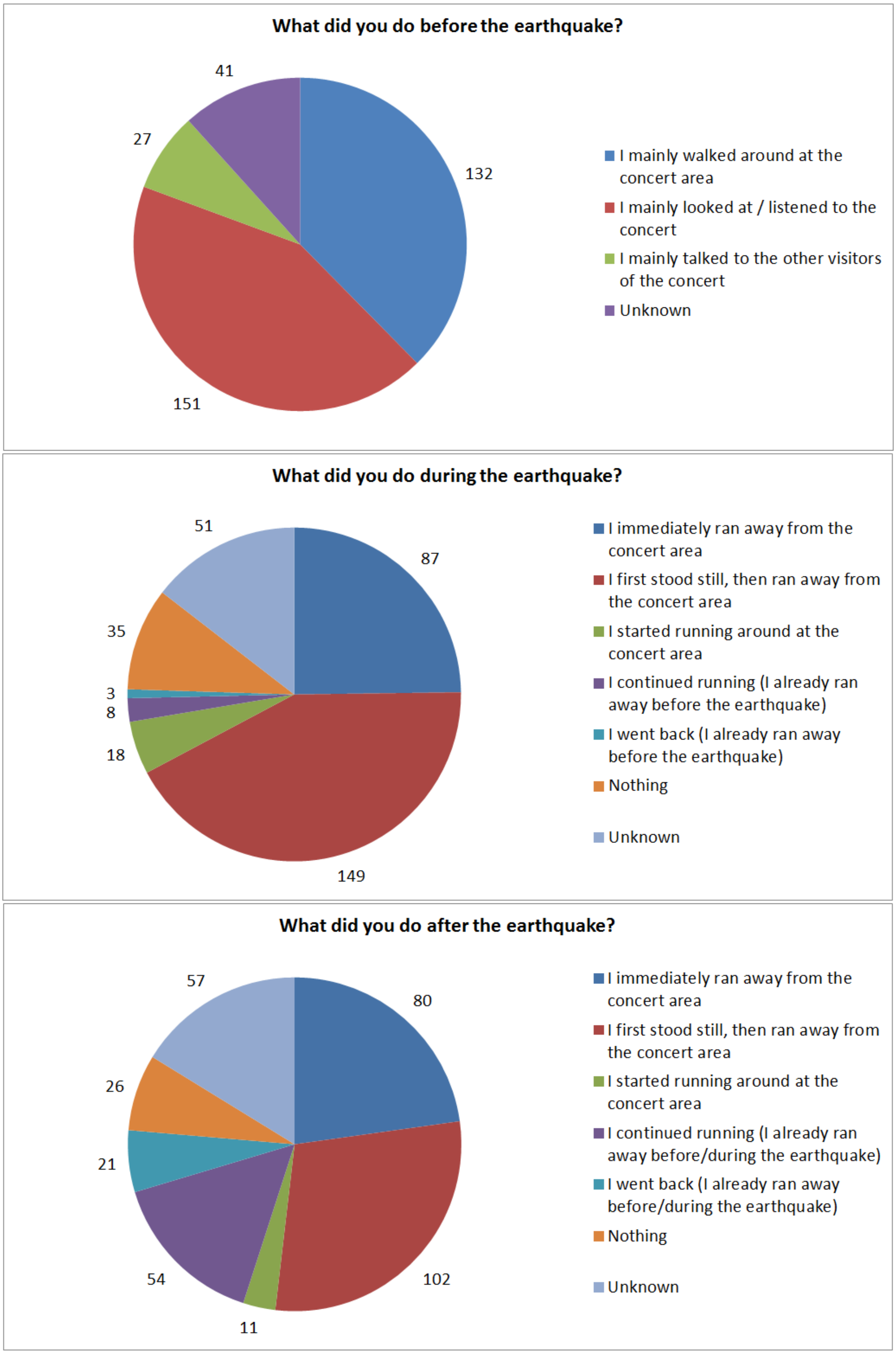

Figure 4.25: What participants said they did before, during and after the earthquake

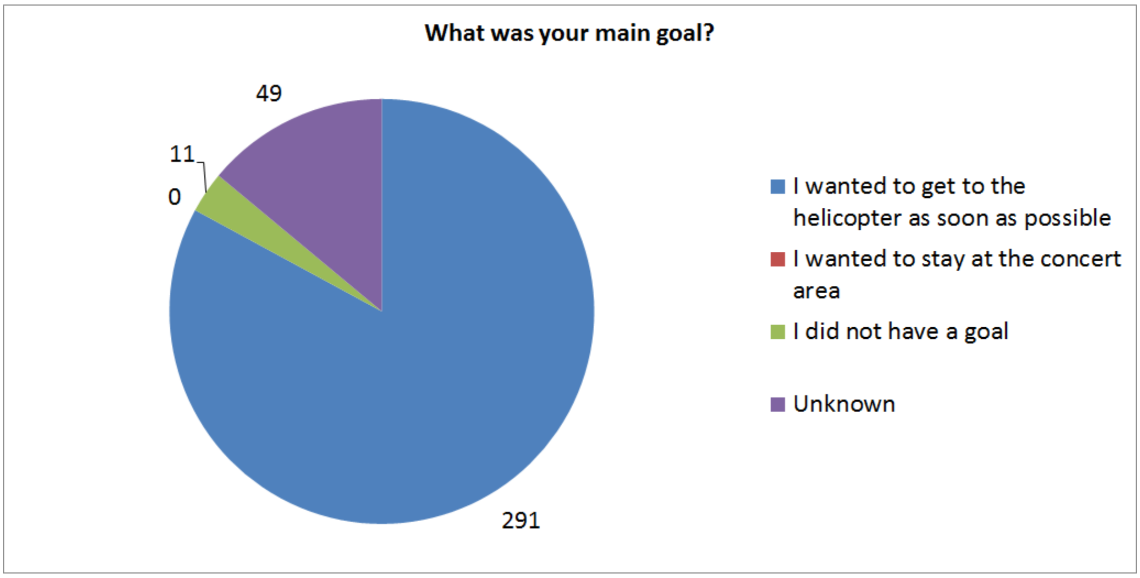

Figure 4.26: What participants said their main goal was after leaving the concert area

they all left the concert area and tried to get an available mode/route option to travel to the helicopter.

The herding scenarios also influenced departure choice and mode/route choice but it seems that this was not because the actions of the spooks were copied by the participants. The next chapter will consider herding further by quantifying the actions of other people that were seen by the participants.

The reason for focussing on the effect of herding on departure choice is that with departure choice more participants were together at the moment they made their decision. Herding might be better quantified because participants were able to see more people. For mode/route choice the participants were more spread over different locations. Therefore, they were less likely to see as many people as they saw when making their departure choice.

Concluding, with the results of this chapter kept in mind, the next chapter will focus on the effect of herding on departure choice further by quantifying the actions of other people that were seen by the participants.

Chapter 5

Quantifying the effect of herding on the decision to evacuate

This chapter presents one of the main theoretical contributions of this thesis by quantifying the effect of herding on the decision to evacuate.

As defined in Chapter 2, herding is defined as seeing other people doing something (e.g. leaving) and believing that what they are doing is a good alternative, resulting in doing the same thing. With the observable characteristics from the experiments as described in 3.5.6, it is possible to derive who each participant saw during these experiments and what these other people were doing. How this is derived will be explained in Section 5.1. Section 5.2 will then provide the descriptive analysis of these processed herding data to find out how many people were seen by the participants and if they were staying at or leaving from the concert area (all prior to each participant's decision to evacuate).

To find out what the effect of herding was on the decision to evacuate, sequential choice models were estimated with the derived herding data. To find out if and how other characteristics (see Table 3.4, numbers 2, 3, 4 and 5) have influenced this herding behaviour during the experiments, these other factors are also included in the choice modelling process. Section 5.3 presents the actual process of choice models that were estimated. The results of these estimated choice models are discussed in Section 5.4, 5.5 and 5.6.

Based on the results of the estimated choice models, Section 5.7 will focus on finding out whether and how participants can be segregated by estimating latent class models. The conclusions of this chapter are presented in Section 5.8.

5.1 Processing Everscape data into herding data

This chapter focusses on quantifying herding by estimating choice models because the experimental set-up was designed such that elements in the experiments are actual observable elements or characteristics (e.g. whether the earthquake is happening, whether the news item is heard or seen) or elements related to the participants (e.g. age, gender).

As discussed in Chapter 2, herding is defined as seeing other people doing something (e.g. leaving) and believing that what they are doing is a good alternative, resulting in doing the same thing (Ariely, 2008). If this is actually done consciously is debatable due to a large part of people responding in a semi-automatic manner, see results from Leach (1994) presented in 2.6. In this thesis, it is assumed that herding is done consciously, which is needed to estimate choice models. It was decided to quantify the effect of herding by quantifying the actions of other people. This makes it possible to include observable characteristics of herding as an attribute into the utility function. How this is done will be explained in Section 5.3.

Before choice models can be estimated, the available data from Everscape were processed to derive the actual observed herding variables. This process is explained in this section. Several steps needed to be taken for the data to be processed such that it was possible to estimate choice models that include the effect of herding on departure choice. The first step was determining the departure choice moments. This is explained in 5.1.1. The second step was to calculate the actual herding attributes, the actions of other people that were seen by the participants. This step is explained in 5.1.2.

5.1.1 Determining the departure choice moment as the moment the evacuation started

Since the focus is on the effect of herding on departure choice, the departure choice moment had to be determined and defined. To estimate the moment consistently for all participants, it was decided to fix this moment at the second a participant started to walk towards the exit.

Fixing the departure choice moment involved a trial and error process with movies made of the experiments, see Figure 5.1 for a screenshot of one of the movies. Each circle and number represent a participant and include his viewing direction with two small lines. The concert stage and entrance/exit are schematically indicated in the figure. The following aspects were considered in the iterative process:

1. the location of the entrance/exit (between 1175 and 1200 in Figure 5.1),
2. the minimum walking speed,

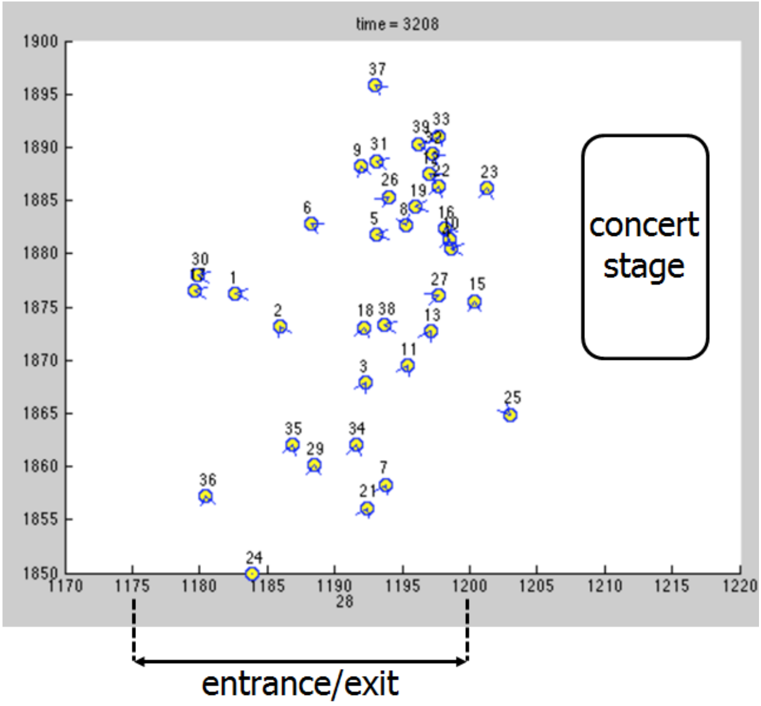

Figure 5.1: Screenshot of movie used for approximating departure choice moment

3. whether the participant was walking towards the exit and

4. whether the participants afterwards actually passed the exit.

The extracted departure choice moment was checked with the movie. If it did not match, the walking speed towards the exit was adjusted and the departure choice moment was again extracted and checked with the movie, etc. This iterative process was repeated for different experiments and for different participants, who were at different locations at the concert area and who were walking with different speeds and via different 'routes' (straight or curved line) towards the exit of the concert area.

After this iterative process, for every participant it was known at every second whether he or she was staying or leaving (evacuating from) the concert area. This process also resulted in moments where the evacuation started for all participants. From this point onwards, the herding results were calculated.

5.1.2 Determining observable herding results

Choice models cannot be estimated when only the decision to evacuate is included. It is assumed that the participants also decided to stay before they decided to leave, resulting in a sequential set-up of the choice to stay or leave. Figure 5.2 shows the decision tree of the decision to evacuate from the concert area and stay at the concert area.

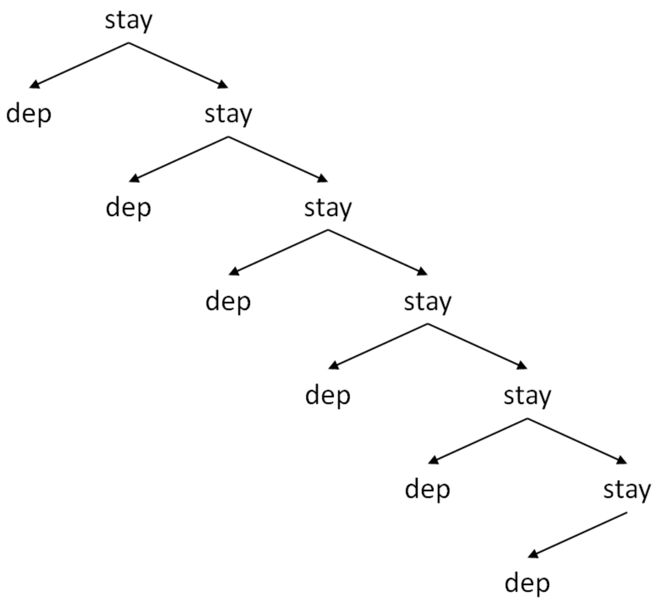

Figure 5.2: Decision tree staying at (stay) and evacuating from (dep) the concert area

It is unknown whether and how often this trade-off is made. A systematic approach is used to determine the interval times between the decision to stay at the concert area and evacuate from the concert area. Figure 5.3 schematically shows the extracted herding data per participant. For every departure choice moment (D), six stay choice moments (S) were added, with intervals of 5 seconds, to be able to see differences in evacuating and staying over time. The characteristics of the phases in the Everscape scenario changed over time. Differences in herding attributes occurred, which will be shown below.

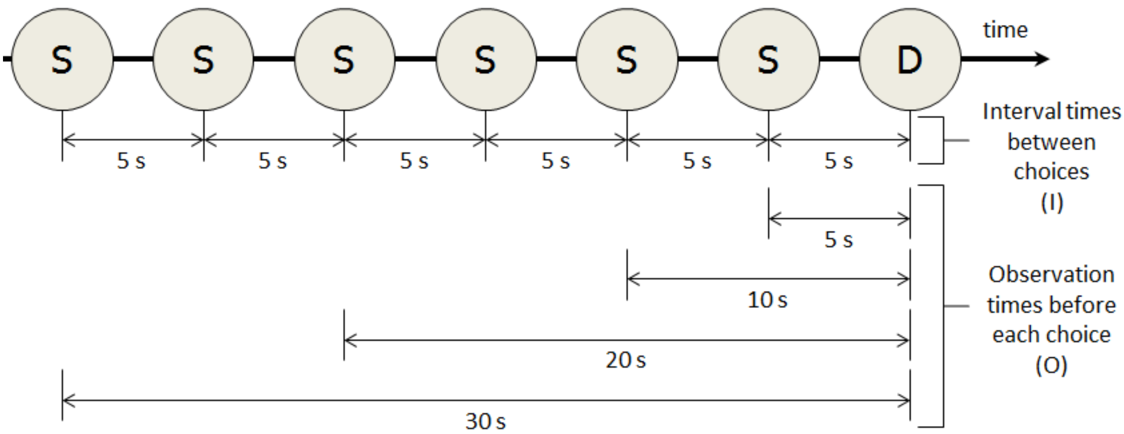

Figure 5.3: Overview of extracted herding attributes from virtual experiment

Herding is about doing the same thing as other people are doing. The actions of other people were characterised, also in a systematic way, because it is unknown how this is actually considered by people. Since the available data from Everscape included at every second the location and viewing direction of all participants, the numbers (and percentages) of people each participant could see were extracted for each second.

These numbers and percentages were determined from the departure choice moment back in time, for four different observation times per choice moment. Figure 5.3 shows only the observation times before the departure choice moment. They were also calculated before all stay choice moments.

Table 5.1 summarises the herding results for these different observation times. The observation times are considered to be time intervals that might be considered by the participants when making their departure choice. For the calculated observation times of 5 seconds, 10 seconds, 20 seconds and 30 seconds before each choice, only the unique number of participants each person saw leaving and staying were considered, so no one was considered more than once. These different observation times were chosen to systematically cover a range of options because no literature was found on how much observation time someone actually considers in such a situation.

Table 5.1: Example of herding data of Participant 'p' before his departure choice

Number of people seen	**while leaving**	**while staying**
0-1 second before departure	1 (33,3%)	2 (66,7%)
0-5 seconds before departure	1 (25,0%)	3 (75,0%)
0-10 seconds before departure	2 (40,0%)	3 (60,0%)
0-20 seconds before departure	3 (50,0%)	3 (50,0%)
0-30 seconds before departure	4 (40,0%)	6 (60,0%)

The table shows the number of people that Participant 'p' saw leaving from and staying at the concert area 1 second, 5 seconds, 10 seconds, 20 seconds and 30 seconds before his own departure. For example, within the 5 seconds before Participant 'p' left the concert area, he saw 1 person leaving and 3 persons staying. The percentages of people that Participant 'p' saw leaving from and staying at the concert area were also calculated. In case of the same example, from the people seen by Participant 'p', he saw 25% leaving and 75% staying.

Since no results from empirical research on quantifying herding were found in literature and it is unknown which observation time is considered by people, a systematic approach was used. Having multiples of 5 seconds observation time with a maximum of 30 seconds was chosen to find a way to cover different options. A maximum of 30 seconds was chosen due to the duration of the experiment and the different phases in the experiment. Consistent with literature where herding is described as, seeing other people doing something (e.g. leaving) and believing that what they are doing is a good alternative, resulting in doing the same thing (Ariely, 2008), herding is defined as: the influence of the number of people that were seen while they were leaving from or staying at the concert area on every individual's decision to leave (or stay).

Before presenting and discussing the estimated choice models, the herding attributes are presented in the next section to gain an idea of these attributes.

5.2 Descriptive analysis on herding attributes

To gain a first understanding of the results, this section presents the descriptive analysis for the herding attributes in relation to departure choice. The average numbers of people that were seen while they were staying at or leaving from the concert area are presented for the different observation times.

Table 5.2: Average and st. dev. of the number of people each participant saw staying and leaving

Observation time	**Average number staying (st.dev.)**	**Average number leaving (st.dev.)**
5 seconds before departure	2,77 (3,54)	0,78 (1,22)
10 seconds before departure	3,26 (4,01)	0,88 (1,37)
20 seconds before departure	4,28 (4,94)	1,08 (1,52)
30 seconds before departure	5,18 (5,76)	1,31 (1,80)

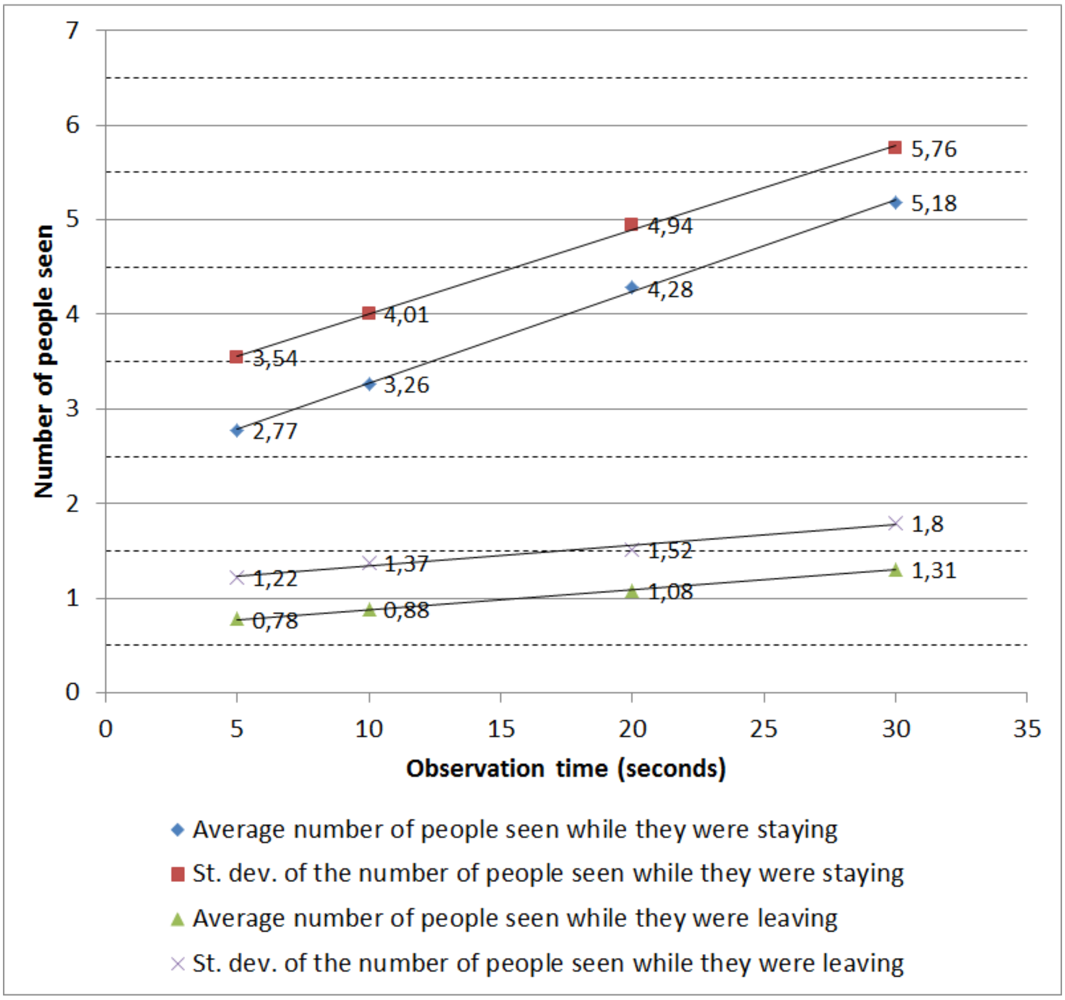

Figure 5.4: Average and st. dev. of the people seen by the participants, incl. linear trendline

Table 5.2 shows the average number of unique people the participants saw staying at the concert area and leaving from the concert area. In each experiment 27 people participated on average. This means that within the 5 seconds before the departure 3,55 (2,77+0,78) participants were on average seen; this is 13% of the participants who were taking part in the same experiment. From the people taking part in the experiment, around 10% (2,77) were seen while they were staying at the concert area and almost 3% (0,78) were seen while they were leaving. Figure 5.4 shows that the average and standard deviation of the number of people that were seen while they were staying and while they were leaving are linear. Concluding, there is a constant increase in the number of people that were seen for increasing observation times.

5.3 Process of estimating choice models

To quantify the effect of herding, this chapter will focus on estimating choice models with the data from the Everscape experiments. Before presenting and discussing the results, this section will explain the choice modelling process that was followed. To do this in a structured way, this section is split into two sub sections. The first sub section explains which models are estimated and which attributes are used in these estimations. The second sub section explains which extra aspects are checked in the choice modelling process (e.g. excluding certain participants, checking panel effect).

