The influence of national culture on response behaviour during an evacuation

An Agent-based approach

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TU Delft

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by

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Associated code and models are available at request at https://github.com/elviravandamme/EvacuationResponseCulture.

TU Delft

Summary

Accidents in buildings happen frequently and if people are not evacuated in time, this can have major consequences. The behaviour of building occupants is one of the most critical determinants herein. Evacuation behaviour of a building occupant consists of two phases: the response phase and the evacuation movement phase. During the response phase, a building occupant is notified of an incident and performs a series of information and action tasks. Information tasks are aimed at seeking or sharing information on the incident and required actions. Examples of information tasks are: seeking information through a member of staff, engaging with electronic media to seek information and actively searching for others in the building to provide information. Action tasks include all other tasks not aimed at seeking / sharing information, during which the building occupant undertakes a physical activity. Examples are collecting belongings or physically helping others. When the response phase is finished, a building occupant will initiate movement towards an exit or safe place during the evacuation movement phase.

In this thesis, the focus is on response-phase behaviour. There are many factors influencing response-phase behaviour, four of these are: culture, cues, affiliation and setting. Culture is defined as ”the collective programming of the mind distinguishing the members of one group or category of people from others” (Hofstede et al., 2010). For this research, national cultures have been considered. Cues are any kind of changes in the environment which indicate that something is not normal. Examples of cues are the sound of an alarm system and signs of smoke. Affiliation can be described as the tendency for people to seek the familiar in uncertain situations. This includes searching for relatives, but also leaving the building to the exit with which one is most familiar. Lastly, setting limits the knowledge obtained and the type of actions which can be performed based on the location of the building occupant.

The following research question has been answered: ” How does culture, in combination with cues, settings and affiliation, influence response-phase behaviour and time and total evacuation time? ”.

To answer the research question, a case study was introduced. In this case study library evacuations have been considered in Czech Republic, Poland, Turkey and the UK. Within the context of this case study a questionnaire and an agent-based model have been developed. The questionnaire was developed to obtain insights in response-phase behaviour of the four countries. The results from this questionnaire are used as input for an agent-based evacuation model. Herein, the response behaviour of the four countries has been adjusted based on the received cues, the setting and affiliation. It has been analysed how this influences the response time and evacuation time.

The results show that that there are significant differences in the number of response tasks being performed. Turkey performs the highest number of response tasks, followed in a decreasing order by Poland, Czech Republic and the UK. Furthermore, it has been found that response behaviour in all countries is influenced by cues, setting and affiliation, which results in significant differences between the countries for their response and evacuation time. It has been found that, as with number of response tasks, Turkey has the highest evacuation and response times, followed in a decreasing order by Poland, Czech Republic and the UK. Lastly, it has been found that affiliation and being informed by a staff member highly affect response and evacuation times, while the setting and seeing fire do not. The degrees to which these factors influence response and evacuation times, differ per country.

Overall, this research acknowledges the importance of performing cross-cultural research for evacuation behaviour. It has shown the need for policy makers and emergency planners to discuss effects of culture on evacuations. Additionally, it provides a new approach to study the effect of cultures, in combination with cues, setting and affiliation, on response-phase behaviour and response and evacuation times.

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1

Introduction

Accidents in buildings happen frequently and if people are not evacuated in time, this could have major consequences. Examples of these accidents could be fire inside a theatre, a bomb inside a shopping mall, and toxic gas release inside an air terminal. One can easily imagine what could go wrong and how many people could get injured, or even die if there are no well-arranged escape routes and mechanisms. For example in 2019 a building fire was reported every 65 seconds in the United States and these fires caused more than 3700 casualties and 16.600 injuries (National Fire Protection Association, 2020).

The behaviour of building occupants is one of the most critical determinants for a successful evacuation (Pan et al., 2006). The importance of human factors has been discovered during real evacuations in the past (He et al., 2013). Reasons why crowds might not escape in time, could be because of their lack of awareness, their choices of wrong paths or obstacles standing in the way. The understanding of occupant behaviour is of importance to mitigate negative impacts of building emergencies (Lin et al., 2020). It can be used to make informed policy decision, to support emergency relief efforts and to help with facilitating building design and developing public emergency education (Lin et al., 2020). The first studies on human behaviour during building emergencies were done in the 1950s. During this time, an increase in natural disasters took place, which resulted in an increase of federal funding for relevant research (Fritz and Marks, 2010; Haddow et al., 2010). Since then, many studies have been executed on emotions (Van Minh et al., 2012), way-finding behaviour(Lovreglio, Fonzone, et al., 2016),queuing (Nicolas et al., 2017), social influence (Nilsson and Johansson, 2009), group decision-making (Bosse et al., 2013) and leader-follower behaviour (Ding and Sun, 2020).

Evacuation behaviour consists of two major phases (Galea et al., 2012). During the response phase, an occupant is notified of unusual happenings and the occupant will search for information to validate what is happening. Furthermore, the building occupant will perform tasks in order to prepare for the next phase. These preparations can be anything, from collecting personal belongings and informing others to searching for friends. The duration of the response phase takes a certain time; the response time. While incident analyses have shown a connection between the response time and the number of fatalities (Kobes et al., 2010), response-phase research has been frequently ignored or oversimplified (Vistnes et al., 2005). The response phase is followed by the evacuation movement phase, during which an occupant will perform purposeful movement towards an exit or a place of safety. The duration of the response phase will result in an evacuation movement time. By adding up the response time and the evacuation movement time, one can find the total evacuation time. This time describes how long it takes for a building occupant to leave the building after identifying the first cues of the incident.

One aspect which influences behaviour during these two phases is culture (Hofstede et al., 2010; Matsumoto, 2007; Spencer-Oatey, 2012). Culture is defined as ”the collective programming of the mind distinguishing the members of one group or category of people from others”(Hofstede et al., 2010). Culture can be found anywhere and can be of multiple forms; from organisational cultures to cultures within social classes and cultures associated with religion (Cohen, 2009). For this study, culture is defined as national culture. For national culture, we consider the culture of people with the same nationality, living in the same country.

To date, three types of relevant research can be identified which consider cross-cultural differences

in evacuation behaviour: studies on fires in buildings, studies on evacuations during natural disasters and studies within the general crowd dynamics domain. These studies have shown amongst others how culture influences tasks performed during the different phases of an evacuation (Galea et al., 2015; Marincioni, 2001), levels of emotions (Almejmaj et al., 2016) and tendencies to evacuate (Almejmaj et al., 2015; Bryan, 1978; Lazo et al., 2015). Furthermore the studies have shown how culture influence personal space (Samovar et al., 2016) and walking speed (Hofstede et al., 2010; Kaminka and Fridman, 2018; Levine and Norenzayan, 1999).

Most of the evacuation research is executed for countries with similar cultural backgrounds: UK, USA, Canada, Australia and New Zealand (Galea et al., 2015). Outside of these countries, there is little research available on the effect of culture on evacuation behaviour. Furthermore, only few collaborations can be identified in which publications are co-authored by authors from different countries (Lin et al., 2020). Due to this lack of research on national culture, the same evacuation data is used to provide evacuation insights within very different cultures. However, studies have shown that there could be significant differences in how people from different cultures behave during an evacuation and therefore findings from one country cannot always be applied directly to others.

The focus in this thesis lies on the influence of culture on response-phase behaviour in the case of fire. Response phase behaviour is a broad concept, to which many behavioural theories have been applied (Lin et al., 2020) and which can be influenced by all kinds of factors (Liu et al., 2020; Mu et al., 2013). Three of these influencing factors are cues, setting and affiliation.

Firstly, a cue can be described as " a change in the environment indicating something to be wrong or different from normal" (Sime, 1983). These cues can come from the fire itself (flames, smoke) , from warning systems (alarm, light flashes) and from other people (occupants, fire fighters) (Brennan, 2000). Each cue can have a different impact on an occupant, as the perception, interpretation and decision-making process is closely associated with one's demographics and personal characteristics (Proulx, 2007; Sime, 1983).

Secondly, setting can be explained by looking at the theory of occupancy (Shields, 2005; Shields and Boyce, 2004; Sime, 1999) , which is described in an evacuation context as "the constraints on, conditions and possibilities of knowledge and actions afforded by the social, organisational and physical locations occupied by people over time" (Samochine et al., 2005). According to this theory, the setting may influence how an occupant behaves. Herein the social context plays a role. For example, someone may not be able to speak to others, when there is no one around, and this may influence possible actions that someone can perform and the information that can be exchanged.

Thirdly, affiliation causes people to seek for familiar people and places when in a dangerous situation (Mawson, 2005). This can cause high delays, as people will wait for their coworkers, friends or anyone else they feel responsible for (Meacham, 1999).

1.1. Knowledge gap and research questions

A knowledge gap has been identified on the influence which culture, in combination with cues, setting and affiliation, has on response-phase behaviour. In a previous study, the BeSeCu project (Galea et al., 2015), has been found empirically that there is a significant difference in the response time and behaviour from building occupants in Czech Republic, Poland, Turkey and the UK (Galea et al., 2015). However, an explanation on what causes these behavioural differences is missing. This thesis goes more into depth to find the causes of these cross-cultural differences and to inspect the effect of cues, setting and affiliation on response behaviour. It is not only of value to see how the response-phase behaviour itself is affected by culture, but also how this influences the response and evacuation time. Building occupants will influence each other during the evacuation in their intentions to start evacuating. Thus the distribution of the response-times will affect the flow of people through the building and the total evacuation time (Guanquan and Jinhua, 2006).

This leads to the following research question:

"How does Culture, in combination with cues, setting and affiliation, influence response-phase behaviour and time and total evacuation time? "

Conducting physical evacuation experiments during an emergency is often considered as being unethical and impractical. Thus, in order to identify how response-phase behaviour influences the

response time and total evacuation time, another method is necessary. Modelling and simulation approaches are commonly used to analyse evacuation processes. (Bunea et al., 2016; Galea and Perez Galparsoro, 1994), so this is used in this thesis as well.

Based on the main research question, the following sub questions have been identified:

1. What similarities and differences can be found among response-phase behaviour of library visitors from Czech Republic, Poland, Turkey and the UK during an evacuation?
2. What are the effects of cues, setting and affiliation on the observed cultural response-phase behaviours?
3. How can cultural response-phase behaviour be modelled with an agent-based model in order to measure the response time and total evacuation time?
4. What effects can be identified, through simulations, of cultural response-phase behaviour on response time and total evacuation time?

A mixed research approach is used in order to answer the research question and its sub questions, where literature research and a questionnaire is combined with a simulation model. This research approach is applied to the case-study evacuation of a library in Czech Republic, Poland, Turkey and the UK.

Firstly, Literature research is performed on all relevant aspects of the study: evacuations, its stages and influencing factors, cultures during evacuations and evacuation models. The findings of this literature research are applied to the case-study in order to analyse this study in more depth. The literature study and the application hereof can be found in chapter 2. The background information provides support for answering all of the research questions.

The first and second sub-questions are answered through the development of a questionnaire. The goal of this questionnaire is to find the response-phase behaviour of building occupants during an emergency in a library and the influence of culture herein. Furthermore, the effect of cues, setting and affiliation on the behaviour are considered within the questionnaire. An in-depth explanation of the questionnaire and the detailed research approach can be found in chapter 3. In chapter 4, the results from the questionnaire are discussed.

Sub-question three is answered by developing an agent-based simulation model, based on all the previously discussed research. The obtained questionnaire data is used as input to the model, to measure the effects of differences in response-phase behaviour on response time and total evacuation time. The explanation, validation and verification of this model can be found in chapter 5.

The fourth sub-question is answered by conducting experiments with the developed model.The outcomes of these experiments are discussed in chapter 6.

By answering all of the sub-questions, the main research question is answered and a discussion and conclusion of the work are made. This can be found in chapter 7.

An overview of all chapters is provided in figure 1.1.

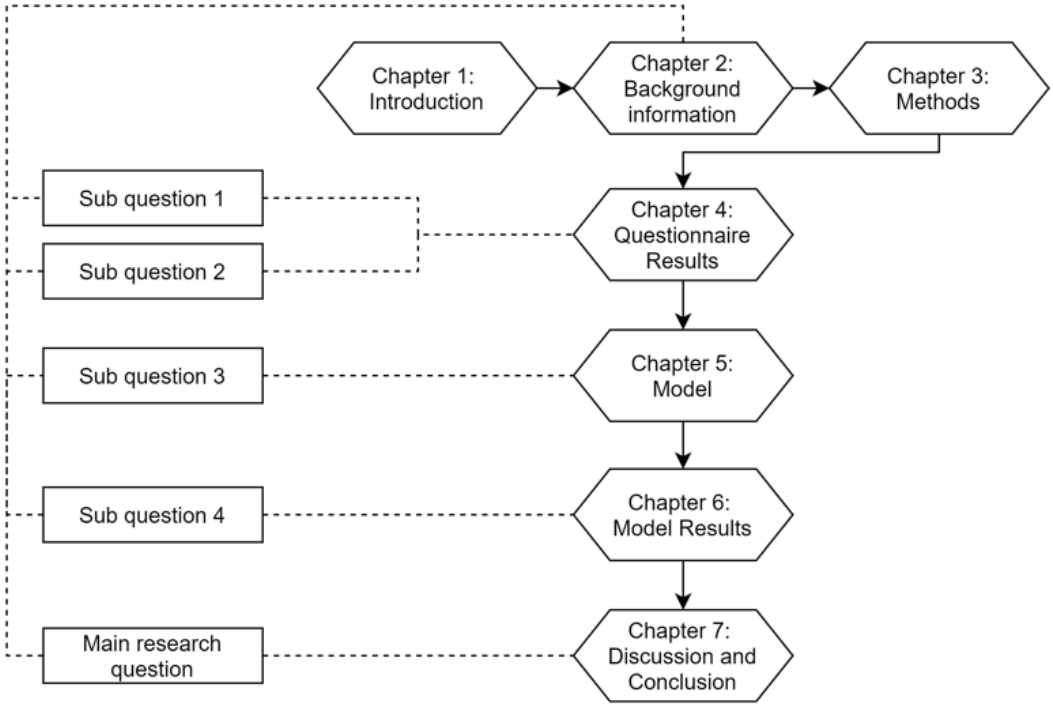


Figure 1.1: Research flow diagram of this thesis

2

Background information

This chapter provides background information for answering the main research question and the sub questions. First of all, the phases of an evacuation are discussed, followed by a section on culture and how culture influences evacuation behaviour. The third section provides information on evacuation modelling and cultural aspects considerd in evacuation models. The fourth section explains the case study and applies the obtained information to this study. Afterwards, a summary follows.

2.1. Evacuations and its stages

An evacuation can be defined as: ”moving individuals or a crowd to a (safe) location due to a threat or a warning or due to safety reasons”(Adrian et al., 2019). Figure 2.1 illustrates the phases that an evacuee goes trough, as described by Galea et al.(2012): a response phase and an evacuation movement phase. The duration of and activities executed during the two phases are affected by human behaviour. This thesis will focus on evacuee behaviour during the response phase. Therefore, cultural influences have only been measured for this phase. Although the evacuation movement phase has also been considered in this research, it has not been studied in as much detail.

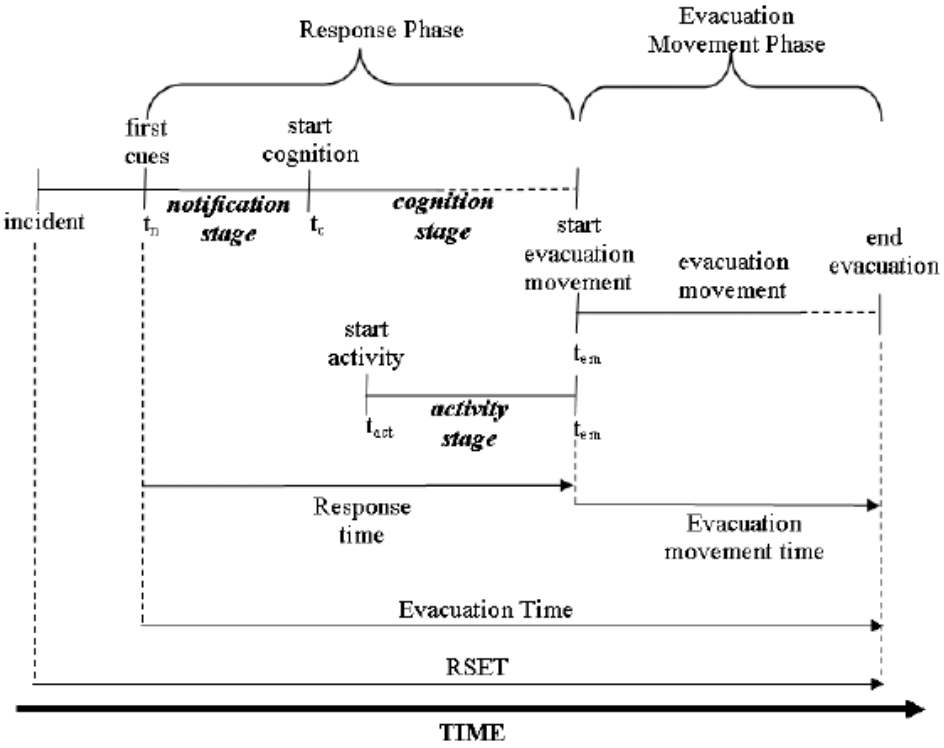


Figure 2.1: Framework for describing evacuation behaviour (Galea et al., 2012)

The response phase starts when people are notified of unusual happenings and it ends when someone starts to evacuate. This phase can be be split up into a notification stage and a cognition stage (Galea et al., 2012). During the notification stage, a person is exposed to the first notification cues. These can be regulated cues like sirens or voice messages or unregulated cues like fire or being informed by another person. The notification stage ends when a person mentally disengages from his/her activities and recognises that the notification cues indicate unusual happenings. During the cognition stage, people start interpreting the information, which has been provided by the notification cues.They decide how to respond to these cues. So there is an activity stage during part of the cognition stage. During this stage, two kinds of tasks can be performed:

- Action tasks: ”involves the occupant physically undertaking an activity such as: shutting down a work station; packing work items; moving to another location, etc” (Galea et al., 2015)
- Information tasks : ”involves the occupant seeking, providing or exchanging information concerning the incident or required course of action.” (Galea et al., 2015)

The response time, also called pre-movement time or pre-evacuation time, encompasses the time passed while a person is in the response phase. It is the time for people to decide to initiate evacuation (Hurley et al., 2016). There are many factors influencing the response time, these will be further explained in section 2.1.1.

The evacuation movement phase follows up on the response phase. During this phase, a person moves towards a building exit or another place of safety. The evacuation movement time encompasses the time passed while a person is in the evacuation movement phase.

The evacuation time consists of the response time and the evacuation movement time. It is the time for a person to reach an exit or place of safety after receiving the first cues.

2.1.1. Influencing factors of response behaviour: Cues, Setting and Affiliation

Response phase behaviour can significantly delay occupants’ response and increase the total evacuation time by hours (Kuligowski and Hoskins, 2011). It is complex to determine the exact factors influencing individual behaviours in a fire, as each individual has a freewill and different psychological features (Kobes et al., 2010).

Liu et al. (2020) has performed a literature research on factors influencing response times and has identified the following factors: Age, Gender, Education level, Training and Experience, Health status, Feeling and Emotion, Cognition and Capability, Familiarity with the environment, Occupant location, Affiliation, Social influence, Pre-fire activities, Cues of fire perception, Actions at recognition stage and Actions at response stage.

Interpretive Structure Modelling (ISM) was to identify the relations between these factors and to identify the direct influence factors (level 1), indirect influence factors (level 2 and 3) and root factors (level 4 and 5) of response time (Liu et al., 2020). This resulted in a 5-levels hierarchical structure, visible in figure 2.2. What is not shown in the figure however, is that the factors on the same level could also influence each other.

The two factors ”Actions at recognition stage” and ”Actions at response stage” fall into the definition of response-phase behaviour as used within this thesis. All three indirect factors from level 2 are considered in this research: Familiarity, Occupant location and Affiliation. Cues of fire perception has been added to this, as it is influenced by two of the indirect factors and this factor itself influences response behaviour as well. Although Feeling and emotion is also influenced by two indirect factors, this factors is not further considered due to the limitations of measuring this factor through a questionnaire. This focuses on the effect of cues in combination with setting (occupant location) and affiliation on response behaviour. Familiarity is only considered further as an input factor to the model, because this factor is not influenced by any cultural aspects.

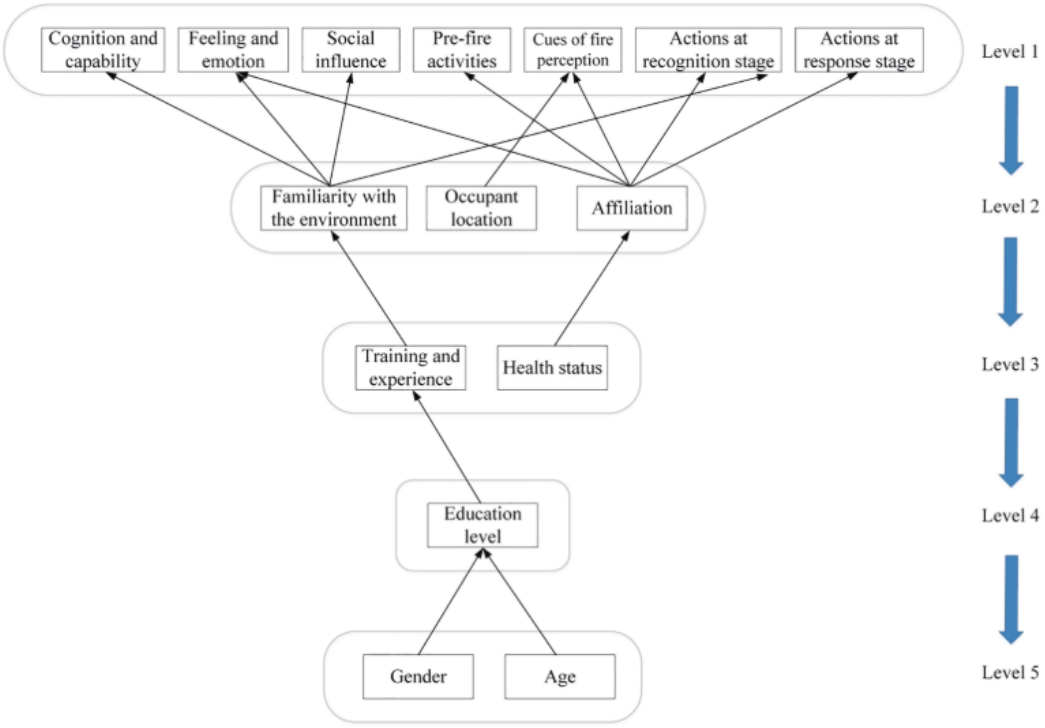


Figure 2.2: Hierarchical structure of factors influencing the response time (Liu et al., 2020)

Cues

A cue can be described as ”a change in the environment indicating something to be wrong or different from normal” (Sime, 1983). Building occupants experience an extensive decision-making process in which they continuously receive different information from cues, they process this information, solicitate additional information if necessary and they take actions accordingly (Lindell and Perry, 2012; Zheng et al., 2020). One example of an extensive decision process is the Protective Action Decision Model by Lindell and Perry. In this model cues influence pre-decision processes (Exposure, Attention, Comprehension), which on its turn influence threat perceptions, protective action perceptions and stakeholder perceptions. These different perceptions result in a decision which causes a behavioural response. By

going through this decision process, occupants experience all evacuation phases. Each cue can have a different impact on an occupant, as the perception, interpretation and decision-making process is closely associated with one's demographics and personal characteristics (Proulx, 2007; Sime, 1983).