5.3.1 Choice modelling approach

The available discrete choices per participant were **leave from the concert area** or **stay at the concert area**. The number of included stay choices was six per choice to leave. Because herding has not been quantified, it was decided to start simple by starting with basic binary choice models and using the sequential choice set-up presented in Figure 5.2.

In general, with binary choice models, the equations respresent the utility that a person obtains from choosing one of the two alternatives (leave versus stay). This person chooses the alternative that provides the highest utility. The obtained utility depends on an alternative specific constant (ASC) and attributes. These attributes could include characteristics of the person or alternative specific characteristics.

$$U_{dep} = ASC_{dep} + \beta_n * attribute_n \tag{5.1}$$

$$U_{stay} = ASC_{stay} \tag{5.2}$$

In the case that is considered in this thesis, Equation 5.1 is the utility function representing the choice to leave from the concert area and Equation 5.2 is the utility function representing the choice to stay at the concert area. In both utility functions, an alternative specific constant is included. The alternative specific constant in Equation

5.2 was fixed to easily compare both utilities when all attributes are equal. This shows whether people were inclined to leave or stay. Here, the attributes are included in Equation 5.1 but it depended on the actual attributes in which utility function they were included. Characteristics of the person were included in U_{dep}. Alternative specific characteristics were included in the utility function they were related to.

The choice models were estimated with Biogeme (Bierlaire, 2003). The process that was followed consisted of three steps, summarised in Table 5.3.

Table 5.3: Choice modelling process

Step	Explanation of step	Reasoning behind step
1	The effect of non herding characteristics on the departure choice: age, gender, stress, information via news item, gaming experience and scenarios	To (1) find out which results match the conceptual framework presented in Chapter 2 and (2) check whether gaming experience caused a bias
2	The effect of herding on departure choice	To quantify herding
3	Combining Step 1 & Step 2	To find out which combination of attributes results in the best model

The main objective is to quantify herding but before the actual herding data were used in the choice modelling process, the effect of the other characteristics that were also considered in Chapter 4 and Section 5.2 were considered here as well in **Step 1**. This is done to find out whether the results support results from literature, hence the conceptual framework presented in Chapter 2. These characteristics are: the effect of information participants received via the news item and stress experienced by the participants. The effect of age, gender and gaming experience could not be considered because all participants made the same choices to stay and leave. The characteristics considered in this step were considered separately to find out whether the results confirm or contradict results from literature, which will be needed for the validity discussion in Chapter 6. The results of Step 1 are discussed in Section 5.4.

Step 2 of the choice modelling process focusses only on herding by using the data that were presented in Section 5.1. Figure 5.5 presents an overview of Step 2. The data included numbers and percentages of people that were seen by each participant before every choice. Based on the available data, different choice set combinations were created, including the departure choice and one, two, three or six accompanying choices to stay.

The dataset also includes the possibility to consider different observation times (5, 10, 20 and 30 seconds) before each choice moment and different interval times between the choices that were included. All combinations are shown in the box in the lower right corner of Figure 5.5. For example, O5.I5.VII means an observation time of 5 seconds

(O5), an interval time of 5 seconds (I5) and 7 choices were included (1 departure choice and 6 stay choices). It is stressed out that there were no models with overlapping observation times included to make sure that the actions of other people were only included once. The results of this step are discussed in Section 5.5.

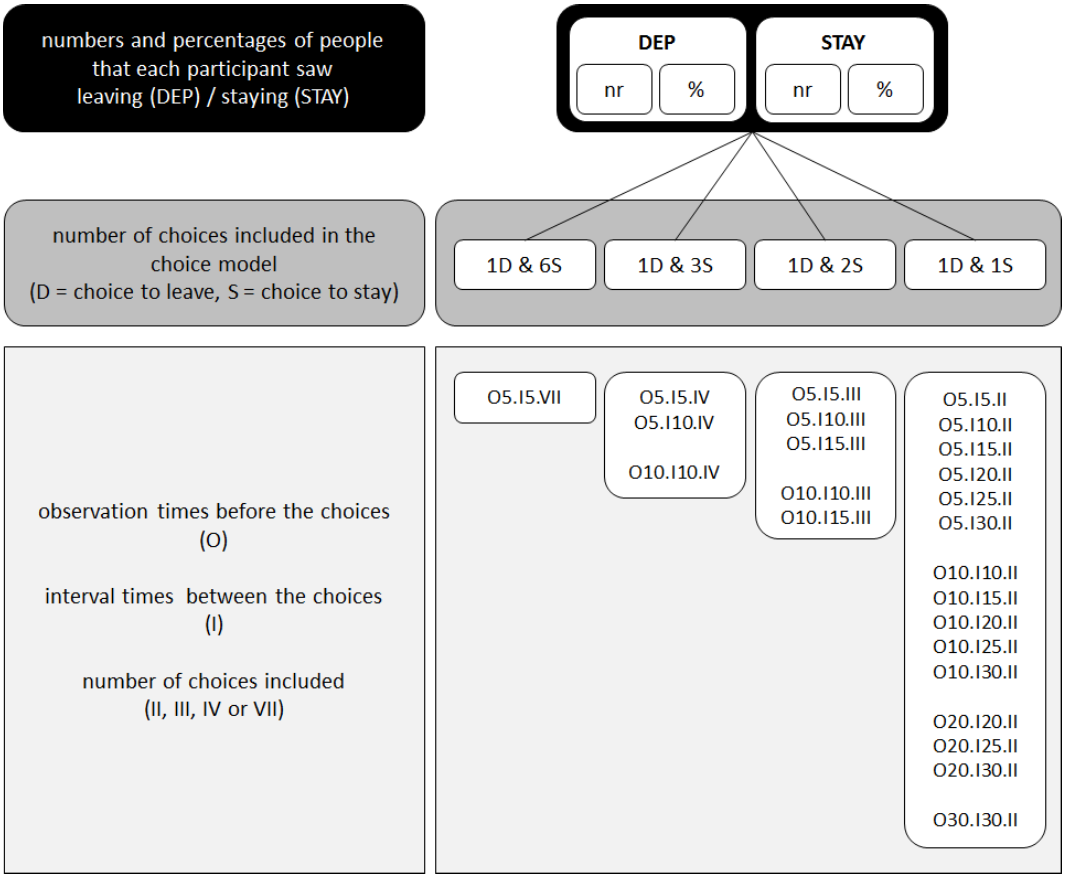

Figure 5.5: Choice modelling process Step 2

Based on the results from Step 1 and Step 2, **Step 3** focusses on combinations of herding and non herding attributes in the choice models to find out which combination results in the best model and see how herding is related to other attributes. Two options were considered, see Equations 5.3 and 5.4. Note that only the utility functions for the decision to leave are shown.

$$U_{dep} = ASC_{dep} + \beta_1 * attribute_1 + \beta_2 * attribute_2 \tag{5.3}$$

$$U_{dep} = ASC_{dep} + \beta_{1-2} * attribute_1 * attribute_2 \tag{5.4}$$

Equation 5.3 shows the utility function where herding (i.e. the number of people the participant saw leaving within the 5 seconds before his own departure) and an other attribute (i.e. age) are separately included. Equation 5.4 shows the utility function where herding is combined with the other characteristic. For example, to find out whether there is a relation between herding and age; younger people might be more inclined to follow others than older people. The results of Step 3 are discussed in Section 5.6.

Before discussing the results of Steps 1, 2 and 3, the rest of this section will describe extra aspects that were checked during the choice modelling process.

5.3.2 Panel effect, number of draws and outliers

The choice modelling process was described in 5.3.1 but extra aspects were checked as well. These checks, including the results, are briefly discussed in this sub section.

Check for panel effect
Since for every participant at least two choices were included in the modelling process, it was expected that these choices were correlated. Therefore, the panel effect is considered. No panel effect was found and it was not considered further during the choice modelling process.

Increasing the number of draws
Different number of draws were tested but they did not improve the modelling results.

Excluding participants whose behaviour differs from the rest
In the data there were different types of possible outliers, participants whose behaviour might cause a bias in the results. These outliers included participants with their departure choice before the earthquake and participants with prior knowledge. Participants who might have caused a bias were participants with 'daily' gaming experience. To find out whether they influenced the modelling results, they were removed from the dataset and the choice models were estimated again. Because the results showed no effect at all or no significant effect, it was concluded to keep all the data in the dataset.

Concluding, since these three checks did not improve the models (they did not have any effect at all on the results or they did not have a significant effect), it was decided to leave out the panel effect and keep the number of draws consistent at the value that Biogeme automatically uses. It was also decided to keep all the data to make sure there was as much data as possible.

5.4 Effect of different factors on departure choice

This section presents and discusses the results from the estimated choice models of Step 1. The same aspects will be considered that were also discussed in Chapter 4 and in Section 5.2.

Information via the news item is discussed to find out whether the results match the conceptual framework presented in Chapter 2. The stress levels participants experienced before and due to the disaster are discussed to find out whether and how they influenced departure choice. Finally, the results on socio-economic characteristics (age and gender) and gaming experience were not considered as explained in 5.3.1.

All these aspects were separately included as attributes in the choice models, as shown by Equations 5.1 and 5.2. To be able to compare the results, the estimated models of all different sets (different combinations of interval times, observation times and number of included choices) needed to lead to proper results. However, the estimated choice models with two included choices all resulted in negative values for the adjusted ρ^2. With an increasing number of choices included, the value for the adjusted ρ^2 were positive for three choices (around 0,080), four choices (around 0,186/0,187) and seven choices (between 0,406-0,408). The p-values of all estimated attributes were too high, in most cases even over 0.75.

Based on these results, it is concluded that from the data of the Everscape experiments information via the news item alone did not influence departure choice as would have been expected from the conceptual framework. Stress also did not influence departure choice.

5.5 Effect of herding on departure choice

To quantify the effect of herding, this section presents the herding results, Step 2 of the estimated choice models. The available data, see Section 5.1, include for all participants their available departure choice(s) and six created stay choices per departure choice. Before each choice moment, the numbers and percentages of people that were seen while they were leaving and while they were staying are calculated over different observation times before each choice moment.

First the results of the herding scenarios are discussed in 5.5.1 as a starter for the rest of the results. Then, the results of estimated choice models with the data as presented in Section 5.1 are discussed in the rest of this section.

To do this in an organised way, first the effect of the number of choices included in the estimated choice models are discussed in 5.5.2, followed by the effect of seeing people stay versus seeing people leave in 5.5.3 to find out what has more impact, especially on the decision to leave. Then, to find out whether it is the actual numbers or the percentages that have more impact on the departure choice, the differences from estimated choice models that included these two are discussed in 5.5.4. To find out how observation time could have been considered by the participants, the results from estimated choice models with different observation times are discussed in 5.5.5. Finally, with every departure choice moment, six stay moments were created, implying that these stay choices were assumed choices. To find out whether anything could be concluded about these stay choices, the effect of different interval times are considered in 5.5.6. The conclusions of Step 2 are discussed in 5.5.7.

5.5.1 Effect of herding scenarios on departure choice

Based on the results that were already discussed in Chapter 4 and Section 5.2, it is expected that the herding scenarios themselves do not show herding how it was supposed to (copying of the actions of the spooks). To be sure, the results are summarised here.

The different scenarios were included as attributes in the choice models that were shown by Equations 5.1 and 5.2. Similar to the results discussed in Section 5.4, the scenarios themselves were not able to show herding. Herding will in the rest of this chapter only be considered with the data as they were processed in the beginning of this chapter, so the actions of all people are included. These people consist of the participants and depending on the scenario also on the spooks.

5.5.2 Effect of the number of included stay choices

The prepared data included per departure choice, six stay choices. This made it possible to estimate choice models with a different set of choices, see bottom right part of Figure 5.5. Not all results are shown because they are consistent with each other. A selection is made in Table 5.4, showing the results for observation times of 5 seconds (O5), interval times of 5 seconds (I5) but for two (II), three (III), four (IV) and seven (VII) choices included in the choice sets.

Table 5.4: Results Step 2 - effect of including a different number of stay choices

	O5.I5.II $T_{obs} = 5$s $T_{int} = 5$s 2 choices	**O5.I5.III** $T_{obs} = 5$s $T_{int} = 5$s 3 choices	**O5.I5.IV** $T_{obs} = 5$s $T_{int} = 5$s 4 choices	**O5.I5.VII** $T_{obs} = 5$s $T_{int} = 5$s 7 choices
Adjusted ρ^2 Final log-likelihood	0,011 -561.770	0,093 -773.305	0,201 -908.094	0,417 -1.161.422
ASC_{NSTAY}	0 (0,00)	0 (0,00)	0 (0,00)	0 (0,00)
ASC_{NDEP}	-0,159 (0,05)	-0,856 (0,00)	-1,28 (0,00)	-1,96 (0,00)
β_{NDEP5}	0,261 (0,00)	0,269 (0,00)	0,307 (0,00)	0,289 (0,00)

The table shows the results for two, three, four and seven choices; O5.I5.II, O5.I5.III, O5.I5.IV and O5.I5.VII respectively. In all cases, both the interval time (I) between and observation time (O) before the choices were five seconds. The p-values are included between parentheses.

In essence, these results may not be compared because of the different size in datasets. In line with this, they of course show that the adjusted ρ^2 increases with an increasing size in dataset. The same holds for the final log-likelihood.

What is interesting to see in all of these results is that the negative value of ASC_{NDEP} shows that participants were inclined to stay at the concert area at that moment. The results also show that, the positive value of β_{NDEP5} shows that the more people a participant saw leaving, the more inclined the participant is to leave.

Concluding, it should be stressed out that the number of stay choices included in the estimation of the choice models, influences the size of the adjusted ρ^2 and final log-likelihood based on the size of the dataset. When discussing the results, comparisons will be made between estimated choice models based on the same dataset size. The results in Table 5.4 clearly show consistency in the results.

5.5.3 Effect of seeing people leave versus stay

This sub section will discuss the differences between the effect of seeing people stay versus seeing people leave on departure choice. Table 5.5 presents a selection of the results because all results are consistent with each other. It shows the results for O5.I5.II (includes 2 choices) and O5.I5.VII (includes 7 choices). The first and third column show the results that include the number of people that were seen while they were leaving (NDEP5). The second and fourth column include the results for the number of people seen while they were staying (NSTAY5). The p-values are included between parentheses. Note that, on the contrary to Equations 5.1 and 5.2, the stay attributes were included in the utility function for stay because the people seen while they were staying are expected to influence the decision to stay more than the decision to leave.

Table 5.5: Results Step 2 - effect of seeing people stay versus seeing people leave

	O5.I5.II **NDEP5** $T_{obs} = 5$s $T_{int} = 5$s 2 choices	**O5.I5.II** **NSTAY5** $T_{obs} = 5$s $T_{int} = 5$s 2 choices	**O5.I5.VII** **NDEP5** $T_{obs} = 5$s $T_{int} = 5$s 7 choices	**O5.I5.VII** **NSTAY5** $T_{obs} = 5$s $T_{int} = 5$s 7 choices
Adjusted ρ^2 Final log-likelihood	0,011 -561.770	-0,003 -569.740	0,417 -1.161.422	0,407 -1.179.891
ASC_{NSTAY}	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)
ASC_{NDEP}	-0,159 (0.05)	-0,0128 (0.89)	-1,96 (0.00)	-1,80 (0.00)
β_{NSTAY5}	n.a.	0,00466 (0.82)	n.a.	0,00242 (0.87)
β_{NDEP5}	0,261 (0.00)	n.a.	0,289 (0.00)	n.a.

When comparing the first with the second column and the third with the fourth column in the table, it can be seen that in both cases participants were inclined to stay at the concert area at that moment (ASC_{NSTAY} is fixed and ASC_{NDEP} has a negative value in all cases). The results of the models that include the number of people that were seen while they were leaving (NDEP5) perform better. Comparing the results for O5.I5.VII (includes 7 choices), it can be seen that when seeing between six and seven people leave (1,96/0.289=6,78), the participants left. Concluding, seeing people leave influenced participants to leave the concert area as well.

5.5.4 Effect of numbers and percentages of people that were seen

This sub section presents the results for the differences when considering numbers and percentages of people that were seen. Table 5.6 shows the results for comparing the effect of numbers and percentages for O5.I5.II (includes 2 choices) and O5.I5.VII (includes 7 choices). NDEP means number of people that were seen while they were leaving and PDEP means the percentage of people that were seen while they were leaving. The p-values are included between parentheses.

Table 5.6: Results Step 2 - effect of differences between including numbers and percentages

	O5.I5.II NDEP5 $T_{obs} = 5$s $T_{int} = 5$s 2 choices	**O5.I5.II PDEP5** $T_{obs} = 5$s $T_{int} = 5$s 2 choices	**O5.I5.VII NDEP5** $T_{obs} = 5$s $T_{int} = 5$s 7 choices	**O5.I5.VII PDEP5** $T_{obs} = 5$s $T_{int} = 5$s 7 choices
Adjusted ρ^2 Final log-likelihood	0,011 -561.770	0,002 -566.734	0,417 -1.161.422	0,413 -1.168.432
ASC_{NSTAY}	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)
ASC_{NDEP}	-0,159 (0.05)	-0,0971 (0.23)	-1,96 (0.00)	-1,92 (0.00)
β_{NDEP5}	0,261 (0.00)	n.a.	0,289 (0.00)	n.a.
β_{PDEP5}	n.a.	0,00266 (0.02)	n.a.	0,00942 (0.00)

The results confirm that participants were inclined to stay at the concert area at that moment. This table also shows that the models including the numbers of people that were seen while they were leaving clearly perform better than the models that include the percentages of people that were seen while they were leaving (see adjusted ρ^2 and p-value). Apparently, it does not matter what share of people is leaving, it suggests that by just seeing people leave, participants were inclined to follow at that moment.

5.5.5 Effect of observation times before each choice when considering herding

This sub section discusses the differences in included observation times for the timeslots in which the number of people that were seen by the participants stayed or left. Table 5.7 shows a selection of the results for the number of people that were seen while they were leaving the concert area. The results for the number of people seen while they were staying are not shown but they are consistent with the results that are presented below. The p-values are included between parentheses.

Table 5.7: Results Step 2 - effect of different obervation times

	O5.I30.II NDEP5 $T_{obs} = 5$s $T_{int} = 30$s 2 choices	**O10.I30.II NDEP10** $T_{obs} = 10$s $T_{int} = 30$s 2 choices	**O20.I30.II NDEP20** $T_{obs} = 20$s $T_{int} = 30$s 2 choices	**O30.I30.II NDEP30** $T_{obs} = 30$s $T_{int} = 30$s 2 choices
Adjusted ρ^2 Final log-likelihood	0,014 -559.543	0,008 -563.457	0,005 -564.896	0,006 -564.432
ASC_{NSTAY}	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)
ASC_{NDEP}	-0,176 (0.03)	-0,143 (0.08)	-0,141 (0.09)	-0,157 (0.06)
β_{NDEP}	0,300 (0.00)	0,201 (0.00)	0,154 (0.00)	0,142 (0.00)

The table shows the results for different observation times keeping the number of choices and intervals between the included choices the same. To keep the interval time the same for all models, the largest interval time was used. Based on the adjusted ρ^2 and p-values, the model with an observation time of 5 seconds performs best. In general, shorter observation times result in a better model. This suggests that the last few seconds influence the decision to leave the most.

As discussed in 2.4.2, Prechter (2001) stated that herding behaviour results from impulsive mental activity in individuals responding to signals from the behaviour of others. In line with this, it makes sense that the last few seconds before the decision to leave are most important, have most impact on the decision to leave.

5.5.6 Effect of different interval times between choices when considering herding

It is assumed that participants did not continuously make the trade-off between staying and leaving. Since extra stay choice were created with the dataset, it is expected that they influence the results. In 5.5.2 the effect of the number of choices were discussed.

One aspect that should be considered because of these created stay choices, is the effect of interval times between the choices to stay and leave.

When considering a stay choice moment further away from the departure choice moment, the situation was most likely more different compared to considering a stay choice moment closer to the departure choice. For example, when considering choices further away from each other, the departure choice might be during the news item and the stay choice during the earthquake. In line with this, when considering choices closer together, both choices might have been during the news item. So, with a shorter interval time, the situation before the decision was much more similar than with a longer interval time. It is expected that when the situation is more similar, the effect of herding might be easier identifiable because this was the aspect most likely to be different (or the only aspect that was different). The results are shown in Table 5.8, including again the p-values between parentheses.

The table shows some differences in the adjusted ρ^2 over the different interval times. The values for ASC_{NDEP} and β_{NDEP5} also differ a little. When calculating ASC_{NDEP} / β_{NDEP5}, see bottom row in the table, O5.I15.II (interval time 15 seconds, 2 choices) shows the lowest value and O5.I5.II (interval time 5 seconds, 2 choices) the largest value.

What can be concluded from this with respect to behaviour remains guessing. It might just be caused by coincidence. Because all participants left, the question is when they left, so for each participant it is the question when the climax was reached.

5.5.7 Conclusions on herding results

Based on the basic herding results presented in this section, the following main conclusions are drawn:

- No matter the amount of choices included in the estimation of the choice models, the results are consistent:
  - For any random moment during the experiment, participants are inclined to stay at the concert area.
  - The more people a participant sees leaving, the more inclined this participant was to leave.
- Seeing people leave has more impact on the decision to leave than seeing people stay.
- Numbers of people that are seen influence the decision to leave or stay more than percentages.
- Seeing other people leaving the last few seconds before a departure influences the decision to leave the most.

Table 5.8: Results Step 2 - effect of different interval times

	O5.I5.II **NDEP5** $T_{obs} = 5$s $T_{int} = 5$s 2 choices	**O5.I10.II** **NDEP5** $T_{obs} = 5$s $T_{int} = 10$s 2 choices	**O5.I15.II** **NDEP5** $T_{obs} = 5$s $T_{int} = 15$s 2 choices	**O5.I20.II** **NDEP5** $T_{obs} = 5$s $T_{int} = 20$s 2 choices	**O5.I25.II** **NDEP5** $T_{obs} = 5$s $T_{int} = 25$s 2 choices	**O5.I30.II** **NDEP5** $T_{obs} = 5$s $T_{int} = 30$s 2 choices
Adjusted ρ^2	0,011	0,012	0,024	0,014	0,017	0,014
Final log-likelihood	-561.770	-560.761	-554.375	-559.990	-558.279	-559.543
ASC_{NSTAY}	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)
ASC_{NDEP}	-0,159 (0.05)	-0,174 (0.03)	-0,225 (0.01)	-0,178 (0.03)	-0,183 (0.02)	-0,176 (0.03)
β_{NDEP5}	0,261 (0.00)	0,288 (0.00)	0,405 (0.00)	0,299 (0.00)	0,321 (0.00)	0,300 (0.00)
ASC_{NDEP} / β_{NDEP5}	0,609	0,604	0,556	0,595	0,570	0,587

One remark is to be made with respect to the set-up of the departure and stay choices. It is unknown whether the stay choices were actually considered by the participants. Not deciding to leave is assumed to be the same as making the decision to stay. This assumption had to be made to estimate choice models.

Because every participant left, it was the question when they left and which influencing factors played a role in their decision to leave. Since it is unknown how this works, a structured approach was used with different interval times between the choices to leave and stay and different observation times before the choices. This structured approach confirmed herding. Especially the last few seconds before participants decided to leave were influenced by herding. This makes sense because from literature it is known that herding results from impulsive mental activity.

To find out whether herding can be explained further and especially be related to other aspects, the following section will focus on combining herding with other aspects. Because of the similarities in results, the sets O5.I5.II (interval time of 5 seconds, including 2 choices) and O5.I5.VII (interval time of 5 seconds, including 7 choices) will be mainly considered. The set O5.I15.II (interval time of 15 seconds, including 2 choices) is also included in the analysis because of slightly better modelling results with respect to interval time.

5.6 Aspects influencing herding

Sections 5.4 and 5.5 showed that only herding influenced departure choice of the participants in the Everscape experiments. To find out whether there are differences in herding for the different aspects also considered in Section 5.2, this section will discuss the results of Step 3 of the estimated choice models that included a combination of herding and these aspects.

The models that were estimated are shown by Equations 5.3 and 5.4. The results of models shown with the first equation did not improve the modelling results of Step 2. Therefore, they are not discussed. On the contrary, the set of models from Equation 5.4 showed similar results or improved the results. This section will discuss these results. Based on the basic herding results which showed that most of the results are consistent with each other, the discussion on the results will focus on the sets O5.I5.II (interval time of 5 seconds, including 2 choices) and O5.I5.VII (interval time of 5 seconds, including 7 choices). Due to a difference in results in interval time, O5.I15.II (interval time of 15 seconds, including 2 choices) is also included.

The results on socio-economic characteristics are presented in 5.6.1 to consider differences in herding with respect to age and gender. To find out whether differences in herding were found because of the news item, estimated choice models including a combination of herding and the news item are discussed in 5.6.2. The effect of stress on herding is considered in 5.6.3. To find out whether gaming experience caused a bias, the effect of gaming experience on herding is discussed in 5.6.4. After the results of each aspect together with herding are discussed, 5.6.5 discusses the results on combining two aspects with herding.

In line with the discussion on the effect of observation and interval times in Section 5.5, the effect of different observation and interval times are discussed in 5.6.6 and 5.6.7 respectively. Besides the sets O5.I5.II, O5.I15.II and O5.I5.VII, the other sets are also considered here. The conclusions of this section are discussed in 5.6.8.

5.6.1 Effect of socio-economic characteristics on herding results

In this sub section, the relation between age and gender are discussed by presenting the results on estimated choice models that included both herding and age or gender.

Herding and age
To find out whether there is a relation between age and herding, choice models have been estimated that included both aspects in one attribute, see Equation 5.3. The results are shown in Table 5.9, including the p-values between parentheses.

Based on the results presented in 4.4.1, it was decided to split the age groups into two: 12-40 and 41-80. This was done because participants of 12-20 and 21-30 showed similar departure choice behaviour and participants of 41-50 and 51-60 showed this as well. The other age-groups were much less represented and could not form a separate group. Participants of 31-40 were added to the youngest group because their departure choice behaviour was more similar to them than to the group of 41-60. The groups of 61-70 and 71-80 were then added to the 41-60 group.

Table 5.9: Results Step 3 - herding and age

	O5.I5.II $T_{obs} = 5$s $T_{int} = 5$s 2 choices	**O5.I15.II** $T_{obs} = 5$s $T_{int} = 15$s 2 choices	**O5.I5.VII** $T_{obs} = 5$s $T_{int} = 5$s 7 choices
Adjusted ρ^2 Final log-likelihood	0,009 -561.750	0,023 -553.673	0,416 -1.160.781
ASC_{NSTAY}	0 (0.00)	0 (0.00)	0 (0.00)
ASC_{NDEP}	-0,160 (0.05)	-0,219 (0.01)	-1,960 (0.00)
$\beta_{age12-40\_NDEP5}$	0,256 (0.00)	0,446 (0.00)	0,305 (0.00)
$\beta_{age41-80\_NDEP5}$	0,287 (0.06)	0,254 (0.08)	0,206 (0.04)

Table 5.9 confirms that participants were inclined to stay at the concert area. It confirms that for both age groups, the more people a participant saw leaving, the more inclined

this participant was to leave at that moment as well. The values for β show that with the sets O5.I15.II (interval time 15 seconds, including 2 choices) and O5.I5.VII (interval time 5 seconds, including 7 choices), the younger age group was more inclined to follow other people while they were leaving. With O5.I5.II (interval time 5 seconds, including 2 choices) the older age group was a little bit more inclined to follow at that moment. The results of the other sets are not shown but they all confirm that the younger age group was more inclined to follow at that moment. The table also shows that O5.I15.II (interval time 15 seconds, including 2 choices) has a higher adjusted ρ^2 and a smaller final log-likelihood than O5.I5.II (interval time 5 seconds, including 2 choices) and performs better.

Herding and gender

Choice models have also been estimated that included a combination of gender and herding in one attribute, see Equation 5.3. The results are shown in Table 5.10 for O5.I5.II (interval time 5 seconds, including 2 choices), O5.I15.II (interval time 15 seconds, including 2 choices) and O5.I5.VII (interval time 5 seconds, including 7 choices), including the p-values between parentheses.

Table 5.10: Results Step 3 - herding and gender

	O5.I5.II $T_{obs} = 5$s $T_{int} = 5$s 2 choices	**O5.I15.II** $T_{obs} = 5$s $T_{int} = 15$s 2 choices	**O5.I5.VII** $T_{obs} = 5$s $T_{int} = 5$s 7 choices
Adjusted ρ^2 Final log-likelihood	0,009 -561.592	0,022 -554.374	0,416 -1.161.411
ASC_{NSTAY}	0 (0.00)	0 (0.00)	0 (0.00)
ASC_{NDEP}	-0,161 (0.05)	-0,225 (0.01)	-1,960 (0.00)
β_{fem_NDEP5}	0,232 (0.01)	0,407 (0.00)	0,295 (0.00)
β_{male_NDEP5}	0,304 (0.01)	0,403 (0.00)	0,282 (0.00)

The values for β in the table confirm that participants were inclined to stay at the concert area at that moment. Like with the results for age, O5.I5.II (interval time 5 seconds, including 2 choices) is an exception and shows that men were more inclined to follow other people while they were leaving. All other results show that women were more inclined to follow other people but the difference is small. Based on this, herding is not clearly different for men than women.

5.6.2 Effect of information on herding results

To find out whether herding was influenced by the information participants received via the news item, choice models have been estimated that included a combination of these aspects in one attribute, see Equation 5.3. The results are shown in Table 5.11, including the p-values between parentheses.

Table 5.11: Results Step 3 - herding and information via news item

	O5.I5.II $T_{obs} = 5$s $T_{int} = 5$s 2 choices	**O5.I15.II** $T_{obs} = 5$s $T_{int} = 15$s 2 choices	**O5.I5.VII** $T_{obs} = 5$s $T_{int} = 5$s 7 choices
Adjusted ρ^2 Final log-likelihood	0,009 -561.631	0,023 -553.414	0,416 -1.161.400
ASC_{NSTAY}	0 (0.00)	0 (0.00)	0 (0.00)
ASC_{NDEP}	-0,157 (0.05)	-0,226 (0.01)	-1,960 (0.00)
β_{newsno_NDEP5}	0,289 (0.00)	0,507 (0.00)	0,296 (0.00)
$\beta_{newsyes\_NDEP5}$	0,226 (0.02)	0,316 (0.00)	0,279 (0.00)

The table again confirms that participants were inclined to stay at the concert area at that moment and in both cases (before and after receiving information via the news), participants were inclined to follow others. Participants were more likely to follow others before the news item, so before the information was presented to them. This makes sense because when someone knows more about a situation he or she does not need to depend on other people's actions.

5.6.3 Effect of stress on herding results

To find out whether and how herding is influenced by stress, the results on estimated choice models including a combination of herding and stress in one attribute (see Equation 5.3) are shown in Table 5.12, including the p-values between parentheses.

Since the stress levels experienced before the disaster were very similar over all participants, these stress levels are not considered. The stress levels participants experienced due to the disaster are split into two groups: 1-5 and 6-10. These groups were chosen based on the average level being around five.

Since all participants left and most of them had as their main goal to get to the helicopter, their behaviour is considered to be rational. In line with this, it is expected that for those who experienced higher stress levels, they were more inclined to follow others while they were leaving.

Table 5.12: Results Step 3 - herding and stress due to the disaster

	O5.I5.II $T_{obs} = 5$s $T_{int} = 5$s 2 choices	**O5.I15.II** $T_{obs} = 5$s $T_{int} = 15$s 2 choices	**O5.I5.VII** $T_{obs} = 5$s $T_{int} = 5$s 7 choices
Adjusted ρ^2 Final log-likelihood	0,009 -522.237	0,023 -514.812	0,416 -1.080.613
ASC_{NSTAY}	0 (0.00)	0 (0.00)	0 (0.00)
ASC_{NDEP}	-0,164 (0.05)	-0,232 (0.01)	-1,960 (0.00)
$\beta_{stressdueto1-5\_NDEP5}$	0,296 (0.01)	0,387 (0.00)	0,276 (0.00)
$\beta_{stressdueto6-10\_NDEP5}$	0,252 (0.00)	0,440 (0.00)	0,301 (0.00)

The table shows that participants were inclined to stay at the concert area at that moment. In line with the results presented earlier in this section, O5.I5.II (interval time 5 seconds, 2 choices) seems to be an exception. With this set, participants who experienced a lower stress level were more inclined to follow others. With the other sets, participants who experienced higher stress levels were more inclined to follow. Concluding, in most cases the results confirm that participants who were more stressed were more inclined to follow others while they were leaving. Note that the final log-likelihood for O5.I5.VII (interval time 5 seconds, 7 choices) is smaller for stress than e.g. information from the news item because of less respondents. This was caused by problems when uploading the questionnaires.

5.6.4 Effect of gaming experience on herding results

To find out whether gaming experience influenced herding, a combination of these two aspects is included as an attribute. The results are shown in Table 5.13, including the p-values between parentheses.

It was expected that participants with less experience are more likely to follow others because for them their actions suggest that they know what they are doing.

In general, the rows in the middle show participants who were more inclined to follow. So, participants with daily gaming experience and participants with much less or no gaming experience show that they are the least inclined to follow other people. But in general, the table does not clearly show a relation between herding and gaming experience.

Table 5.13: Results Step 3 - herding and gaming experience

	O5.I5.II $T_{obs} = 5$s $T_{int} = 5$s 2 choices	**O5.I15.II** $T_{obs} = 5$s $T_{int} = 15$s 2 choices	**O5.I5.VII** $T_{obs} = 5$s $T_{int} = 5$s 7 choices
Adjusted ρ^2 Final log-likelihood	0,004 -560.669	0,022 -554.374	0,414 -1.161.855
ASC_{NSTAY}	0 (0.00)	0 (0.00)	0 (0.00)
ASC_{NDEP}	-0,157 (0.05)	-0,219 (0.01)	-1,950 (0.00)
$\beta_{gameDaily\_NDEP5}$	0,288 (0.17)	0,370 (0.06)	0,257 (0.04)
$\beta_{gameWeekly\_NDEP5}$	0,270 (0.04)	0,511 (0.00)	0,315 (0.00)
$\beta_{gameMonthly\_NDEP5}$	0,409 (0.03)	0,409 (0.02)	0,319 (0.02)
$\beta_{gameLess1month\_NDEP5}$	0,452 (0.03)	0,515 (0.01)	0,291 (0.01)
$\beta_{gameNmyCoT\_NDEP5}$	0,231 (0.09)	0,344 (0.02)	0,263 (0.00)
$\beta_{gameNever\_NDEP5}$	0,138 (0.28)	0,359 (0.01)	0,291 (0.00)

5.6.5 Effect of combining more aspects with herding

Based on the results discussed in this section so far, it was decided to also combine two aspects with herding to find out whether the models would improve. The models that were estimated are an extension of Equation 5.4 and shown by Equation 5.5.

$$U_{dep} = ASC_{dep} + \beta_{1-2-3} * attribute_1 * attribute_2 * attribute_3 \tag{5.5}$$

The estimated choice models did not provide new insights or improve the results and are therefore not discussed.

5.6.6 Effect of observation times before each choice when considering the influence of other aspects on herding

This sub section discusses the differences in included observation times for the timeslots in which the number of people that were seen by the participants while they were leaving the concert area. Since the number of people that were seen while they were staying at the concert area had less effect, they are not considered. The results are shown in Table 5.14 for models including herding and age, including the p-values between parentheses. The other results are in line with these. To compare the results for different observation times, the interval times are the same (30 seconds).

Table 5.14: Results Step 3 - effect of different obervation times

	O5.I30.II NDEP5 $T_{obs} = 5$s $T_{int} = 30$s 2 choices	**O10.I30.II NDEP10** $T_{obs} = 10$s $T_{int} = 30$s 2 choices	**O20.I30.II NDEP20** $T_{obs} = 20$s $T_{int} = 30$s 2 choices	**O30.I30.II NDEP30** $T_{obs} = 30$s $T_{int} = 30$s 2 choices
Adjusted ρ^2 Final log-likelihood	0,014 -558.634	0,008 -562.176	0,004 -564.466	0,004 -564.206
ASC_{NSTAY}	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)
ASC_{NDEP}	-0,171 (0.03)	-0,139 (0.09)	-0,138 (0.10)	-0,154 (0.07)
$\beta_{age12-40\_NDEP}$	0,344 (0.00)	0,247 (0.00)	0,176 (0.00)	0,155 (0.00)
$\beta_{age41-80\_NDEP}$	0,149 (0.27)	0,059 (0.58)	0,0848 (0.35)	0,0983 (0.21)

As can be seen in the table, the interval time is the same for all four modelling results (30 seconds). The results show that the highest adjusted ρ^2 for the shortest observation time. It can be seen that for shorter observation times, herding has more impact.

5.6.7 Effect of interval times between choices when considering the influence of other aspects on herding

The effect of different interval times between the choices are discussed here to find out how they influence the results. Since the results are in line with each other, they are presented for a selection of the estimated choice models. The results for herding and age are shown in Table 5.15, including the p-values between parentheses.

The table confirms the results in 5.5.6, showing the highest adjusted ρ^2 for O5.I15.II (interval time 15 seconds, 2 choices). The results of O5.I5.II (interval time 5 seconds, 2 choices) are different from the rest (again) because it suggests the older age group to be more inclined to follow others, while the other results show the opposite.

5.6.8 Conclusions effect of other aspects influencing herding

This section presented the results on aspects that might have influenced herding, which is Step 3 of the choice modelling process. The results confirmed that participants were inclined to stay at the concert area at that moment. They showed that all different groups (younger participants versus older participants, men versus women, etc.) have confirmed herding. The differences in results due to different observation and interval times from Section 5.5 were confirmed as well. Based on the adjusted ρ^2's, the models in this section (Step 3) did not significantly improve the models in Section 5.5 (Step 2).

The results did not show that it was possible to conclude what type of people are more likely to follow than others. The next section will take a closer look at this by considering latent class models.

5.7 Segmentation of people based on herding

Based on the herding results discussed in this chapter, this section focusses on grouping participants with latent class models. These latent class models were estimated to find out whether a segmentation could be made based on herding. Some background information is needed to clarify this.

Chapter 2 described typical human evacuation behaviour based on phases that are distinguished during all types of natural disasters. Leach (1994) stated that during the impact phase a classification of people can be made into three groups based on their psycho-behavioural responses. The first group of people undertakes action and remains calm and rational, the second group reacts in a semi-automatic manner and the third group responds uncontrolled and inappropriate. According to Leach (1994), the second group consists of about 75% of the people. The other two groups consist of about the same shares of people (10-15%).

Table 5.15: Results Step 3 - effect of different interval times

	O5.I5.II **NDEP5** $T_{obs} = 5s$ $T_{int} = 5s$ 2 choices	**O5.I10.II** **NDEP5** $T_{obs} = 5s$ $T_{int} = 10s$ 2 choices	**O5.I15.II** **NDEP5** $T_{obs} = 5s$ $T_{int} = 15s$ 2 choices	**O5.I20.II** **NDEP5** $T_{obs} = 5s$ $T_{int} = 20s$ 2 choices	**O5.I25.II** **NDEP5** $T_{obs} = 5s$ $T_{int} = 25s$ 2 choices	**O5.I30.II** **NDEP5** $T_{obs} = 5s$ $T_{int} = 30s$ 2 choices
Adjusted ρ^2	0,009	0,011	0,023	0,014	0,015	0,014
Final log-likelihood	-561.750	-560.756	-553.673	-559.069	-558.101	-558.634
ASC_{NSTAY}	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)
ASC_{NDEP}	-0,160	-0,173	-0,219	-0,169	-0,180	-0,171
	(0.05)	(0.03)	(0.01)	(0.04)	(0.03)	(0.03)
$\beta_{age12-40\_NDEP}$	0,256	0,290	0,446	0,340	0,338	0,344
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
$\beta_{age41-80\_NDEP}$	0,287	0,275	0,254	0,136	0,246	0,149
	(0.06)	(0.06)	(0.08)	(0.32)	(0.09)	(0.27)

Uncontrolled or inappropriate behaviour (or panic) has been shown by several researchers to be quite uncommon (Aguirre, 2005; Blake et al., 2004; Bohannon, 2005; Cornwell, 2003; Mawson, 2005). An example of where panic behaviour did occur is the Love Parade in July 2010 in Germany (Helbing and Mukerji, 2012). This panic behaviour is easily transferred to other people and in case of that Love Parade made the situation into a crowd disaster.

Based on the results presented in Chapter 4 and in Chapter 5 so far, uncontrolled and inappropriate behaviour did not occur during the experiments because all participants have been seriously trying to evacuate safely. The main and very simplified difference between participants was that some left earlier and others left later. The objective for this section, which is based on this and the literature of Leach (1994), is to find out whether a segmentation can be made of people who undertake action and who react semi-automatic. In other words, the objective is to find out whether a segmentation can be made based on people who can be considered as leaders and people who can be considered as followers. This will be done with latent class models.

The same choice modelling approach will be used as with the estimated choice models in the previous sections. The results of these latent class models are discussed in 5.7.1. The conclusions of this section are presented in 5.7.2.

5.7.1 Results estimated latent class models

In this sub section, the results of estimated latent class models are discussed to focus on segmentation of the participants into classes. With latent class models it is assumed that different classes exist that each have homogeneous preferences. The classes cannot be observed and emerge from the estimation process. A separate set of parameters (of MNL type) is estimated for each class. The approach was based on the same approach that was also used for estimating the choice models in the previous sections (Steps 1, 2 and 3).

As a reminder, in Step 1 no herding but only other characteristics were included in the models. These were information via news item and stress experienced due to the disaster. Since the focus is on grouping people based on herding, Step 1 is not considered with the latent class models.

In Step 2, not the other characteristics but only herding was considered. On the contrary to Step 1, this step is considered with the latent class models. Because the numbers showed to have more effect than the percentages, these numbers of people that were seen are considered with the latent class models as well. Even though NSTAY[1] showed to have less effect than NDEP[2] with the MNL models, NSTAY is considered with the latent class models for completeness sake.

[1] As a reminder NSTAY is the number of people that were seen while they were staying. NSTAY5 then means within the 5 seconds before that decision.

[2] As a reminder NSTAY is the number of people that were seen while they were leaving. NDEP5 then means within the 5 seconds before that decision.

In Step 3, combinations of herding and other characteristics (see Step 1) were included in the MNL models. This was also done with the latent class models to find class membership on the basis of these other characteristics.

With respect to the choice sets, the choice sets used with the MNL choice models and leading to the best results were O5.I5.II (interval time 5 seconds, including 2 choices), O5.I15.II (interval time 15 seconds, including 2 choices) and O5.I5.VII (interval time 5 seconds, including 7 choices). The sets that included only 2 choices will not be discussed because their parameters resulted in no or too few significance levels of 1%, 5% and 10% or it was even impossible to estimate the models. The selection of results presented in this section shows the estimated choice models with the choice set O5.I5.VII[3].

To summarise, the following modelling steps were taken with the choice set O5.I5.VII:

1. Only herding:
   (a) NDEP (2 classes), no class membership variables.
   (b) NSTAY (2 classes), no class membership variables.
   (c) NDEP & NSTAY (2 classes), no class membership variables.
   (d) NDEP & NSTAY (3 classes), no class membership variables.
   (e) NDEP & NSTAY (2 classes), including as variables for class membership:
      i. the age of the participants,
      ii. gender of the participants,
      iii. information via the news item,
      iv. stress experienced due to the disaster,
      v. gaming experience.
2. Herding and information via the news item:
   (a) NDEP & information via the news item (2 classes), no class membership variables.
   (b) NSTAY & information via the news item (2 classes), no class membership variables.
   (c) NDEP & NSTAY & information via the news item (2 classes), no class membership variables.
   (d) NDEP & NSTAY & information via the news item (2 classes), including as variables for class membership:
      i. the age of the participants,
      ii. gender of the participants,

[3] As a reminder O5.I5.VII means an observation time before the decisions of 5 seconds, interval time between the decisions of 5 seconds and 7 choices included in the choice set.

iii. stress experienced due to the disaster,
iv. gaming experience.

This list is the list of which the results will be shown and discussed. The latent class models involved more classes and all combinations of the other characteristics from the list above but they resulted in:

- no or too few significance levels of 1%, 5% and 10%,
- class probabilities of 1,0 & 0,0,
- models that could not be estimated.

Table 5.16 shows the results on herding for the latent class models without class membership. It includes Steps 1a, 1b, 1c and 1d from the list above. The MNL results (the top row in the table) show the overall model results, the LC results (the second row in the table) show the latent class results. The third row shows the overall MNL results for the constant and parameters (NDEP5 and NSTAY5), the fourth, fifth and sixth row show the results for the constant and parameters per class. The row at the bottom of the table shows the class probabilities.

The first column in Table 5.16 shows NDEP (2), which presents the modelling results when the number of people seen while they were leaving are included, for a model including (2) latent classes. The second column shows NSTAY (2), which presents the modelling results when the number of people seen while they were staying are included (also for a model including (2) classes). When comparing these two modelling results, it can be concluded that based on the McFadden Pseudo R-squared and Akaike's Information Criterion NDEP (2) performs better. This is consistent with the results in 5.5.3.

The third column in Table 5.16 shows the results for the 2 classes model when both NDEP5 and NSTAY5 are included, so the number of people that were seen while they were leaving and while they were staying 5 seconds before the decision moment. In this case, seeing people leave has more impact on the decision than seeing people stay. When considering the coefficients of the classes, class 1 is influenced by NDEP5 (not by NSTAY5), based on the significance level between parentheses being larger than 10%. Class 2 does not seem to be influenced by NDEP5 or NSTAY5. This means that members of class 1 were influenced by people who left 5 seconds before their decision moment and members of class 2 were not influenced by people they saw leaving or staying.

The fourth column in Table 5.16 shows the results for the (3) classes model when both NDEP5 and NSTAY5 are included. Based on Akaike's Information Criterion, which means that the best model has the lowest AIC, this model performs a little worse than the 2 classes model. With none of the classes NDEP or NSTAY seem to have influenced

Table 5.16: Latent class results on herding ***without class membership***

Herding attribute (nr. of classes)	NDEP (2)	NSTAY (2)	NDEP & NSTAY (2)	NDEP & NSTAY (3)
MNL - Log likelihood function	-1.161.422	-1.179.891	-1.160.002	-1.160.002
MNL - Restricted log likelihood	-1.179.905	-1.179.905	-1.179.905	-1.179.905
MNL - Significance level	.000	.871	0.000	0.000
MNL - McFadden Pseudo R-squared	.016	.000	.017	.017
MNL - Inf.Cr.AIC	.809	.822	.808	.808
LC - Log likelihood function	-1.159.398	-1.179.891	-1.154.294	-1.151.770
LC - Restricted log likelihood	-1.161.422	-1.179.891	-1.160.002	-1.160.002
LC - Significance level	.399	1.000	.044	.058
LC - McFadden Pseudo R-squared	.002	.000	.005	.007
LC - Inf.Cr.AIC	.809	.824	.807	.808
Constant	1.96 (.00)	1.80 (.00)	1.90 (.00)	1.90 (.00)
NDEP5	-,29 (.00)	n.a.	-.32 (.00)	-.32 (.00)
NSTAY5	n.a.	-0.0024 (.87)	.03 (.10)	.03 (.10)
Constant class 1	2.77 (.47)	4.06 (1.00)	.06 (.96)	8.24 (.29)
NDEP5 class 1	.11 (.92)	n.a.	-1.21 (.04)	-12.70 (.22)
NSTAY5 class 1	n.a.	-.49D-04 (1.00)	.13 (.19)	.93 (.19)
Constant class 2	.99 (.62)	-.15 (1.00)	7.36 (.29)	-7.81 (.43)
NDEP5 class 2	-.87 (.33)	n.a.	32.73 (1.00)	29.12 (1.00)
NSTAY5 class 2	n.a.	-.005 (1.00)	-.34 (.42)	1.42 (.43)
Constant class 3	n.a.	n.a.	n.a.	2.89 (.00)
NDEP5 class 3	n.a.	n.a.	n.a.	-.19 (.13)
NSTAY5 class 3	n.a.	n.a.	n.a.	-.06 (.23)
Class1Pr	.72 (.00)	.76 (1.00)	.27 (.06)	.16 (.00)
Class2Pr	.28 (.23)	.24 (1.00)	.73 (.00)	.08 (.00)
Class3Pr	n.a.	n.a.	n.a.	.75 (.00)

the decision moment because of too high significance levels that are shown between parentheses.