While some consider an extensive decision-making process, as described above, most studies only considerrisk perception. These studies describe how cues influence risk perceptions, which influence the state which an occupant is in (Kinateder et al., 2014; Lovreglio, Ronchi, and Nilsson, 2016; Sherman et al., 2011). The Evacuation Decision Model (EDM) (Lovreglio, Ronchi, and Nilsson, 2016) is an example hereof. This is an expansion to the EDM by Reneke (2013). In this model, the perceived risk of an individual is affected by cues and by an occupants demographics and characteristics. The state of an individual changes when specific thresholds of perceived risk are met, where the occupant starts in a normal state an goes trough investigating and evacuating state. The states determine the kinds of actions that an occupant executes.

In this thesis there is no focus on risk perception or on the exact decision-making process, instead it is analysed how cues lead to changes in behaviour. These changes arise due to risk perception and decision-making processes, however these risk perceptions and decision-making processes are not studied in great detail.

The cues come from all kinds of sources: from the fire itself (flames, smoke), warning systems (alarm, light flashes) and other people (occupants, fire fighters) (Brennan, 2000). All kinds of categorizations are available for these cues. First of all, cues can be categorized by their intensity (Kuligowski, 2012; Lovreglio, Ronchi, and Nilsson, 2016). Kuligowski distinguishes high intensity and low(er) intensity cues. Herein he distinguishes physical cues and social cues. Lovreglio, Ronchi, and Nilsson splits up the physical cues into constant-intensity cues, variable-intensity cues. Where a constant-intensity cue is a cue which has a constant intensity over time. An example is an alarm which provides a continuous sound over time. Variable intensity cues do vary their intensity over time, for example smoke or an explosion.

Setting

The types of cues that an occupant receives can be highly dependent upon the location and the setting that the occupant is in. This is also described by the theory of occupancy (Shields, 2005; Shields and Boyce, 2004; Sime, 1999). Herein setting is described as "the constraints on, conditions and possibilities of knowledge and actions afforded by the social, organisational and physical locations occupied by people over time" (Samochine et al., 2005). According to this theory, the setting may influence how an occupant behaves. Herein he social context plays a role. For example, someone will not be able to speak to others, when there is no one around, and thus does this influence possible actions that someone can perform and the information that can be obtained.

McConnell et al. (2010) has observed the 9/11 ramp and found differences in response activities among the different floors within the building. He associates the type of activities with the amount of cues that has been received by a building occupant. He also found significant differences on the perceived risk together with the types of activities executed.

Samochine et al. (2005) has done a similar study, in which he analysed the unannounced evacuation of five retail stores. Significant differences have been found among staff members in their response times and first actions after hearing an alarm. These differences were found by comparing the type of setting which a staff member could be in, for example, staff working at changing rooms, the coffee shop, customer service, till banks and the shop floor.

Affiliation

Besides the environmental setting that an occupant is in, affiliation can cause high delays during the evacuation. It is such a strong concept, that it overrides high risk perceptions (Liu et al., 2020). According to the theory of affiliation (Sime, 1983), people have the tendency to seek the familiar in uncertain situations, as they feel safer in a known environment. Many building occupants tend to find their friends and relatives before starting evacuation (Mawson, 2005; Sime, 1985) . In addition, some temporary affiliations cause forming of small groups. For example, someone physically helping a disabled person during the evacuation.

Affiliation causes high delays, as people will wait for their coworkers, friends or anyone else they feel responsible for (Meacham, 1999). No one of the group will evacuate, unless all are ready. Furthermore,

the slowest member of the group determines the walking speed for the entire group.

2.2. Culture and cultures during evacuations

This section explains how culture influences behaviour during evacuations. In order to be able to explain this, a short introduction to culture and cultural theories is given in 2.2.1. This is followed by previously performed cross-cultural research on evacuations.

2.2.1. Culture and national culture theories

There is no one generally used definition of culture within literature (Schein, 1991). In a review by Kroeber and Kluckhohn in (1952), 164 distinct definitions of culture have been found and this number is only growing further (Taras et al., 2009).

Based on all definitions used within literature, Spencer-Oatey(2012) distinguished multiple characteristics of culture. The most relevant concepts are described here. First of all, culture is a descriptive not an evaluative concept. It is manifested at different layers of depth,the various parts of culture are all interrelated and culture can change gradually over time. Furthermore, culture is associated with social groups, however culture is always both socially and psychologically distributed in a group, and so the delineation of a culture's features will always be fuzzy. Lastly, culture affects behaviour and interpretations of behaviour.

As Hofstede was the pioneer in cultural measurement (Taras et al., 2009), his definition of culture is used within this thesis:*"the collective programming of the mind distinguishing the members of one group or category of people from others."*(Hofstede et al., 2010). By interpreting this definition for the concept of national culture, it would mean that within-country variances are considerably less than between-country variances (Gerhart, 2009).

By using country level to analyse cultures, it is possible to dimensionalize culture, which provides the possibility to compare national cultures (Almutairi et al., 2018). There are multiple national culture theories developed and available in literature. Frequently used theories are the ones developed by Hofstede (2010), GLOBE (House et al., 2004), Trompenaars (1998) and Schwartz (2009). These theories all focuses on distinctive aspects of societal values and norms, thereby the theories include several national culture characteristics (Almutairi et al., 2018). For example, Hofstede has identified multiple cultural dimensions. For each of the dimensions, values can be allocated to a population, which describe the norms and values and behaviour of that population. As the cultural characteristics are similar within the different theories, only the cultural dimensions theory of Hofstede will be further explained in the next section.

Cultural dimensions by Hofstede

Hofstede et al. (2010) has defined six dimensions of national culture, based on surveys executed among IBM employees. The dimensions are described below, as well as the extremes herein. Actual country characteristics can be anywhere between these two extremes.

1. Power Distance
   Power Distance is defined as: "the extent to which the less powerful members of organisations and institutions (like the family) accept and expect that power is distributed unequally"(Hofstede, 2011). This dimension represents inequality within a society. A large Power Distance means that power is considered as basic fact of a community. Children are taught to be obedient to their parents, older people are both respected and feared and subordinates are expected to be told what to do. A small Power Distance means that power should be used legitimately. Parents and children are treated equally, older people are neither respected or feared, hierarchies are used for establishing convenience and subordinates are expected to be consulted (Hofstede, 2011).

2. Uncertainty Avoidance
   Uncertainty avoidance is defined as: "to what extent a culture programs its members to feel either uncomfortable or comfortable in unstructured situations" (Hofstede, 2011). Herein, unknown situations are defined as situations which are surprising and different from the usual. Cultures with a high uncertainty avoidance try to avoid and minimise unstructured situations. This is done through strict rules, disapproval of deviant opinions and a believe in the absolute truth. Cultures

with a low uncertainty avoidance accept that uncertainty is part of everyday life. These cultures are comfortable with ambiguity and chaos, dislike rules and have generally lower stress levels and anxiety compared to cultures with a stronger uncertainty avoidance.

3. Individualism versus Collectivism
   Individualism and Collectivism are considered as two opposites. This dimension is defined as ”the degree to which people in a society are integrated into groups”(Hofstede, 2011). In individual societies everyone is supposed to take care of themselves and their close family, there is a right of privacy and people are expected to have their own opinions. In a collectivist society, people are integrated into strong and cohesive groups. Within the group, people protect each other and and they are loyal to their in-group members. Right of privacy is replaced by a strong belonging and opinions are predetermined by the group.

4. Masculinity versus Femininity
   This dimension consists of two opposites again, masculinity on one side and femininity on the other. This dimensions is defined as: ”the distribution of values between the genders” (Hofstede, 2011). Feminine values include modesty, cooperation and caring for the weak, whereas masculine values include assertiveness, competitiveness and heroism. In a feminine society, all people should be modest and caring and, there is sympathy for the weak and a balance between family and work. In a Masculine society, there is more emotional and social role differentiation between genders. Additionally, people in this society should be assertive and ambitious, there is an admiration for the strong and work prevails over family (Hofstede, 2011).

5. Long Term versus Short Term Orientation
   This dimension is defined as: ”the choice of focus for people’s efforts: the future or the present and past” (Hofstede, 2011). A short-term oriented society focused on the past and the present. The most important events in life occur within these time-spans. A person should be steady and stable and there are guidelines on what is good and evil. Traditions are of high importance as well as service to others and being proud of your own country. A long-term oriented society is focused on important events happening in the future. Good people adjust to the circumstances and what is good and evil depends on the circumstances as well. Traditions can be adapted to current times, one can learn from other countries and thrift and perseverance are important goals (Hofstede, 2011).

6. Indulgence versus Restraint
   This dimension is defined as ”the gratification versus control of basic human desires related to enjoying life”(Hofstede, 2011). Indulgence within a society allows for relatively free gratification of desires related to joy. Generally these people are happier and they have a perception of controlling their personal lives. Important characteristics are leisure and freedom of speech. There is no high priority within the nation to maintain order. Restraint means that there are strict social norms and there is controlling of gratification. People are generally less happy and they have a perception of helplessness. Importance of speech and leisure are not considered as being of high importance and there is a higher number of police officers present within the country. (Hofstede, 2011)

2.2.2. Culture during evacuations

One aspect which influences behaviour, is culture (Hofstede et al., 2010; Matsumoto, 2007; Spencer-Oatey, 2012). Three types of relevant research can be identified for considering cross-cultural differences in evacuation behaviour.

First of all, cultural differences in behaviour can be seen during fires in buildings, one of these studies is the BeSeCu project(Behavior, Security and Culture) (Galea et al., 2015). Galea et al. (2015) has shown a high significance on the influence of culture on response phase behaviour. Within this project, evacuation data of four libraries was compared in Czech Republic, Turkey, Poland and the United Kingdom. The study found significant differences in response time distributions and response phase parameters between the four populations (European Commission, n.d.). Research on the U.S. and Saudi Arabia was done by Almejmaj et al. (2015), he focused on the differences in experience with fire drills and alarm signals. He found that Saudi populations are less experienced with fire drills,

compared to U.S. populations and that the two populations perceive different urgencies for similar alarm signals. He states that participants from the U.S. respond faster to an alarm compared to participants from Saudi Arabia. He also has observed different levels of emotions among the two populations (Almejmaj et al., 2016). Thirdly, Bryan(1978) has conducted interviews with 584 respondents on their experience with evacuation during fires. Based on these interviews, he found that cultures have a different extent to which they notify others about the existence of fire. Besides this, he observed how U.S. respondents have a higher tendency to evacuate, compared to respondents from England. The cross-cultural studies that have been done so far, do however not find any significant cross-cultural differences in way-finding behaviour. Chinese and Europeans make their way-finding choices in a comparable way, their connotations with signage colours are similar. Both cultures prefer green exit signs over red exit signs (Troncoso, 2014). Furthermore, no significant differences can be found among building occupants in London, Beijing and Los Angeles on the influence of crowd flows on their egress behaviour (Lin et al., 2020).

Additionally, cross-cultural research has been performed during natural disasters. Bernardini et al.(2019) provides an overview of behaviours which have been observed during an earthquake emergency evacuation among occupants from New Zealand, Italy and Japan. His research shows how the occurrences of the behaviours differ between the three populations. His data shows a higher number of observations on attractions for group ties and information exchange in Italy, compared to Japan. Vaiciulyte et al.(2021) found however, that behavioural itineraries were similar during wildfires in France and Australia, only their priorities sometimes differed. Lazo et al.(2015) and Morss et al.(2020) have investigated the influence of cultural worldviews on evacuation behavior during hurricanes. Based on a survey, Lazo et al. has detected that respondents which score higher on individualism, are less likely to evacuate, compared to those who score lower on this dimension. According to Morss et al., a higher score on individualism can also be associated with a lower cognitive risk perception. Marincioni (2001) has compared human responses during floods in Italy and the United States and found that the two countries show different behaviour during the different phases of the disaster.

Multiple cross-cultural studies are available within the crowd dynamics domain, which are applicable to evacuations. These studies describe variations in personal space and walking speed, where more individualist cultures tend to have a bigger personal space (Samovar et al., 2016) and faster walking speed (Hofstede et al., 2010; Levine and Norenzayan, 1999). Furthermore, findings from Iraq, Canada, Israel, England and France show cultural differences in avoidance side, group formations, walking speed and personal space (Kaminka and Fridman, 2018).

2.3. Evacuation models and culture

This section explains the types of evacuation models, which are currently being used in research. By assessing all pros and cons, a decision has been made to perform this research by using an agent-based model. Additionally, models are discussed which have incorporated cultural aspects. These models provide insights in the possibilities for incorporating cultural aspects.

2.3.1. Evacuation modelling

Evacuation simulation models are used to predict the performance of evacuations in a building, which can be analysed to assess risk and improve evacuation methods (Zheng et al., 2009). Overall, three hierarchical levels of pedestrian behaviour can be identified in evacuation models: Strategical, Tactical and Operational (Hoogendoorn and Bovy, 2004). In the strategic level, pedestrians make decisions on their activities and destination (Feng et al., 2021). This level considers behaviours which take place prior to a trip, so this can be seen as the response-phase activities. On the tactical level, decisions are made on route and exit-choices (Feng et al., 2021). At the operational level, pedestrians make continuous, short-term movement decisions on their routes. These choices are responses to their immediate environment (Daamen, 2004). Both the tactical level and operational level are of importance during both phases of the evacuation.

Generally, seven kinds of models can be identified in order to study crowd evacuation. All of these models have their pros and cons in modelling the three levels of pedestrian behaviour. The models and their pros and cons are described below.

Cellular automata models are discrete systems, which consist of a grid of cells (Zheng et al., 2009). Each cell communicates with a finite number of other cells (Delorme, 1999), by which the variables at

each cell are being simultaneously adjusted. Lattice gas models are a special case of cellular automata, which have become popular in the 1980s (Fredkin and Toffoli, 1982; Wolfram, 1983). In these models, each pedestrian is considered an active particle on the grid. As both cellular automata and lattice gas models are discrete in space and time, these are useful for large-scale computer simulations (Zheng et al., 2009). These models are however not able to take into account some important evacuation aspects, like injuries and pressure due to external forces

In Social force models, different forces influence the motivations of an individual to act. There are forces which cause acceleration towards the desired velocity of motion, which cause pedestrians to keep certain distances from other pedestrians and from borders of buildings. Lastly, there are attractive effects in place (Helbing and Molnar, 1998). The social force model is very successful in simulating crowd flows (Helbing et al., 2000), however it does not consider the decision-making process of individuals based on personal strategies (Zheng et al., 2009) and it oversimplifies way-finding behaviour (Hoogendoorn et al., 2001).

Helbing et al. (2002) has stated that pedestrian crowds at medium and high density show analogies with the motion of fluids. This principle is used in fluid-dynamic models, which describe how density and velocity change over time by using partial differential equations (Zheng et al., 2009). These models are very suitable for simulating flows of a crowd. However, fluid-dynamic equations are difficult to understand and not flexible (Antonini et al., 2006).

In Agent-based models, a ”bottom-up” approach is used to build social structures (Goldstone and Janssen, 2005). Pedestrians are represented by agents which have their own characteristics, for example age, gender, mobility and fear. These agents are capable of interacting with their environment and with other agents (Fang et al., 2015). The benefits of an ABM are described by Bonabeau (2002) as: an ABM captures emergent phenomena, it provides a natural description of a system, and it is flexible. A con of an ABM can be found in the difficulty to model human agents' behaviour (Zheng et al., 2009), for example their interactions with others and their perceptions of the environment.

Game theoretic models consider rational choices through which they try to understand conflict and cooperation (Myerson, 2013). In these models, players go through a decision process in which they assess all possible options and choose the option which provides the highest utility for them. This type of models is applicable for human reasoning and strategic thinking during an evacuation. As the outcome of the game consists of a payoff matrix, it is difficult to identify the appropriate matrix for a large number of players (Zheng et al., 2009).

Experiments with animals are used for studying crowd evacuations. Examples of these experiments are mouse escaping from a water pool (Saloma et al., 2003) and simulations of high and low panic situations with ants (Altshuler et al., 2005). These experiments are able to mimic ”real” evacuations, however it is impossible to reproduce the comprehensive behaviour of humans (Zheng et al., 2009).

2.3.2. Culture in evacuation models

Relatively little crowd evacuation models have taken into account the aspect of culture. The models that do consider cultural factors, usually focus on a few aspects which are influenced by culture, for example the understanding of the English language (van der Wal et al., 2017), and the effects of clothing style and alarm recognition (Almejmaj and Meacham, 2014). Furthermore Kaminka and Fridman (2018) stated that the tendency to notify others, the seriousness with which people consider en event and the tendency towards evacuating in groups, is influenced by culture. These aspects have been implemented in an evacuation model to find out its effects on evacuation times.

2.4. Case study: Library evacuations in Czech Republic, Poland, Turkey and the UK

This section discusses the case study and the application of the previously discussed literature to this case study of. As a case-study, the evacuation of a library is chosen. This situation is chosen as it is expected that this situation is similar for all countries in this study: Czech Republic, Poland, Turkey and the UK. First of all, library buildings in the four countries are expected to be similar and building occupants are expected to have similar demographics. Furthermore the types of activities performed in the libraries are of a similar nature.

Usually two kinds of people can be found within a library, staff and visitors. Based on the role-rule model (Tong and Canter, 1985), the behaviour of an occupant is affected by an implied set of rules

connected to the everyday role of that person (Forssberg et al., 2019). Therefore, staff members and visitors are expected to perform different types of behaviour during a library evacuation. For example, staff members will feel a higher responsibility to inform others to evacuated, in comparison to library visitors. The focus within the case study will lie on the response-phase behaviour of library visitors, it is expected that their behaviour is influenced by culture. Whereas the behaviour of library staff could be largely affected by the types of training that they have had (Formolo et al., 2018).

In the sections below, response tasks in a library situation have been identified, as well as cues, setting and affiliation. Additionally, the cultural and behavioural differences between Czech Republic, Poland and Turkey are discussed.

2.4.1. Response tasks identification in a library situation

Scientific literature research has been executed to find different types of response tasks. Herein scientific papers on response-phase decision making have been considered, as well as incident reports. After a minimum of 10 articles have been analysed, only additional articles have been added which described tasks not identified earlier in the process. The research has led to the identification of a number of information and action tasks, which have been filtered based on their applicability to a library situation. Tasks which not relevant for the case study, were for example: getting dressed in a hotel situation and notifying neighbours in a residence building

This has led to the identification of 9 information tasks, 11 action tasks and one extra task, described in 15 articles. The information tasks have been split up into information seeking tasks and information sharing tasks. The task ”Ignore the alarm” has been added as an extra task. This is not really an information or action task, as occupants are not physically doing something. However it is described in many articles that occupants ignore the alarm and continue their previous activities or they wait to be instructed. Therefore, it is of interest to see how this influences the notification time.

The identified information and action tasks are depicted in table 2.1.

Table 2.1: Information and action tasks in a library situation, identified through literature research

Articles	**Bryan (1982)**	**Bernardini et al. (2019)**	**Cordeiro et al. (2011)**	**Day et al. (2013)**	**Galea et al. (2011), (2012), (2013), (2015), (2017)**	**Kuligowski and Hoskins (2011)**	**Lo et al.(2000)**	**Proulx and Reid (2006)**	**Sherman et al. (2011)**	**Zhao et al. (2009)**
Information seeking tasks		X	X							
Phone someone to seek information	X			X	X		X	X	X	
Engage with electronic media to seek information				X	X				X	
Seek information through conversations with other people nearby				X	X	X		X	X	X
Move to another location to seek information					X		X			
Look around and listen to what is happening	X			X	X	X	X			X
Seek information through professional bodies (building security/ reception)				X				X	X	
Information sharing tasks										
Phone someone to provide information	X				X		X	X		
Actively provide information and / or instructions to others nearby	X	X	X	X	X	X	X	X		X
Actively search for others in building, to inform them	X					X	X	X	X	
Action tasks										
Shut down work station, lock files, tidy desk etc (work-related duties).				X	X	X			X	
Pack personal and work items in close vicinity(laptop, documents, phone, keys etc)	X			X	X	X	X	X	X	X
Collect and put on coat	X				X	X				
Change footwear/glasses/clothing	X			X			X		X	
Physically assisting others (help others put on coat or collect items)		X		X	X					
Collect emergency equipment (flash lights, water etc)						X		X	X	
Move to another location to collect items					X					
Move to another location to find friends/ coworkers									X	
Wait for a friend/coworker to leave				X						
Call alarm number			X				X			X
Fight fire			X		X		X			X
Extra										
Ignore the alarm			X	X	X	X	X	X		X

2.4.2. Cues, setting and affiliation in a library situation

This section discusses the cues, setting and affiliation considered in this research. These aspects stand on itself, however the execution of some response tasks can be restricted or encouraged due to cues, setting and affiliation.

Cues

As discussed in section 2.1.1, cues come from all kinds of sources. The cues considered in this research are based on cues as described by Brennan (2000). Three major and two additional types of cues are considered in this research.

Firstly, a fire alarm is considered as a constant-intensity cue, which provides a continuous sound over time. The second cue comes from the fire which occurs in the library. This cues combines both flames and smoke. Besides the adjustment of response tasks due to this cue, it encourages the execution of two extra response tasks: fighting fire and calling an alarm number. Visitors are expected to only perform these actions, when they have actually seen signs of fire and/ or smoke. Thirdly, informing by staff members has been considered as a major cue.

Additionally, two other cues have been considered in the model. The effect of these cues is however not researched in detail through the questionnaire. These cues include communication with other visitors and seeing others evacuate.

Affiliation

As described in section 2.1.1, many building occupants tend to find their friends / relatives before initiating evacuation (Mawson, 2005). For this library case, it has been assumed that visitors are in the library together with maximally one friend or colleague. Affiliation is split up in two aspects: a person is either in close vicinity to his / her friend or colleague or not. This means that when friends / colleagues are together, a visitor needs to decide if he / she will wait for his/her friend or colleague before evacuating. Setting comes into play, as described in the section below, when friends are not near each other. Both of the friends / colleagues will need to decide if they search for their friend / colleague before initiating evacuation.

Setting

The theory of occupancy describes a setting as the social, organisational and physical locations influencing knowledge and actions (Samochine et al., 2005). Examples provided in section 2.1.1, describe settings as different floors or different types of locations in which someone is working.

For the library study, it has been assumed that all visitors perform similar types of behaviour: working / reading / browsing around the library / meeting with friends / colleagues. Therefore, the setting will only be considered as the type of a location in which the visitor finds him /herself. For this research, the setting is dependent upon the number of people around. This includes both being in a closed off space, e.g. private office, and being in a space with not many people around.

Additionally, two types of actions are influenced by the setting. Firstly, any actions related to collecting personal belongings, are affected by the setting. These tasks can only be performed when a visitor is close to his / her belongings. In the case has been assumed that all visitors have a sitting place in the library, where their persona belongings are located. Whenever a visitor is not near his/ her sitting place, a decision has to be made to return to the sitting place or not.

Secondly, affiliative behaviour is influenced by the setting. As discussed in the section above, affiliative behaviour is considered as evacuating together with a friend or colleague. If this friend / colleague is not nearby, the visitor will need to decide if he / she is searching for his / friend or colleague or not.

2.4.3. Cultures and observed differences in response phase behaviour

The four cultures which are considered, are those of Czech Republic, Poland, Turkey and UK. These are the countries for which Galea et al. (2015) has found significant differences in the number of information and action tasks, as can be seen in figure 2.3. The figure shows that Czech evacuees perform

the highest average number of tasks, followed by Poland, the UK and Turkey. Although the total number of tasks is based on the number of information tasks and action tasks, both of these do not show the same orders of magnitudes.

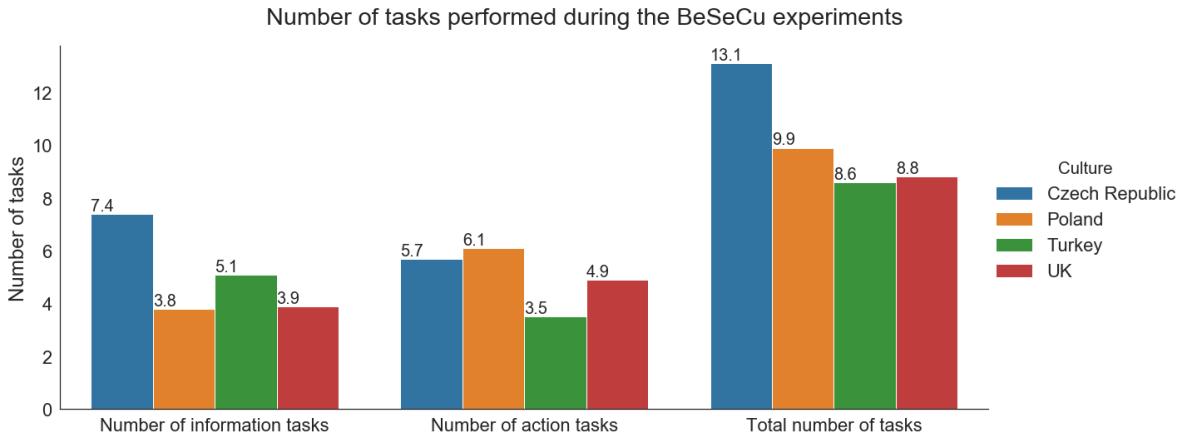


Figure 2.3: Number of tasks performed during the BeSeCu experiments for Czech Republic, Poland, Turkey and the UK (Galea et al., 2015)

These differences in response phase behaviour can be explained by the cultural differences of these countries. Hofstede's cultural dimension scores for each of the countries can be seen in figure 2.4. The sections below discuss how each of the dimensions could possibly influence evacuation behaviour. These are however speculations and these are not confirmed by research.

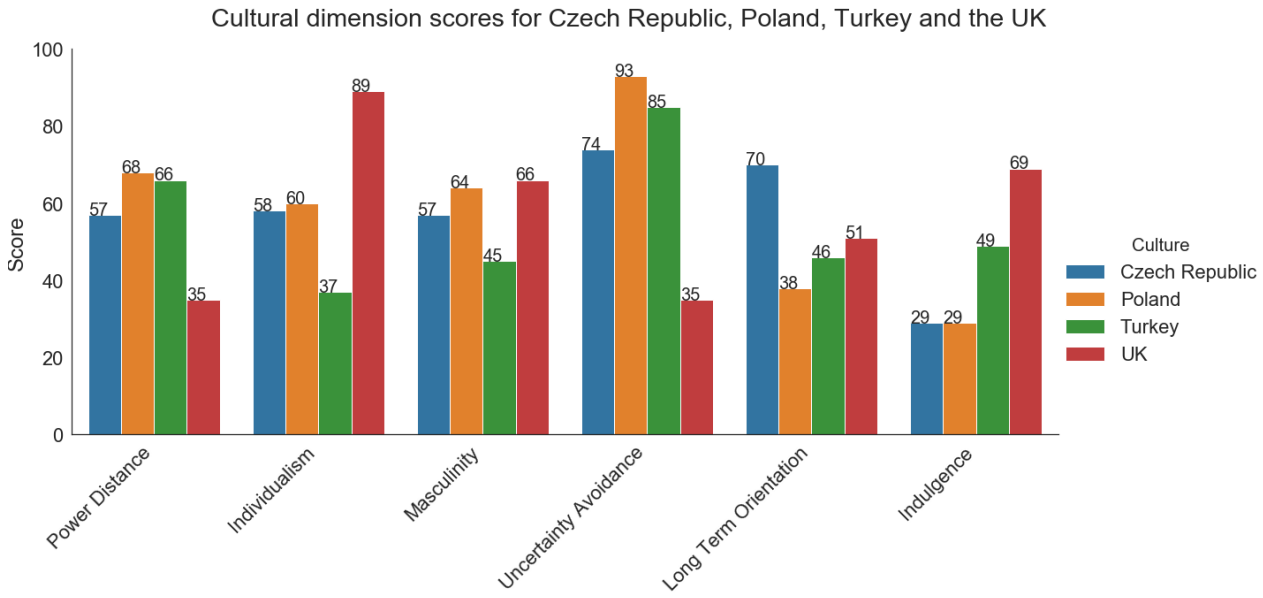


Figure 2.4: Hofstede dimension Scores for Czech Republic, Poland, Turkey and the UK (Hofstede et al., 2010)

Poland and Turkey score relatively high on power distance. People from these societies are more obedient to authorities compared to the countries with a lower power distance. Within the Library case this could result in a quicker response to an alarm or to a higher likelihood of following staff instructions.

The UK scores relatively high on Individualism, whereas Czech Republic and Poland score somewhat lower on this dimension and Turkey has the lowest score. This could mean that Turkey is more group-oriented than the other countries, which could reflect to the amount of groups present in the library. Furthermore, this could be connected to the likelihood of waiting for or seeking friends before leaving the library. A higher score on this dimension could however be related to more proactive

behaviour during the evacuation.

The division of the four countries on the Masculinity dimension is similar to the Individualism dimension. A feminine society is more likely to care of the weak people.This could mean that Turkish people are more likely to assist others in need, in comparison to the other countries.

Poland and Turkey score highest on Uncertainty avoidance, followed by Czech republic and the UK. A higher score on this dimension means that people feel more uncomfortable during unpredictable situations. Therefore higher levels of anxiety could be seen among Poland and Turkey, in comparison to the UK. This could mean that these cultures are more likely to follow rules and instructions in order to take away the uncertainty of the situation. Additionally, uncertainty avoidance could be related to the number of information tasks being performed. A higher uncertainty avoidance could mean that occupants are more likely to try collect more information before starting the evacuation.

Czech Republic scores highest on Long Term orientation, followed by the UK, Turkey and Poland. Long-term orientation could be associated with certain tasks during the evacuation. Some tasks, like seeking belongings, could possibly be associated with a short-term orientation. Long-term oriented people might prioritise evacuating, over these tasks which mostly fulfil short-term desires.

The dimension of Indulgence is concerned with the gratification of desires related to joy. This dimension is expected to not be very relevant within the case study.

Again, as stated above, all of these relations between the dimension scores and evacuation behaviour are speculated. From the above can be concluded, though, that all four countries are quite different in their cultures. It is up to this research to find out if and how these cultural differences influence behaviour during the response phase.

2.5. Summary

This chapter has provided an overview of the background information needed to answer the research questions. First of all, the two phases of an evacuation have been discussed: the response phase and the evacuation movement phase. The response phase consists of an notification phase, after which two types of tasks are being performed during the activity phase: action tasks and information tasks.

Multiple influencing factors of the response time have been discussed. In this thesis, the focus is on three of these factors: cues, setting and affiliation. Another influencing factor which has been considered is culture. In this research, culture is defined as national culture. Difference in national cultures can be explained through the six cultural dimensions of Hofstede: Power distance, Individualism, Masculinity, Uncertainty avoidance, Long term orientation and Indulgence.

Although, cues setting and affiliation on itself can influence response-phase behaviour, culture might influence these factors as well. Therefore, this research considers how combinations of these factors influence the overall response-phase behaviour (figure 2.5).

Evacuation modelling is a frequently used method to research evacuations and evacuation behaviour. Seven types of evacuation models have been been discussed with its pros and cons: Cellular automata, Social force, Fluid-dynamics, Agent-based, Game-theoretic and experiments with animals. Additionally, models have been discussed, which have incorporated cultural aspects. It has been found that relatively few evacuation models have incorporated any cultural aspects.

Lastly, the case study has been explained in more detail. Twenty information and action tasks have been identified, which are applicable to a library situation. Additionally, Cultural dimensions scores for Czech Republic, Poland, Turkey and the UK have been discussed. Speculations have been made on how these dimensions could possible be related to different types of behaviour during the response phase.

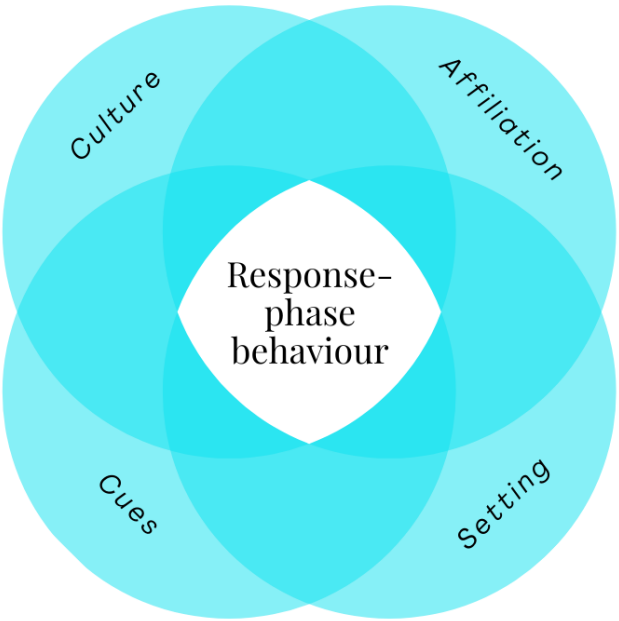


Figure 2.5: Elements researched in this thesis with their influence on response phase behaviour: Culture, Cues, Setting and Affiliation

3

Methods

This chapter describes the methods used within this thesis. The general approach is explained, after which the different parts are explained in more detail.

Firstly, a literature research has been conducted, in order to obtain background information on all of the relevant aspects of the study: Evacuations and influencing factors, culture and cultures during evacuations and evacuation modelling. The obtained information has been applied to the case study to shed light on the different aspects of library evacuations in Czech Republic, Poland, Turkey and the UK. The appropriate information was collected though Scopus, Science Direct, Google Scholar and Web of Science.

Secondly, a questionnaire was developed, based on the insights obtained through the literature study. The aim of this questionnaire is to answer the first and second sub-question by analysing the similarities and differences among response phase behaviour of Czech Republic, Poland, Turkey and the UK. Additionally, it was used to find the influence of cues, setting and affiliation on response phase behaviour in each of the four countries. The data collected through the survey was analysed with SPSS and Python and it was used as input to an Agent-based model.

By developing an Agent-based model, the third research question has been answered. This model simulates the evacuation of a library with Czech, Polish, Turkish and British building occupants.

Experiments have been conducted with the model, to answer sub-question four. The data of the experiments were analysed with SPSS and Python and it provided the results.

Figure 3.1 provides an overview of the methods used.

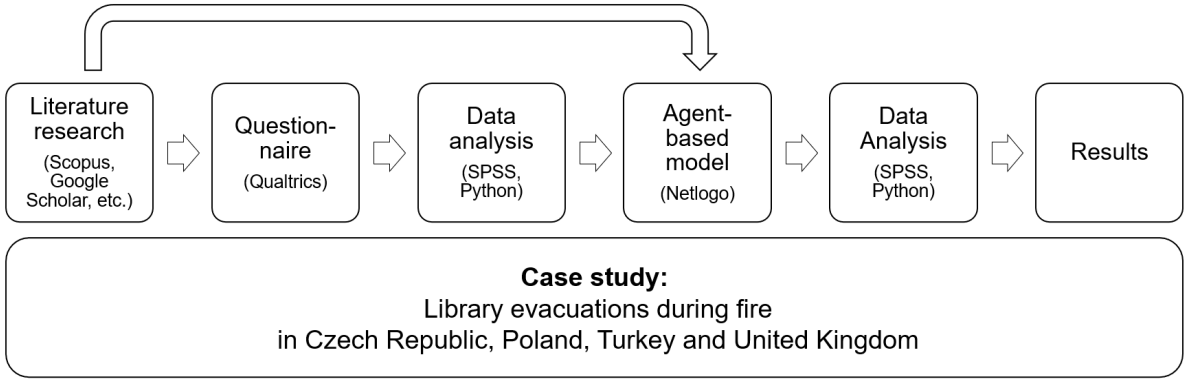


Figure 3.1: Overview of methods used

3.1. Questionnaire development

In order to develop the model, data on response-phase behaviour was needed for Czech Republic, Poland, Turkey and the UK. Timmermans (2009) describes various techniques for collecting data on

pedestrian behaviour: questionnaires, pedometers, GPS data, inspecting videos and observing behaviour in real situations. Pedometers and GPS data are not able to provide us the desired data on performed response tasks. To the knowledge of the author, there are no videos available for Czech Republic, Poland Turkey and the UK which show evacuations in libraries. Observing real-time behaviour of library visitors is close to impossible, as one cannot predict when an emergency evacuation will take place. Another option would be to conduct physical evacuation experiments, however, this often considered as being unethical and impractical. Additionally, this research took place during the Covid-19 pandemic, which narrowed down options for conducting physical experiments.

This leads to one remaining method for collecting data: a questionnaire. Pros of obtaining data through a questionnaire are the number of people which could be reached online and the ability to ask respondents detailed questions on their behaviour. Cons of this method are that self-reported behaviour may not fully reflect actual behaviour during an emergency evacuation (Shiwakoti, Tay, et al., 2020; Shiwakoti, Wang, et al., 2020) and respondents might answer questions in a socially desirable way (Fisher, 1993; Grimm, 2010). To the best ability, both of these cons have been assessed, by actively avoiding steering questions and by accurately describing each of the possible behaviours. While developing the questionnaire, method biases, item biases and construct biases (van de Vijver and Leung, 1997) have been avoided . The questionnaire was developed with Qualtrics software.

Research has been done on possible information and action tasks within the library (section 2.4.3) to develop the questionnaire. As has been discussed in section 2.1.1, cues, setting and affiliation can influence response-phase behaviour. Therefore scenarios have been developed around these aspects, for which respondents have been asked to select relevant tasks and task sequences. After the questionnaire was developed, it was translated into the native languages of the respondents. The respondents have been selected based on multiple requirements. Below, this is all explained in more depth. The full questionnaire can be found in Appendix A and is accessible through the following link: https://tudelft.fra1.qualtrics.com/jfe/form/SV_8GIM2LfcfVaTCke.

3.1.1. Scenario development

Below, all of the scenarios are discussed. In real-life there is a possibility of overlap among the different scenarios. As the questionnaire couldn't be too lengthy, questions on overlapping scenarios are only asked if it was expected that these combinations would cause considerable differences in an occupants' behaviour.

Basic Scenario

As a basic scenario, the scenario is chosen which is expected to occur most often among building occupants. In this scenario, a respondents imagines himself/ herself sitting down at a desk in a library, while working on a personal computer or reading a book. The building occupant is sitting there by himself/ herself and does not have any acquaintances in the building. He/ she can see some other people working or walking around the library. Then an alarm starts sounding. The building occupant does not have any information on why the alarm went of and others around him / her are behaving calmly.

For this scenario all of the information and action tasks are available, except for "Fighting fire" and "Call alarm number". These two tasks are not included, as an occupant is not expected to execute these tasks when he / she has not experienced any signs of danger. Respondents will be asked to put the tasks in the right sequence.

Besides the basic scenario, alternative scenarios have been developed which differ with respect to the basic scenario, by their cues, setting and affiliation. An overview of the factors changed compared to the basic scenario, can be seen in table 3.1. All of these alternative scenarios are discussed below.

Scenario 1: Informed by a staff member

In this scenario, the situation is similar as before. However, while hearing the alarm, the building occupant is informed by a staff member to leave the building. Respondents will be asked to put the tasks in the right sequence.

Scenario	Description	Cues	Setting	Affiliation
1	Informed by a staff member	X		
2	Collection of personal belongings		X	
3	Situated in a Closed off space		X	
4	Friend/ colleague in close vicinity			X
5	Friend/ colleague not in close vicinity		X	X
6	Fire and/ or smoke seen; Basic Scenario	X		
6.1	Fire and/ or smoke seen; Friend/ colleague in close vicinity	X		X
6.2	Fire and/ or smoke seen; Friend/ colleague not in close vicinity	X	X	X
6.3	Fire and/ or smoke seen; Collection of personal belongings	X	X	

Table 3.1: Scenarios considered in the survey, with Cues Setting and Affiliation changes in comparison to the basic scenario

Scenario 2: Collection of personal belongings

In this scenario, the building occupant is walking around the library when the alarm starts sounding. The building occupant does not have his / her personal belongings with him / her, these are still at the place where he / she was sitting earlier. The respondent is asked if he / she will collect his / her belongings before leaving the library. The respondent has three answer options: ”yes”, ”no” and ”Only if I can find my belongings in a short amount of time”.

Scenario 3: Situated in a Closed off space

In this scenario, the building occupant is not in close proximity to others. This could be because there is no one sitting in his/ her immediate surrounding or he /he is in a closed off space. For this scenario, an occupant is not able to execute all of the same information tasks as before. Therefore, only the information tasks are displayed, which not include any persons being nearby.

Scenario 4: Friend/ colleague in close vicinity

In this scenario the building occupant is in the library together with a colleague or friend. They are sitting close to each other while working. The respondent is asked if he / she will wait for his / her friend before leaving the building. The respondent has three answer options: ”yes”, ”no” and ”Only if I can find friend belongings in a short amount of time”.

Scenario 5: Friend/ colleague not in close vicinity

In this scenario the building occupant is in the library together with a colleague or friend. However, his / her friend is not in close vicinity and the building occupant is not sure of where his / her friend is. The respondent is asked if he / she will search for his / her friend before leaving the building. Similarly to scenario 4, the following options are provided: ”yes”, ”no” and ”Only if I can find my friend in a short amount of time”.

Scenario 6: Fire and/ or smoke seen; Basic Scenario

In this scenario the building occupant sees signs of fire and / or smoke. This scenario is split up into 4 sub-scenarios.

- **Fire and/ or smoke seen; Basic Scenario**. For this scenario all of the information and action tasks are available, also ”Fighting fire” and ”Call alarm number” are available now. Respondents will be asked to put the tasks in the right sequence.
- **Scenario 6.1: Fire and/ or smoke seen; Friend/ colleague in close vicinity**. For this scenario, the respondent is asked if he / she will wait for his / her friend before leaving the building.
- **Scenario 6.2: Fire and/ or smoke seen; Friend/ colleague not in close vicinity**. For this scenario, the respondent is asked if he / she will search for his / her friend before leaving the building.

- **Scenario 6.3: Fire and/ or smoke seen; Collection of personal belongings**. For this scenario, the respondent is asked if he / she will collect his / her belongings before leaving the library.

3.1.2. Setup

The questionnaire is set up as follows:

Firstly, an introductory statement to the research is provided. This statement explains the objective of the research and the way the data will be processed. Furthermore it mentions the risk of a data breach and the methods used to mitigate this risk.

Secondly, four questions will be asked to filter the respondents. If the respondents do not comply with the respondent requirements, they will not be able to continue the survey.

Thirdly, the basic scenario will be described and the respondent is asked for his / her behaviour during this scenario.

Fourthly, all of the other scenarios are described and the respondent is asked for his / her behaviour during these scenarios.

Lastly, the respondent is asked to fill in general demographics. These are his/ her gender, highest level of education, frequency of visiting libraries, group size with which he /she visits a library and experience with fire emergency training and fire drills.

3.1.3. Translation

The questionnaire was translated to the languages spoken in the four countries. Guidelines by Brislin (1986) have been followed for optimising translatability. In order to assure validity of the translations (van de Vijver and Leung, 1997), at least two translators have worked on it per language. One translator has translated the text from English to Polish/ Czech/ Turkish and another translator translated this back to English. The second translator adjusted for any discrepancies between the two English versions. All of translators are native speakers of the foreign language, except for one Turkish translator. However, this translator lived in Turkey for over thirty years and obtained enough knowledge of the language to be able to do the back translation to English.

3.1.4. Respondent requirements and incentive

A minimum of 100 respondents per country was required. The demographics of the respondents should be similar over all four countries and these are comparable to the demographics of building occupants in the BeSeCu project (Galea et al., 2015). This way, the results can be validated through comparison with the BeSeCu data (Galea et al., 2015). The respondents had to meet the following requirements:

- **Age: 18 to 40**. This requirement has been set in order to target a group of respondents which is likely to find themselves studying or working in a library and to avoid age-effects on response-phase behaviour (Bode and Codling, 2019). Furthermore, these age requirements are similar to the ages among the participants of the BeSeCu project (Galea et al., 2015).

- **Residency and nationality should be the same**. This requirement has been set to control the cultural characteristics of the respondents. Exposure to a new homeland could modify or override ones organic cultural influences (Litvin, 2003; Samovar and Porter, 1972). Therefore, it is required that the a respondent lives in the same country as is his / her nationality.

- **Equal distribution of male / female respondents: both minimum 40 %**. This requirement has been set, as earlier research has shown that gender can influence response phase behaviour (Liu et al., 2020). By setting this requirement, a good representation of the society can be reached and the influence of gender of behaviour can be accounted for.

- **Respondents need to have visited a public library at least once** This requirement has been set as it is deemed necessary that respondents have any experience with visiting libraries. If they do not have any experience with this, it would be hard for them to imagine themselves in the correct scenarios.

The respondents were collected by a survey research firm, Dynata. Dynata has made sure that sufficient responses of good quality were collected. The company has pre-filtered the respondents, to meet the requirements. Each respondent received an award from Dynata in the form of points, these

points can be traded for vouchers or discounts. For this survey, the rewarded points equalled +/- 1 euro per completed response.

3.1.5. Questionnaire results analysis

The results of the survey were analysed statistically in Python and SPSS, in order to find the frequency and sequence of the tasks within each of the countries. Differences and similarities among the countries have been further assessed and statistically tested. These results have been processed into usable input for the model, which consists of the following per country:

- For the initial setup of response tasks:
  - Probability trees for performing response tasks for each situation (section B.6)
  - Chances of doing remaining tasks for each situation (section B.7)
- For the adjustment of response tasks based on cues:
  - Chances of task adjustment after being informed by a staff member (section A.2)
  - Chances of task adjustment after seeing signs of fire and/or smoke (section A.2)
  - Chances of collecting personal belongings while not having seen fire (section 4.5)
  - Chances of collecting personal belongings while having seen fire (section 4.9.4)
- For finalising response tasks:
  - Chances of collecting personal belongings while not having seen fire (section 4.5)
  - Chances of collecting personal belongings while having seen fire (section 4.9.4)
  - Chances of waiting for a friend while not having seen fire (section 4.7)
  - Chances of waiting for a friend while while having seen fire (section 4.9.2)
  - Chances of searching for a friend while not having seen fire (section 4.8)
  - Chances of searching for a friend while having seen fire (section 4.9.3)

The following input has been kept constant for all four countries

- Initial notification times of staff (section 5.3.3)
- Initial notification times of visitors (section 5.3.3)
- Chances of doing response tasks for staff (section 5.3.5)
- Initial walking speed and adjustment based on density (section 5.3.2)

The in-depth explanation of each of these inputs can be found in chapter 5.

3.2. Model development

To find the effects of cultural response behaviour, in combination with cues, setting and affiliation on the response time and total evacuation time, a model has been developed.

Section 2.3.1 provided an overview of the seven types of modelling methods available for modelling pedestrian behaviour. The focus in this thesis is on microscopic response-phase behaviour and the effects of interactions between visitors. As Agent-based models provide the ability to build up social structures and to capture emergent phenomena, this modelling method is considered most suitable to answer the research question. A downside of ABMs is described as the difficulty to model human agents' behaviour (Zheng et al., 2009). This has been overcome in three ways. Firstly, by clearly scoping the problem and focusing on only one phase of the evacuation. Secondly, by executing extensive research on response behaviour and collecting the needed data through the questionnaire. Thirdly, by researching common methods to model response behaviour as described below.

Generally, three methodologies can be identified for simulating occupant behaviour during the response phase (Gwynne et al., 1999; Kuligowski et al., 2010). One method is to assign a time of delay to

individuals to account for any actions that might be performed during the response-phase (Kuligowski, 2013). With this method, occupants remain stationary in their position, until they start moving towards an exit. In the second method, the building occupants are assigned a specific behavioural itinerary or a specific task. A specific time has been assigned for performing each of these tasks. The building occupant performs its' itinerary actions, before starting the evacuation movement. The third method uses a predictive-style model, where one particular type of cue influences a particular type of evacuation behaviour. Examples of these cue-behaviour linkages are: presence of exit signage leading to choice of a specific evacuation route and smoke obscuration level influencing exit choices (Kuligowski, 2013).