Table 5.17 shows the results for Step 1e from the list on herding for the latent class models with class membership. In all cases both NDEP5 and NSTAY5 are included. The first through the fifth column show the results for age, gender, information via the news item, stress experienced due to the disaster and gaming experience respectively.

Based on Akaike's Information Criterion the best model is when news determines class membership. In this case AIC is the lowest (.807). For this model, seeing people leave has more impact on the decision to leave than seeing people stay. For class 2, people are not influenced by the actions of others, while in class 1 they are influenced by this. With class 1 people are influenced by seeing people while they are leave and while they are staying but the effect of seeing people leaving is stronger because the value of NDEP5 is larger than the value of NSTAY5.

The results show that before the news people were more influenced by the behaviour of others than after the news. The results for class membership show that 25% of the people are part of class 1 and 75% are part of class 2. Concluding, most of the participants were not influenced by the actions of others.

Table 5.18 shows the results for Steps 2a, 2b and 2c from the list on herding for the latent class models without class membership. Now information via the news item is also part of the independent variables. The first column shows the resuls for only NDEP and the news, the second column for only NSTAY and the news and the third column shows the results for NDEP, NSTAY and the news.

Based on Akaike's Information Criterion, the model including NDEP, NSTAY and NEWS performs best because AIC is the lowest (.807). The results for NDEP and NSTAY are consistent with the results discussed above. So, with class 1 people are influenced by seeing people while they are leaving and while they are staying but the effect of seeing people leaving is stronger because the value of NDEP5 is larger than the value of NSTAY5. There also seems to be some effect of the news but this effect is not significant though (significance level of 14%).

Table 5.19 shows the results for Step 2d from the list on herding for the latent class models with class membership. Now information via the news item is also part of the independent variables and the other characteristics are added to determine class membership.

Based on Akaike's Information Criterion, the model including age for class membership performs best because AIC is the lowest (.807). Compared to the results in Table 5.18, the significance levels for NDEP5, NSTAY5 and NEWS are now all below 10%, which suggests that both herding and information via the news item influenced members of class 1. The results also suggests that age determines class membership. However, the results are not very convincing because of a significance level of 12% and a low value (-.01). This suggests that age is not an aspect which influences herding.

Table 5.17: Latent class results on herding ***with class membership***

Membership attribute	Age	Gender	News	Stress	Gaming exp.
MNL - Log likelihood function	-1.160.002	-1.160.002	-1.160.002	-1.160.002	-1.160.002
MNL - Inf.Cr.AIC	.808	.808	.808	.808	.808
LC - Log likelihood function	-1.152.762	-1.154.278	-1.152.213	-1.154.283	-1.154.293
LC - Restricted log likelihood	-1.160.002	-1.160.002	-1.160.002	-1.160.002	-1.160.002
LC - Significance level	.399	1.000	.029	.121	.121
LC - McFadden Pseudo R-squared	.002	.000	.007	.005	.005
LC - Inf.Cr.AIC	.809	.824	.807	.808	.808
Constant	1.90 (.00)	1.90 (.00)	1.90 (.00)	1.90 (.00)	1.90 (.00)
NDEP5	-,32 (.00)	-,32 (.00)	-,32 (.00)	-,32 (.00)	-,32 (.00)
NSTAY5	0.03 (.10)	0.03 (.10)	0.03 (.10)	0.03 (.10)	0.03 (.10)
Constant class 1	13.90 (.29)	.06 (.95)	2.69 (.19)	7.33 (.29)	7.37 (.28)
NDEP5 class 1	-17.03 (.29)	-1.20 (.04)	-4.30 (.06)	38.17 (1.00)	27.38 (1.00)
NSTAY5 class 1	1.04 (.33)	.13 (.20)	.22 (.00)	-.33 (.41)	-.34 (.41)
Constant class 2	1.83 (.00)	7.34 (.29)	1.74 (.00)	.05 (.96)	.05 (.95)
NDEP5 class 2	-.08 (.56)	34.90 (1.00)	2.66 (.56)	-1.21 (.04)	-1.21 (.03)
NSTAY5 class 2	.02 (.23)	-.33 (.42)	.02 (.50)	.13 (.19)	.13 (.16)
ONE1	-1.08 (.06)	-.94 (.24)	-.85 (.00)	.98 (.19)	.98 (.12)
AGE1, GENDER1, NEWS1, STRESS1, GAME-EXP1	-.04 (.12)	-.02 (.86)	-.46 (.02)	-.37D-04 (.88)	-11D-04 (.96)
ONE2	fixed	fixed	fixed	fixed	fixed
AGE2, GENDER2, NEWS2, STRESS2, GAME-EXP2	fixed	fixed	fixed	fixed	fixed
Class1Pr	.10	.27	.25	.73	.73
Class2Pr	.90	.93	.75	.27	.27

Table 5.18: Latent class results on herding combined with news ***without class membership***

Membership attribute (nr. of classes)	NDEP & NEWS	NSTAY & NEWS	NDEP, NSTAY & NEWS
MNL - Log likelihood function	-1.161.337	-1.179.889	-1.160.002
MNL - Inf.Cr.AIC	.809	.822	.809
LC - Log likelihood function	-1.157.010	-1.178.515	-1.152.555
LC - Restricted log likelihood	-1.161.337	-1.179.889	-1.160.002
LC - Significance level	.124	.739	.021
LC - McFadden Pseudo R-squared	.004	.001	.006
LC - Inf.Cr.AIC	.809	.824	.807
Constant	1.99 (.00)	1.80 (.00)	1.90 (.00)
NDEP5	-,29 (.00)	n.a.	-,32 (.00)
NSTAY5	n.a.	-.003 (.86)	0.03 (.11)
NEWS	-0.04 (.68)	-.008 (.94)	0.002 (.98)
Constant class 1	5.34 (.94)	391.90 (1.00)	.96 (.35)
NDEP5 class 1	-.05 (.93)	n.a.	-2.82 (.09)
NSTAY5 class 1	n.a.	-26.17 (1.00)	.24 (.04)
NEWS class 1	-3.79 (.96)	-393.61 (1.00)	1.59 (.14)
Constant class 2	0.62 (.74)	1.53 (.00)	2.55 (.01)
NDEP5 class 2	-1.15 (.30)	n.a.	1.12 (.29)
NSTAY5 class 2	n.a.	.03 (.21)	-.02 (.71)
NEWS class 2	3.21 (.44)	74.68 (1.00)	-.81 (.29)
Class1Pr	.70 (.02)	.15 (.00)	.26 (.00)
Class2Pr	.30 (.33)	.85 (.00)	.74 (.00)

Table 5.19: Latent class results on herding combined with news ***with class membership***

Membership attribute	Age	Gender	Stress	Gaming exp.
MNL - Log likelihood function	-1.160.002	-1.160.002	-1.160.002	-1.160.002
MNL - Inf.Cr.AIC	.809	.809	.809	.809
LC - Log likelihood function	-1.150.985	-1.152.549	-1.152.555	-1.152.553
LC - Restricted log likelihood	-1.160.002	-1.160.002	-1.160.002	-1.160.002
LC - Significance level	.021	.061	.061	.061
LC - McFadden Pseudo R-squared	.008	.006	.006	.006
LC - Inf.Cr.AIC	.807	.808	.808	.808
Constant	1.90 (.00)	1.90 (.00)	1.90 (.00)	1.90 (.00)
NDEP5	-,32 (.00)	-,32 (.00)	-,32 (.00)	-,32 (.00)
NSTAY5	.03 (.11)	.03 (.11)	.03 (.11)	0.03 (.11)
NEWS	.002 (.98)	.002 (.98)	.002 (.98)	0.03 (.98)
Constant class 1	1.82 (.29)	.93 (.35)	2.56 (.01)	2.55 (.01)
NDEP5 class 1	-4.06 (.06)	-2.78 (.10)	1.12 (.30)	1.11 (.29)
NSTAY5 class 1	.31 (.07)	.23 (.05)	-.04 (.71)	-.02 (.72)
NEWS class 1	1.93 (.09)	1.57 (.15)	-.81 (.29)	-.81 (.30)
Constant class 2	2.03 (.00)	2.58 (.01)	.95 (.35)	.96 (.35)
NDEP5 class 2	.82 (.27)	1.13 (.30)	-2.81 (.09)	-2.83 (.10)
NSTAY5 class 2	.01 (.91)	-.02 (.70)	.24 (.04)	.24 (.05)
NEWS class 2	-.39 (.43)	-.83 (.29)	1.59 (.15)	1.60 (.14)
ONE1	-.76 (.00)	-1.00 (.01)	1.04 (.00)	1.04 (.00)
AGE1, GENDER1, NEWS1, STRESS1, GAME-EXP1	-.01 (.12)	-.02 (.91)	-.17D-04 (.97)	.30 (.94)
ONE2	fixed	fixed	fixed	fixed
AGE2, GENDER2, NEWS2, STRESS2, GAME-EXP2	fixed	fixed	fixed	fixed
Class1Pr	.24	.26	.74	.74
Class2Pr	.76	.74	.26	.26

Concluding, a segmentation into classes was made for herding. The results of the models were similar showing that with one class people are influenced by the behaviour of others while with the other class(es) they are not influenced by the behaviour of others.

When information via the news item is included, it seems that before the news people were more influenced by the behaviour of others than after the news, see Table 5.17. This makes sense because without information, it is logical to respond similarly to the behaviour of others, hence herding is logical because the actions of other people are considered as a source of information.

5.7.2 Main conclusion on segregating participants

Based on the results of the latent class models presented in this section, the main conclusion is that a segmentation can be made with respect to herding behaviour. Especially, the effect of information appears. When people do not have information (from for example media) they rely on the behaviour of others as a source of information, hence herding behaviour occurs. When people have information (from for example media) they do not need to rely on the behaviour of other people.

5.8 Conclusions

This chapter presented and discussed the results for herding by estimating choice models. First, an explanation was given on how the data were processed to make it possible to quantify herding. Based on this, the general results from the data were presented first. After that, the results from estimated choice models were discussed to actually quantify herding. This was done for herding itself and herding in relation to the other aspects that were also considered in the previous chapter (socio-economic characteristics, age and gender, information via the news item, stress experienced by the participants and gaming experience).

The general results showed that when participants left earlier, they have seen more people as well. It is unknown whether this is because they were able to see more people or were specifically focussing on the actions of others because earlier on in the experiment the situation was less clear to them.

Based on the estimated choice models in Step 1 (the models with only the other aspects (information via the news item and stress)), it was concluded that they did not influence the departure choice behaviour of the participants. These results could not confirm any of the aspects of the conceptual framework presented in Chapter 2.

From choice models estimated with only herding included as an attribute (Step 2), the main conclusion is that herding behaviour influenced the decision to evacuate.

Participants were inclined to stay at the concert area at that moment but when they saw other people leaving, they were more inclined to leave themselves. Especially, the last few seconds before the decision to leave was made, herding behaviour had most impact, implying that herding is impulsive.

The results on herding in combination with the other aspects (Step 3), it was also shown that participants were inclined to stay at the concert area at that moment. The results did not show that it was possible to conclude what type of people are more likely to follow than others. Therefore, latent class models were estimated. Based on the results of these models, it is concluded that a segmentation could be made based on information via the news item. These results showed that herding especially occurs when people have no information. When people have information, they are less likely to follow others. These are interesting and new results and therefore it is concluded that progress is made with this thesis in quantifying the effect of herding on evacuation behaviour.

Since the experimental set-up was a novel way to collect data, the validity needs to be discussed in order to be able to answer the research questions and discuss whether and how the main objective was reached. The next chapter will reflect on aspects of validity.

Chapter 6

Reflection on the validity of the tool and the results

In this thesis evacuation behaviour was analysed by focussing on herding behaviour in case of a natural disaster. Empirical data were collected with a serious game (Everscape) in which an earthquake and tsunami were simulated.

Chapter 2 provided a literature review on evacuation choice behaviour, resulting in a conceptual framework that provides an overview of evacuation behaviour research. This framework consists of the elements: information (including e.g. disaster characteristics and instructions), personal context (including e.g. socio-economic characteristics and direct surroundings), choice options and human evacuation behaviour (consisting of the perception of the situation, the decision mechanism and the actual choices). Based on this literature review, possible research directions were identified. In combination with limitations of existing data collection techniques, the focus was set on quantifying herding behaviour in case of a natural disaster with a newly developed experimental set-up. In Chapter 3, the new experimental set-up was developed to focus on herding behaviour in case of an earthquake and tsunami. Chapters 4 and 5 focussed on analysing the data and estimating choice models with the data that were collected with the experimental set-up. This made it possible to actually quantify herding behaviour.

Since the developed experimental set-up uses a serious game as a data collection technique and since it was specifically developed to focus on quantifying herding behaviour, this chapter aims to critically assess the experimental set-up and results. How this will be done is discussed in Section 6.1, which starts with an introduction to this chapter and presents the approach for this chapter. Section 6.2 will then reflect on the experimental set-up. The same will be done for the results in Section 6.3. The conclusions of this chapter are presented in Section 6.4.

6.1 Introduction and approach to the reflection

It is important to determine whether the behaviour that was found with Everscape actually resembles behaviour in real life. To find out whether this is the case, both the experimental set-up and the results will be reflected upon in this chapter by discussing aspects of validity.

As stated by Hoogendoorn (2012), validity has no single agreed definition. In general, it refers to how accurately the results or conclusions correspond to real life. With respect to this thesis, it concerns how accurately the experimental set-up with Everscape measures evacuation behaviour and especially herding behaviour.

This section introduces relevant terminology for the validity discussion. Since the experimental set-up was based on a serious game, validity with respect to gaming will be introduced in 6.1.1. Validity aspects relevant for the reflection on the results will be introduced in 6.1.2.

6.1.1 Introduction to terminology on the validity of serious games

The experimental set-up consisted of three parts (see Section 3.5): an introduction to the experiment, the virtual experiment with Everscape and the questionnaire. Since the core of the experimental set-up is the virtual experiment (or serious game) Everscape, the validity of the data collection tool Everscape will be considered.

With respect to the validity of games as a means to collect data on human behaviour, Raser (1969) suggested the following four validity aspects: psychological reality, structural validity, process validity and predictive validity. These aspects are nowadays still used for research that uses gaming simulation, for example by Meijer (2009).

For Everscape to be valid with respect to ***psychological reality***, the environment should seem realistic to the participants. This means that during an experiment participants had to be emotionally involved and act how they would do in a real life situation (Peters et al., 1998). If they would not consider Everscape to be realistic, they possibly could take more risks than they would in real life and their behaviour would not match their behaviour in real life.

Structural validity is defined by Raser (1969) as 'a game is valid to the degree that its structure (theory and assumptions on which it is built) can be shown to be isomorphic to that of the reference system'. This means that in Everscape the most important features or elements of the reference system should have been included (Peters et al., 1998) and should be similar to those in a real life situation. The reference system is basically the same situation in real life and examples of features or elements are characteristics of the disaster and actors.

Process validity is defined by Raser (1969) as 'a game is valid to the degree that the processes observed in the game are isomorphic to those observed in the reference system'. Where structural validity focusses on the features or elements, process validity focusses on processes. Examples of processes are flows of information or resources but also interactions between actors (Peters et al., 1998).

Predictive validity is defined by Raser (1969) as 'a game is valid to the degree that it can reproduce historical outcomes or predict the future'. This makes it possible to compare the results with reality (Peters et al., 1998). Since this aspect focusses on the results, it will also be discussed in Section 6.3, where the results will be reflected on their validity. Section 6.2 focusses on the predictive validity of the experimental set-up.

As already introduced in 3.1.3, ***controllability*** also needs attention because this concerns the experimental control researchers have during their experiments. It is important to possess a high degree of experimental control to reduce the risk of confounding variables. Therefore, controllability will also be discussed.

The experimental set-up was based on the serious game Everscape. Everscape will be reflected on these aspects of validity and on controllability in Section 6.2 by discussing the choices that were made during the development of the experimental set-up.

6.1.2 Introduction to terminology on validity of the results

Before discussing the impact on the results of the choices made when developing theory on herding behaviour, terminology related to validity needs to be introduced, which is done in this sub section. When reflecting on the validity of the results, the descriptive analysis, the choice modelling process and the results from this choice modelling process are important and will therefore be discussed.

Typical validity aspects for this discussion are face validity, internal validity, predictive validity and external validity.

Face validity is a subjective estimate to consider whether the experimental set-up with Everscape actually measures evacuation choice behaviour and especially herding behaviour.

With ***internal validity***, the focus is on using the appropriate data collection method. It concerns the degree to which conclusions about relations between variables are justified using the experimental set-up with Everscape.

Predictive validity was already introduced in the previous section and will be considered to find out whether the results reproduce historical outcomes, hence support results from literature, and predict the future.

External validity focusses on whether and how the results can be held true for other cases as well, so whether the findings can be 'validly generalised' (Hoogendoorn, 2012). For example for people with a different level of experience with the same natural disaster, or with other natural disasters.

These aspects are discussed in Section 6.3 for the choices made during the descriptive analysis and estimation of choice models and how these choices affected the validity of the results.

6.2 Reflection on experimental set-up

This section will reflect on the choices made during the development of the experimental set-up and how they have influenced the validity and therefore results on evacuation and especially herding behaviour.

To do the reflection on the validity of the results in a structured way, the same choices are considered that were discussed in Chapter 3. These choices are related to the Everscape scenario (see Section 3.3), which includes the emergency feeling and the choices made during prototyping. Choices were also made on the basis of the pilot experiments (see Section 3.4) to finalise the experimental set-up before actually conducting the experiments.

All choices are summarised in Tables 6.1 and 6.2. The first column of each table summarises the choices, the second column shortly explains the choices for the validity and how they were dealt with and the third column presents the concerning validity aspect.

Everscape scenario
In essence, all of the scenario related choices are of importance for psychological reality because the whole scenario in Everscape had to be realistic for the participants to behave the same as they would do in real life. The looks of the objects build by a graphics designer in Everscape (e.g. trees, rocks, beach, concert stage) were all designed with the goal to make them as realistic as possible. Since the looks of all objects as a whole are important for a psychologically realistic experience, they are not separately discussed but they were tested during prototyping (see 3.3.2 of Everscape and the pilot experiments with Everscape (see 3.4.2)).

The choices related to the Everscape scenario are shown in Table 6.1. The starting point was the chosen disaster in Everscape, which is an earthquake followed by a tsunami. This choice is not added to the table because it is expected that the choices made on how to simulate the earthquake and tsunami are of importance for the discussion here. These are discussed in this section. The numbers are included in the discussion to easily look for the choice in the table.

In Everscape, a non-existing island was built (choice number 1). This is related to structural validity because it concerns the features or elements needed to build this island. An island being hit by an earthquake and tsunami is realistic. Since people might experience a disaster in an environment they are (somewhat) familiar with, they might respond differently. That is why they all received the same instruction in the

Table 6.1: Choices related to the Everscape scenario

Nr.	Design choices	Explanation	Validity aspect
1	Non existing island.	In reality people might experience a natural disaster in a (more) familiar environment.	Structural validity
2	Goal of the participants: visit the island to see a concert.	All participants were together at the start of the disaster. No prior knowledge of the disaster.	Process validity
3	Triggers departure choice: disaster characteristics and news item.	Disaster characteristics were added to invoke the emergency feeling. The news item was added to inform participants about the situation and what they should do. The timing of the news item was not realistic.	Process validity
4	Travel modes: car, train and walking. Route choice included for car. Information provided on traffic signs.	Usage of all of the included travel modes was less realistic.	Process validity
5	Evacuate the island by helicopter or on top of the mountain.	Evacuating all participants with the same helicopter seems unrealistic. Not one participant tried to survive on top of the mountain.	Process validity
6	Create emergency feeling: simulating the earthquake, adding alarm sounds, adding time-pressure on screen and making the weather go from sunny to a thunderstorm.	Not all of these aspects are realistic.	Process validity
7	Third person viewpoint from avatar.	To minimise motion sickness. Might be weird for participants to see themselves running.	Process validity
8	Male or female avatar randomly appointed to participants.	Men might be appointed to a female avatar and vice versa, which is not realistic.	Process validity
9	Communication through chat.	To make it more realistic a chat was included. Drawback of the chat: group chat.	Process validity

Table 6.2: Choices made before conducting the experiments

Nr.	Choices	Explanation	Validity aspect
10	Participants were allowed to participate once.	To make sure participants did not know what was going to happen.	Predictive validity
11	Computer experience was required.	To make sure controlling the avatar and car would not be an issue.	Predictive validity
12	A demo was included in the introduction on how to control the avatar and car. A hand-out provided this information as well.	To make sure controlling the avatar and car would not be an issue.	Predictive validity
13	One (and the same) person managed all experiments and gave the introduction. One person was in charge of the Admin computer. At least two extra people walked around for questions.	To make sure all experiments were organised the same way and participants were not influenced by this.	Predictive validity
14	The maximum number of people per experiment was 38.	Groups were smaller than preferred.	Predictive validity
15	Every participant used a headphone.	To make sure participants were part of the experience.	Psychological

introduction, which included an explanation of the lay-out of the island and the travel modes.

Related to process validity is the decision that participants had to have a goal to visit the island and be at the same location at the time the disaster started (choice number 2). It was decided to let them visit a concert because this made it possible to easily let them be together at the start of the earthquake. The original idea behind this was also that participants were not allowed to know that a disaster was going to occur because this might have influenced their behaviour.

To focus on evacuation choice behaviour, participants needed to be able to make travel choices (choice number 3). These are all related to process validity. With respect to departure choice, several triggers were added related to disaster characteristics and information via the news item. These were based on the conceptual framework presented in Chapter 2 and they are related to process validity. The disaster characteristics were added to create the feeling of emergency that will be discussed further below. A news item was added to inform people about the situation and about what they should and could do. The timing of the news item was not realistic because it was within seconds after the earthquake. In reality, it takes much longer before such information can be provided to people. It was done like this to influence the sense of emergency.

With respect to mode choice, three modes were included (choice number 4): two fast modes (car and train) and one slow mode (walking). Route choice was included for car, with differences in risk and travel time. The shorter route included a dangerous bridge and the longer route was through the mountains. Information on the car routes was provided on traffic signs. In general this seems realistic. However, usage of the travel modes was less realistic due to several reasons. Car driving was less realistic. To make it easy for people to drive the car, a steering assistant was added that automatically made the car realign with the road tangent. Participants were not able to get out of the car or train when they wanted. To simplify the controls, participants could only let their avatar run and not walk. This makes it difficult to focus on for example driving or walking behaviour in the Everscape scenario.

Participants could evacuate the island by helicopter or on top of the mountain (choice number 5). Evacuating all people with the same helicopter seems unrealistic but this aspect is not related to the actual focus of this thesis. It was important that participants could survive and they would receive information on how to survive. This made it possible to see the impact of information on evacuation and especially herding behaviour. It was also possible to evacuate on top of the mountain but none of the participants actually tried this. This might be because it was not presented to them as an option.