In this model, the second and third method were combined. The occupants have an itinerary and execute these tasks, however, cues and affiliation cause adjustments in the itinerary.

A model previously developed by the author and two other students (Baijanova et al., 2021), has been used as a basis for the model in this study. This model has been extended to include detailed response behaviour and considerations of cues, setting and affiliation. Netlogo software has been used to develop a computer simulation of the model.

The evacuation model includes both library visitors and staff members. It simulates all phases of the evacuation, starting with when the alarm starts to ring, until all of the occupants have left the building. The response-phase tasks of the visitors are altered, based on findings from the survey. This means that four versions of the model will be created, one for each culture, which differ in response-phase activities. The model includes a floor plan, of the first floor, from the TU Delft Library.

After the model was developed, it was verified and validated. Verification has been performed by visually inspecting the model, logging visitor behaviour and executing extreme value tests. /validation has been performed through comparing the model outcomes with those of the BeSeCu project (Galea et al., 2015): the response time distributions and the number of people evacuated over time.

3.3. Experiments

After the model was developed, experiments have been performed to provide an answer to sub question 4.

3.3.1. Experimental setup

The evacuation KPI's which have been considered, are average response time, average evacuation time and Evac 95. Although the total evacuation time is part of the research questions, this has been replaced by Evac 95. The total evacuation time is highly scattered, as during most simulations there are few people which evacuate much slower in comparison to the majority of the population. Therefore it its not useful to analyse this time, as it is not a good indicator of when people have left the building. This is also further discussed in chapter 6. The KPI's and its' description is provided in table 3.2.

Table 3.2: Evacuation KPI's used for the experiments

Parameter	Explanation	Unit
Average evacuation time	The average over all evacuation times of the visitors	s
Average response time	The average over all response times of the visitors	s
Evac 95 (Replaces total evacuation time)	The point in time after which 95% of the visitors has evacuated	s

Three types of experiments have been performed: general analyses of the model outcomes through a basic scenario, effect of uncertainties on the model outcomes and the effect of cues, setting and affiliation on the model outcomes. The following parameters have been altered within these scenarios: Culture, Number of visitors in the building, Number of staff members in the building, Percentage of visitors familiar with the building and Percentage of visitors as part of a friend group. All of these factors are either described in literature as having a high influence on evacuation outcomes, or they are deemed of importance for testing the cues, setting and affiliation. Multiple scenarios with corresponding parameters are considered, as an ABM is a complex adaptive system functioning under deep uncertainty (Bankes, 2002).

A basic scenario was developed, as can be seen in table 3.3. This basic scenario was used in all

experiments, while some of the parameters have been adjusted.

The number of visitors is 100 to 200 in the basic scenario. The library contains 1250 study places (*Overview study places*, n.d.) and it consists of 6 floors. Not all study places are always occupied, therefore an average number of 100 to 200 visitors is considered to be present on the first floor at any point in time.

The number of staff members on the first floor is set to 20 in the basic scenario. This is based on the expected number of staff working at the information desk (+/- 3), working the coffee corner (+/- 5), working at private offices (+/- 8) and cleaning and maintenance personnel (+/- 4).

Familiarity is set to 50 percent. This value has been chosen, as it is expected that about half of the visitors visit the library on a frequent basis. It is also shown in the survey results that about 50 % of the people visit a library more than 5 times a year.

The Percentage of visitors, as part of a friend group is set to 30% in the basic scenario. This is based on the outcomes of the survey, in which about 30 % of the respondents report to usually be together with others while being in a library.

Table 3.3: Experiments: Basic scenario parameter values as used for general analysis experiments

Parameters	**Explanation**	**Values**
Culture	Culture	Czech Republic, Poland, Turkey, UK
initial-number-visitor	Number of visitors in the building	100, 150, 200
initial-number-staff	Number of staff members in the building	20
Familiarity-meter	Percentage of visitors familiar with the building	50%
Chance-friends-in-building	Percentage of visitors as part of a friend group	30%

Note. Number of runs performed for general analysis is 4*3*1*1*1*60=720

General analyses of the model outcomes

For the general analysis, it is researched what type of relationship can be found between the different KPI's. Furthermore, the countries are compared for each of the KPI's. The parameter values of the basic scenario are used within this experiment. Each of the scenarios has been run 60 times, as discussed below in section 3.3.2.

Effect of uncertainties on the model outcomes (sensitivity analysis)

In the second type of experiment, it is researched how each of the model uncertainties influences the model outcomes, also called a sensitivity test.

For these experiments, the basic scenario is considered. However, as we want to clearly see the effect of each parameter on the outcomes, the number of visitors has been set to a constant of 150 visitors.

This experiment consists of two parts. Firstly, experiments in which the basic scenario was considered and one of the four factors was varied structurally. Ranges for the parameters have been chosen based on the minimum and maximum assumed parameter values and values in between these ranges. The values considered can be found in table 3.4.

Additionally, it has been tested how adjustment of two factors simultaneously, influences the model outcomes. This means that per culture two out of the four input parameters were varied structurally, while the other two parameters were kept constant to the basic scenario values. This has been done to test if any surprising effects occur for any combination of two parameter values. For these experiments, less values have been considered in comparison to the one-factor tests. It is out of the scope of the project to test the effects of small changes in the parameters. The values considered can be found in table 3.5.

Table 3.4: Experiments: Sensitivity analysis 1. Single parameter testing. During each experiment one parameter was varied structurally, while keeping the other three parameters constant to the basic scenario values

Parameter adjusted	Parameter values
initial-number-visitor	25, 50, 75, 100, 150, 200, 300, 400
initial-number-staff	10, 20, 30, 40, 50, 75
Familiarity-meter	0, 25, 50, 75, 100
Chance-friends-in-building	0, 15, 30, 60, 90

Note.
Number of runs performed for initial-number-visitor is 4*8*1*1*1*60=1920.
Number of runs performed for initial-number-staff is 4*1*6*1*1*60=1440.
Number of runs performed for Familiarity-meter is 4*1*1*5*1*60=1200.
Number of runs performed for Chance-friends-in-building is 4*1*1*1*5*60=1200

Table 3.5: Experiments: Sensitivity analysis 2. Double parameter testing. During each experiment two parameters were structurally varied, while keeping the other two parameters constant to the basic scenario values

Parameters adjusted	Parameter values
initial-number-visitor	75, 150, 200, 300
initial-number-staff	10, 20, 30, 40
Familiarity-meter	0, 25, 50, 100
Chance-friends-in-building	0, 15, 30, 60

Note.
Number of runs performed for initial-number-visitor x initial-number-staff is 4*4*4*1*1*60=3840.
Number of runs performed for initial-number-visitor x Familiarity-meter is 4*4*1*4*1*60=3840.
Number of runs performed for initial-number-visitor x Chance-friends-in-building is 4*4*1*1*4*60=3840.
Number of runs performed for initial-number-staff x Familiarity-meter is 4*1*4*4*1*60=3840.
Number of runs performed for initial-number-staff x Chance-friends-in-building is 4*1*4*1*4*60=3840.
Number of runs performed for Familiarity-meter x Chance-friends-in-building is 4*1*1*4*4*60=3840.

Effect of cues, setting and affiliation on the model outcomes

Table 3.6 provides an overview of the model parameters and the indicators while experimenting for the effects of the Cues, setting and affiliation. The table shows four experiments, one for each cue, and for setting and affiliation. Per experiment, the table shows which parameters varied structurally. The empty cells indicate parameter values which are the same as in the basic scenario.

As indicator for the first cue, it is measured which percentage of the visitors has been informed by a staff member at any moment during the evacuation. To measure this, initial-number-staff has been varied.

As indicator for the second cue, it is measured which percentage of the visitors has seen fire at any moment during the evacuation. To measure this, the base case has been considered and no parameter values have been varied.

As indicator for affiliation, the input variable Chance-friends-in-building has been varied This parameter has been varied to measure its effects on the model outcomes.

As indicator for setting, it the input variable initial-number-visitor has been used. This parameter is used as a proxy for the chances of having people around or not. This parameter is varied up to a maximum value of 150. It is expected that more people in the building will not affect the setting.

Table 3.6: Experiments: Effects of cues, setting and affiliation. During each experiment a maximum of one parameter was structurally varied, while keeping the other parameters constant to the basic scenario values

Test	Parameter adjusted	Parameter values	Test indicator
Cue: Informed by staff	initial-number-staff	10, 20, 30, 50,75	Percentage of visitors who have been informed by staff
Cue: Fire seen	-	-	Percentage of visitors who have seen fire
Affiliation	Chance-friends-in-building	0, 15, 30,60,90	Chance-friends-in-building
Setting	initial-number-visitor	25, 50, 75,100, 150	initial-number-visitor

Note.
Number of runs performed for Cue: informed by staff is 4*3*5*1*1*60=3600.
Number of runs performed for Cue: fire seen is 4*3*1*1*1*60=720.
Number of runs performed for Affiliation is 4*3*1*1*5*60=3600.
Number of runs performed for Setting is 4*5*1*1*1*60=1200

3.3.2. Convergence test

To determine the number of runs needed per scenario, a convergence test was performed. A basic scenario was considered, with 75 and 150 visitors. The outcomes are depicted in figure 3.2. The figure shows the total evacuation times, averaged over the amount of runs performed. Convergence occurs around 60 repetitions, as the deviation of the total evacuation time becomes somewhat constant. Therefore, each of the scenarios described in the experiments above, has been run 60 times.

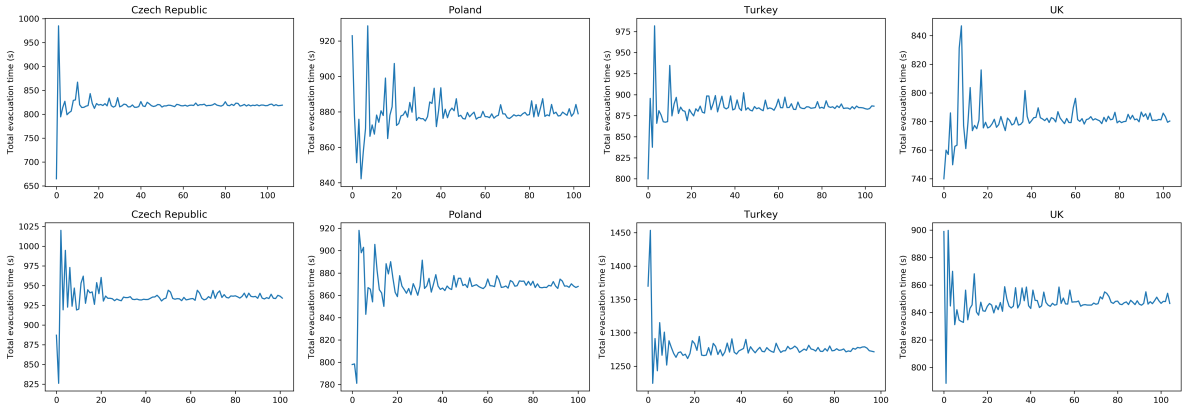


Figure 3.2: Convergence test with 100 runs for 75 visitors (top) and 150 visitors (below)

3.4. Model results analysis

The data have been analysed and visualised by using python. Observed differences between the countries and scenarios have been statistically tested by using SPSS.

During the analysis, a similar structure has been kept as for the experiments. First of all, a general analysis has been conducted, in which the relationships have been considered between the average response time on one side and the average evacuation time, total evacuation time and Evac 95 on the other side. Additionally, One-way ANOVA tests have been used to test if the countries have reported significantly different model outcomes. Furthermore, the response times have been inspected in more depth, in order to clarify the cause of differences in model outcomes.

Secondly, a sensitivity analysis has been performed as described in the experiments. Scatter plots have been developed so that the effects of input parameters on model outcomes can be analysed.

Thirdly, the effects of cues, setting and affiliation (influential factors) on model outcomes have been considered. This has been visualised with scatter-plots for continuous parameters and box plots for discrete parameters. Deeper analyses have been performed to find the causes of the outcomes. For each combination of influential factors, Pearson correlations have been calculated. These correlations provided the possibility to compare countries with its' effects of each of the influential factors.

4

Questionnaire Results

This chapter answers the first sub-question, *"What similarities and differences can be found among response-phase behaviour of library visitors from Czech Republic, Poland, Turkey and the UK during an evacuation?"*, and the second sub-question, *"What are the effects of cues, setting and affiliation on the observed cultural response-phase behaviours?"*.

First, the cleaning of the data is discussed, after which more information on the respondents is provided. This is followed by data collected for each scenario.

4.1. Data cleaning

As described in chapter 3, survey research firm Dynata arranged the respondents for the questionnaire. A total of 680 respondents filled out the questionnaire, however not all of the entries were of a good quality. The obtained data were cleaned further in 3 ways.

Firstly, the responses which did not comply with the filter questions. This resulted in deleting 94 responses from the data.

Secondly, responses were deleted, which contained illogical responses to the open question. Answers were provided such as "good" and "test". This resulted in deleting 45 responses from the data.

Thirdly, speeders were removed from the collected responses. These are survey respondents who complete the survey without fully reading it. They quickly go through all of the questions in order to receive an award from the research firm (Schoenherr et al., 2015). According to Qualtrics it would take approximately 11 minutes to fill out the full questionnaire. As a time constraint, a third of this time was used, which is a minimum time of 3.5 minutes. This resulted in removing another 98 respondents.

After cleaning, the remaining numbers were 105 responses for Czech Republic, 106 responses for Poland, 106 responses for Turkey and 125 responses for the United Kingdom. In order to reach an equal number of respondents per country (105), responses were removed randomly by taking into account the male/female ratio.

4.2. Respondent characteristics

Table 4.1 provides an overview of the respondent characteristics. The only characteristic for which a goal was set, was gender: to have at least 50 males and 50 females per country. This goal was set, to have comparable populations for the four countries. Due to an error with the data cleaning, only 47 responses of females have been collected for Turkey. The respondents described as *other* in the table below, identified themselves as being non-binary / third gender, or they preferred not to reveal their gender.

The average ages of the respondents are not incorporated in the table, these are the following: 25.77 (SD=4.52) for Czech Republic, 25.88 (SD=4.93) for Poland, 27.24 (SD=4.51) for Turkey and 29.19 (SD=5.25) for the UK. Among the respondents, a minimum age of 18 was found for all countries and maximum ages of 38 (Czech Republic), 39 (Poland, Turkey) and 40 (UK).

Table 4.1: Questionnaire respondent characteristics per country

	Czech Republic	Poland	Turkey	UK	Total
Gender					
Male	47.62%	47.62%	54.29%	49.52%	49.76%
Female	50.48%	51.43%	44.76%	49.52%	49.05%
Other	1.90%	0.95%	0.95%	0.95%	1.19%
Education level					
Up to High school	82.90%	54.30%	24.80%	23.80%	46.30%
College	11.40%	18.10%	65.70%	46.70%	35.40%
Masters Degree	5.70%	26.70%	6.70%	21.90%	15.20%
Doctorate or Professional degree	0.00%	1.00%	2.90%	7.60%	2.90%
Visiting frequency					
Never	8.60%	1.00%	1.00%	11.40%	5.50%
1 -5 times a year	64.80%	51.40%	36.20%	57.10%	52.30%
6-10 times a year	14.30%	30.50%	23.80%	11.40%	20.00%
1- 3 times a month	7.60%	15.20%	24.80%	12.40%	15.00%
1-2 times a week	1.90%	1.90%	12.40%	5.70%	5.50%
3-7 times a week	2.90%	0.00%	1.90%	1.90%	1.70%
Groups size					
By myself	68.75%	75.96%	54.81%	64.52%	66.00%
With 1 or 2 other people	30.20%	23.07%	44.23%	35.48%	33.25%
With 3 or more people	1.04%	0.96%	0.96%	0.00%	0.76%
Formal emergency training					
Yes	74.30%	62.90%	59.00%	41.00%	59.10%
No	25.70%	37.10%	41.00%	59.00%	40.60%
Fire drill in last 5 years					
None	44.80%	25.70%	57.10%	32.40%	39.90%
1 to 2	37.10%	55.20%	38.10%	39.00%	42.30%
3 to 5	13.30%	14.30%	4.80%	16.20%	12.10%
More than 5	4.80%	4.80%	0.00%	12.40%	5.50%

4.3. Results of the Basic Scenario

4.3.1. Number of tasks

Figure 4.1 provides box plots for the total number of tasks reported per country in the basic scenario. Turkey performs on average the highest number of tasks with 5.42 tasks (SD=2.82) and the UK performs the lowest number of tasks with 3.86 tasks (SD= 2.14). The number of tasks for Czech Republic (M= 4.54, SD = 2.18) and Poland (M=5.05, SD=2.08) can be found in the middle. A higher variance in the number of tasks, was found for Turkey, compared to the other three countries. A one-way ANOVA test was performed to statistically compare the countries, with an alfa value of p =.05. A significant difference was found ($F(3.416)=8.888$; $p=0.000$). A post-hoc Games-Howell test shows significant differences in the number of tasks for UK and Poland ($p = 0.000$) and UK and Turkey ($p = 0.000$).

The box plots for the number of information and action tasks can be found in figure 4.2. Turkish respondents report to perform the highest number of information tasks (M= 2.98, SD = 1.97), followed by Polish (M=2.86, SD=1.33), Czech (M=2.72, SD=1.63) and lastly, British respondents (M= 2.13, SD= 1.32). A significant difference has been found between the four countries($F(3.416)=5.905$; $p=0.000$). A post-hoc Games-Howell test shows significant differences in the number of information tasks between UK and Czech Republic ($p = 0.022$), UK and Poland ($p = 0.001$) and UK and Turkey ($p = 0.002$).

The highest number of action tasks are reported by Turkish respondents with 2.44 tasks (SD=1.20). This is again followed by Poland, 2.19 tasks (SD=1.19), Czech Republic, 1.82 tasks (SD=1.06) and UK with 1.72 tasks (SD=1.18). A significant difference between the four countries has been found. ($F(3.416)=8.755$; $p=0.000$). A post-hoc Tukey test shows significant differences in the number of action tasks between Czech Republic and Turkey ($p = 0.001$), Poland and UK ($p = 0.018$) and Turkey and UK ($p = 0.000$).

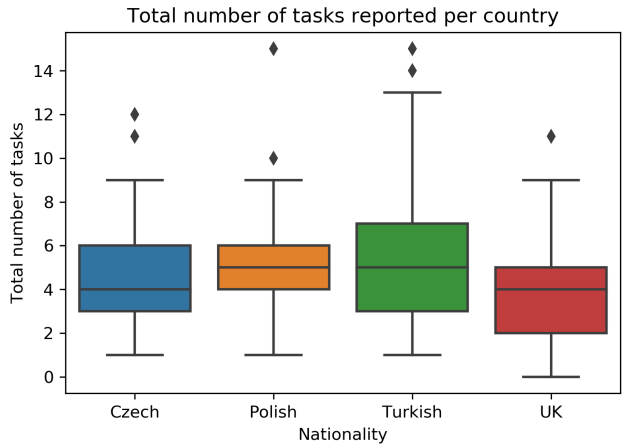


Figure 4.1: Box plots of the total number of response tasks reported per country

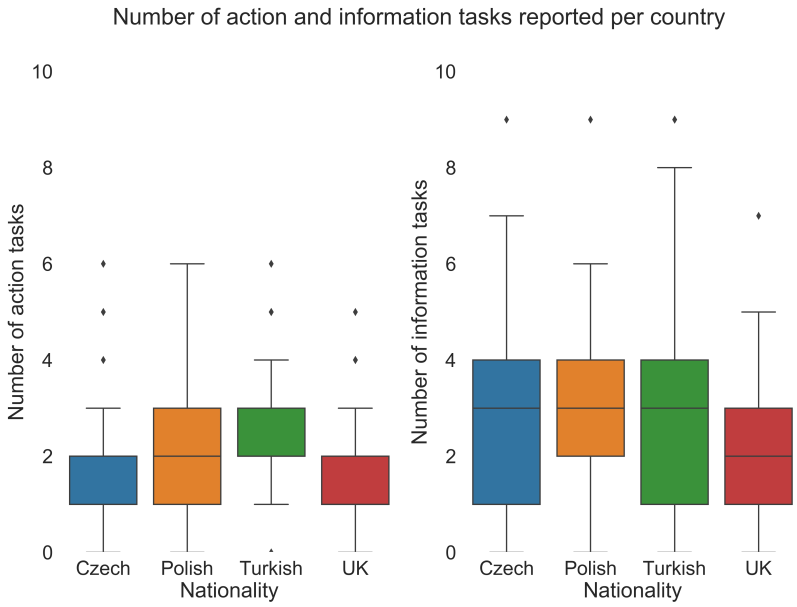


Figure 4.2: Box plots of the number of action and information tasks reported per country

4.3.2. Task types

Figure 4.3 provides an overview of the percentages of respondents per country that report each of the information and action tasks. All of the tasks are further discussed below.

In order to test if there are statistical differences in the types of tasks that respondents would do, Chi square tests are executed. For 10 out of the 15 depicted tasks, a significant difference between the countries was observed. This difference was not observed for ” Phone someone to provide information”, ”Actively provide information to others nearby”, ”Actively search for others in the building to provide information”, ”Pack personal and work items in close vicinity” and ”change footwear/ glasses/ clothing”. The ten tasks for which a significant difference was observed, are further discussed below.

Relatively many Turkish respondents would perform the task ”phone someone to seek information” (17.1%), compared to Czech (6.7%), Polish (4.8%) and UK respondents (7.6%), with x^2 (3) = 11.69, p = 0.009.

Similarly, Turkish respondents are most likely to search for information through electronic media (22.9%), followed by 6.7% of UK as well as Czech and 2.9% of Poland, with x^2 (3) = 28.41, p = 0.000.

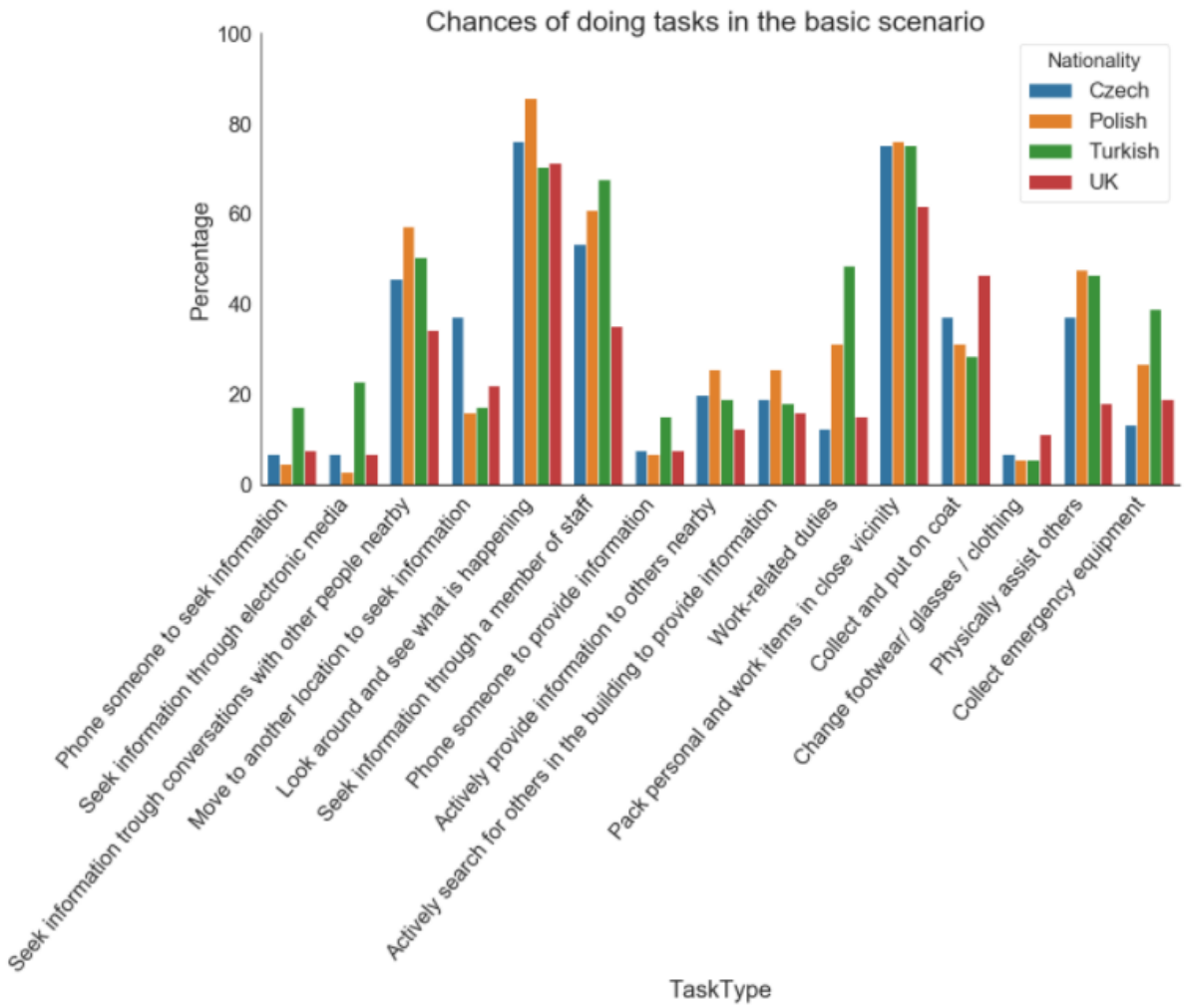


Figure 4.3: Percentages of respondents per country reporting tasks in the Basic Scenario

The Polish population is most active in seeking information trough conversations nearby, with 57.1% of its population performing this action. Followed by Turkey (50.5%), Czech (45.7%) and UK (34.3%), with x^2 (3) = 11.73, p = 0.008.