In case of a tsunami, people in a (soon to be) affected area experience a feeling of emergency to move out of the area (choice number 6). Several choices were made to create the feeling of emergency. The earthquake is simulated by making the ground shake, adding a rumbling sound and crashing of parts of the concert stage. Earthquake after-shocks were also added and alarm sounds were added to the concert area to influence the sense of emergency even more. This might happen in reality as well.

After the news item, the expected arrival time of the tsunami was shown in a corner of the screen, also indicating the departure time of the helicopter. During the remainder of the experiment this was visible. The departure time of the train was then also shown on screen and it was correct as well. This is not realistic because people might not have access to this information and it might not be correct either.

During an experiment, the weather gradually became worse. In the beginning there was sunshine, then it started to rain and towards the end it resulted in a thunderstorm. This would most likely not happen in reality but it was added to influence the feeling of emergency.

Even though not all of the aspects that were included to influence the feeling of emergency were realistic, it was shown in Chapters 4 and 5 that participants experienced stress. It was shown that stress experienced due to the disaster influenced their evacuation and also herding behaviour. The aspects that were included to invoke the feeling of emergency are considered to have caused this.

In Everscape, each participant controlled his own avatar and car from a third person perspective (choice number 7). This was done to limit the chance to experience motion sickness. The third person perspective might have been weird because one could see his own avatar during walking and car during driving at all times. This is not the case in reality. However, the effects of this for the validity are unknown.

Each participant was randomly appointed to a male or female avatar (choice number 8), resulting in some of the men or boys participating with a female avatar and some of the women or girls participating with a male avatar. This might have felt strange for the participants. However, it is unknown whether and how this affected their behaviour.

During prototyping it was decided after a test experiment to include the chat in Everscape (choice number 9). This made the whole experience in Everscape more realistic. The chat had one drawback. It was a group chat which meant that all participants could read all messages all times. In reality, people talk in person to other people who are close-by and not on the other side of the island. In Everscape participants could read those messages as well, making the chat itself less realistic.

Final experimental set-up

Besides the choices discussed above, some final choices concerning the experimental set-up were also made. These choices are shown and numbered in Table 6.2. Most of them are related to predictive validity and one choice concerns psychological reality.

Participants were allowed to participate once (choice number 10) because they were not supposed to know that a disaster was going to happen. Besides that, every participant had to have the same amount of prior knowledge to make sure this would not influence the results.

Since the experiments were conducted on computers, participants had to have some computer experience (choice number 11). Otherwise, even taking part in the experiment would have been difficult and would have influenced the results. To still be sure that controlling the avatar and car would not be a problem, a demo was given in the introduction (choice number 12) on how to use the controls and a hand-out was distributed including this information as well.

Choice number 13 involves the organising people. To make sure all experiments were organised the same way and participants were not influenced by this, one (and the same) person managed all experiments and also gave the introduction. An other person was in charge of the Admin computer and received separate instructions. At least two extra people walked around for questions and received their own instructions as well.

During the experiments, a maximum number of people per experiment had to be set to 38 (choice number 14). This resulted in splitting up groups because people already registered. Two groups received the introduction at the same time, then one of the groups had to wait outside while the other group started the virtual part of the experiment. When this group started the questionnaire, the first group walked into the room and did the virtual experiment. This resulted in smaller groups than originally preferred for analysing herding behaviour.

To make sure participants were part of the experience, every participant used a headphone (choice number 15) to make sure participants were really part of the experience and not easily distracted in the room. This is important for the psychological reality. In line with this, the discussions with the participants during the pilot experiments already confirmed that the experience in Everscape felt realistic, e.g. simulation of the earthquake.

Controllability of the experimental set-up
With respect to controllability, in order to possess a high degree of control, several aspects were kept consistent over all experiments. The first is related to the Everscape scenario, which was kept the same over all experiments. The timing of the earthquake and news item were exactly the same and the spooks received the same instructions depending on the scenario. The second aspect that was kept consistent is related to the organisation and instructions. The same person was managing each experiment, the same number of people were present and received the same instructions. Finally, at each experiment the same introduction was given to the participants by the same person.

Conclusions on reflection of the experimental set-up
Concluding, discussing these choices clearly made it possible to become aware of the strengths and weaknesses of the validity of the experimental set-up. However, the weaknesses (e.g. no realistic driving and walking behaviour in Everscape) are considered to not have influenced the main findings on herding behaviour in relation to departure choice.

6.3 Reflection on results

This section will reflect on the choices made during the descriptive analysis and estimation of choice models and how these choices affected the validity of the results. The results on the behaviour of the participants related to these choices are discussed as well. Each validity aspect is discussed separately, starting with face validity. This is followed by a discussion on predictive validity, internal validity and finally external validity.

Face validity
The results are said to be face valid when it was possible with the experimental set-up with Everscape to measure evacuation behaviour and more specifically herding behaviour. To decide whether this is the case, two topics will be discussed.

1. The behaviour of the participants.
2. The design of the choice sets.

The behaviour of the participants will be considered to find out whether what they did resembles what people do in real life. The design of the choice sets will be reflected on to decide how this influenced the results on herding behaviour.

The behaviour of the participants
With respect to evacuation behaviour, the results are consistent with the conceptual framework from Chapter 2, which means that realistic evacuation behaviour was found.

Participants also showed that their mindset was how it was supposed to be because their main goal was to survive the island by helicopter. This was confirmed with the trajectory data. Finding out why participants did 'not survive' confirms this by checking these trajectory data. Table 6.3 presents how many participants 'survived' and how many of them did 'not survive'. It also presents the reasons for not surviving.

Table 6.3: Why people did 'not survive'

	Number of people
Did 'not survive' because the bridge collapsed	17 (5%)
Did 'not survive' because participant was too slow	56 (16%)
'Survived'	*278 (79%)*
Total	**351**

Most participants (278) 'survived' the experiment. From the participants who did 'not survive', 17 took the shorter beach route. They passed the bridge after it collapsed and drove into the water. For them, this meant the end of the Everscape experiment.

The rest of the participants (56) who did 'not survive' were too slow. Some of them were already in a car but they were not far away from the area that was affected by the tsunami. Most of them were not in a car or the train. The trajectory data shows that most of them have tried to reach a car or the train but they were not there yet. Not reaching a car is plausible in real life as well.

As already shown in Chapter 4, with one experiment, most of the participants wanted to do an other run. Their behaviour shows that when participating the second time, two differences occur in behaviour compared to the first run. Figure 6.1 shows that when participating the second time, most of the participants left earlier. This makes sense because they knew what was going to happen. Around 25% of them even left before the earthquake while not one of them did this during the first run. None of the participants left after the news item.

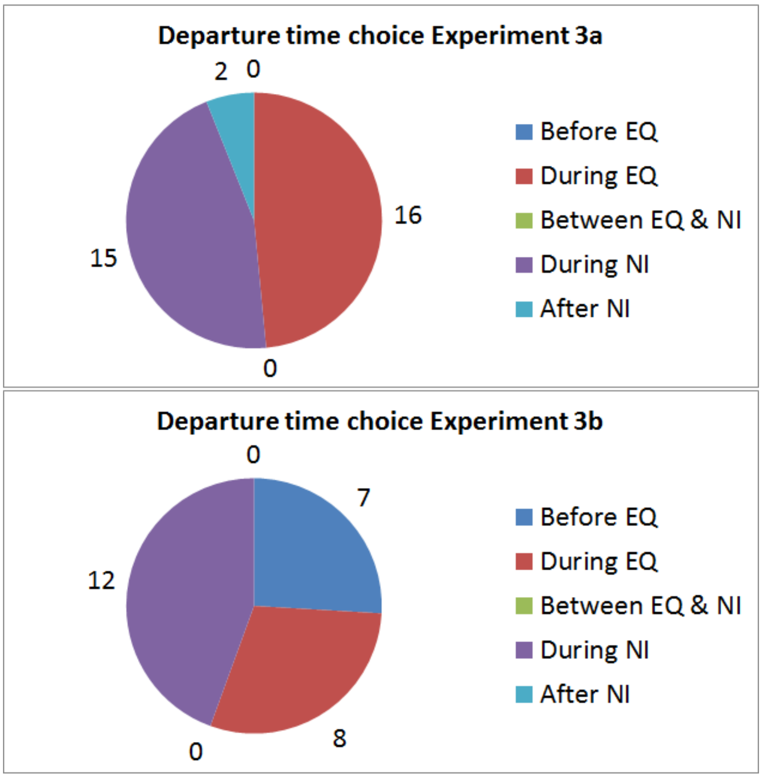

Figure 6.1: Departure choice - Experiments 3a (run 1) versus 3b (run 2)

Figure 6.2 suggests a learning process when considering the number of participants who were too slow. With these runs, more of them 'survived', meaning knowledge or experience made participants want to and know how to 'survive'. The only participant who was too slow in Experiment 3b even did not leave the concert area because this person was curious what would happen. The other two participants who did 'not survive' in the second run took the short route and drove into the water because the bridge had collapsed. The trajectory data also showed that some participants went all the way to the helicopter but before they entered it, they walked around to find out what was there to see and do. They have entered the helicopter on time and 'survived'.

The results on what participants said what they will do next time show that a little over 50% of the participants will take the car, see Figure 6.3, which is comparable to the

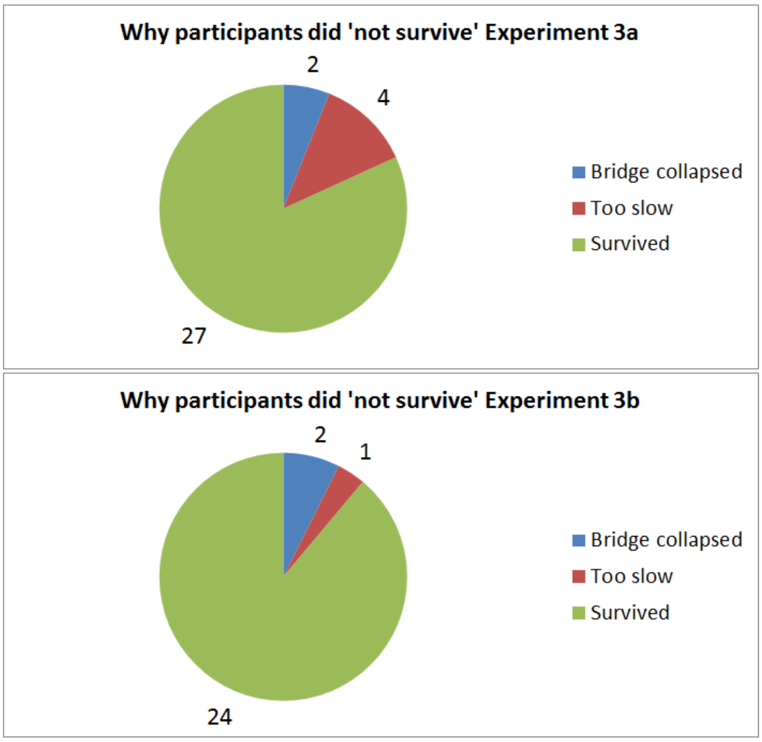

Figure 6.2: Why participants did 'not survive' - Experiments 3a (run 1) versus 3b (run 2)

number of participants that actually took the car (see Figure 4.17). There are some differences between choosing the shorter beach or the longer mountain route. Since there were also participants who took the mountain route because they thought it was shorter, this might have caused the difference between the two figures.

Figure 6.3 shows when participants will do this next time. Compared to when they actually left in the first run (see Figure 4.6 and the total numbers in Table 4.10), more participants will leave before the earthquake and after the news item. Both options can be explained with prior knowledge of the situation. When knowing a disaster is going to occur, people might want to leave in advance or leave when all information is received.

The design of the choice sets
With respect to herding behaviour, Chapter 5 showed that it was possible to quantify herding behaviour. The question is whether this is actually herding behaviour.

The general results on evacuation behaviour supported results from literature. Participants acted how they were supposed to act and their mindset seemed realistic because they all tried to evacuate the island by helicopter. Especially during the first time they participated their behaviour is considered to be realistic. Those who were not able to evacuate the island and did 'not survive', had realistic reasons for this.

As concluded in Chapter 5, one remark was made with respect to the set-up of the stay and departure choices that were used to estimate the choice models. It is unknown whether and how many of the stay choices were actually considered by the participants.

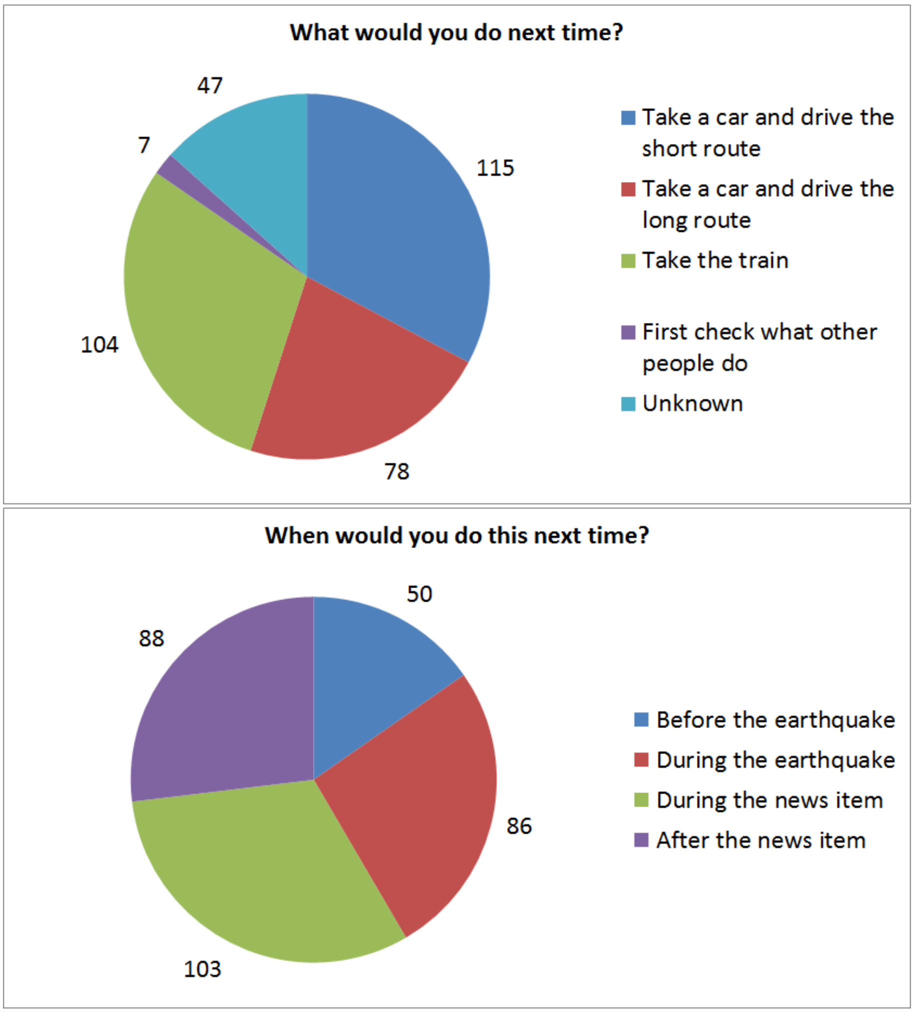

Figure 6.3: What participants said they will do next time and when they will do this

It is assumed in this thesis that not deciding to leave is the same as making the decision to stay. This assumption had to be made to estimate choice models.

Because every participant left, it was the question when they left and which influencing factors played a role in their decision to leave. Since it is unknown how the decision to leave is actually made, different interval times between the choices to leave and stay and different observation times before the choices were considered. With this organised approach the best combination of interval and observation time was determined and this confirmed herding behaviour. Since other results on evacuation behaviour supported results from literature, it is reasonable to conclude that this actually was herding behaviour. The results of the estimated choice models suggest that especially the behaviour of other people in the last few seconds before someone's departure influence the decision to leave.

Herding behaviour is considered as an attribute in the choice models by including the numbers of people that each participant saw leaving (and staying) before his own departure. With respect to mode and route choice, the results of the questionnaire show that a small number of participants explicitly stated that they followed someone (see presented results in Chapter 4), implying that herding behaviour exists for mode and route choice. No questions in the questionnaire can confirm this for departure choice behaviour.

The average number of people seen by the participants seemed low. This might have been caused by the limit of 38 people that could participate at most in one experiment (see Section 6.2). The results of the estimated choice models showed in 5.5.4 that seeing an actual number of people leaving influenced the decision to leave and not seeing a percentage of people leaving. This implies that if only one or a few people take actions, they are followed. In Everscape, these actions meant leaving and more specifically running away from the concert area. They showed clear leaving behaviour that could have been considered by participants as 'they know what they are doing so I should follow'.

It is reasonable to conclude that the experimental set-up seems to provide results that are face valid. But it has to be noted that, from the results of the participants who took part in two runs, it seems that a learning effect occurs the second time people participate. Depending on the research goal, Everscape might only be suitable once when considering evacuation choice behaviour.

Predictive validity
The results of data collected with the experimental set-up with Everscape is predictively valid if historical outcomes can be reproduced (support results from literature) or future aspects can be predicted. The reflection on face validity already discussed that the results support results from literature.

With respect to predicting future aspects, the focus is on herding behaviour in case of an earthquake and tsunami. As already discussed in 2.4.2, in case of an evacuation from a natural disaster, people experience stress. This stress causes behaviour to be more impulsive than rational and this influences herding behaviour.

Several factors were included in the Everscape scenario to invoke a sense of emergency. Not all of these factors necessarily belong to the situation of an earthquake and a tsunami. It is even questionable whether they are realistic (e.g. bad weather, time-pressure on screen). From the questionnaire it is known that participants have clearly experienced stress when these aspects were available compared to the situation where they were not available, which in Everscape was before the earthquake. With respect to predictive validity it is concluded that the results showed to be a good first step to quantify herding behaviour in a stressful situation.

Internal validity
The focus of internal validity is whether the experimental set-up is the appropriate data collection technique to measure evacuation and more specifically herding behaviour. Because the results support the results from literature and a first step was made towards quantifying herding behaviour, the experimental set-up definitely is appropriate.

Since collecting real time data when a natural disaster occurs has limitations, see Chapter 3, collecting data with a virtual environment seems to be the appropriate technique because of ethical reasons and because the researchers can control the experiments.

The set-up with Everscape that was used in this thesis focusses on individual behaviour. Depending on the situation in real life, people might not have to evacuate only themselves. Usually, they want to protect people (other household members) and possessions (their homes or pets), see 2.4.2.

To find out whether people participated together and communicated with each other, the questionnaire asked about contact with other participants during the experiments. Also included were questions where they explained how they communicated with other participants, in case they communicated with other participants. Due to technical issues from some participants, (parts of) the questionnaire were not properly uploaded so their results are (partly) missing.

Table 6.4 shows that 195 participants knew any of the other participants. Of these participants, 123 communicated and 72 did not communicate with those other participants. It also shows that 204 participants did have some sort of contact with any of the other participants. Table 6.5 shows that most of them communicated through the chat inside Everscape. Even though the participants were instructed to not communicate in the room but only via the chat, still 36 of them admitted in the questionnaire they only communicated in the room.

The data from the chat messages have shown two different types of messages. The first is related to some more general talking or chit chatting that was not related to the disaster. Examples are ‘Dad, where are you?’, ‘What a nice scenery.’ or ‘What a boring concert.’. The second relates to the disaster and includes messages such as ‘Help!’, ‘Run!’ and ‘Get to the helicopter!’.

Table 6.4: Contact with other participants

	yes	no
Did you know any other participants	195	138
Did you communicate with these participants	123	72
Did you have any contact with any of the participants	204	129

Table 6.5: How did participants communicate with each other

	Number of participants
only through the chat	154
only via people in the room	36
through chat and via people in the room	0

The experimental set-up that was used was not suitable itself but by adjustments can be made suitable for research on household evacuation behaviour because communication, especially in the chat, has shown to provide this opportunity. These adjustments will be discussed in the recommendations in Chaper 7.

It is concluded that the used experimental set-up provided an appropriate technique to take a first step in quantifying herding behaviour. By adjustments, these kind of set-ups can be improved and steps can be taken forward in research on evacuation, and especially herding behaviour. These recommendations are discussed further in Chapter 7.

External validity
The focus of external validity is on whether and how the results can be held true for other cases as well. Chapter 2 already showed differences on evacuation behaviour in literature that might be due to differences in situations (e.g. people respond differently to different natural disasters). It makes it therefore also difficult to conclude that the results in this thesis can be held true for other cases as well. However, in general it is concluded that the results from the data conducted with the experimental set-up have shown evacuation behaviour that is consistent with literature and a first step was made in quantifying herding behaviour in a stressful situation.

6.4 Conclusions

This chapter presented a reflection on the data collection method, the actual experimental set-up with Everscape, and the results from the descriptive and analysis and estimated choice models.

First, the reflection on the experimental set-up discussed the choices concerning the Everscape scenario that were made during the development of Everscape and the final choices that were made concerning the experimental set-up before conducting the experiments. This made it possible to become aware of the strengths and weaknesses of the validity of the experimental set-up. The focus of the thesis was on quantifying the effect of herding behaviour on the moment to evacuate. The observed weaknesses of the experimental set-up are considered to not having influenced the main findings on herding behaviour.

With respect to the results, it was concluded that the results on both evacuation choice behaviour and herding behaviour are valid. Results support the conceptual framework where expected and the data collection technique seemed to be appropriate to quantify herding behaviour because the data collection is done ethically (no participants were injured or 'died'), the researchers can control the experiments and the results provided new insights in quantifying herding behaviour.

With respect to answering research question 7, the following is concluded: based on the reflections in this chapter and the results of the other chapters in this thesis, this research is considered to be a first step towards validly quantifying herding behaviour in unexpected and stressful situations with empirical data.

The last chapter will answer the research questions and discuss the main objective. It will also summarise the main conclusions and provide recommendations for further research.

Chapter 7

Conclusions and recommendations

This thesis focussed on developing new insights on evacuation choice behaviour by empirical research with an experimental set-up which was specifically designed to deal with disadvantages of existing data collection techniques. More specifically, the idea was to gain a better understanding of evacuation choice behaviour. In order to get this, this thesis focussed on quantifying herding behaviour in case of an earthquake and tsunami. This was done with a novel data collection approach that used the virtual environment (or serious game) Everscape.

Chapter 6 provided a reflection on the experimental set-up and results. This chapter will discuss the conclusions of this thesis in Section 7.1. The recommendations for further research and practice are presented in Section 7.2.

7.1 Conclusions

Chapter 6 reflected on the experimental set-up and the results. Before discussing the recommendations of this research in Section 7.2, this section discusses the conclusions by answering the research questions in 7.1.1 and discussing the main objective in 7.1.2.

7.1.1 Answering the research questions

This sub section will answer the research questions that are defined in Chapter 1. The questions are chronologically organised from literature review on evacuation choice behaviour that results in the conceptual framework (Chapter 2), via developing the experimental set-up (Chapter 3), presenting the descriptive analysis (Chapter 4), estimating choice models to quantify herding behaviour (Chapter 5) to the reflection on the experimental set-up and results (Chapter 6).

As stated in the introduction, to better model and predict people's evacuation choice behaviour, the influence of factors on this choice behaviour needs to be quantified. This needs to be done by empirical research. Due to limitations of existing data collection techniques for empirical research on evacuation choice behaviour, an experimental set-up with the virtual environment Everscape is developed. Before the experimental set-up is developed, a literature review is made on evacuation choice behaviour. The literature review on evacuation choice behaviour concerns the first two research questions.

1. Which factors, related to both the characteristics of the individual and characteristics of the situation this individual is in, influence evacuation choices?
2. What is the scientific knowledge about how people make evacuation choices?