Czech respondents are most likely to seek information by moving to another location (37,1%), compared to UK (21.9%), Poland (16.2%) and Turkey (17.1%), with x^2 (3) =16.66, p = 0.001.

Most respondents would look around to detect abnormalities in their environment. Polish respondents are most likely to do this (85.7%), followed by Czech respondents (76.2%), British respondents (71.4%) and Turkish respondents (70.5%), with x^2 (3) = 8.38, p = 0.039.

Respondents of the UK are least likely to seek a staff member to obtain any information on the alarm (35.2%). The other three countries all have more similar scores with Czech (53.3%), Poland (61.0%) and Turkey (67.6%), with x^2 (3) = 24.79, p = 0.000.

Turkey and Poland are most likely to perform work-related duties before leaving, with respectively 48.6% and 31.4% .This is followed by UK with 15.2% and Czech Republic with 12.4%, with x^2 (3) =44.69, p = 0.000.

Respondents from the UK are most likely to collect and put on their coat before leaving (46.7%). This is followed by Czech (37.1%), Poland (31.4%) and Turkey (28.6%), with x^2 (3) =8.717, p = 0.033.

The Polish population is most likely to physically assist others (47.6 %). Followed by Turkish (16.7 %), Czech (37.1%) and UK (18.1%), with x^2 (3) =25.26 p = 0.000.

The highest number of respondents collecting emergency equipment was found in Turkey (39.0%), followed by Poland (26.7%), UK (19.0%) and Czech Republic (13.3%), with x^2 (3) =21.03 p = 0.000.

For each country, few people have reported the extra task, ignore the alarm. Czech Republic re-

ported to be most likely to ignore the alarm (2.9%), followed by Poland and Turkey (1.9%) and the UK (2%). No significant difference can be found between the countries, with x^2 (3) =1.019 p = 0.797. As these percentages reported are so low, this does not provide any valuable insights. This thus task is not further considered.

4.3.3. Sequences of tasks

The respondents were asked in which sequence they would perform their chosen tasks. Table4.2 reports the tasks which are mostly reported to be performed during the first five tasks.

The sequences are exactly the same for respondents from Czech Republic and Poland, the frequencies in which these occur do differ though. Turkey shows somewhat the same sequence, except for the fifth task, during which Turkish people are most likely to pack their items in close vicinity.

The sequence of tasks from the UK is remarkably different compared to the other countries. Respondents from the UK are most likely to collect and put on their coat during their fourth task and they change footwear / glasses / clothing during their fifth task. More detailed decision trees of the orders of tasks execution are described in chapter 5 and can be found in Appendix B.

Table 4.2: Most frequently reported tasks per country per order number

Order No		Frequency	Percentage
	Czech Republic		
1	Look around and see what is happening	72	68.57%
2	Seek information trough conversations with other people nearby	26	24.76%
3	Seek information trough a member of staff	19	18.10%
4	Pack items in close vicinity	18	17.14%
5	Physically assist others	8	7.62%
	Poland		
1	Look around and see what is happening	72	68.57%
2	Seek information trough conversations with other people nearby	35	33.33%
3	Seek information trough a member of staff	25	23.81%
4	Pack items in close vicinity	19	18.10%
5	Physically assist others	16	15.24%
	Turkey		
1	Look around and see what is happening	53	50.48%
2	Seek information trough conversations with other people nearby	21	20.00%
3	Seek information trough a member of staff	20	19.05%
4	Pack items in close vicinity	17	16.19%
5	Pack items in close vicinity	11	10.48%
	UK		
1	Look around and see what is happening	53	50.48%
2	Pack items in close vicinity	23	21.90%
3	Pack items in close vicinity	12	11.43%
4	Collect and put on coat	14	13.33%
5	Change footwear / glasses / clothing	6	5.71%

4.4. Results of Scenario 1: Informed by a staff member

In the first scenario, a respondent is informed by a staff member and told to leave the building. The respondents are asked how this will change their tasks. They are asked which of the previously selected tasks they would not do anymore and which of the not previously selected tasks they would do now.

Polish respondents are most likely to remove tasks from their itinerary (M=1.15, SD= 1.364). This is followed by Turkey (M=1.07, SD=1.794), Czech Republic (M=1.02, SD=1.256) and the UK (M=0.79, SD=1.098). No significant difference can be observed though for the four countries with (F(3.416)=1.278; p=0.282).

Turkish respondents are most likely to add new tasks to their itinerary (M=0.75, SD=0.978), followed by Poland (M=0.68, SD=1.042), UK (M=0.66, SD=0.949) and Czech Republic (M=0.56, SD=0.831). Again, no significant difference can be observed for the four countries with (F(3.416)=0.709; p=0.547).

Figures 4.4 through 4.7 illustrate the deviations in task types. The percentages are expressed as people who did not do a certain tasks and decided to add a new task to their itinerary and people who

did it the other way around. The graphs show differences between the four countries.

Figure 4.8 shows how these adjustment play out in the overall percentages of the population performing certain tasks in this scenario.

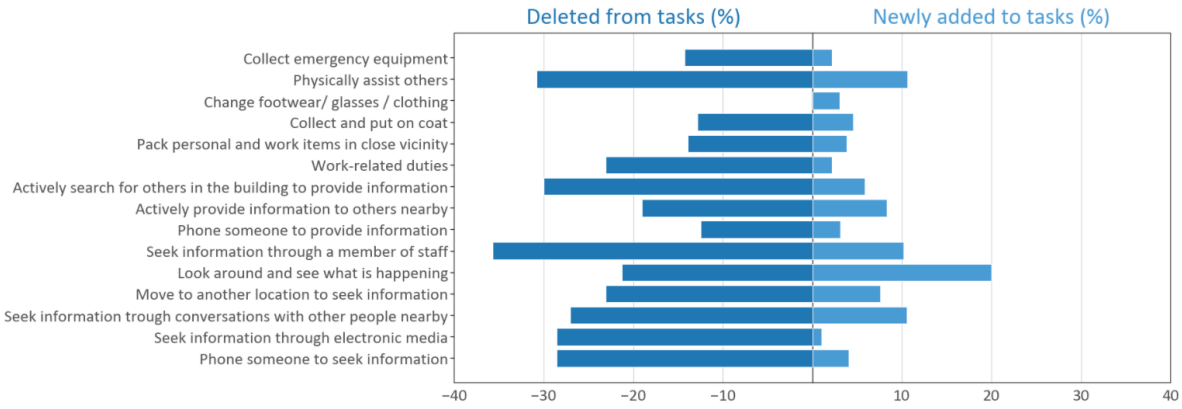


Figure 4.4: Percentile adjustments of response tasks, after being informed by staff in Czech Republic

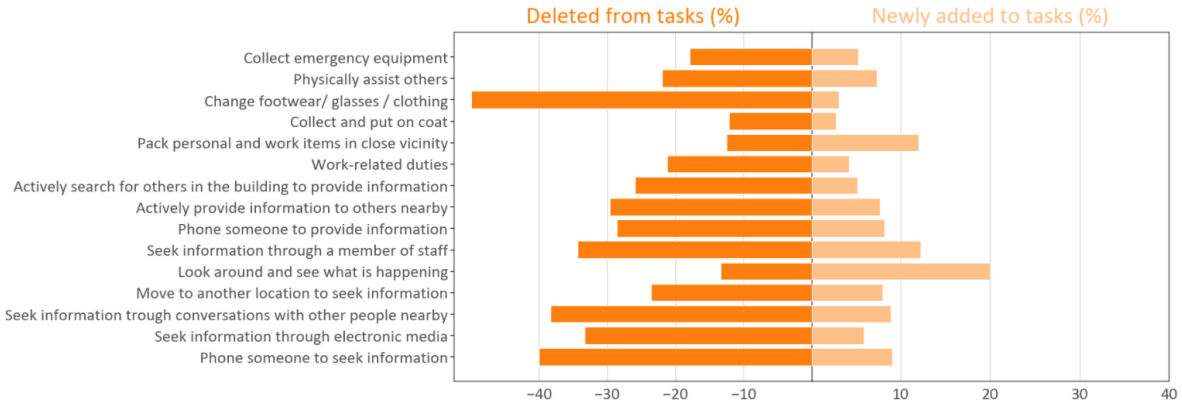


Figure 4.5: Percentile adjustments of response tasks, after being informed by staff in Poland

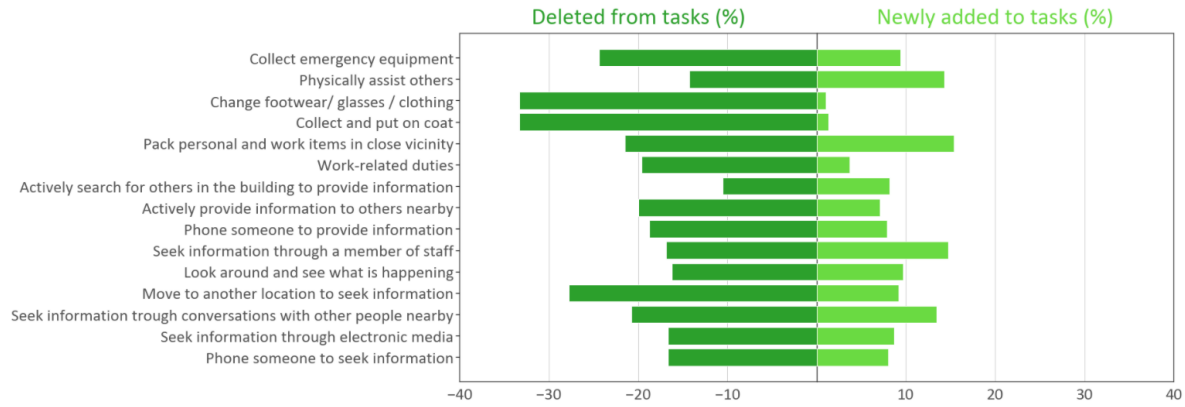


Figure 4.6: Percentile adjustments of response tasks, after being informed by staff in Turkey

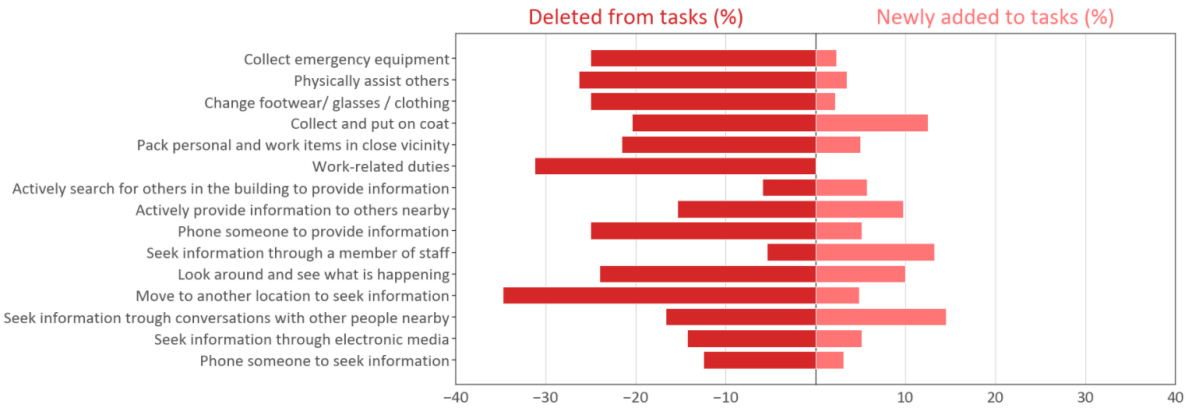


Figure 4.7: Percentile adjustments of response tasks, after being informed by staff in the UK

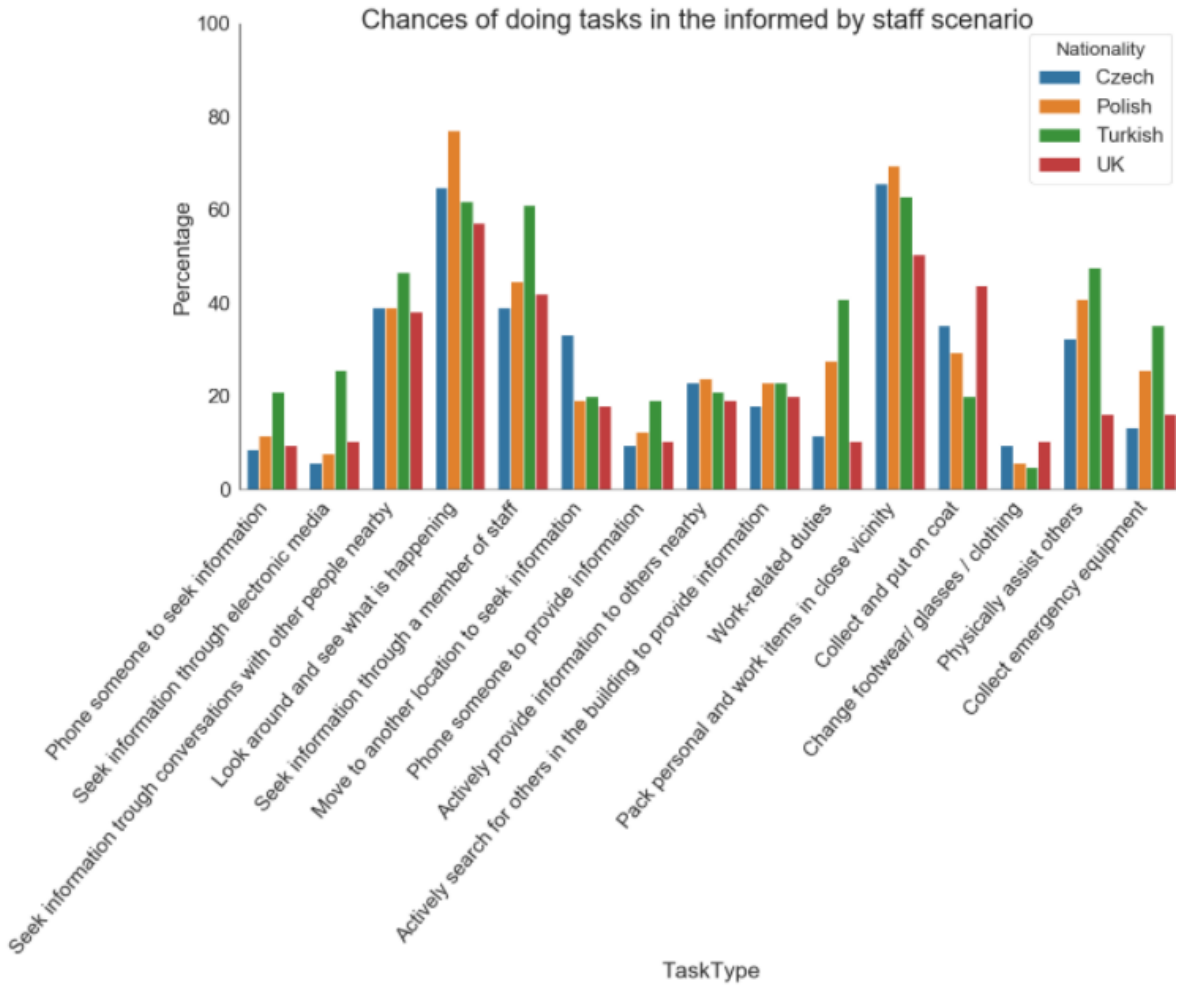


Figure 4.8: Percentages of respondents per country reporting tasks, after being informed by staff

4.5. Results of Scenario 2: Collection of personal belongings

In the second scenario, respondents were asked for their likelihood to collect personal belongings which were not in close vicinity.

Table 4.3 provides insight in how each of the cultures respond to this question. No significant difference can be found by statistically comparing the countries, x^2 (6) = 5.574, p = 0.473.

Table 4.3: Percentages per country for collecting personal belongings in the basic scenario

	Czech Republic		Poland		Turkey		UK	
	Freq.	%	Freq.	%	Freq.	%	Freq.	%
No	11	10.50%	9	8.60%	6	5.70%	13	12.40%
Only if I can reach my personal belongings in a short amount of time	54	51.40%	62	59.00%	57	54.30%	49	46.70%
Yes	40	38.10%	34	32.40%	42	40.00%	43	41.00%

4.6. Results of Scenario 3: Situated in a Closed off space

For the third scenario, respondents have been asked how setting, being in a closed off space or not having any others around, influences their behaviour. They have only been asked to re-choose which information tasks they would perform. The comparisons of the basic scenario and scenario 3 can be seen in figures 4.10 to 4.12. Figure 4.13 provides an overview of all countries together.

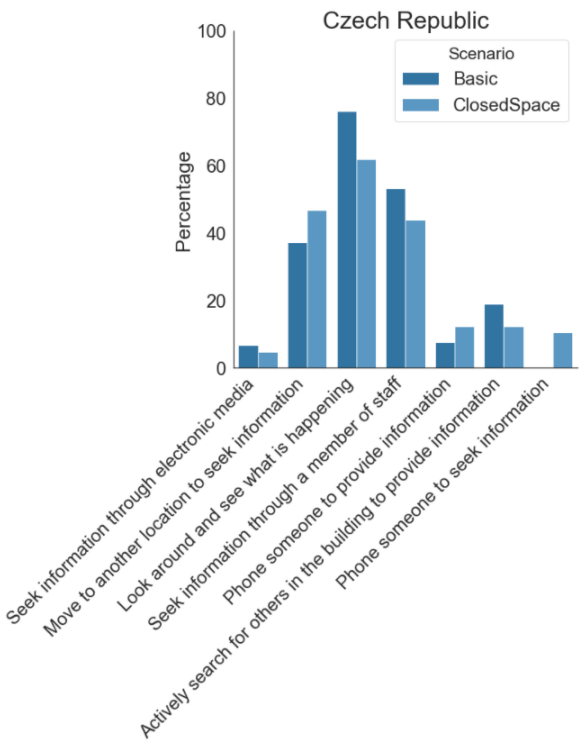


Figure 4.9: Information tasks comparison basic scenario and closed space for Czech Republic

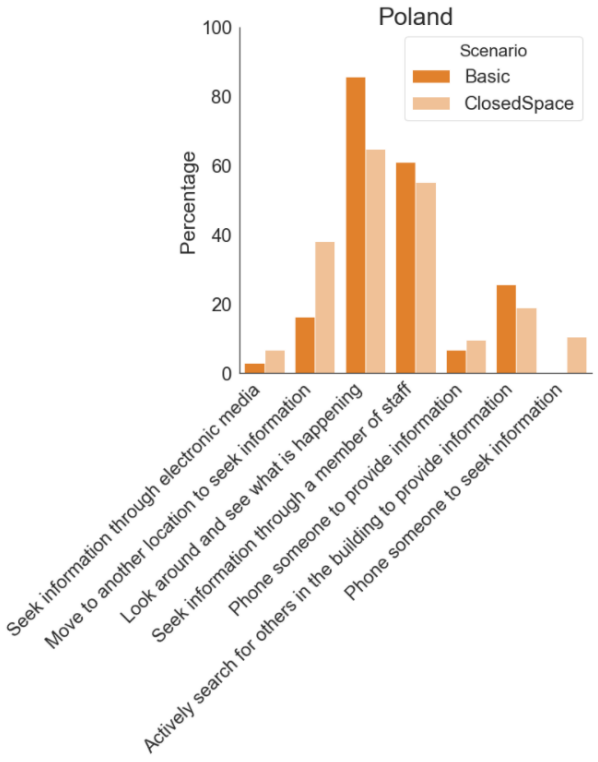


Figure 4.10: Information tasks comparison basic scenario and closed space for Poland

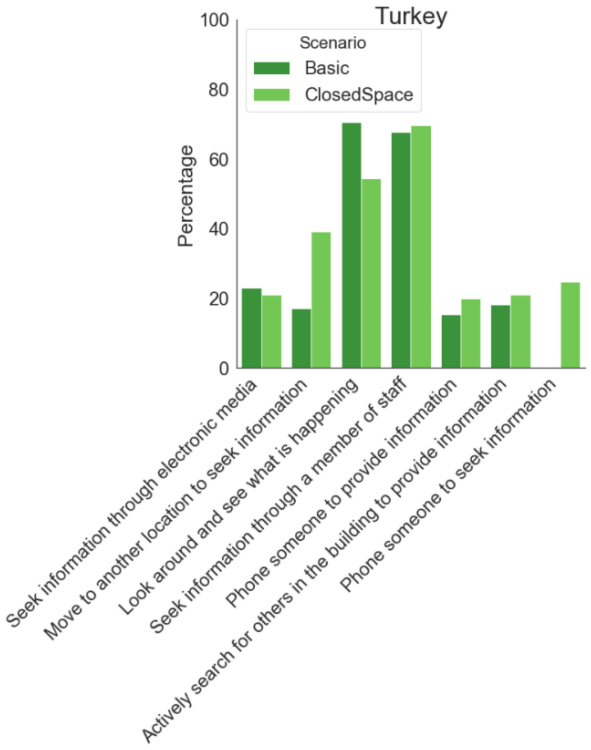


Figure 4.11: Information tasks comparison basic scenario and closed space for Turkey

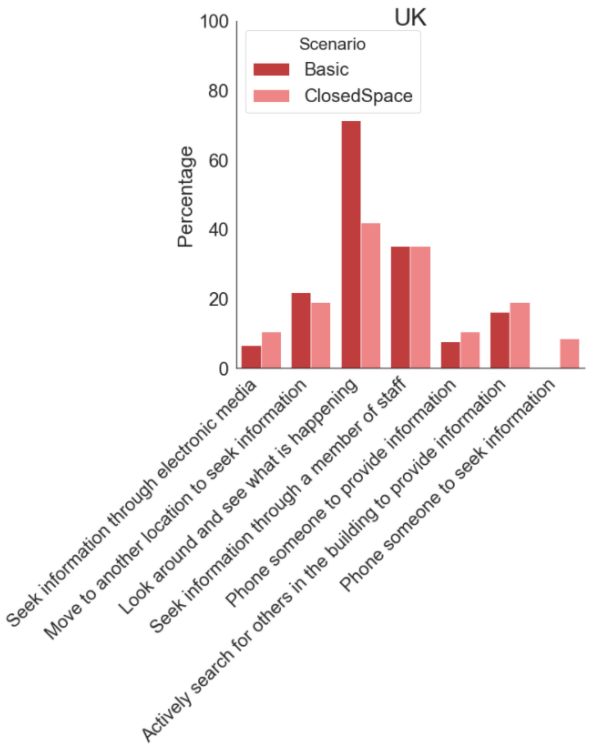


Figure 4.12: Information tasks comparison basic scenario and closed space for the UK

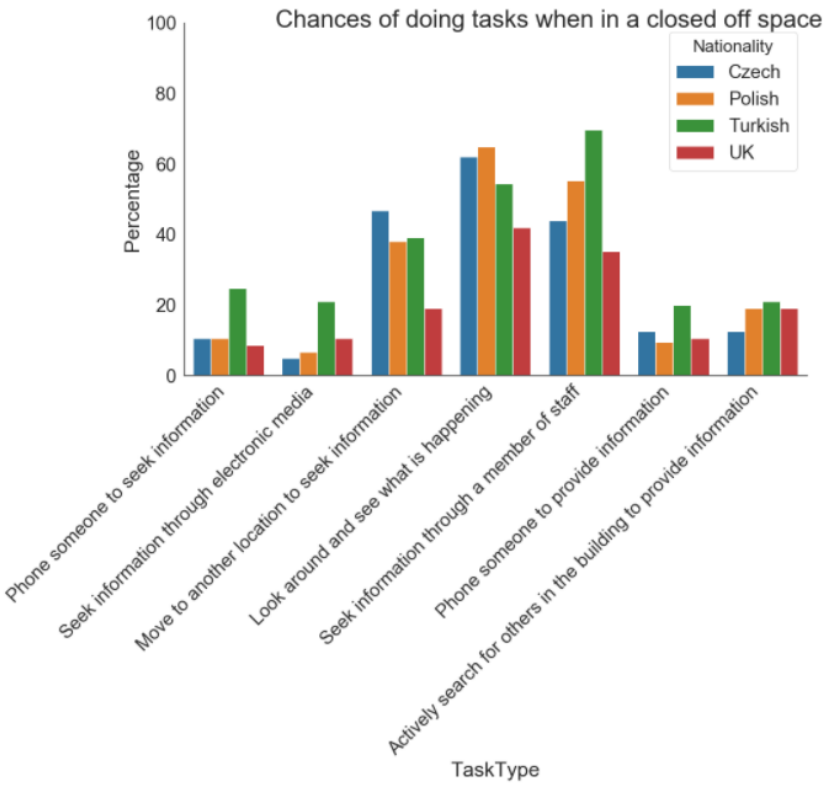


Figure 4.13: Percentages of respondents per country reporting tasks in the in a closed off space

4.7. Results of Scenario 4: Friend/ colleague in close vicinity

In Scenario 4, respondents are in the library together with a friend or colleague. They are asked if they would wait for their friend before leaving the building. The results are shown in table 4.4. A statistical difference can be found among the four countries, with x^2 (3) = 15.513, p = 0.001.

Table 4.4: Percentages per country for waiting for friends in the basic scenario

	Czech Republic		**Poland**		**Turkey**		**UK**	
	Freq.	%	Freq.	%	Freq.	%	Freq.	%
No	10	9.50%	19	18.10%	18	17.10%	32	30.50%
Yes	95	90.50%	86	81.90%	87	82.90%	73	69.50%

4.8. Results of Scenario 5: Friend/ colleague not in close vicinity

In the fifth scenario, respondents are in the library together with a friend or colleague. However, they are not in close vicinity to each other and they are not sure where their friend or colleague is located. The respondents are asked if they would search for their friend. The results are shown in Table 4.5. No statistical difference can be found among the four countries, with x^2 (6) = 17.283, p = 0.275.

Table 4.5: Percentages per country for searching for friends in the basic scenario

	Czech Republic		**Poland**		**Turkey**		**UK**	
	Freq.	%	Freq.	%	Freq.	%	Freq.	%
No	12	11.40%	9	8.60%	10	9.50%	14	13.30%
Only if I can find my friend within a relatively short amount of time	51	48.60%	54	51.40%	51	48.60%	63	60.00%
Yes	42	40.00%	42	40.00%	44	41.90%	28	26.70%

4.9. Results of Scenario 6: Fire and/ or smoke seen

In the sixth scenario, respondents see signs of smoke and/or fire. They are asked for their behaviour in 4 situations.

4.9.1. Scenario 6: Fire and/ or smoke seen; Basic Scenario

Figures 4.14 to 4.17 illustrate the deviations in tasks after seeing fire. The graphs show differences between the four cultures. Polish respondents are most likely to remove tasks from their itinerary (M=1.41, SD=1.426). This is followed by Turkey (M=1.24, SD=2.2101), Czech Republic (M=1.20, SD=1.376) and the UK (M=1.07, SD=1.171). No significant difference can be found between the countries though, with (F(3.416)=0.863; p=0.460). Turkish respondents add most tasks to their itinerary after seeing fire (M=1.23, SD=1.258), followed by Polish (M=1.18, SD=1.026), Czech Republic (M=1.06, SD=1.099) and the UK (M=0.88, SD=1.124). Figure 4.18 shows the remaining percentages the tasks reported.

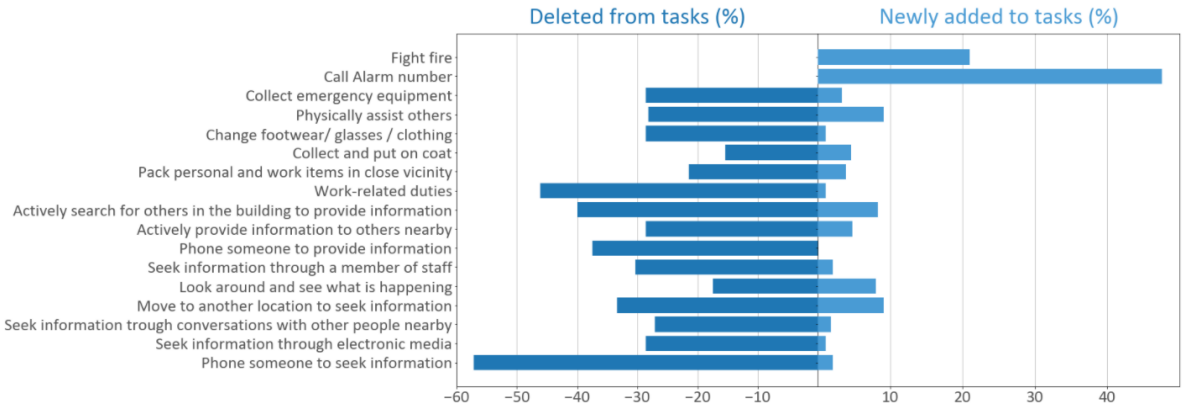


Figure 4.14: Percentile adjustments of response tasks, after seeing fire in Czech Republic

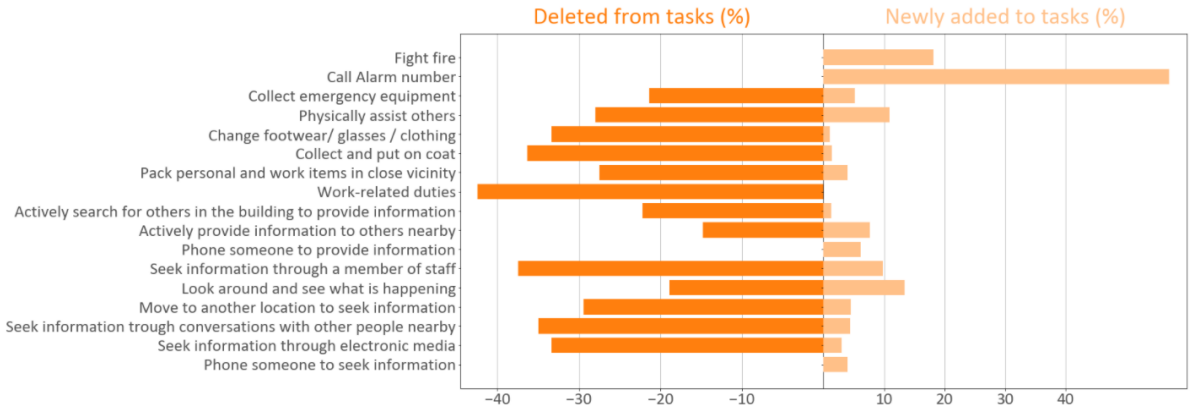


Figure 4.15: Percentile adjustments of response tasks, after seeing fire in Poland

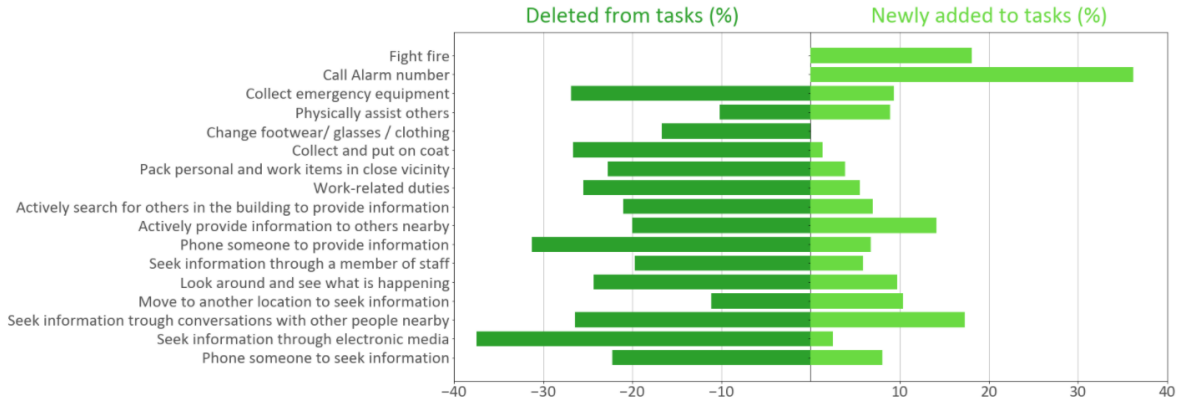


Figure 4.16: Percentile adjustments of response tasks, after seeing fire in Turkey

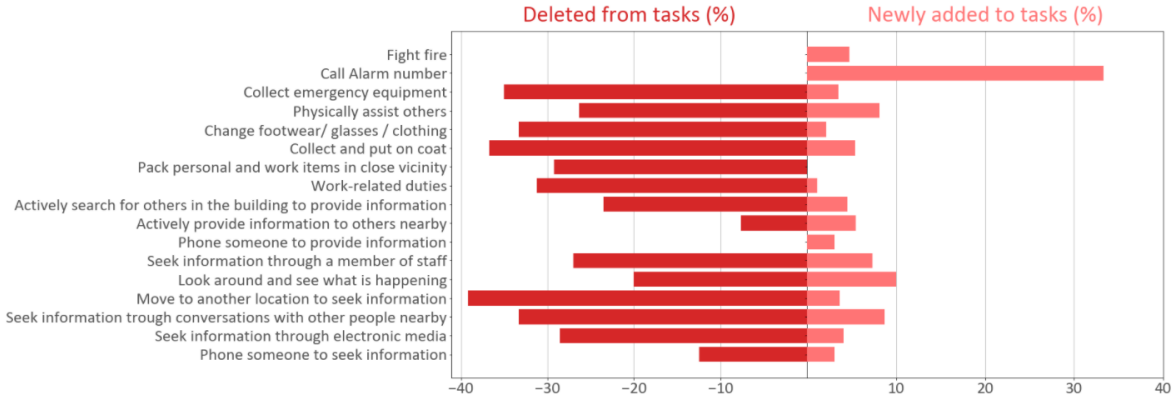


Figure 4.17: Percentile adjustments of response tasks, after seeing fire in Czech Republic in the UK

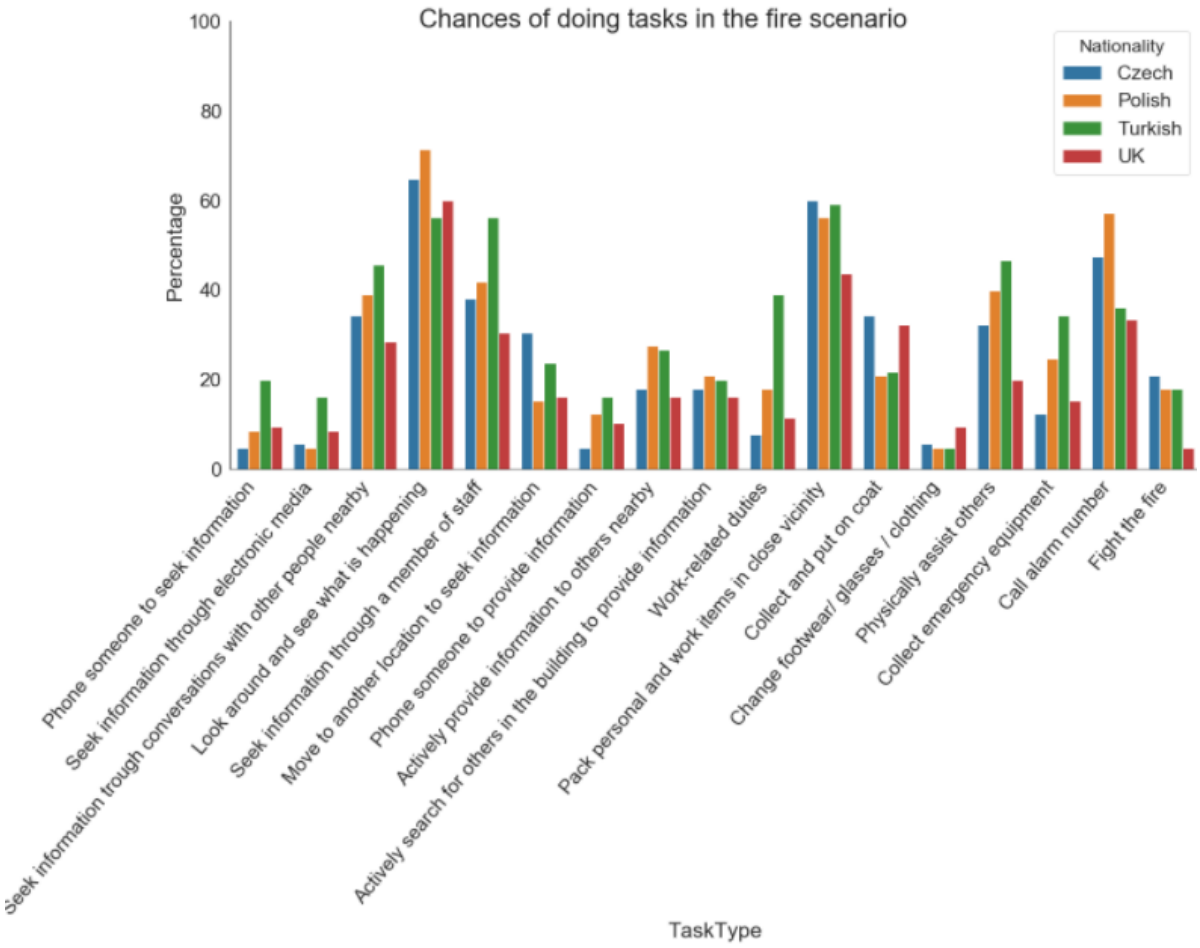


Figure 4.18: Percentages of respondents per country reporting tasks after seeing fire

4.9.2. Scenario 6.1: Fire and/ or smoke seen; Friend/ colleague in close vicinity

Table 4.6 shows that respondents from Czech republic are most likely to wait for their friends after seeing fire (82.9%). This is followed by Poland (76.2%), Turkey (72.4%) and the UK (61.0%). A statistical difference can be found here, with x^2 (3) = 13.499, p = 0.004.

Table 4.6: Percentages per country for waiting for friends after seeing fire

	Czech Republic		**Poland**		**Turkey**		**UK**	
	Freq.	%	Freq.	%	Freq.	%	Freq.	%
No	18	17.10%	25	23.80%	29	27.60%	41	39.00%
Yes	87	82.90%	80	76.20%	76	72.40%	64	61.00%

4.9.3. Scenario 6.2: Fire and/ or smoke seen; Friend/ colleague not in close vicinity

Table 4.7 shows comparable percentages for Czech Republic, Poland and the UK when it comes for searching for a friend colleague. People from the UK are not as likely to search for their friends, as only 22.9% of this population will definitely search for their friend. A statistical difference can be found here between the four countries,with x^2 (6) = 21.300, p = 0.002.

Table 4.7: Percentages per country for searching for friends after seeing fire

	Czech Republic		**Poland**		**Turkey**		**UK**	
	Freq.	%	Freq.	%	Freq.	%	Freq.	%
No	15	14.30%	13	12.40%	10	9.50%	30	28.60%
Only if I can find my friend within a relatively short amount of time	51	48.60%	55	52.40%	49	46.70%	51	48.60%
Yes	39	37.10%	37	35.20%	46	43.80%	24	22.90%

4.9.4. Scenario 6.3: Fire and/ or smoke seen; Collection of personal belongings

Table 4.8 shows the likelihood of collecting personal belongings whenever these are not in close vicinity. No statistical difference can be found here, with x^2 (6) = 8.889, p = 0.180.

Table 4.8: Percentages per country for collecting belongings after seeing fire

	Czech Republic		**Poland**		**Turkey**		**UK**	
	Freq.	%	Freq.	%	Freq.	%	Freq.	%
No	28	26.70%	25	23.80%	14	13.30%	30	28.60%
Only if I can reach my personal belongings in a short amount of time	55	52.40%	57	54.30%	61	58.10%	54	51.40%
Yes	22	21.00%	23	21.90%	30	28.60%	21	20.00%

4.10. Comparison of scenarios: Basic, Informed by staff and Fire seen

The previous sections have already shown how percentages of people performing tasks types have been adjusted by the different scenarios. So this section will only go deeper into the number of tasks performed during the different scenarios and the influence which the cues have on collecting belongings and waiting and searching for friends.

Table 4.9 provides an overview of the total number of tasks performed in the basic scenario, compared to the two scenarios in which a cue has been perceived.

Paired t-tests were performed to compare the number of tasks in the basic scenario, with the other two scenarios. The table shows that there are not many significant differences when comparing the basic scenario to the other scenarios. Only Czech Republic and Poland show significantly different numbers when comparing the basic scenario to the scenario in which occupants are informed by staff.

No significant differences have been observed between the basic scenario and the fire scenario. It needs to be noted, that two extra tasks were available in the fire scenario: ”Call alarm number” and ”Fight the fire”. As many respondents reported these tasks, it has caused in increase in the number of tasks reported for the fire scenario.

Table 4.9: The number of tasks reported in the basic scenario and after being informed by a staff member or seeing fire

Country	Basic Scenario	Informed by staff	Fire
Czech Republic	4,54	4.09 (-11,9 %)*	4.40 (-3,1%)
Poland	5,05	4,57 (-9,5%)*	4,82 (-4,6%)
Turkey	5,42	5,10 (-5,9%)	5,41 (-0,2%)
UK	3,86	3,72 (-3,6%)	3,67 (-4,8%)

Note. Significance: * p < 0.05
In the fire scenario, two extra tasks were available: ”Call alarm number” and ”Fight the fire”. These tasks cause an increased number of tasks reported in the fire scenario.

McNemar tests have been performed to compare if the chances of collecting belongings, waiting for friends and searching for friends are significantly different in the basic scenario in comparison to the fire scenario. An overview can be seen in table 4.10. Chances of collecting belongings are significantly different for the two scenarios for each of the cultures. For the chances of waiting for friends, only a

significant difference between the two scenarios was found for Turkey. Searching for friends is only significantly different among the two scenarios for Poland and the UK.

Table 4.10: Percentages per country for collecting belongings, waiting for friends and searching for friends in the basic scenario compared to the fire scenario

	Collect belongings (No/ Only, if.../ Yes)		Wait for friend (No/ Yes)		Search for friend (No/ Only, if.../ Yes)	
	Basic	Fire	Basic	Fire	Basic	Fire
Czech Republic	11/ 51/ 38	27/ 52/ 21*	10/ 91	17/ 83	11/ 49/ 40	14/ 49/ 37
Poland	9 / 59/ 32	24/ 54/ 22*	18/ 82	24/ 76	9 / 51/ 40	12/ 52/ 35*
Turkey	6 / 54/ 40	13/ 58/ 29*	17/ 83	28/ 72*	10/ 49/ 42	10/ 47/ 44
UK	12/ 47/ 41	29/ 51/ 20*	31/ 70	39/ 61	13/ 60/ 27	29/ 49/ 23*

Note. Only, if...= Only if I can find my friend / belongings in a short amount of time
Significance: * $p < 0.05$

4.11. Comparison to BeSeCu outcomes

The BeSeCu reports(Galea et al., 2015) have only provided numbers on the amount of tasks performed and not on any types of tasks performed. Therefore, only the number of tasks can be compared. Table 4.11 provides an overview, in which the values are colour coded. A red value indicates a higher number of tasks reported/ performed in this country in comparison to the average over all four countries. A green value indicates a lower number in comparison to the average.

The table shows that the number of information tasks, action tasks and total tasks in the BeSeCu project (Galea et al., 2015) are about double to those in the questionnaire. This is caused by differences in measurements and thus these exact values cannot be compared. The values from the BeSeCu project (Galea et al., 2015) show the number of tasks performed, while the questionnaire shows the number of task types performed.

The overall ratios do provide possibility for comparisons. These show that, during the BeSeCu experiments (Galea et al., 2015), occupants performed on average the same amount of information and action tasks, both 50 percent. For the questionnaire the number of information tasks performed was slightly higher (57%) than the number of action tasks(43%). Per country these ratios can be compared as well. Czech republic and Turkey show relatively similar ratios for the number of information and action tasks in both the questionnaire and the experiment outcomes. For Poland and the UK, ratios of information and action tasks in the BeSeCu project (Galea et al., 2015) differ more from those in the questionnaire.

Comparing the values from the questionnaire with those found in the BeSeCu project (Galea et al., 2015), does not show many similarities. The figure shows the UK performs relatively few tasks in both the BeSeCu experiments (Galea et al., 2015) and the questionnaire. In the BeSeCu experiment (Galea et al., 2015) Czech Republic performed most tasks in total, while in the questionnaire this was Turkey. One of the similarities which can be observed, is that the UK performs relatively few tasks in both the experiments and the questionnaire.

Table 4.11: Comparison of the number of tasks performed during the BeSeCu experiments (Galea et al., 2015) and reported in the questionnaire

	Czech Republic		Poland		Turkey		UK		Average over all 4 countries	
	BeSeCu	Questionnaire	BeSeCu	Questionnaire	BeSeCu	Questionnaire	BeSeCu	Questionnaire	BeSeCu	Questionnaire
Number of information tasks	7.4 (56%)	2.7 (60%)	3.8 (38%)	2.8 (56%)	5.1 (59%)	3.0 (56%)	3.9 (44%)	2.2 (56%)	5.1 (50%)	2.7 (57%)
Number of action tasks	5.7 (44%)	1.8 (40%)	6.1 (62%)	2.2 (44%)	3.5 (41%)	2.4 (44%)	4.9 (56%)	1.7 (44%)	5.1 (50%)	2 (43%)
Total number of tasks	13.1 (100%)	4.5 (100%)	9.9 (100%)	5.0 (100%)	8.6 (100%)	5.4 (100%)	8.8 (100%)	3.9 (100%)	10.1 (100%)	4.7 (100%)

Note. The tasks in the BeSeCu project could be repeated, while this was not possible in the questionnaire. Therefore exact numbers cannot be compared.

4.12. Summary

This chapter has answered sub-question one, *"What similarities and differences can be found among response-phase behaviour of library visitors from Czech Republic, Poland, Turkey and the UK during an evacuation?"*, and sub-question two, *"What are the effects of cues, setting and affiliation on the observed cultural response-phase behaviours?"*.