To answer ***research questions 1 and 2***, a literature review is performed resulting in a conceptual framework in Chapter 2 to structure literature on evacuation choice behaviour, see Figure 7.1. Literature is available on different types of factors influencing evacuation choice behaviour. To structure these factors, they are split into the following groups: information, personal context, choice options and human evacuation behaviour. The following remarks are made:

- Differences in results have been found on the influence of factors on evacuation choice behaviour. These differences might be caused by:
  - The differences between different types of disasters and the available information about the disasters.
  - The set-up of the research that was conducted (e.g. how and which data was collected).
  - Causal relations between the many influencing factors are to be expected.

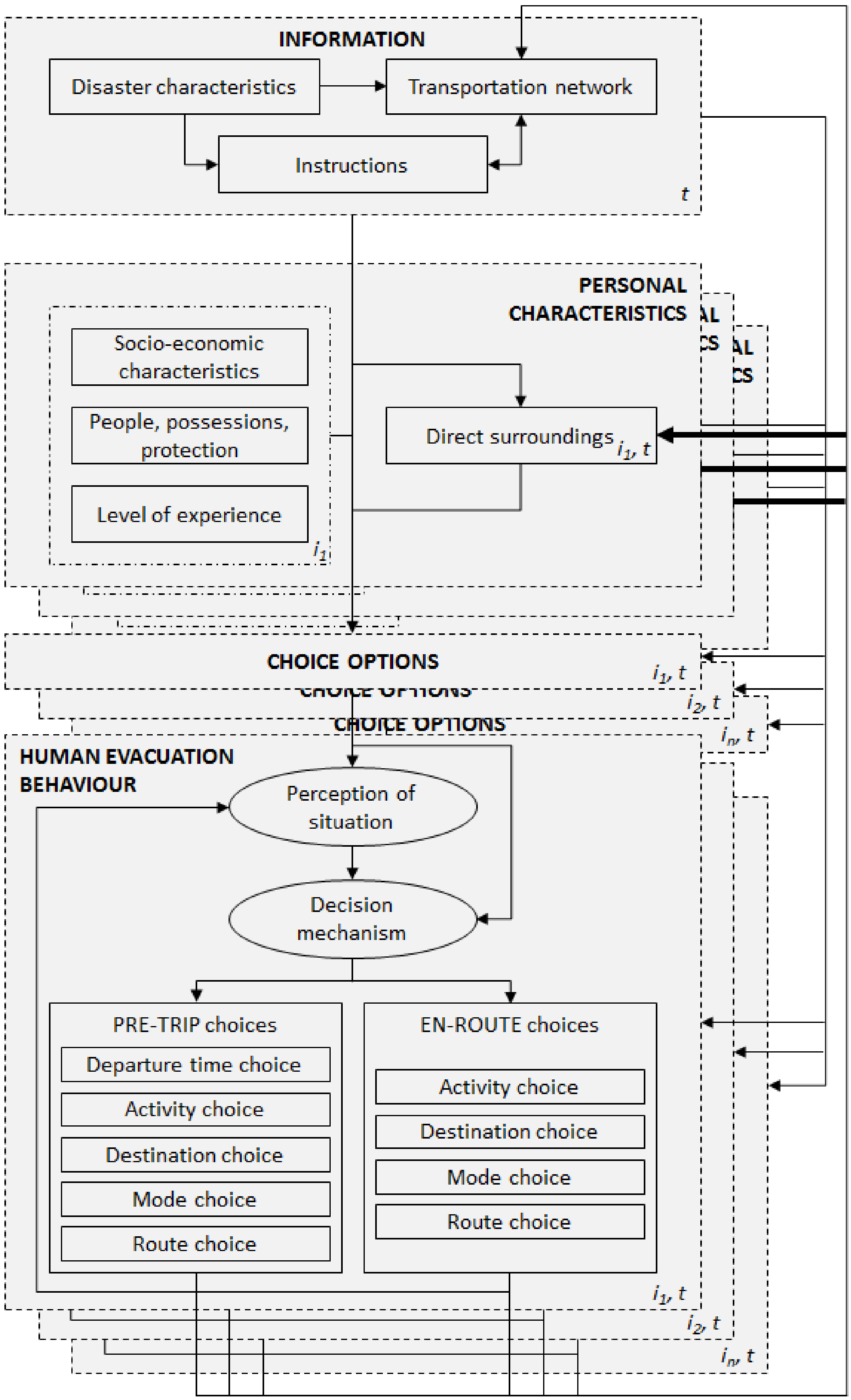

Figure 7.1: Conceptual framework representing the whole system of travel choice behaviour in case of an evacuation from a natural disaster

- No literature was found on quantifying the effect of herding on evacuation decisions based on empirical data.
- The perception people have of a situation is difficult to quantify because it is highly subjective.

Due to limitations of existing data collection techniques in combination with these results, it is decided to develop an experimental set-up specifically to quantify the effect of herding behaviour in case of an evacuation. The development of this experimental set-up is shown in Chapter 3. Before the experimental set-up is developed, the third and fourth research questions are answered.

3. What are the advantages and disadvantages of existing data collection techniques for empirical research on evacuation choice behaviour?
4. What are the requirements for the experimental set-up?

To answer ***research question 3***, advantages and disadvantages of existing data collection techniques are determined in a structured way by roughly dividing these techniques into Stated Preference (SP) and Revealed Preference (RP) techniques. The main advantage of SP is that researchers can include all aspects they want to consider and that are of importance for estimating choice models with the data from these techniques. The main disadvantage is that there are doubts whether people respond like they would in reality, especially in case of an unknown situation.

The main advantage of RP is that the actual behaviour is considered. Key disadvantages are discussed. Researchers are limited to available disasters which are hard to predict and data collection on human behaviour is hard to plan. There is limited or no time to prepare for them and the researchers cannot control these disasters. When asking people what they did, an other disadvantage is that reconstruction of the situation they were in is hard when it is based on what people remember from the situation. This might not be accurate enough for the researchers.

To answer ***research question 4***, the requirements of the experimental set-up are structured by differences in themes. They depend on setting the scene, travel choice behaviour in case of an evacuation, quantifying herding behaviour, representativeness of the population that participates in the experiments and validity of the experimental set-up. For setting the scene, the requirements are that a natural disaster has to occur. This also means that a feeling of emergency has to be invoked.

To consider evacuation choice behaviour, different travel choices have to be possible (e.g. departure choice, mode choice and route choice). To make these choices realistic evacuation choices, they have to differ in risk level and travel time.

To quantify herding behaviour, it is required that participants see each other and each other's actions, especially at the moment the disaster starts. To quantify the behaviour of other people, it has to be possible to record the behaviour of the participants on a detailed level, including where each participant is looking at.

Since the experimental set-up uses a virtual environment or tool, attention is paid to the type of people that are going to participate. Usage of the tool has to be simple and logical to make sure not only very experienced gamers can participate.

Finally, requirements are set for the validity. The experience for participants has to be realistic in order for their evacuation behaviour to match behaviour in real life. Then, results are predictively valid.

After the requirements are set, the experimental set-up is developed and experiments are conducted with it. Chapters 4 and 5 focus on the descriptive analysis and estimation of choice models to quantify herding behaviour with the data that are collected with the experimental set-up. These chapters focus on research questions 5 and 6.

5. Which results of the experiments with the experimental set-up show similar and different results when comparing them with existing research?
6. What are new behavioural insights from the results of experiments with the experimental set-up?

In the descriptive analysis, three main aspects are considered: whether the results are consistent with the conceptual framework presented in Chapter 2, realism of the experiment and whether herding behaviour is found with the herding scenarios. In general, the results are consistent with the conceptual framework. Departure choice behaviour supports the conceptual framework best. For mode and route choice behaviour, using the controls was an issue during the development of Everscape. This resulted in adjusting driving behaviour which means that driving behaviour is simplified and different from real life.

With respect to realism of the experiment, the discussions with participants in the pilot experiments show that the experience is realistic. Combining this with the mindset of the participants during the experiments, it is concluded that when people participate in an experiment for the first time, the experience and their behaviour can be considered as realistic.

With the herding scenarios themselves, participants did not copy the behaviour of the spooks. Possibly because (the actions of) the spooks were not seen. This suggests that a group of people cannot just be influenced by the actions of a few other people in a situation such as the Everscape scenario.

Chapter 5 focusses on the effect of herding behaviour on departure choice by estimating choice models with the Everscape data. The main theoretical contribution of this thesis involves this aspect and several conclusions with respect to the effect of herding behaviour are drawn.

- Participants were inclined to stay at the concert area at a certain moment and the more people a participant saw leaving, the more inclined this participant was to leave, which suggests that herding behaviour occurred.

- Seeing people leave has more impact on the decision to leave than seeing people stay and numbers have more effect than percentages.
- Seeing other people leaving the last few seconds before a departure influences the decision to leave the most.

The results also show that when participants left earlier, they have seen more people as well. It is unknown whether this is because they were able to see more people or they were specifically focussing on the behaviour of others. It is known that earlier on in the experiment the situation and what to do was not made explicitly clear to them. Later on, information was provided through a news item.

The results on herding behaviour in combination with other aspects (e.g. age, gender, information via the news item, stress experienced by the participants and gaming experience), show that participants are inclined to stay at the concert area. They also confirm herding behaviour for all different groups (younger participants versus older participants, men versus women, etc.).

It is not possible to conclude what types of people are more likely to follow than others. Therefore, latent class models are estimated. Based on the results of the latent class models, it is concluded that a segmentation can be made based on information via the news item. The results suggest that without information people are more inclined to follow others than with information. This is plausible because when it is unknown what to do, people who seem to know what they do (in Everscape, the people who leave the concert area), are followed.

To answer ***research question 5***, results support the conceptual framework, hence they are consistent with results from literature. Besides that, the data conducted with the experimental set-up provide a first step in quantifying herding behaviour in a stressful situation, which answers ***research question 6***. The final research question (research question 7) concerns the validity and Chapter 6 focussed on this question.

7. How valid are the results conducted with the experimental set-up?

The experience of participants during the Everscape experiments has to be realistic in order for their evacuation behaviour to match behaviour in real life and for the results to be predictively valid. The results have to be face valid and internally valid as well.

The results are considered to be face valid, see discussion in Section 6.3, because Everscape shows evacuation choice behaviour consistent with the expectations based on the literature review and therefore support the conceptual framework from Chapter 2. The results also provide evidence that herding behaviour exists. With respect to internal validity, the experimental set-up with Everscape seems to be the appropriate data collection technique because it is an ethically sound way of collecting data and the researchers can control and plan experiments. With adjustments to the set-up, and especially the tool itself, the set-up can be made suitable for e.g. research on household evacuation behaviour.

To answer ***research question 7***, the following is concluded: based on the reflections in this chapter and the results of the other chapters in this thesis, this research is considered to be a first step towards validly quantifying herding behaviour in an unexpected and (possibly) stressful situation with empirical data.

7.1.2 Discussing the main research objective

As defined in Chapter 1, the twofold main objective is:

1. **To develop, apply and assess a new experimental set-up[1] to study evacuation choice behaviour.**

2. **To quantify the effect of herding on evacuation choice behaviour.**

In short, this objective is reached because new insights are gained on herding behaviour with a specifically developed experimental set-up with at its core the serious game Everscape. This means that there is a better understanding on one of the aspects of evacuation choice behaviour. The following clarifies this more into detail by explaining what was done throughout this thesis.

Based on the literature review in Chapter 2, this thesis focusses on one aspect, namely quantifying herding behaviour in case of a natural disaster. An experimental set-up with Everscape is developed such that the data make it possible to quantify herding behaviour in case of an earthquake and tsunami.

The Everscape data are collected at a 1.0 [s] time and at a 0.1 [m] position resolution along with viewing directions (resolution of 1°). Furthermore, event data (i.e. timing of the earthquake and news item) are logged. The data are combined with the questionnaire. A descriptive analysis of the data is provided in Chapter 4, showing that results on evacuation behaviour are consistent with the conceptual framework, hence results from literature.

In Chapter 5, the Everscape data are processed to estimate choice models. The results of these choice models provide evidence that herding behaviour is quantified with the experimental set-up with Everscape. It also shows that there are differences in herding behaviour based on the effect of information. Without information, people are more inclined to follow others than with information. The results are considered as a first step in quantifying herding behaviour in a stressful situation.

[1] In this thesis the experimental set-up is considered to be the full experiment people participate in, including all phases of a set-up from beginning (arrival at the experiment) to end (departure from the experiment) and including different scenarios.

7.2 Recommendations for future research and practice

This thesis has shown that a first step is made in quantifying herding behaviour by empirical research. Since this is a first step, several recommendations are to be made. These recommendations are related to realism of the Everscape scenario, realism of such environments for research on evacuation behaviour in general, including other measuring devices, analysing herding behaviour and other gaps that resulted from the literature review, hence the framework, that were not considered in this thesis. These aspects are all discussed in this section. At the end of this section recommendations for practice are given.

7.2.1 Realism of the Everscape scenario

This sub section discusses recommendations relevant for improving realism of the Everscape scenario.

Comparing virtual reality and real life situations
Kobes et al. (2010) compared a real life situation with a virtual environment by simulating the response to a hotel fire. This is a sound way to confirm (or show differences in) behaviour. It is recommended to compare the results presented in this thesis to data that were collected in real life. In case of a natural disaster this is difficult (in terms of e.g. preparations and controllability by the researchers) but it would be ideal to specifically consider herding behaviour with empirical research from a real life stressful situation that is similar on important aspects that are considered to influence herding behaviour. This might also mean creating two experimental set-ups, one virtual environment and one in real life, that are specifically designed to compare herding behaviour.

Experiments with people who have tsunami experience
None of the participants in the experiments have had the actual experience of evacuating from a tsunami. It would be interesting to find out whether people with tsunami experience respond in the same way as the results from the Everscape experiments presented in this thesis or whether differences occur. From research it is known that people with experience respond differently, see 2.4.2.

Experiments in known environments
The main strength of a non-existing island was that all participants had the same amount of prior knowledge of the island. In real life, people usually have at least some experience with the environment, which makes them for example more aware of where they could go in case a situation becomes stressful. The question then is whether herding is also confirmed when similar experiments are conducted in an environment that is familiar to the participants.

Timing of the news item
In the Everscape experiments the timing of the news item after the earthquake was very

short (only a few seconds). The results showed differences in the effect of herding behaviour on the decision to evacuate for participants who left before the news and participants who left during or after the news. It is therefore recommended to do extra experiments when the timing of the news item is different to see whether the effect of herding still occurs in the same way.

7.2.2 Realism of data collection with virtual environments for research on evacuation behaviour

This sub section discusses recommendations relevant for realism when conducting experiments with virtual environments for research on evacuation behaviour.

Realism of walking and driving behaviour
Being able to perform more research on evacuation behaviour in a virtual environment such as Everscape, it is interesting to consider walking and driving behaviour in these kind of circumstances. Then, more realistic walking and driving behaviour is needed than were available in Everscape.

Appoint male avatar to men and female avatar to women
In Everscape, each participant was randomly appointed to a male or female avatar. Some of the participants indicated they experienced this as weird. It is unknown whether and how this influenced the results. To improve the reality, it is recommended to appoint a male avatar to men and a female avatar to women. In line with this, including a variety of age for the avatars is useful to find out whether older people are more often followed than younger people.

Improving realism of the chat
In Everscape, the chat messages were available to all participants at all times. It would be more realistic to make the chat visible to those standing close to each other, as if they actually hear it. In line with this, including actual talking (for example through a microphone) improves realism as well.

More people taking part in the same experiment
Due to technical issues at the time of the experiments, the participants had to be split in two smaller groups. The results have shown that only seeing some people leave already influenced departure choice. It is interesting to find out whether this results will also be found when more people participate.

In real life, a stressful situation might occur at large scale events where thousands of people gather (e.g. at festivals). Gaining insight into the effect of herding in larger crowds is helpful for developing plans to organise possible stressful situations to limit the number of casualties.

In line with this, it might be interesting to considering including bots. These are extra avatars not controlled by any of the participants but whose tasks are simulated or scripted. Before this can be done, it has to be possible to let them behave realistically.

For this to be the case, more research is needed on how people act in such environments when these kind of scenarios are simulated. When these bots are included, no extra people have to participate as spooks and the whole concert scenario can easily be made more crowded, hence more realistic.

7.2.3 Measuring devices

This sub section discusses recommendations related to extra measurement devices for the stress levels and viewing direction.

Measuring stress levels
In the questionnaire, participants were asked how much stress they experienced during the experiment. Devices exist to measure for example heart rate that might be used as constructs to indicate stress levels. These stress levels might then be linked to evacuation behaviour and more specifically herding behaviour.

Measuring viewing directions
The data that were recorded included the viewing directions of the participants. If this is what the participants actually looked at is unknown. It would be interesting to use measurement devices that are able to record what people look at on their screens. Then it is more certain what they considered.

7.2.4 Analysing herding behaviour

This sub section discusses recommendations related to analysing herding behaviour.

Following over a longer period of time
In this thesis, the focus was on the effect of herding behaviour on the decision to evacuate. It is interesting to find out whether certain people stick together over a longer period of time. The question might be whether people only follow at the moment they make the decision or if, in stressful situations, they stick together over a longer period until they are safe.

The effect of herding behaviour on mode and route choice
This thesis considered the effect of herding behaviour on departure choice. Since the results of the questionnaires also confirmed herding behaviour in mode and route choice, it is recommended to consider this aspect as well. For this to be possible, walking and driving behaviour need to be made more realistic, as well as taking the train (i.e. make it possible to take a car or the train together, make it possible to get out of a car or the train when participants want to).

Analyse chat messages
The data that were recorded during the Everscape experiments included the chat message as well. A quick analysis has shown two types of messages: disaster related

and no disaster related messages. It would be interesting to find out whether these messages influenced the behaviour of the participants. For example, when the chat included disaster related messages earlier on during the experiment, did this make people leave the concert area earlier. It should be noted that the chat itself has to be improved with respect to its realism.

7.2.5 Gaps from the framework

This sub section discusses recommendations related to other gaps that resulted from the literature review in Chapter 2, hence the gaps from the framework.

Households or groups participating together
In real life, people usually do not have to evacuate only themselves but they want to protect people (e.g. household members) and possessions (e.g. their homes or pets). Before a household or group of people (such as friends) can participate in Everscape experiments, the following aspects need to be improved: chat, getting in and out of a car and the train, make it possible to take a car with a group of people. Next, for example, communication between household members or friends can be considered. In case of the current Everscape scenario (the concert), focussing on groups of friends would be realistic because they visit concerts or festivals in real life as well.

Simultaneous versus sequential choices
In this thesis, it is assumed that the participants made their choices sequentially. It is assumed that their departure choice is made before and independent of their mode and route choice. If this is actually the case is unknown and might be interesting for further research.

With the set-up of the choices sets that were used to estimate the choice models, several stay choices were assumed to be made by the participants. All these choices were assumed to be made sequentially and independently as well. It is also unknown it this is the case. Maybe the previously made stay choices influenced next stay choices or the decision to leave.

As shown in this section many recommendations were made. However, it has to be noted that the data that were collected with the newly developed experimental set-up with the serious game Everscape at its core has made it possible to gain new insights on the effect of herding behaviour on the decision to evacuate in a stressful situation.

7.2.6 Recommendations for practice

The results from the choice models estimated with the data from the novel data collection approach are considered to be important for practice. This sub section explains why.

The results of the choice models quantified the effect of herding behaviour on the decision to leave. The results specifically showed that there are differences in herding behaviour based on the effect of information. Without information, people are more inclined to follow others than with information.

As discussed in Chapter 2, herding might guarantee the imitation of successful alternatives (Helbing et al., 2000). However, it is unknown when people choose a successful alternative and when this successful alternative is imitated.

Based on the results of this thesis, it is therefore important for evacuation management strategies (needed to evacuate an area as safely and quickly as possible), to provide people with timely, accurate and useful information to make sure they will choose successful alternatives. This will then also increase the chance of imitating these successful alternatives.

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Appendices

Appendix A

Pilot experiments Everscape

This appendix presents the extended version of the results from the pilot experiments that are discussed in Section 3.4.

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This appendix is based on edited parts of 'Van den Berg, M., Doirado, E., Van Lint, J.W.C., Nakasone, A., Hoogendoorn, S.P., Prendinger, H. and Van Nes, R. (2012). Application of a 3D multi-user virtual environment for research on travel choice behaviour. The case of a tsunami. In M. Roorda and E. Miller (Eds.), International conference on travel behaviour research, pp. 103-125'

Since Everscape is a new data collection method for research on evacuation choice behaviour, three pilot experiments have been conducted with the method. This appendix discusses these pilot experiments, which are used as input for designing the experimental set-up in Section 3.5.

Since Everscape is a new method, the **main goal of the pilot experiments** was to maximise the added value of Everscape for data collection on travel choice behaviour in case of natural disasters.

The focus was on evacuation choice behaviour and factors influencing this evacuation choice behaviour. Knowing when people make their choices will help with determining which aspects (e.g. disaster characteristics, behaviour of other people) could be considered when they make these choices. Based on this, the following **research questions** have been formulated:

- In case of natural disasters, when do people make their travel choices?
- Which aspects (w.r.t. to aspects presented in the frameworks in Chapter 2) influence and how do they influence this travel choice behaviour?

The experimental set-up of the pilot experiments is described in 3.4.1. The results from these pilot experiments are presented in A.1 and A.2. The research questions, requirements and main goal of the pilot experiments are discussed in A.3. The conclusions of the pilot experiments are discussed in A.4.

A.1 Results pilot experiments

In this section a general overview of the available data and the choices that were made is provided, followed by the findings on departure time and mode/route choice behaviour. Then it is explained why some people did 'not survive'. This section ends with some promising observations on how other people's behaviour influences someone's travel choices.

Available data and overview of choices made by the participants
During the virtual experiment, the behaviour of each participant was closely monitored: the data were collected at a 1.0 [s] time and at a 0.1 [m] position resolution along with viewing directions (resolution of 1°). Furthermore, the following data from the events that occurred were logged:

- starting time of the earthquake,
- timing of the tsunami,
- departure time of the train,

- departure time of the helicopter and
- when a participant got in a car, the train or the helicopter.

Figure A.1 shows an impression of the pilot experiments at TRB 2012. Table A.1 summarises the general results.

Figure A.1: Impression of pilot experiment at TRB 2012

Table A.1 shows that most of the participants were male and the average age was between 36 and 37 years. Most people chose the longer route (approximately 65%), followed by train (approximately 32%). Only very few people chose the shorter route by car (approximately 4%). Walking was not presented as an evacuation option in the news item but it was still chosen by a few people.

Table A.1: General results from virtual part of pilot experiments

	TRB-1	**TRB-2**	**PLATOS**	**Total**
Number of participants	16	26	37	79
Number of women	6	8	2	16
Age (average)	34.4	33.2	40.0	36.7
Age (standard deviation)	9.7	9.6	11.2	10.8
Number of people by train	5 (31%)	9 (35%)	11 (30%)	25 (32%)
Number of people by car	9 (56%)	16 (62%)	26 (70%)	51 (65%)
Number of people via short route	1	Unknown	2	Unknown
Number of people via long route	8	Unknown	23	Unknown
Number of people walking	2	1	0	3 (4%)
Number of people who did not survive	2 (12.5%)	4 (15.4%)	3 (8.1%)	9 (11%)

Figures A.2 and A.3 show from the first pilot experiment at TRB the full trajectories and the trajectories at the concert area. These trajectories show via which route each participant drove to the concert and which routes were chosen by the participants to travel back to the helicopter. The straight lines to the concert area indicate the trajectories of the participants who were teleported to the concert. From the people who got teleported, two were already at the parking area, the others were still in their cars.

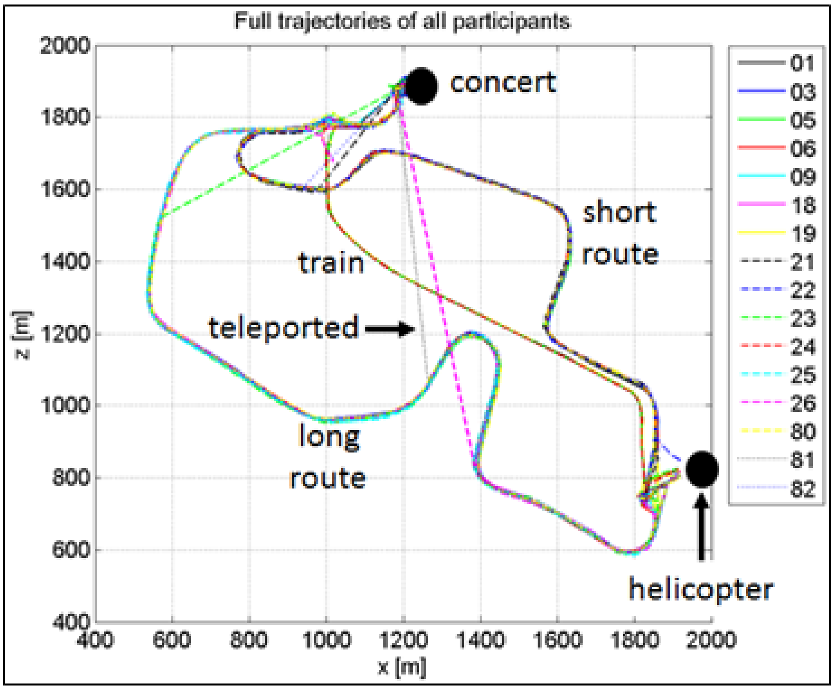

Figure A.2: Full trajectories (data from first pilot experiment at TRB)

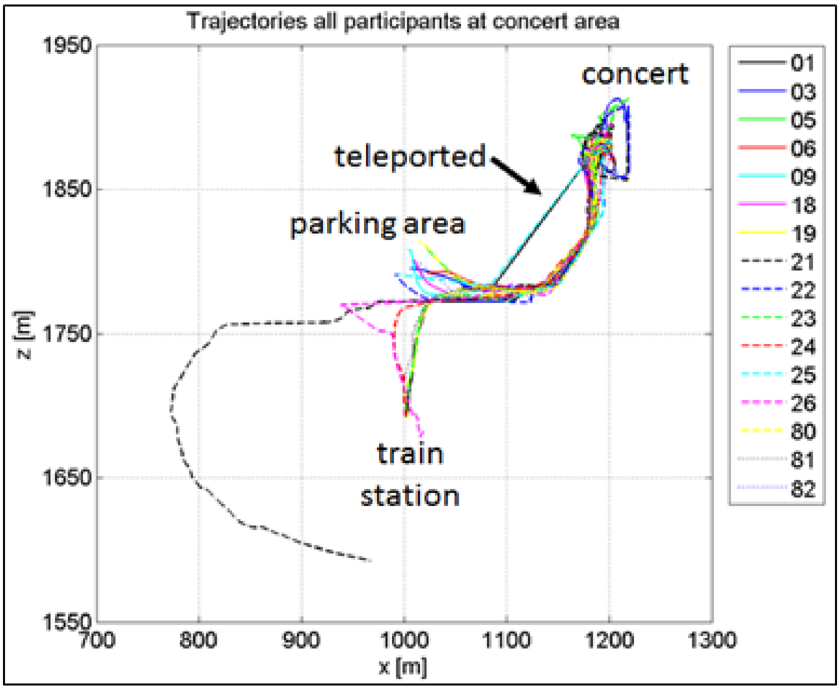

Figure A.3: Trajectories at concert area (data from first pilot experiment at TRB)

In total around 11% of the participants did ‘not survive’. This is explained later in this section. First, departure time choice and mode/route choice behaviour are considered.

Departure time choice analysis

Departure time choice, so the decision when people left the concert area, is considered in this section. Since there was a difference in how the information was presented to people and when people could leave the concert area during the different pilot experiments, an overview is given on who received which information.

Table A.2 presents what people said they saw or heard about the news item. At TRB, the news item was shown full screen to almost all of the participants. Due to a technical error, one person did not hear or see the news item. At PLATOS, two people fully saw and heard the news item, 13 people say they have already left before the news item fully ended and another 14 did not see but they did hear the news item. There were even seven people who did not see or hear the news item at all.

Since trajectory data of the participants is available, it was checked where they were at the time of the news item. Figure A.4 shows the concert area, including two exits. If people pass exit 1 they can still hear the news item. If people pass exit 2 they cannot hear the news item; between exit 1 and 2 the volume decreases. Tables A.3 and A.4 show when people passed exit 1 and exit 2.

Table A.2: How and if the news item was received by the participants

	TRB-1	TRB-2	PLATOS	Total
Full screen	16	25	0	41
Fully saw and heard the news item	0	0	2	2
Saw part of the news item, but ran away halfway	0	0	13	13
Did not see but did hear the news item	0	0	14	14
Did not see nor hear the news item	0	1	7	8
Unknown	0	0	1	1

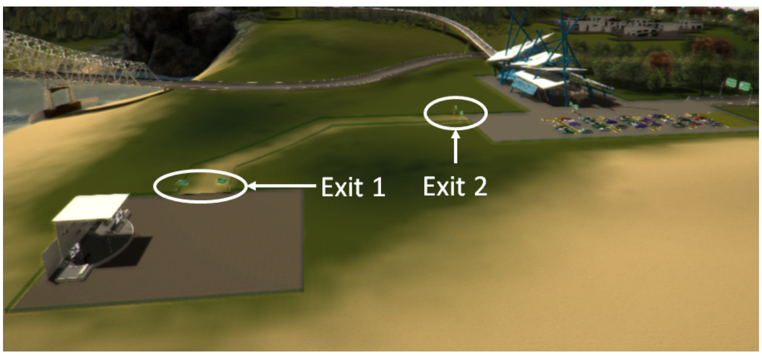

Figure A.4: Exit 1 and 2 of concert area

Two participants said they fully saw and heard the news item. From a distance, the screens at the concert stage can be seen so therefore this is possible. This also holds for three participants who saw part of the news item but ran away halfway. The

Table A.3: When people passed exit 1 of the concert area (data from PLATOS)

	Before Earth-quake	**During earth-quake**	**Between earth-quake and news**	**During news**	**After news**
Fully saw and heard the news item	0	0	0	1	1
Saw part of the news item, but ran away halfway	0 (+1)[b]	3 (+1)	0	9	0
Did not see but did hear the news item	0	8 (+1)	0 (+1)	5	1
Did not see nor hear the news item	1[c] (+1)	5	0	0	1
Unknown	0	1	0	0	0
All[a]	3	19	1	15	3

[a] The trajectory data of 1 participant is missing, because the Internet of this participant got disconnected during the experiment.

[b] Five people passed exit 1 twice. One of them passed exit 1 the second time during the earthquake; four passed exit 1 the second time during the news item. The first time these 5 people passed exit 1 is shown between brackets.

[c] One person passed exit 1 before the earthquake started and exit 2 during the earthquake.

Table A.4: When people passed exit 2 of the concert area (data from PLATOS)

	During earth-quake	**Between earth-quake and news**	**During news**	**After news**
Fully saw and heard the news item	0	0	0	2
Saw part of the news item, but ran away halfway	0	0	3	9
Did not see but did hear the news item	0	0	7	7
Did not see nor hear the news item	1	1	3	2
Unknown	0	0	1	0
All	1	1	14	20

participants, who said they did not see but did hear the news item, were not exactly looking at the screens. One participant did not hear or see the news item. The only explanation here is that the headphone did not work properly.

Participants, who passed exit 2 during or after the news item, could have heard the news but also could not have heard it because the volume was decreasing and/or the volume of the headphone was set too low. From the people who passed exit 1 before the news item, 19 people (53%) already ran out of the concert area during the earthquake. Two of them turned around and in total 15 people (42%) left during the news item.

Mode and route choice analysis

In this section, mode/route choice behaviour is considered, including what people said about their own behaviour in the questionnaire. First, it is shown what people said about when they made their mode/route choice. Table A.5 shows the overview.

By far, most people say they made their mode/route choice while running away from the concert area, or when they were already at the parking area. This implies that when there is danger, people respond by first leaving the area and second by making their mode/route choice.

Table A.5: When the participants made their decision (data from PLATOS)

	Number of people
During the earthquake	2
Between the earthquake and the news item	1
During the news item	2
Directly after the news item	5
When I ran away from the concert area	13
When I was at the parking area	3
When the train was full	1
I always take the car	1
I just ran after someone	1
No conscious decision	1
Unknown	7

Table A.6 presents other aspects related to the choices people made. In most cases people say they were able to execute their first choice. In 82% of the cases people said they clearly made a conscious decision. With 52% of the people, they believe that stress influenced their choice. After people made their decision, so during their trip to the helicopter, still over 50% felt some sort of sense of urgency.

Participants were asked why they made their decisions, see Table A.7. As can be seen, at PLATOS, 11 people (30%) travelled by train and 26 people (70%) travelled by car; 65% travelled via the mountain route, which was the long route, and 5% travelled via the beach route, which is the short route. The reasons that were given, were reasons for the car or train.

Table A.6: What the participants said about their choices (data from TRB)

	Yes	**No**	**Unknown**
Able to execute first choice	55 (=70%)	16	8
Choice was a conscious decision	65 (=82%)	5	9
If stress influenced choice	40 (=52%)	38	1
A sense of urgency was felt during the trip to the helicopter	41 (=51%)	37	1

In most cases it is unclear why people who chose car, chose long or short route. Only very few people chose the beach route. During the discussions with the participants, some people added they chose the longer route because it was in the mountains and therefore located in a higher area. There was also one person who chose the train because the railway track was higher.

The car was often chosen because people could control that themselves. However, of the people who travelled by train, 18% did this because they could not control the car. There was one person who wanted to travel by train because of this but because the train was full, this person switched to car. Another reason why people chose the train was because it would clearly leave on time and it seemed to arrive on time at the heliport. However, this was not explicitly mentioned during the experiment. The participants apparently assumed that the train connection was reliable or they did not consider unreliability of mode/route options. Two people say they chose car because the train was full but looking at the event data that were logged, seven people tried to get into the train when it was full. All of these people got into a car and took the long route.

Participants were also asked what they would do next time. The results are in line with what people actually did during the experiment. Most people said that next time they would take the car and travel via the long route, followed by the train and then the car via the short route. Even one or two people might go running.

Why people did 'not survive'

It has already been mentioned that not everyone 'survived' the virtual experiment. In total around 11% of the participants did 'not survive'. This was due to different reasons. Table A.8 shows the reasons for 'not surviving'.

Not many women participated but they do seem to run a higher risk; from the nine people who did not survive, six of them were female. What can be seen is that with three of them, it clearly was the control that caused problems.

With two people, the train was full and they were able to take a car but the tsunami was too quick for them to 'survive'. One person who took a car right away was just not fast enough and one person drove into the water because the bridge collapsed. One woman did 'not survive' because the train was full and she just kept on trying to get in the train over and over again. Because the trajectory data of the second experiment at TRB are not available, it is unclear why one woman did 'not survive'.

Table A.7: What people actually did and their motivation (data from PLATOS)

	Number of people who travelled via:		
	short route	**long route**	**train**
I chose car because I could control that myself	0	10	0
I chose train because it would clearly leave on time	0	3	4
I chose train because I could not control the car	0	1	2
I chose car because the train was full	0	2	0
I chose car because the train would be standing still before it would leave	1	0	0
Because it was the shortest	1	0	0
I chose car because I did not know when the train would arrive	0	1	0
I always take the car	0	1	0
Because that is how I drove to the concert	0	1	0
I just followed someone	0	1	0
Because it was higher	0	0	1
I expected traffic chaos	0	0	1
See what the possibilities of the game are	0	0	1
Unknown	0	4	2

Considering the trajectory data, the participants who did 'not survive', they did not try anything that was not allowed (e.g. walking into the water); they were clearly trying to evacuate. From the questionnaire this also resulted because their main goal was to travel back to the helicopter. In total 87% of the participants indicated this was their main goal.

Observations concerning the behaviour of other people

Due to combining the data of the virtual experiments, the questionnaires, the discussions with the participants and paying attention during the virtual experiments, several observations became clear about the influence of other people's behaviour on the choices people make.

During the discussions with the participants it had to become clear what they thought of the experience, especially being part of the same virtual environment. They stated that they are aware of the other participants. In the questionnaires, about 32% of the people say that their behaviour was influenced by the behaviour of other people. Explanations people gave are: 'because we decided to take the train together', 'I just followed someone' and 'I wanted to be in a car before the others so I was sure that I was the first one on the road'.

During the second experiment at TRB, there was an error with the data logging. When the earthquake was triggered, one person was still in the helicopter. After his helicopter landed, he got teleported to the concert immediately, but he missed the earthquake and

Table A.8: Reasons why people did 'not survive'

Reason	**Gender**	**Age**	**Pilot experiment**
Problems with controlling the car and started running	Female	49	TRB-1
Problems with controlling the avatar and car	Female	Unknown	TRB-1
Unknown	Female	26	TRB-2
Train was full, then took car but was not fast enough	Male	33	TRB-2
Took short route but drove into water because bridge collapsed just in front	Female	27	TRB-2
Train was full, kept on trying to get in but boarding was impossible	Female	31	TRB-2
Train was full, then took car but was not fast enough	Male	57	PLATOS
Took mountain route but was just a little too slow	Male	34	PLATOS
Problems with controlling the avatar and car	Female	41	PLATOS

he did not receive the news item. He suddenly saw everyone running away from the concert area and he followed. Even though this was only one person, it does suggest that people are inclined to follow others in an unknown situation.

One woman did not survive because she was participating together with her boyfriend and they decided to take the train together. Her boyfriend got in the train first but then the train was full when she wanted to get in. Although the idea was not that people would discuss in the room what they were doing during the virtual experiment, it did happen.

A.2 Everscape as a data collection method for research on evacuation choice behaviour

In this section the results from the discussions with the participants are presented. In general, the participants were very enthusiastic. They believe the method provides opportunities for data collection on travel choice behaviour, because of the following:

- The earthquake felt realistic. Fourteen participants had experience with earthquakes. None of the participants had any tsunami experience.
- People were aware of the other participants around them in the environment.

- Controlling the avatar, i.e. walking, is good.

The following aspects could improve realism of the ‘experience’:

- As already became clear in the previous section, controlling the car seems difficult, especially for women. However, it is a more logical explanation that this is related to computer and gaming experience. Since problems with controlling the car is already the case for people who work with computers on a daily basis, it is expected to be a problem for those who are less experienced with computers. Therefore, controlling the car needs to be improved.
- During the virtual experiments there were two messages on screen showing the exact departure time of the train and the estimated arrival time of the last wave on a very detailed level. In reality these estimated times might not be correct and if they are provided they might be given on a less detailed level (e.g. about 3 minutes left, instead of the exact amount of minutes and seconds).
- People who are experienced gamers feel less stressed and therefore the current version of Everscape might not be realistic enough for these people. Besides the evacuation alarm that is heard right after the news item, adding screaming sounds of people to increase the sense of emergency might be realistic.
- Right now, the experiment is designed to let people participate individually. If a small group of people decides to take the train together and one of them is in the train but the others cannot enter the train anymore because it is full, the one who is in the train cannot exit the train anymore. In reality, they could do this or they could even try to pull the other person in. Besides that, it is impossible to take a car together.

In the next section the results are discussed more thoroughly.

A.3 Synthesis pilot experiments

In this section the research questions and the main goal of the pilot experiments are discussed.

Research questions pilot experiments
The first question was when do people make their travel choices in case of natural disasters. It seems possible to estimate this. The combination of the data from the virtual experiment and the questionnaire is useful.

The trajectory data of the virtual experiment shows every second for each participant where he was and whether he was e.g. walking, standing still, turning around. Since a combination of the data of the virtual experiment and the data of the questionnaire is available, it was checked whether what people said they saw or heard from the news item matched with the data from the virtual experiment. In most cases, it did, but the combination makes it possible to clarify some aspects, meaning the combination of data is a useful source for the analysis.

With respect to when people make their decisions, it is possible to ask people in the questionnaire when they made a certain choice (e.g. departure time choice). It is possible to check with the trajectory data when that was and whether they were for example turning a lot prior to running towards the exits of the concert area. This turning clearly shows they were absorbing information and trying to find out what to do.

The second question concerns which aspects influence people's travel choices in case of natural disasters. In order to answer this, departure time choice, mode/route choice and observations made with respect to the influence of other people's behaviour need to be considered.

Concerning departure time choice, around half of the people left the concert area during the earthquake and the other half left during or just after the news item. This indicates that both the earthquake but also presented information influence departure time choice. Concerning their mode/route choice, there was variation in the responses on why people chose a certain mode/route. Finally, 32% of the people indicated that their behaviour was influenced by other people. By combining the data from the virtual experiments, the questionnaires and the discussions with the participants it is concluded that clearly a combination of disaster characteristics, information and behaviour of other people influences a person's choice behaviour in such situations.

Main goal pilot experiments
The main goal of the pilot experiments was to maximise the added value of the 3D multi-user method for data collection on travel choice behaviour in case of natural disasters. It was considered important input for the experimental set-up discussed in Section 3.4.1.

Pilot experiments were conducted with experts from the field of traffic and transport. Based on their input, the new method provides potential for data collection on travel choice behaviour in case of natural disasters. Since the participants were experts in the field of traffic and transport and since socio-economic characteristics such as age are not representative either, it is realised that these experts do not represent an average population so no statistically viable or reliable conclusions can be drawn with respect to what they actually did. For future experiments a larger number of participants and a more representative sample are therefore considered.

The main advantage of the new data collection method should be emphasised. By combining the data from the virtual experiment and the questionnaire, it is possible to gain a better understanding of choice behaviour due to the behaviour of other people in combination with disaster characteristics and information. Around 32% of the people indicated that their behaviour was influenced by the behaviour of other people. In combination with when people made their decisions and their main reasons for their mode/route choice (e.g. a car they control themselves, the train would leave on time), it clearly is the combination of disaster characteristics, information and behaviour of other people that influences a person's choice behaviour.

It is believed that the pilot experiments have shown that the new method provides interesting opportunities and therefore a new experimental set-up for a new data collection was planned. The participants of these experiments had to more closely represent the average population. Due to technical feasibility, the number of participants was limited during the pilot experiments. Therefore, in future experiments, it was also decided to preferably increase the number of participants because in real life, the number of people who will be in such situations is also higher.

A.4 Conclusions pilot experiments

In this appendix the results from three pilot experiments with Everscape were presented. The goal of the pilot experiments was to maximise the added value of such a data collection method.

The main conclusion from this is that the experiment is considered to be an enriched stated preference method because it offers the combination of an experiment with the virtual environment and a questionnaire. Like Levinson et al. (2004), the virtual environment is considered to be a virtual experience SP (VESP) and in line with this, the questionnaire is considered to be a virtual experience RP (VERP).

Compared to standard SP surveys, Everscape allows for mimicking a more realistic situation which people are part of, making it easier for them to identify with the situation. An important characteristic of the method is that since participants are all part of the same virtual environment, they are aware of each other's existence because they can see each other and what they are doing at all times. As a result, interaction and emergent behaviour, and therefore herding, can be studied. Compared to existing RP methods, of every individual participant a full trajectory, his path over time, is available. Besides that, from each event it is known (e.g. start earthquake, start tsunami, departure time train, departure time helicopter), when exactly it happens. This allows for determining at every time step the exact situation each participant was in. In combination with the results from the questionnaire, more detailed information is available with respect to the available aspects and aspects people have considered for the choices they made. This is useful for modelling and prediction of choice behaviour. It is therefore concluded that Everscape has potential because it clearly provides opportunities for data collection on travel choice behaviour in case of natural disasters.

Based on these conclusions, an experimental set-up was designed for a large data collection. This experimental set-up is presented in Chapter 3.

Appendix B

Introduction experimental set-up

This appendix consists of the introduction (or briefing) that was held at each experiment. Since it was in Dutch, this appendix is in Dutch.

- -

Slide 1: welkom

Welkom en bedankt dat jullie er allemaal zijn. Mijn naam is Mignon van den Berg en ik ben vandaag jullie gastvrouw. Verder zijn ook de volgende mensen aanwezig van de organisatie (deze dus voorstellen).

Figure B.1: Slide 1: welkom)

Slide 2: introductie, wat gaan we doen

Wat we vandaag gaan doen is het volgende. U gaat deelnemen aan een nieuw soort onderzoek, het is voor ons een nieuwe techniek om data te verzamelen. Het onderzoek bestaat uit de volgende onderdelen. Eerst een introductie, gevolgd door het onderzoek zelf dat uit 2 delen bestaat, een computersimulatie en een vragenlijst. Maar voordat we daadwerkelijk beginnen, delen we u op in 2 groepen (vanwege het grote aantal aanmeldingen). Op het scherm ziet u hoe lang de verschillende onderdelen zullen duren. In totaal zijn we ongeveer een uur bezig.

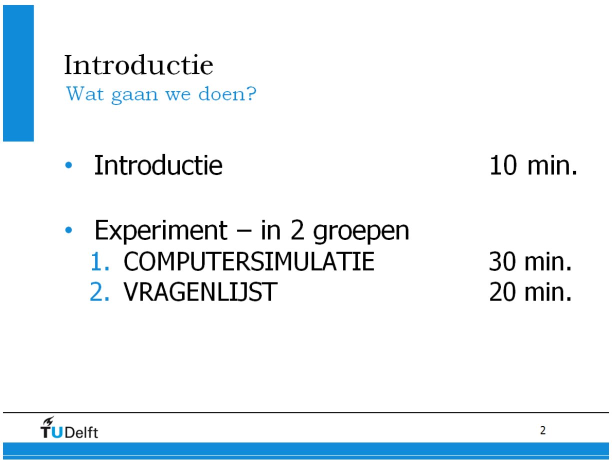

Figure B.2: Slide 2: introductie, wat gaan we doen

Slide 3: deel 1 - computersimulatie

Het eerste deel van het onderzoek is via een computerprogramma. Voor we hiermee gaan beginnen wil ik u wijzen op de volgende punten. Deze hier kort noemen en toelichten. Toevoeging: u heeft ook 2 informed consent formulieren voor u liggen. De ene dient u na afloop getekend in te leveren (in ruil voor de vvv-bon), de andere is voor uw eigen administratie. Bovenaan deze formulieren staat uw participant id die u tijdens het onderzoek gebruikt.

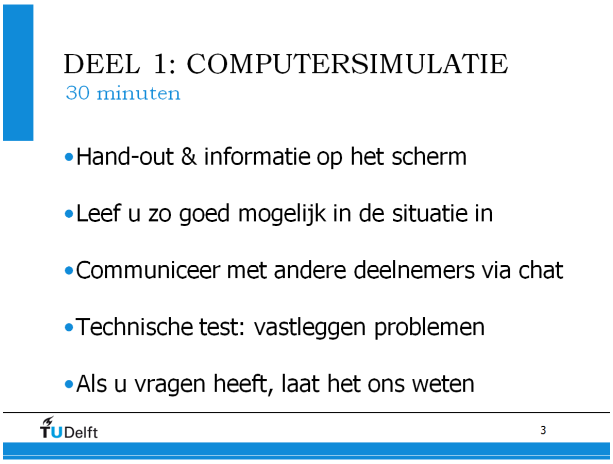

Figure B.3: Slide 3: deel 1 - computersimulatie

Slide 4: deel 1 - computersimulatie

Wat u gaat doen in dit deel is het volgende: u gaat naar een eiland om een concert te bezoeken. Om u een idee te geven hoe het eiland eruit ziet is hier een plattegrond weergegeven. U ziet hier het eiland met het concert. U vliegt naar het eiland met een helikopter, deze zal *hier* landen. U gaat vervolgens zelf met de auto naar het concert rijden: dit kan zijn via (een korte (beach) en lange (mountain) route). Daarnaast is er een treinverbinding op het eiland.