The first finding indicates a significant difference among Czech Republic, Poland, Turkey and the UK for the total number of tasks performed. Turkey performs the highest number of tasks (M=5.42, SD=2.82), followed in descending order by Poland (M=5.05, SD=2.08), Czech Republic (M= 4.54, SD = 2.18) and the UK (M= 3.86, SD= 2.14). Additionally, significant differences among the countries have been observed for both the number of information tasks performed and the number of action tasks performed. For both of these, the countries follow the same descending order as for the total number of tasks performed.

Secondly, the probabilities for performing different task types have been analysed and compared for the four countries. For 10 out of 15 task types, significant differences have been found between the countries. No generalisations can be made over the four countries as there is no pattern visible for which countries perform task most or least often. Furthermore the order of performing tasks has been analysed. This has shown that Czech Republic, Poland and the UK perform similar tasks during their first five tasks. The UK has however shown to give different priorities for performing types of response tasks.

Thirdly, it has been observed that cues do not necessarily influence the number of tasks performed. However, these do influence the probabilities of performing each type of task. These alterations to the probabilities are different among the four countries. A similarity among the four countries is, that after receiving a cue, the respondents are likely to delete on average +/- one task from their itinerary and add +/- one new task. Furthermore, fire has shown to affect the likelihood of collecting belongings and waiting/ searching for friends.

Fourthly, being in a closed off space (setting) has shown to influence probabilities of performing different types of information tasks. Where probabilities for some tasks show to increase, while probabilities for other tasks show to decrease.

Lastly, affiliation has been considered. The questionnaire indicates a significant difference between the four countries for waiting for friends. Whereby Czech Republic is most likely to wait for friends, followed by Poland, Turkey and the UK. Additionally, significant differences have been observed for the probabilities for searching for friends. Respondents from the UK have shown to be less likely to search for friends in comparison to Czech, Polish and Turkish respondents.

5 Model

This chapter answers sub-question 3 *"How can cultural response-phase behaviour be modelled with an agent-based model in order to measure the response time and total evacuation time?"*. In this chapter the the Agent-based model is presented which was developed to identify the influence of cultural differences in response-phase behaviour on the response time and total evacuation time. Firstly, the model is explained by following the Overview, Design concepts and Details (ODD) protocol by Grimm et al. (2020). This protocol is designed for describing Agent-Based models in a standardised way and to facilitate model replication. This is followed by Validation and verification of the model.

5.1. Purpose and overview

The purpose of the model can be described as being of a explanatory nature. This is defined by Edmonds et al. (2019) as "establishing a possible causal chain from a set-up to its consequences in terms of the mechanisms in a simulation". The purpose of the model is to explain how differences (Galea et al., 2015) in response and evacuation times among Czech Republic, Poland, Turkey and the UK are influenced by differences in response phase behaviour. Furthermore, the purpose is to find out to which degree cues, setting and affiliation affect the response and evacuation time.

5.2. Entities, state variables and scales (ontology)

This element of the ODD describes all the things represented in the model (Railsback, 2020).This includes all entities and its state variables.

5.2.1. Agents

The model consists of two types of agents: visitors and staff members of the library. Visitors are people who do not perform official work at the library and staff-members are people who do perform work in the library on a regular basis. Visitors and staff members are modelled as separate agents within the model, as they will show different behaviour according to the rule-role model (Fridolf et al., 2013; Shiwakoti, Wang, et al., 2020; Tong and Canter, 1985).

The most relevant state variables of both the visitors and staff members are described in table 5.1. Additionally, the table shows if the state variables are static or dynamic and the values and ranges of the variables are shown.

Less relevant state variables can be seen in Appendix B.5. These are mostly intermediary variables which are used during performance of response tasks.

Table 5.1: Most relevant state variables used in the model for both staff and visitors

Variable name	Static / Dynamic	Explanation	Values ranges/ units
man?	Static	Indicates if an agents is of the male/ female gender. True if gender is male, False if gender is female.	True / False
walking-speed	Static	The walking-speed of the agent, when there are not other agents nearby	1.1-1.4 meter/ second
familiarity?	Static	Indicates if an agents is familiar with the building. True if an agent is familiar with the building, False if agent is not	True / False
normal-state?	Dynamic	Indicates if an agent is in the normal state. True if an agent is in the normal state, False if agent is in another state.	True / False
response-state?	Dynamic	Indicates if an agent is in the response state. True if an agent is in the response state, False if agent is in another state.	True / False
evacuating-state?	Dynamic	Indicates if an agent is in the evacuating state. True if an agent is in the evacuating state, False if agent is in another state	True / False
evacuated-state?	Dynamic	Indicates if an agent is in the evacuated state. True if an agent is in the evacuated state, False if agent is in another state	True / False
task-time-left	Dynamic	Amount of time left to finish a task during the normal state	0 - 80 seconds
current-destination	Dynamic	The destination that an agent is walking towards during a task / activity	Patch values
path	Dynamic	The full part calculated to reach a destination	Patch values
current-path	Dynamic	The part of the path which the agent still needs to travel	Patch values
exit-destination	Dynamic	The exit patch through which the agent will aim to evacuate	Patch value
fire-seen?	Dynamic	Indicates if the agent has seen signs of smoke and/ or fire or not. True if the agent has seen signs of smoke and/or fire, False if not	True / False
response-tasks-list	Dynamic	Total list of response tasks to be performed in corresponding order	List of tasks
current-response-tasks-list	Dynamic	Remaining list of tasks that still need to be performed at a point in time	List of tasks
current-response-task	Dynamic	The task that an agent is currently performing	Task

Additionally to the state variables shown in the table above, visitors have extra state variables, which staff members do not have. Again the most relevant variables are described in table 5.2, less relevant state variables are described in Appendix B.6.

Table 5.2: Most relevant state variables used in the model for visitors

Variable name	Static / Dynamic	Explanation	Values ranges/ units
friend	Static	ID of the other visitor which is defined as a visitors friend / Colleague	Agent ID
sitting-place	Static	The location defined as an agents sitting-place	Patch value

Table 5.2 continued from previous page

Variable name	Static / Dynamic	Explanation	Values ranges/ units
physical-assistance-needed?	Static	Indicates if a visitor would be in need of physical assistance. True if visitor is in need of assistance, False otherwise	True / False
informed-by-staff?	Dynamic	Indicates if a visitor has been informed by a staff member	True / False
conversationing-with-staff?	Dynamic	Indicates if a visitor is conversationing with a staff member at a certain point in time	True / False
go-collect-belongings	Dynamic	Indicates if a visitor will search for belongings before leaving the building. True if visitor will search for belongings, False if visitor will not do this	True / False / Only search short time

5.2.2. Spatial

The model represents a two-dimensional space, for which a floor plan from the TU delft library has been used. Due to the cross-cultural nature of this research, it was decided to use a floor plan from a library outside of Czech Republic, Poland, Turkey and the UK. This has been done in order to ensure that cultural differences in building structures would not influence the outcomes. As this research was conducted at TU Delft, a floor plan from this library was used. Although the library building consists of multiple floors, only the ground floor has been considered. The used floor plan is depicted in figure 5.1.

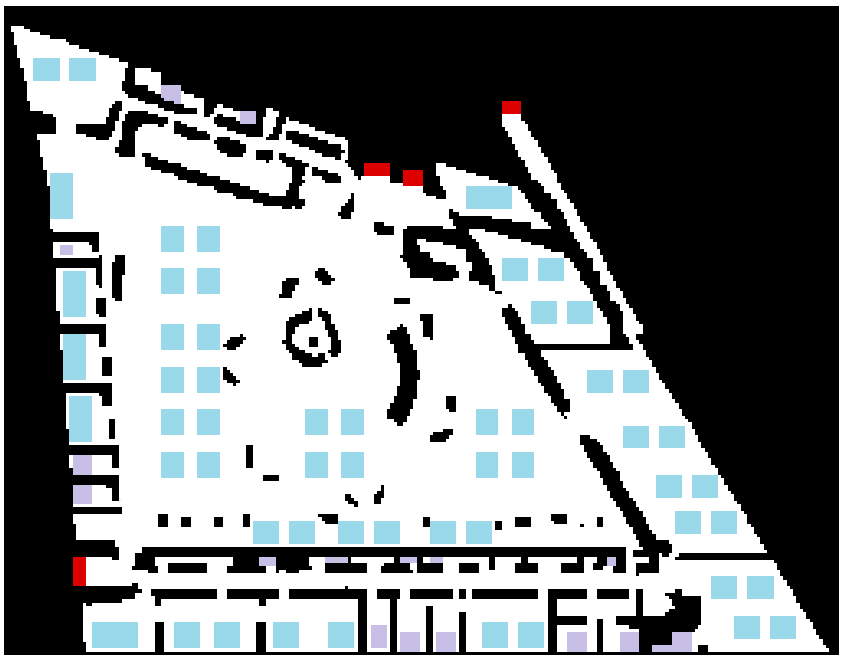


Figure 5.1: Floor plan of the TU Delft library as used in the model

Within the model, the floor plan consists of 200 by 190 patches, with each patch representing an area of 2 by 2 meters. The state variables for the patches are visible in table 5.3.

The patches are coloured in one out of seven colours, with each colour having their own characteristics. *Black* patches represent walls inside the building or areas outside the building. These patches are not accessible by agents. *Red* patches represent exits of the building. *Blue* patches indicate areas where sitting places are located. *Lilac* patches indicate areas which are closed offices, in which only one person can sit at a time. *Orange and yellow* indicate fire. Patches only colour orange or yellow,

Table 5.3: State variables used in the model for patches

Variable name	Static / Dynamic	Explanation	Values ranges/ units
Pcolor	Dynamic	Indicates what color the patch is	Colour value
fire?	Dynamic	Indicates if a patch is on fire	True / False
emergency-equipment-location?	Static	Location where the emergency equipment is located	True / False

whenever a fire occurred within the building. As this area is dangerous, agents are not able to access these patches. Finally, *White* patches represent all other patches inside the building, which are not represented by any of the colours above.

5.2.3. Time

In the model, one time step, also called a tick, represents one second. The simulations start 30 seconds before an alarm starts ringing and it ends when all building occupants have left the building.

5.3. Process overview and scheduling

All of the building occupants go through the four states as depicted in figure 5.2: Normal state, Response state, Evacuating state and Evacuated state. Additionally, the agents interact with their environments through communication with visitors and staff members, through observations and avoidance of fire and obstacles, through signals of a fire alarm and connections with friends and/ or colleagues.

In this section, first, two general modelling elements concerned with the movement of turtles will be further explained. These elements come back during all phases of the evacuation. This is followed by a description of the occupants behaviour during each of the states.

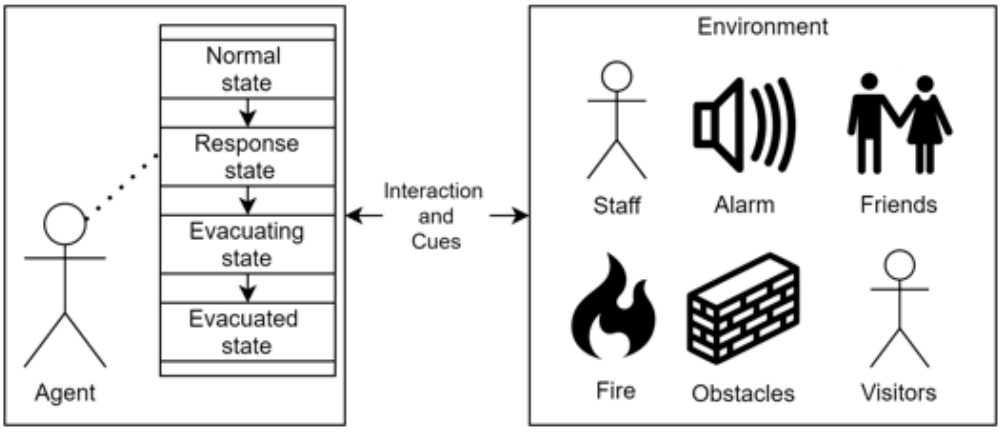


Figure 5.2: States of the agents in the model and interactions with the environment

5.3.1. Shortest-path algorithm: A*

During all phases of the evacuation, building occupants will move themselves to places in the building. For example, during the normal state, occupants will move towards another place in the building to collect a book and during the evacuation state occupants will move towards one of the exits.

In order to determine the path that a building occupant takes towards a destination, the A* shortest-path algorithm has been used. Although there are many shortest-path algorithms available, the A* algorithm is considered as one of the best algorithms. This algorithm outperforms for example the Dijkstra algorithm on time and space complexity (Cui et al., 2012).

5.3.2. Walking speed

The walking-speed of building occupants differs per gender, as males walk slightly faster compared to females (Shi et al., 2009). Furthermore the walking-speed is influenced by number of people located

around someone (Helbing and Molnar, 1998), also called the density (Ibrahim et al., 2016) .

If the density is lower than two, occupants walk with their regular walking speed. Whenever the density increases, occupants will decrease their walking-speed, this leads to equal speeds for males and females if there are four or more people around.

The table below shows the walking-speeds used in the model, based on the speeds mentioned by Shi et al. and Ibrahim et al.

If at any point in time, there are many other occupants around, the building occupant will try to calculate another route where there are less others around.

Table 5.4: Walking-speed influenced by desity

Density	Walking-speed (m/s)	
	Male	Female
<2	1.20-1.40	1.10-1.30
2-3	0.60-0.80	0.50-0.70
4-5	0.50	0.50
6-7	0.38	0.38
>7	0.10	0.10

5.3.3. Normal state (including notification state)

The simulation starts 30 seconds before a fire occurs and an alarm starts ringing. At this point in time, all of the building occupants are in a normal state: they are either be located on their sitting place or are in another place inside the library. The occupants are either doing a task, or they may be walking around the library.

Whenever the alarm starts ringing, a notification time is determined for all building occupants. During this notification time they can still perform tasks or walk around the library. The notification time will decrease with every tick.

For staff members the notification time is a random time between 3 and 11 seconds. This time is based on an article by Samochine et al. (2005) in which staff behaviour was researched during the unannounced evacuation of retail stores. As this article only provides numbers for the total pre-movement time and not solely for the notification time, a fraction of these pre-movement times was used.

The notification time of staff members may be decreased, whenever they see signs of fire and/or smoke. If this happens, and their current notification time was higher than 4, their notification time will be set to a random time between 0 and 4 seconds.

Additionally, the response time of staff members is affected by the actions of others around. This is described by Festinger's social comparison theory (Festinger, 1954), which states that people evaluate the urgency of the situation by comparing opinions of others in the same situation (Choi et al., 2018; Chu, 2015). With respect to this theory, staff members in the model notice the number of people around them which are evacuating. If this number is higher than 7, at any point in time, a staff member will adjust his/her response time. If the response time is more than 8 seconds, it will be set to a random time between 0 and 8 seconds.

For visitors the notification time is a random time between 6 and 96 seconds. This is based on the minimum and maximum notification times mentioned in one of the BeSeCu research Galea et al. (2015). In the model, visitors of different cultures are considered to have the same notification time.

The notification time of visitors may be influenced in the model whenever a visitor receives cues (Lo et al., 2000). The visitors are similarly influenced as staff members whenever they see signs of smoke and/or fire. They will also set their notification time between 0 and 4 seconds. When a visitor is informed by a staff member and his/ her notification time is higher than 5, his/ her remaining notification time will be set to a time between 0 and 5 seconds. Similarly to staff members, visitors will set their notification time between 0 and 8 seconds when they see 7 or more people evacuating.

If the notification time of a building occupant reaches zero, he/she will go into the response state. As Visitors and staff members perform relatively different response behaviour in the model, these states are described separately in the two sections below.

5.3.4. Response state of visitors

The response state decision-making of a visitor consists of three parts: the initial response tasks, adjustment of response tasks due to cues and setting and finalising response tasks. This process is shown in Figure 5.3. The visitors execute all of their itinerary tasks in the given sequence until they are all finished. Whenever someone approaches them to ask something or provide information, they will pause their tasks for the time duration of this conversation.

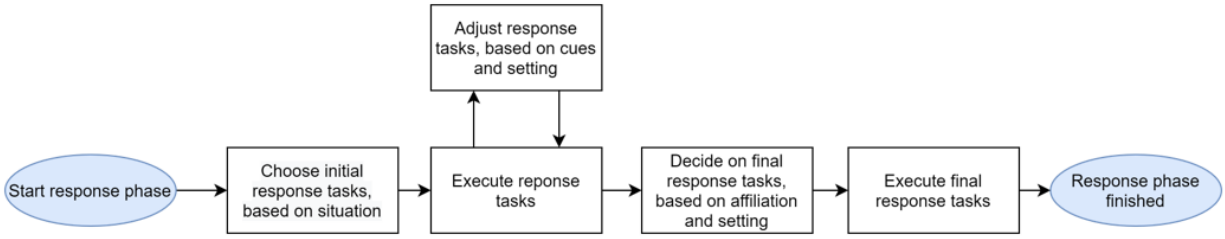


Figure 5.3: Process: Response phase decision-making of visitors

All elements of the response state decision-making are explained below. An example for a Czech visitor is provided in section B.2. A description of how each of the response tasks has been modelled can be found in section B.3.

Initial response itineraries

A visitors initial response tasks is dependent on the cues received before the start the response phase and the setting. Two types of cues are considered: signs of smoke or fire and being informed by a staff member. For the setting we consider two settings. Firstly a setting, whereby there are other building occupants in nearby surroundings. And secondly, a setting whereby there is no-one in the nearby surroundings.

Figure 5.4 shows the combination of these cues and settings and how they result in different response itineraries.

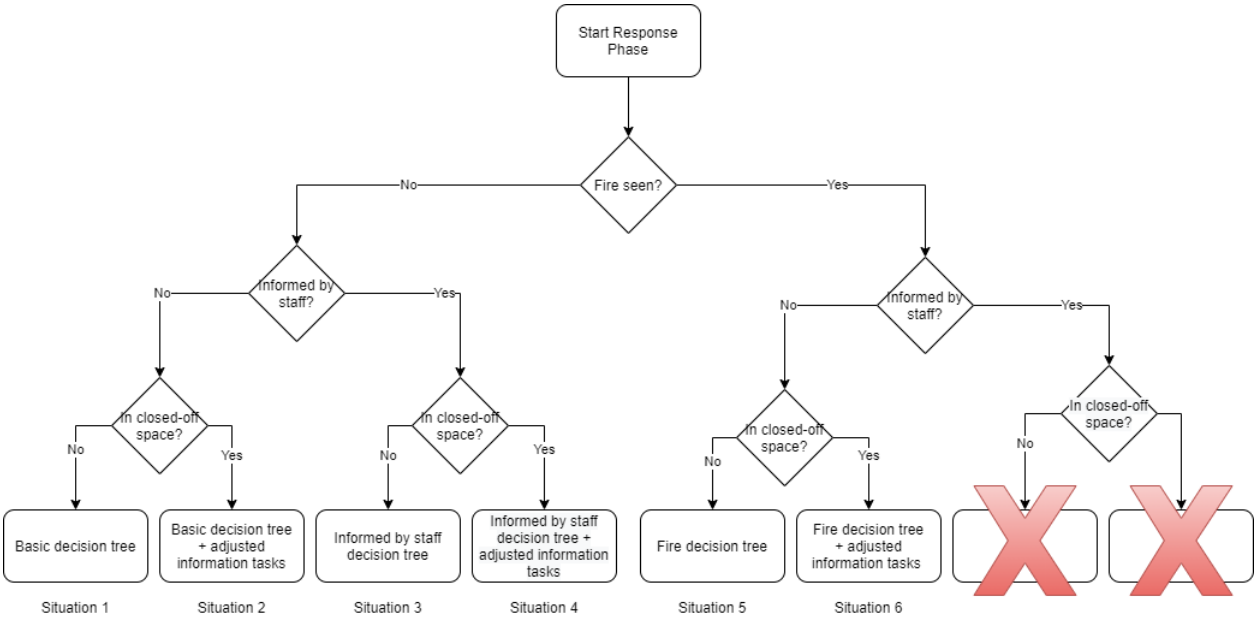


Figure 5.4: Decision tree for the situation and corresponding initial response itineraries based on cues and setting

By combining the two cues and the setting, 8 situations are identified. Out of these situations, only the first six are further examined. When considering logic, the last two situations can be neglected. In these situations a building occupant has seen fire and has been informed by a member of staff. As it

is unlikely for these two events to happen exactly on the same moment, one of these has to happen earlier and will cause a start of the response phase. Therefore it would be illogical to consider these two situations. Table B.1 provides an overview of all situations and the corresponding survey data used.

For all situations, the questionnaire data was used to develop probability trees of performing certain tasks in a certain sequence; the response itinerary. To avoid over fitting of the data, a minimum support of 4 respondents has been considered per sequence in the probability trees. This means that a sequence ends in the probability tree, whenever there were less than 4 people reporting the same task in the same sequence. Based on this support level it is assumed likely that these sequences in the probability trees are to be followed by visitors in the emergency situation.

However, these sequences will not add up to the full chances (figures 4.3, 4.18, 4.8) of doing certain tasks during the response phase. Therefore the sequences from the decision tree are supplemented with extra tasks. These extra tasks are based on the remaining chances of doing a certain task outside of the sequences included in the decision trees. After the initial sequence, these tasks will be added in random order. This leads to the full process of picking initial response tasks (figure 5.5). All probability trees and the remaining chances of performing extra tasks can be found in appendix B.

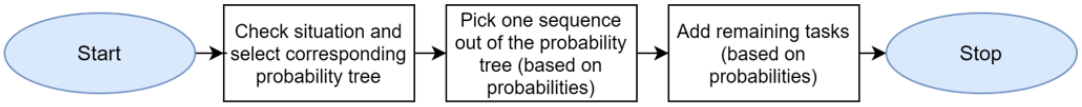


Figure 5.5: Process: Setup initial response tasks

Adjustment of response tasks during the response phase

While a building occupant is executing his/her response tasks, there are different factors which can influence their itinerary. Firstly the two cues, signs of smoke and/or fire and being informed by a staff member. For the first type of cue, signs of smoke and/or fire, scenario 1 of the questionnaire is used to alter the tasks not executed yet. This means that there are certain chances that an occupant does not execute tasks anymore, but there are also chances that the occupant executes tasks which he/she wouldn't do before. The percentages used can be found in figures 4.4 to 4.7. For the second type of cue, being informed by a staff member, scenario 6 of the questionnaire is used, to alter the tasks which have not been executed yet.

For both cues, the tasks are only altered if this has not been done at an earlier point in time (see figure 5.6).

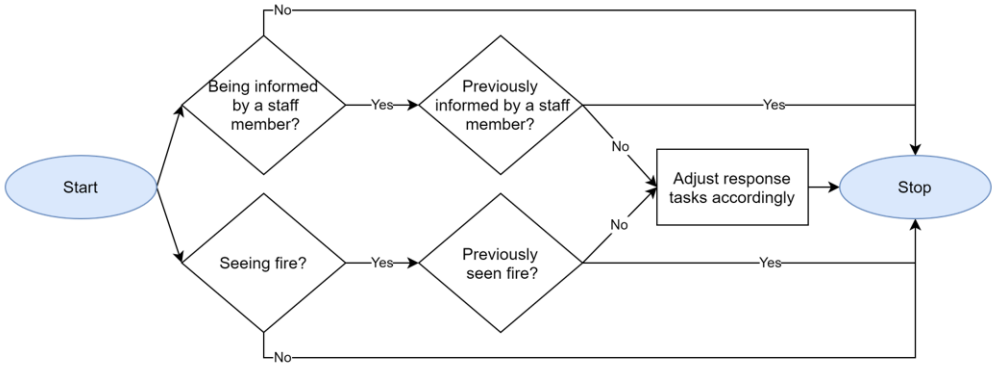


Figure 5.6: Process: Adjustment of response tasks due to cues

Setting comes into play when executing some response tasks, namely being close to personal belongings or not. Whenever an occupant is not close to his/her seating place, while the alarm starts ringing, this could mean that this affects any actions related with personal belongings. These actions are: "Collect and put on coat", "Work-related duties", "Pack personal and work items in close vicinity".