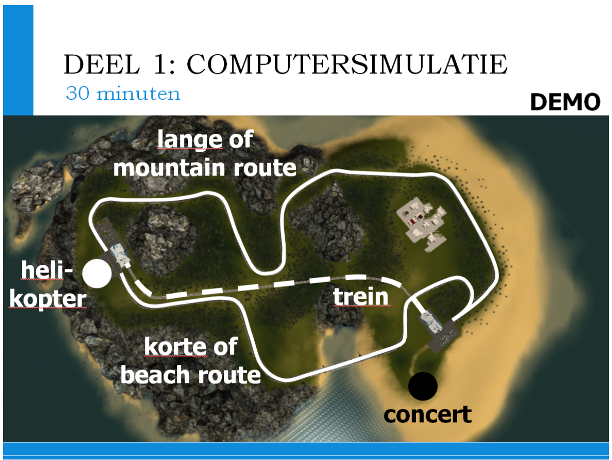

Figure B.4: Slide 4: deel 1 - computersimulatie

Het idee van het virtuele experiment zal ik u m.b.v. een demo (note to myself: via windows+tab) laten zien. U logt in door uw Participant id in te voeren. Deze staat bovenaan de brief die u hebt ontvangen. Let op: u hoeft alleen de cijfers aan te passen dus u laat Participant met een hoofdletter P staan. (note to myself: alt+tab is tijdelijk uit programma & alt + F4 is definitief uit programma).

Verder ziet het er dan zo uit: u arriveert met een helikopter en krijgt een avatar toegewezen. Dit is willekeurig een man of vrouw. Met de pijltjestoetsen kunt u vooruit, achteruit, linksom en rechtsom draaien. U pakt zelf een auto door tegen een auto aan te lopen. Het maakt niet uit welke auto. Daarna volgt u de borden richting het concert. Ik zal niet de gehele route laten zien want het is natuurlijk leuker voor u om het eiland zelf te kunnen ontdekken. Tenslotte kunt u gebruik maken van de chat interface, *dat kan hier*.

Als u bij het concert bent aangekomen, geniet u dan van de muziek en volg de aanwijzingen op die u op het scherm krijgt aangeboden. U kunt op het concertterrein gewoon rondlopen, wederom m.b.v. de pijltjestoetsen. (Note to myself: Nu de helft van de mensen de zaal uit zetten!)

Slide 5: deel 1 - computersimulatie
Dus, we gaan het volgende doen. Nogmaals de punten van de slide noemen en zeggen dat als het concert is afgelopen, de deelnemers zelf terug dienen te reizen naar de helikopter.

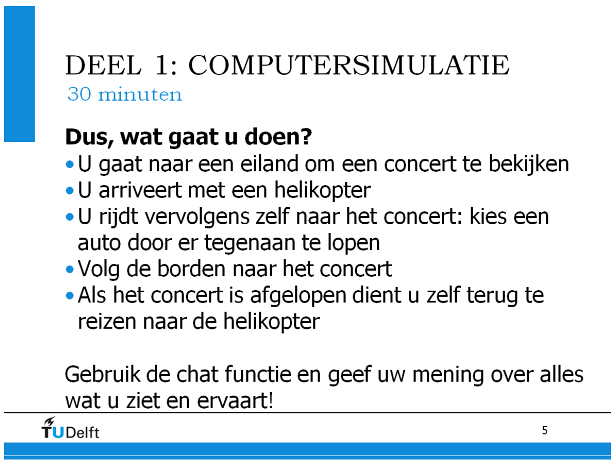

Figure B.5: Slide 5: deel 1 - computersimulatie

Op de hand-out staat informatie over de bediening. Wij vragen u om gedurende het onderzoek alles wat u ervaart en wat u ervan vindt te beschrijven middels de chat interface. Vind u de omgeving mooi, begrijpt u wat u moet doen. Communiceren met andere deelnemers kan via de chat. Het is niet de bedoeling dat tijdens het onderzoek met andere deelnemers in de ruimte communiceert of op zijn/haar scherm kijkt. Alle communicatie met andere deelnemers gaat via de chat interface. (Note to myself: de adminplayer moet ingelogd zijn voor de deelnemers!)

Slide 6: deel 1: computersimulatie
We gaan nu allemaal tegelijk inloggen (en als nodig wachten bij de helikopter tot iedereen geland is). Mocht het nodig zijn: u kunt nu inloggen op de computer met CITG-G393 & Welkom01 (gebruik ctrl+alt+del).

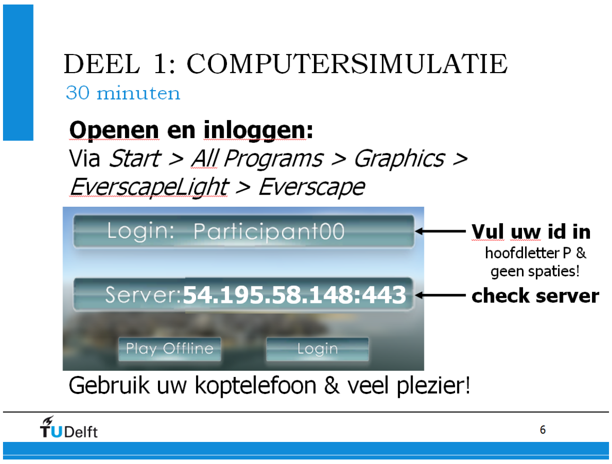

Figure B.6: Slide 6: deel 1 - computersimulatie

U start het programma via Start, All Programs, Graphics, EverscapeLight, Everscape (shortcut). Dan duurt het even en krijgt u een inlogscherm. (even wachten en helpen waar nodig). Note to myself: het inloggen mag pas als de adminplayer is geland op het eiland. Heeft iedereen dit scherm in beeld? (waar nodig mensen helpen)

Log in met uw Participant-id & check server setting: 54.195.58.148:443 (of global-labbproject: 443). Klik op Login, als ik het zeg...(herhalen id en server instructie). Lukt dit iedereen? Ja? Dan kunnen jullie nu inloggen. Na het inloggen en als u bent geland met de helikopter, dan kunt u een auto pakken en naar het concert rijden. Veel plezier & vergeet uw koptelefoon niet!

Slide 7/8/9: deel 2 - vragenlijst
U heeft nu het eerste deel van het onderzoek voltooid. Voordat we beginnen met de vragenlijst vraag ik het volgende van u: omdat er nog meer experimenten gaan komen, verzoek ik u om niets te zeggen over wat er precies zal gebeuren tijdens een experiment. Wij willen namelijk dat alle volgende deelnemers daar niet van op de hoogte zijn.

Na afloop dient u uw formulier getekend in te leveren en krijgt u uw vvv-bon.

Omdat niet iedereen even snel klaar zal zijn verzoek ik u dit zo rustig mogelijk te doen zodat u de andere deelnemers niet afleid. Het invullen van de vragenlijst zal maximaal 20 minuten duren. Ik wil u erop wijzen de vragenlijst alleen in te vullen. Als u vragen heeft, stel ze dan aan 1 van ons, niet aan uw buurman/-vrouw.

Dan wil ik verder nog een belangrijk punt melden. Controleer uw scherm nadat u klaar bent. Bij eerdere experimenten hebben mensen de vragenlijst niet verzonden. Het is belangrijk om aan het einde op Verzenden te klikken, zie hier (slide 8). En dan krijgt

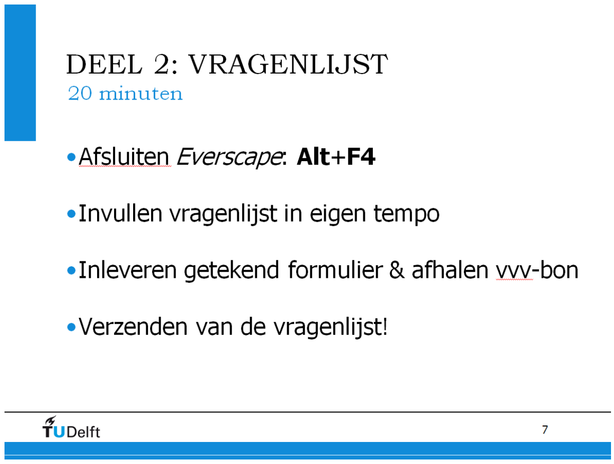

Figure B.7: Slide 7: deel 2 - vragenlijst

u tenslotten dit in beeld slide 9 en dan bent u dusklaar. Voordat jullie beginnen, wil ik jullie bedanken voor jullie deelname!

Figure B.8: Slide 8: deel 2 - vragenlijst

Dan gaan we nu aan de slag met het tweede deel, namelijk het invullen van de vragenlijst. U kunt de vragenlijst openen via Start, All Programs, Graphics, EverscapeLight, VRAGENLIJST (shortcut). (Nadat de eerste groep met de vragenlijst is begonnen, de 2e groep binnen roepen en beginnen vanaf slide 5).

Slide 10: bedankt!
Tenslotte wil ik u allen hartelijk bedanken voor uw medewerking. Voor vragen kunt u contact met mij opnemen.

Figure B.9: Slide 9: deel 2 - vragenlijst

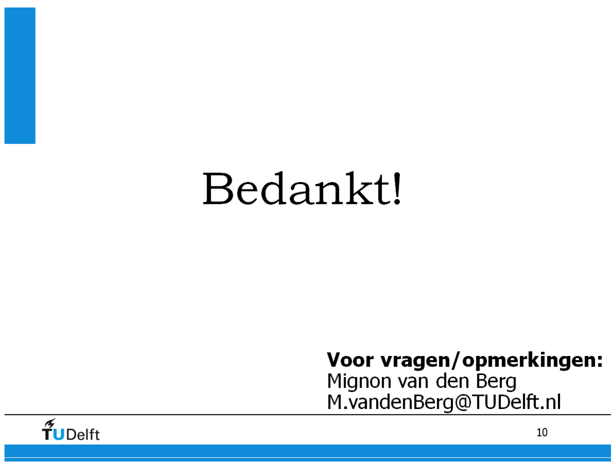

Figure B.10: Slide 10: bedankt!

Summary

In case of natural disasters people have to make evacuation choices, such as the choice to stay at home or leave home, comply to evacuation instructions, use their car or use collective transportation means. These choices have an impact on the number of casualties, which cause personal tragedies and cost societies a significant amount of money.

Insight into factors influencing evacuation choices is essential for modelling and prediction of evacuation choice behaviour. When it is possible to better model and predict people's evacuation choice behaviour, better evacuation management strategies - to evacuate an area that is struck by a disaster - can be developed. Societies can benefit from these strategies because they will change people's perception of the situation and therefore change their choice behaviour. This will then cause less casualties.

Research objective and approach
Extensive research is available on travel choice behaviour which occurs during evacuations in case of natural disasters. Due to the disadvantages of existing data collection techniques, more research is needed to better understand evacuation choice behaviour. The main objective of this thesis is twofold:

1. **To develop, apply and assess a new experimental set-up[1] to study evacuation choice behaviour.**

2. **To quantify the effect of herding on evacuation choice behaviour.**

The research approach consisted of several steps: a literature review, developing the experimental set-up, conducting experiments, analysing the data from the experiments, estimating choice models with the data and reflecting on the experimental set-up and results.

Literature review resulting in conceptual framework on evacuation behaviour
The literature review on evacuation choice behaviour resulted in a conceptual framework that provides an overview of evacuation behaviour research. This framework consists of the elements: information (including e.g. disaster characteristics and

[1]In this thesis the experimental set-up is considered to be the full experiment people participate in, including all phases of a set-up from beginning (arrival at the experiment) to end (departure from the experiment) and including different scenarios.

instructions), personal context (including e.g. socio-economic characteristics and direct surroundings), choice options and human evacuation behaviour (consisting of the perception of the situation, the decision mechanism and the actual choices).

From this overview gaps in literature became visible. Together with limitations to existing data collection techniques, it was decided to focus on quantifying herding in case of a natural disaster.

Experiments conducted with an experimental set-up using serious gaming
An experimental set-up was developed with at its core the virtual environment or serious game Everscape which was able to capture limitations of existing data collection techniques. In total, 14 experiments were conducted with the experimental set-up. With respect to the descriptive analysis, the focus was on if the results supported the conceptual framework and judging realism of the experiment.

In general, the results support results from literature, hence support the conceptual framework. For example, departure choice and mode/route choice were influenced by disaster characteristics and information from a news item. The results also showed that socio-economic characteristics (e.g. age, gender) influenced these choices.

Participants have shown that their mindset was how it was supposed to be because their main goal was to evacuate. The trajectory data confirmed this as well: they all left the concert area and tried to get an available mode/route option to travel to the helicopter. Because it seems that mode/route choice was among other reasons also influenced by the controls, mode/route choice is considered less realistic than departure choice.

An advantage of focussing on the effect of herding on departure choice (the decision to evacuate) is that more participants were together at the moment they made their decision. Therefore, the effect of herding on this decision might be better quantified because participants were able to see more people. For mode/route choice, the participants were more spread over different locations and less likely to see as many people as they saw when making the decision to evacuate.

The effect of herding on the decision to evacuate
Choice models were estimated to consider the effect of herding on departure choice. Several conclusions with respect to the effect of herding were drawn. Participants were inclined to stay at the concert area at a certain moment and the more people a participant saw leaving, the more inclined this participant was to leave.

Seeing people leave had more impact on the decision to leave than seeing people stay and numbers have more effect than percentages. Seeing other people leave the last few seconds before a departure influences the decision to leave the most.

The results showed that a segmentation on herding could be made based on information via the news item. The results suggest that without information people are more inclined to follow others than with information. This makes sense because when it is unknown what to do, people who seem to know what they do, are followed.

Reflection, conclusions and recommendations

Since the experimental set-up consisted of a new set-up using a serious game as a data collection technique and it was specifically developed to focus on quantifying herding, the experimental set-up and results were reflected upon their validity. The focus was on quantifying the effect of herding on the decision to evacuate. In general, the weaknesses of the experimental set-up are considered to not having influenced this.

With respect to the results, it was concluded that both the results from the descriptive analysis and quantifying herding are valid. The results support the conceptual framework and the data collection technique seemed to be appropriate to quantify herding because the data collection is done ethically, the researchers can control the experiments and the results provided new insights in quantifying herding. Based on these reflections and the results of this thesis, the main conclusion is that a new step was taken towards quantifying herding in stressful situations with empirical data, meaning the main objective has been reached.

Since it is considered as a new step, there are also recommendations. These recommendations are related to checking and improving realism of Everscape (e.g. comparing results from virtual experiments to results from real life situations) and realism of such virtual environments in general (e.g. improving realism of walking and driving behaviour). Other measuring devices could be added (e.g. to measure where participants are actually looking at on their screens). The analysis of herding can be improved (e.g. to find out if people follow others over a longer period). Finally, other gaps resulted from the literature review but they were not considered in this thesis. They are also recommended for further research (e.g. group evacuation behaviour).

Samenvatting

Ten tijde van een natuurramp moeten mensen keuzes maken om te evacueren, bijvoorbeeld de keuze om thuis te blijven of hun huis achter te laten, keuzes gerelateerd aan instructies, of men de auto pakt of het OV. Deze keuzes zijn van invloed op het aantal gewonden en doden die de oorzaak zijn van persoonlijke trauma's en de maatschappij veel geld kosten.

Inzicht in factoren die evacuatie keuzes beïnvloeden is essentieel voor het modelleren en voorspellen van evacuatiegedrag. Als het mogelijk is om dit gedrag beter te modelleren en voorspellen kunnen betere evacuatie strategieën - om een gebied te evacueren - ontwikkeld worden. De maatschappij kan hier voordeel uit halen omdat deze strategieën de perceptie die mensen hebben van een situatie kunnen beïnvloeden en dus ook hun keuzegedrag beïnvloeden. Dit zorgt er voor dat er minder gewonden en doden vallen.

Doel van het onderzoek en aanpak
Er is veel onderzoek beschikbaar naar het keuzegedrag van mensen ten tijde van natuurrampen. Door beperkingen aan bestaande dataverzamelingstechnieken is er meer onderzoek nodig om een beter begrip te krijgen van het evacuatiegedrag van mensen. Het doel van dit proefschrift is tweeledig:

1. **Het ontwikkelen, toepassen en op waarde schatten van een nieuwe experimentele set-up[2] voor het onderzoeken van evacuatiegedrag.**
2. **Het kwantificeren van het effect van volggedrag op evacuatiekeuzes.**

De onderzoeksaanpak bestond uit een aantal stappen: een literatuurstudie, het ontwikkelen van de nieuwe experimentele set-up, het doen van experimenten, het analyseren van de data van deze experimenten, het schatten van keuzemodellen met de data en het reflecteren op de validiteit van de experimentele set-up en resultaten.

Literatuurstudie resulterend in een conceptueel raamwerk voor evacuatiegedrag
De literatuurstudie over het evacuatiegedrag van mensen tijdens natuurrampen heeft geresulteerd in een theoretisch raamwerk dat een overzicht geeft van beschikbaar

[2] In dit proefschrift is de experimentele set-up het volledige experiment waar proefpersonen aan deelnemen, waaronder alle fases van begin (aankomst bij het experiment) tot eind (vertrek van het experiment) en inclusief de verschillende scenario's.

onderzoek op dit gebied. Het theoretisch raamwerk bestaat uit de volgende hoofdelementen: informatie (inclusief kenmerken van de ramp en instructies), persoonlijke context (inclusief socio-economische kenmerken en de directe omgeving), de keuzeopties en menselijk evacuatiegedrag (inclusief de perceptie van de situatie, hoe mensen beslissingen nemen en de gemaakte keuzes).

Uit dit overzicht werden de hiaten in de literatuur duidelijk. In combinatie met beperkingen aan bestaande dataverzamelingstechnieken is besloten de focus te leggen op het kwantificeren van volggedrag tijdens natuurrampen.

Experimenten met een experimentele set-up gebruik makend van serious gaming
De experimentele set-up is ontwikkeld met als basis de serious game Everscape. In totaal zijn hier 14 experimenten mee gedaan die uiteindelijk zijn meegenomen in de analyses. Met betrekking tot de beschrijvende analyse lag de nadruk op waar de resultaten aansloten op het theoretisch raamwerk en waar niet. Daarnaast kwam ook realisme van de experimenten aan bod.

Over het algemeen komen de resultaten overeen met de literatuur en dus het conceptuele raamwerk. Bijvoorbeeld, de keuze om te vertrekken en de modaliteits-/routekeuze werden beïnvloed door kenmerken van de ramp en informatie gegeven via een nieuwsbericht. De resultaten lieten ook zien dat de persoonlijke kenmerken (leeftijd en geslacht) van invloed waren op de keuzes.

De proefpersonen hebben zich gedragen zoals de bedoeling was want het was hun doel om te evacueren. De trajectoriën bevestigen dit ook: iedereen is vertrokken en heeft in ieder geval geprobeerd een auto of de trein te pakken richting de helikopter. Omdat de keuze voor de modaliteit en route in ieder geval deels bepaald werden door de besturing, wordt de keuze voor modaliteit en route als minder realistisch ervaren dan de keuze om te evacueren.

Een bijkomend voordeel van het focussen op het volggedrag ten tijde van het vertrekmoment was dat meer personen bij elkaar waren op het moment dat deze keuze werd gemaakt. Hierdoor was het waarschijnlijk makkelijker om volggedrag te kwantificeren omdat elke proefpersoon meer mensen kon zien. Op het moment dat men bij de train of de auto's kwam waren minder personen bij elkaar in de buurt en was het onwaarschijnlijker om volggedrag te kwantificeren.

Het effect van volgen op de beslissing om te evacueren
Er zijn keuzemodellen geschat om het effect van volggedrag op de keuze om te vertrekken te kwantificeren. Verschillende conclusies zijn hieruit getrokken. Proefpersonen waren geneigd om op het concertterrein te blijven op een bepaald moment en naarmate iemand meer personen zag vertrekken was deze persoon zelf ook geneigd te vertrekken.

Mensen zien vertrekken had meer effect dan mensen zien blijven en aantallen hadden meer effect dan percentages. Tenslotte, vooral de personen die iemand vlak voor zijn eigen keuze om te vertrekken zag vertrekken waren van invloed.

De resultaten hebben ook laten zien dat een segmentatie te maken is naar aanleiding van de informatie die de proefpersonen kregen tijdens het nieuwsbericht in Everscape. De resultaten laten zien dat zonder informatie de proefpersonen meer geneigd waren anderen te volgen dan met informatie. Dit is logisch want als men geen informatie heeft en alleen het gedrag van andere personen als bron van informatie kan dienen, dan is het begrijpelijk dat men volgt.

Reflectie, conclusies en aanbevelingen

Omdat de experimentele set-up gebruik maakt van een serious game en speciaal ontwikkeld is tijdens dit onderzoek voor het kwantificeren van volggedrag, zijn zowel de experimentele set-up als de resultaten besproken op hun validiteit. De hoofdconclusie hieruit is dat de wat zwakkere aspecten niet van invloed zijn geweest op de resultaten voor het kwantificeren van het volggedrag.

Met betrekking tot de resultaten is geconcludeerd dat zowel de resultaten van de beschrijvende analyse als het kwantificeren van volggedrag valide zijn. De resultaten komen overeen met de literatuur en dus het conceptueel raamwerk. Daarnaast is de ontwikkelde dataverzamelingstechniek geschikt voor het kwantificeren van volggedrag omdat de experimenten ethisch verantwoord zijn en onderzoekers controle hebben over de experimenten. Op basis van deze reflectie en de resultaten van het onderzoek is de conclusie dat een nieuwe stap is gezet in het kwantificeren van volggedrag in een stressvolle situatie met behulp van empirisch onderzoek. Het doel van het onderzoek is dus gehaald.

Omdat het een nieuwe stap is zijn er ook aanbevelingen. Deze aanbevelingen zijn op het gebied van het onderzoeken en verbeteren van realisme van Everscape (bijvoorbeeld het vergelijken van de resultaten van een virtuele omgeving en de werkelijkheid) en realisme op het gebied van empirisch onderzoek met dit soort omgevingen (bijvoorbeeld het verbeteren van loop- en rijgedrag). Extra meetinstrumenten kunnen toegevoegd worden (bijvoorbeeld apparatuur die vastlegt waar mensen precies naar kijken op hun scherm). Het analyseren van volggedrag kan uitgebreid worden (bijvoorbeeld door volggedrag over een langere periode te bekijken). Tenslotte zijn er nog andere hiaten die uit de literatuurstudie naar voren kwamen maar verder niet bekeken zijn in dit onderzoek (bijvoorbeeld evacuatiegedrag van groepen).

About the author

Curriculum Vitae

Mignon van den Berg is born on the 5th of January 1982 in Haarlem. After finishing her high school she came to Delft to study at the Technical University. She completed her Bachelor's degree in Industrial Design Enginnering in 2005. In 2005/2006 she was part of a student board of StuD Studentenuitzendbureau B.V. in Delft where she worked as an accountmanager.

She completed her Master's degree in Transport, Infrastructure and Logistics in 2009. Her Master's thesis was on pedestrian behaviour and its relation to doorway capacity. It consisted of an analysis of pedestrian evacuation experiments and recommendations for the building decree.

After working at Royal Haskoning, she started her PhD in November 2010. The topic of the PhD consisted for her of an ideal mix of research on people's behaviour and using her organisational skills.

During her PhD she became the proud mother of two daughters, Mira and Isabelle.

Since May 2016 she works as a researcher market analysis at NS Reizigers.

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