Scenarios 2 (non-fire) and 6.3 (fire) of the questionnaire are used to decide if a respondent will walk back to his/her sitting place to execute these tasks or if he/she will not do this. If the visitor decides to not go back to his/ her sitting place, these tasks are removed from the itinerary.

Finalising response tasks

After finalising their previously defined itinerary, there is a possibility that three more tasks will be added.

Firstly, if a building occupant has not executed any tasks concerning his/her belongings, there is still a possibility to pick these up after finishing all tasks.

Secondly, if a building occupant is in the library together with a friend or colleague, he/she has another decision to make. If the friend /colleague is located nearby, the building occupant has to decide if he/she will wait for the other person to finish up their tasks. This will be done based on questionnaire scenarios 4 (non-fire) and 6.1 (fire). If the friend/colleague is not located in close proximity of the building occupant, he/she will have to decide to search for the other person or not. Herein there are three possibilities: not searching for friend/colleague, searching for friend/colleague for a maximum amount of time and searching for friend/colleague, disregarding any time considerations. This is decided through the chances in scenarios 5 (non-fire) and 6.2 of the questionnaire.

After all response tasks have been finished, the evacuation state starts.

5.3.5. Response state of staff

As there are no articles describing response behaviour of staff in a library, response behaviours are based on observations made in retail stores by Samochine et al.(2005). As first reaction after hearing an emergency alarm, five types of staff behaviour were observed in retail stores: ignore the alarm, wait or seek for information, evacuate customers, evacuate themselves or leave the area (probably actively seeking information) (Samochine et al., 2005) . Out of these behaviours, wait / seek information and evacuate customers occur most often, respectively 60.8% and 26.5%. The staff who sought information, usually discussed with their colleagues or tried to reach supervisors. Therefore, the following investigative tasks for staff have been identified: ” Seek information through another member of staff”, ”Phone someone to seek information ”, ”Look around and see what is happening” and ”Move to another location to seek information”.

Sixty percent of the staff members will first execute some type of investigative action, after which they evacuate visitors. These staff members will do between 1 and 4 information tasks. The chances used for doing each of the information-tasks can be seen in table 5.5. For the first task, the chances are slightly higher to perform ”Seek information through another member of staff”, as this is described as a more frequently observed task by Samochine et al. (2005). The other forty percent of the staff will not do any information tasks and will start evacuating visitors immediately.

After finishing all tasks, the evacuating state starts.

Table 5.5: Chances of performing response tasks for staff members if they decide to perform any information tasks

Chances of doing tasks (%)	
	First task
40	Seek information through another member of staff
20	Phone someone to seek information
20	Look around and see what is happening
20	Move to another location to seek information
	Second to fourth information task
25	Seek information through another member of staff
25	Phone someone to seek information
25	Look around and see what is happening
25	Move to another location to seek information
	Final task
100%	Evacuate visitors

5.3.6. Evacuating state

At the beginning of the evacuating state, all visitors and staff will choose an exit through which they will evacuate. Afterwards they will move towards the exit. Below the two parts of this state will be described.

Choose exit

The exit decision is based on familiarity. As staff members are expected to be familiar with the building, they will all choose the nearest exit as their destination.

In making the decision for an exit, the visitors are influenced through obtained information by staff members. If a visitor has been informed by a staff member, the visitor chooses the corresponding exit. However, if there is another exit closer by, which was not recommended by the staff member, the visitor chooses this exit to evacuate through.

If a visitor has not been informed by a staff member, it comes down to familiarity. Visitors are not all familiar with the building and thus they are not all aware of the nearest exit. Visitors who are familiar, choose the nearest exit. However, visitors who are not familiar, first look around if they see any exits. If this is not the case, they choose to go to the main exit.

If a visitor is evacuating together with a friend or colleague, they will compare their exits decisions and move together towards the closest exit of these two. During their evacuation, the fastest of the two will lower its speed so that they both stay together.The decision-process is visualised in figure 5.7.

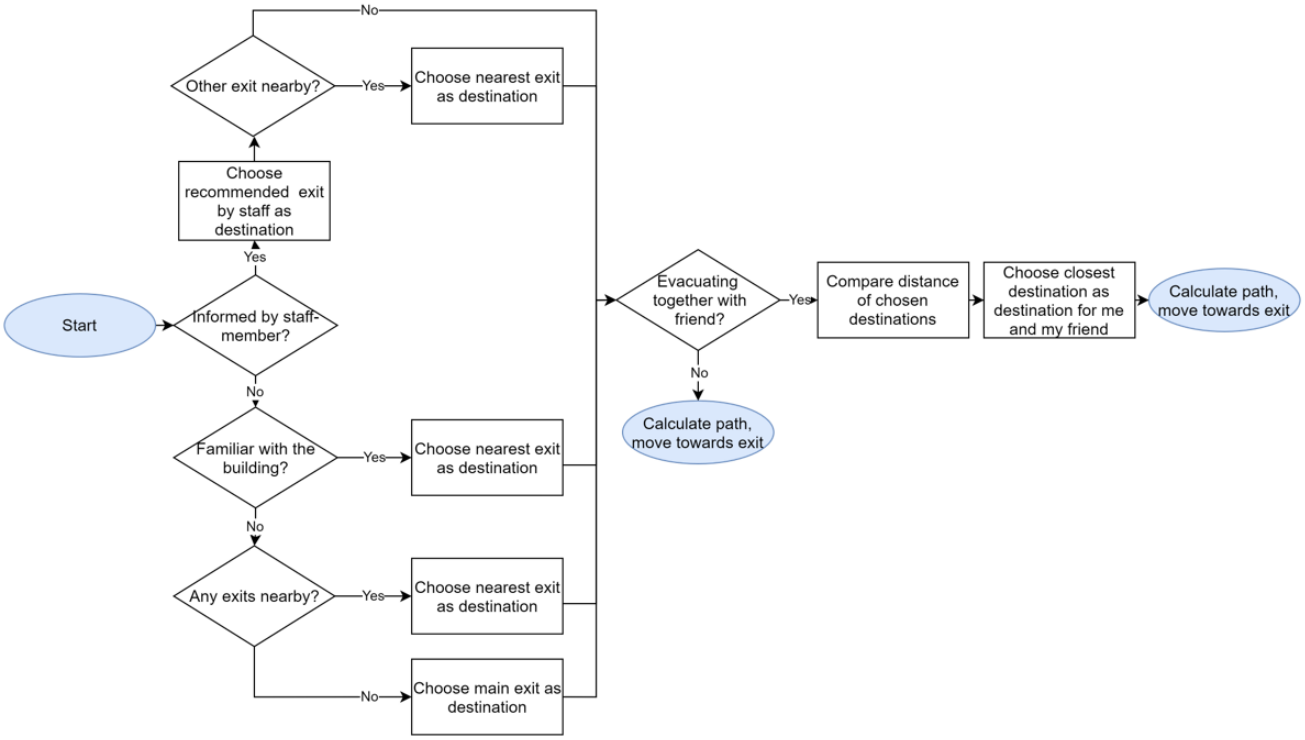


Figure 5.7: Process: Choose exit by visitors

Move towards exit

During the evacuating state both visitors and staff-members will calculate a path towards their chosen exit. They will follow this path until they have reached the exit.

Staff-members will interrupt their movement, if they see any visitors on their way, which are not evacuating yet or not talking to another staff-member. The staff-member will inform these visitors as in the previously described task ”*Evacuate visitors*”. After informing the visitors, the staff member will continue its’ path towards the exit. This process can be seen in figure 5.8.

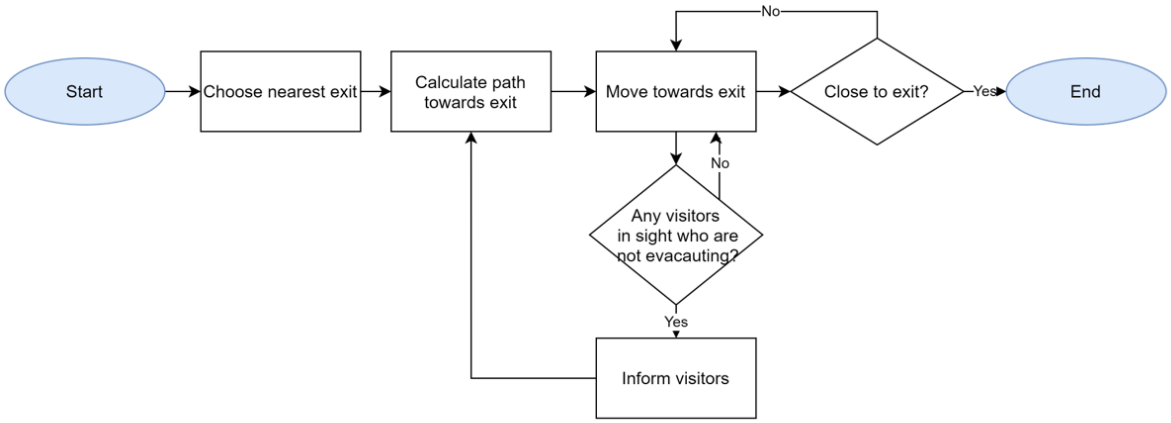


Figure 5.8: Process: Evacuating of staff members

5.4. Design concepts

In this section, the 11 concepts which characterise ABMs (Railsback, 2020) are described. These concepts describe the aspects of the model which are not described well by flow charts.

Emergence

One of the aspects which shows emergent behaviour within the model is the adjustment of walking-speed accordingly to the density.

Another aspect in which emergent behaviour is shown within the model is the notification time distribution. The notification time of visitors is influenced by the people around them. If more people around are evacuating, this is noticed and the notification time of a visitor decreases. Similarly, when a visitor is informed by another visitor or staff member, the notification time decreases. Therefore, overall notification time decreases depending on the states of others around. Thus, if the overall population responds rather quickly to the incident, this will also cause a quicker response for the remainder of the population.

Adaptation

Firstly, visitors adapt their behaviour due to cues, setting, affiliation and communication. These all influence the response tasks which are being performed. The effect of cues, setting and affiliation is already extensively discussed. Communication causes adaptation of the response tasks, when someone is informed by another visitor. If this happens, the informed visitor will remove one or more tasks from their response itinerary.

Secondly, all agents adapt their behaviour and stop performing a response task, when this task cannot be finished successfully. For example, when a visitor wants to inform others nearby, but there is no one around. In this situation the visitor will take some time to realise this and afterwards the task will be ended. Similarly, adaptation can be found for the task ”Collect emergency equipment”. Whenever there are many others around the emergency equipment location, a visitor will decide to stop this response task. This is due to the inefficiency of all trying to collect emergency equipment and the time it takes for everyone to collect this.

Thirdly, visitors adapt their behaviour based on spatial aspects. For example, by avoiding fire and walls. Also visitors' exit-choices are adapted, as an unfamiliar visitor chooses the nearest exit, when this exit is in vision-distance. Furthermore, visitors will adjust their chosen path during some moments in time, whenever there are many others on their walking path and this influences their walking speed. This can be explained by the social force model(Helbing and Molnar, 1998), in which it is stated that evacuees keep certain distances from obstacles, walls and other people.

Objectives

As described above the adaptation of exit choice is led by direct objective-seeking. When starting the evacuating phase, visitors will have the objective of leaving the building as quickly as possible.

Similarly for path adaptation, the objective to reach a destination as quickly as possible will cause this path adjustment.

Observation
The observations collected in this model can be seen in table 5.6.

Table 5.6: Observations reported in the model

Variable name	Global/ Per Agent	Explanation	Units
Total-evacuation-time	Global	The time it takes all visitors to leave the building after the alarm has started ringing	Seconds
Notification-time	Per agent	The total notification time	Seconds
Response-time	Per agent	The response time including notification time	Seconds
response-time-excl-notif	Per agent	The response time excluding notification time	Seconds
Movement-time	Per agent	The time used for the evacuating state	Seconds
Evacuation-time	Per agent	The time to evacuate	Seconds
Visitors-informed-by-staff	Global	The number of visitors who have been informed by a staff member	Number of visitors
Visitors-fire-seen	Global	The number of visitors who have seen fire	Number of visitors
Response-tasks-lists	Per agent	Lists of performed response tasks	List of response tasks

Sensing
One aspect during which sensing is used within the model is for the task ”physically assist others”. During this task, visitors will sense if others around them are in need of help.

Sensing is also used by staff members. When informing visitors, they sense whether a visitor is already evacuating or whether he/she is still in the normal or response phase.

Interaction
All interaction in the model is direct and it can all be found through communication. It happens when people inform each other, when visitors are being informed or when people are physically assisting others.

Stochasticity
Stochasticity can be found throughout the full model. It can be found for the setup of agents and determination of their behaviour. From the setup, where stochasticity determines which agents are male / female and if these agents are familiar or not, to the initial setup and adjustment of response tasks.

Furthermore, stochasticity is used for the placement of the fire. As this fire can occur at any random location within the library, this is done stochastically.

Collectives
Collectives in the model are presented in two ways. Firstly, the people in the model can either be visitors or staff members. Due to the role-rule model (Tong and Canter, 1985) these groups perform different types of behaviour.

Secondly, collectives are represented through friend groups. A visitor can either be part of a friend group or not. If a visitor is part of a friend group, he/she will have another visitor registered as his/her friend.

Learning and *Prediction*
Learning and prediction are not implemented in this model.

5.5. Initialisation

Table 5.7 provides an overview of all parameters which can be adjusted during initialisation.

Table 5.7: Input parameters of the model

Variable name	Explanation	Values ranges/ units
Initial-number-visitor	The number of visitors present in the library at the start of the simulation	Number of visitors
Initial-number-staff	The number of staff members present in the library at the begin of the simulation	Number of staff members
Culture	The culture with which the model is running.	Country
Gender-ratio	Percentage of population being of male gender	0-100 %
Familiarity-meter	The percentage of visitors which are familiar with the building	0-100 %
Visitors-not-on-place	The percentage of visitors which are not located on their sitting-place at the start of the simulation	0-100 %
Chance-friend-in-building	The percentage of visitors which are part of a friend duo	0-100 %
Chance-friends-nearby	The percentage of friend duos being located close to each other	0-100 %
Exits-available	The exits available during the simulation	Exit names
Vision-distance	The distance of how far agents will look ahead	Patches
Vision-angle	The angle of an agents sight when looking ahead	Angle

The *Gender-ratio* parameter defines the ratio of males / females within the building. Based on this parameter, each occupant will be of the male or female gender. Based on the determined gender, the initial walking speed of an occupant will be determined.

With the *Familiarity-meter* input can be provided for the percentage of visitors being familiar with the building. Visitors will be familiar or not based on the chances provided through the input variable. This input parameter will not influence staff members, as all staff members are expected to be familiar with the building.

During the initialisation, all of the staff members will be placed randomly on any location within the floor plan. For the visitors, a sitting-place will be determined first. This will be any one of the blue or lilac patches. Based on the *Visitors-not-on-place* input, the corresponding percentage of respondents will be moved to a random location within the building, which is not a similar location as their sitting place.

Based on *Chance-friend-in-building* in combination with *Chance-friends-nearby* , links will be created among visitors which will form a friend duo. Each of the visitors can have a maximum of one link to connect to any other visitor. The links can either be created to other visitors nearby or to visitors further away; this is done based on the chance by the input parameter *Chance-friends-nearby.*

Exits-available, Vision-distance and *Vision-angle* are kept on a standard level for this research, these could however be altered if this is desired.

5.6. Input data

An overview of the input data is available in section 3.1.5.

5.7. verification and Validation

The main factors to select an evacuation model, among model users, are validation and verification (Lovreglio et al., 2020; Ronchi and Kinsey, 2011). Therefore we must ask ourselves two questions after developing a model: ”did we built the thing right” and ”did we build the right thing?” (van Dam et al., 2012). In this section the model is verified and afterwards validated by comparing the outcomes to those of the BeSeCu project (Galea et al., 2015).

5.7.1. Verification

During verification, it is checked if all relevant entities and relationships from the conceptual model have been translated into the computational model (van Dam et al., 2012). In order to verify the model, the simulation has been inspected visually, agent behaviour and interactions between agents have been logged and extreme value tests have been performed.

Visual inspection

Through visual inspection, it is inspected if model behaviour is similar as what was described in the conceptual model.

Overall the simulations show correct behaviours. All building occupants take some time to notice the alarm, they perform their response tasks and afterwards move towards one of the exits. Interactions between agents can be observed and agents are moving towards different destinations during their response tasks.

Two abnormalities have been observed. Firstly, some agents cannot reach their destinations when fire is blocking their path. For example, a room has only one exit and this exit is blocked by fire. This results in the inability to evacuate. Similarly fire can block one of the only paths towards a building exit. These situations cause an error in the model. Data from these runs has not been considered during the data analysis. Secondly, some friend duos take an extremely long time to find each other. While seeking for a friend, a visitor will set his destination as the latest location of his/her friend and moves towards this location. However, the updates for this destination are limited. Whenever two friends are searching for each other at the same time, it could result in them circling around each other. After some time, the friends will always find each other, however with a high delay. Although the circling behaviour is not logical, it could occur in real life that friends have a hard time finding each other

Logging of visitor behaviour

To validate the processes concerning response-tasks and adjustment here-off, a test has been done. In this test behaviour of 10 visitors was logged, the setup, as well as adjustment of response-tasks were considered. The results of this test can be found in table B.7.

For each of the visitors, the table shows events which caused the setup and adjustment of the response-tasks. The table shows the time at which this event took place and how this caused adjustments to the current response tasks list.

Two types of setup situations have occurred among the logged visitors: a basic setup and a basic setup in a closed off space. Additionally, the table depicts that response-tasks-list are influenced by being informed by staff and seeing fire. We can see that probabilities have been used within the model, as for example staff does influence the response tasks of visitors 35, 45 and 55, but it does not influence the response tasks of visitor 60.

Based on these outcomes it is concluded that the model can be verified for the response tasks of visitors and interactions between agents.

Extreme value tests

With extreme value testing, an attempt is done to ”break” the agent and define edges of normal behaviour (van Dam et al., 2012). For all input parameters, except Culture and Exits-available, extreme values have been tested. As Culture and exits-available are categorical variables, there do not exist extreme values for these variables. Table 5.8 shows the extreme values which were considered as well as the outcomes of the tests. For each test, three repetitions have been run. None of the tests have caused breaking of the model or agents, however three tests did cause some illogical behaviour for the agents.

While performing the extreme tests for initial-number-visitor, the model and agents did not break. However, when there are 600 visitors, some areas within the library become very crowded. The agents only make small adjustments for their path, in order to avoid the crowd. This means that they still all end up within a crowd, instead of going around it. Although the model did not break, this could bias the results.

While testing Vision-distance, the behaviour of agents, and especially staff members, becomes somewhat unlikely. Whenever the vision-distance is on its minimum, agents will not notice other peo-

ple around them and they will have a smaller circle of people with which they interact. The opposite happens when the number becomes extremely large and agents will have a very big circle of others to interact with. Similar deviations occur for the maximum and minimum tests of the vision-angle.

Table 5.8: Extreme values testing with input parameters

Variable name	Extreme values		Breaking of model?	Divergent behaviour?
	Min.	Max.		
Initial-number-visitor	0	600	No	For 600 visitors: Some areas near corners become crowded and agents are not very likely to make big adjustments to avoid the crowd.
Initial-number-staff	0	100	No	No
Culture	-	-	-	-
gender-ratio	0	100	No	No
Familiarity-meter	0	100	No	No
Visitors-not-on-place	0	100	No	No
Chance-friends-in-building	0	100	No	No
Exits-available	-	-	-	-
Vision-distance	2	20	No	These extremes do cause slightly illogical behaviour.
Vision-angle	60	200	No	These extremes do cause slightly illogical behaviour.

5.7.2. Validation

Through model validation, it is checked if the model is an accurate representation of the real-world system (Sargent, 1998). This was done by comparing the model results with those of the empirical library evacuations within the BeSeCu project (Galea et al., 2015). Both distributions of response times, as well as the number of people evacuated over time, are compared.

Figures 5.9 and 5.10 show the response time distributions from the BeSeCu project (Galea et al., 2015) and from the model. The basic model scenario with 150 visitors and 20 staff members has been used for this comparison. The figures show similarities in their overall behaviour. As in both figures a peak can be seen for low response times, after which the probabilities slowly decrease. Based on this, it can be stated that the model shows similar behaviour in determining response times as in the real-world BeSeCu experiments (Galea et al., 2015).

Although the behaviour is similar, the exact results are not. Response times in the BeSeCu experiment (Galea et al., 2015) have been lower, compared to those in the model. Furthermore, the outcomes do not show comparable results for each of the countries. These differences can be caused by any factor which influences response times and by any discrepancies between the model and the experiments. As the model is a simplified version of the real world, many aspects have not been taken into account. Some of the discrepancies are explained in more detail below.

Firstly, as discussed in Chapter 4, the number of tasks used as input to the model does not match the number of tasks as observed in the BeSeCu project (Galea et al., 2015). As these tasks are a main determinant in the response time, this causes differences in the outcomes.

Secondly, it was not possible to create the exact same scenarios within the model as during the empirical experiment. The scenarios in which the experiment took place, have not been discussed in as much detail in literature, in order to be able to create exactly the same scenarios within the model. Furthermore, the floor plans of the BeSeCu libraries (Galea et al., 2015) have not been implemented in the model. This could affect the distances that occupants need to cover, as well as the density within the building, which in its turn influences response times.

Thirdly, the average notification times used within the model, are larger compared to those during the experiment. For the model, the full range of notification times was used, which was found in the BeSeCu project (Galea et al., 2015). Any random value between 5 and 96 seconds was considered as notification time in the model. However, due to notification time of Czech Republis as an outlier (88.6

seconds) compared to the other countries (8.3, 10, 17.8 seconds), the average values in the model are bigger than those in the BeSeCu experiment (Galea et al., 2015).

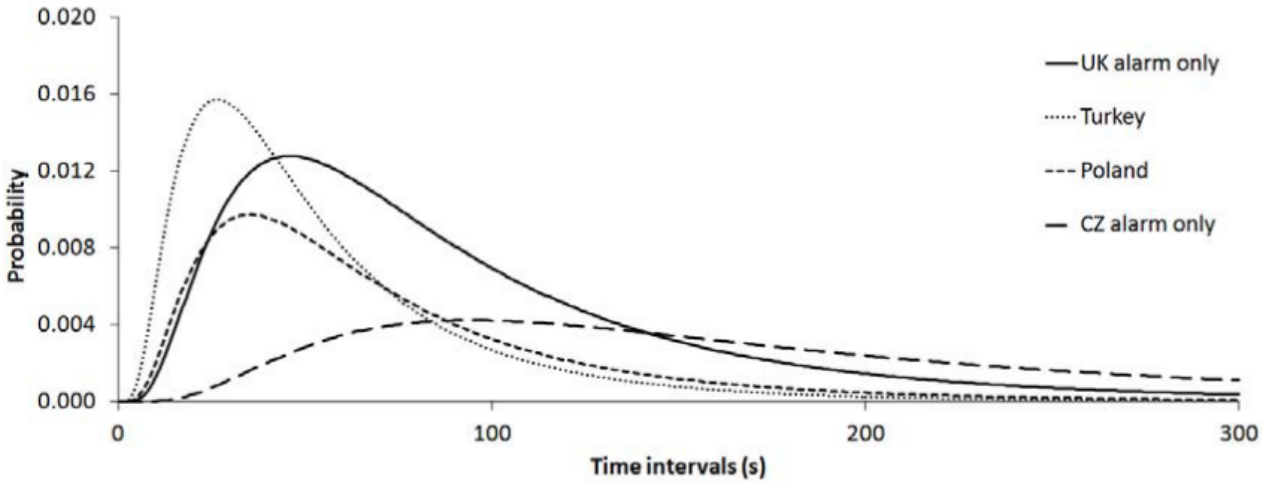


Figure 5.9: Response time distribution per country during the BeSeCu experiments (Galea et al., 2015)

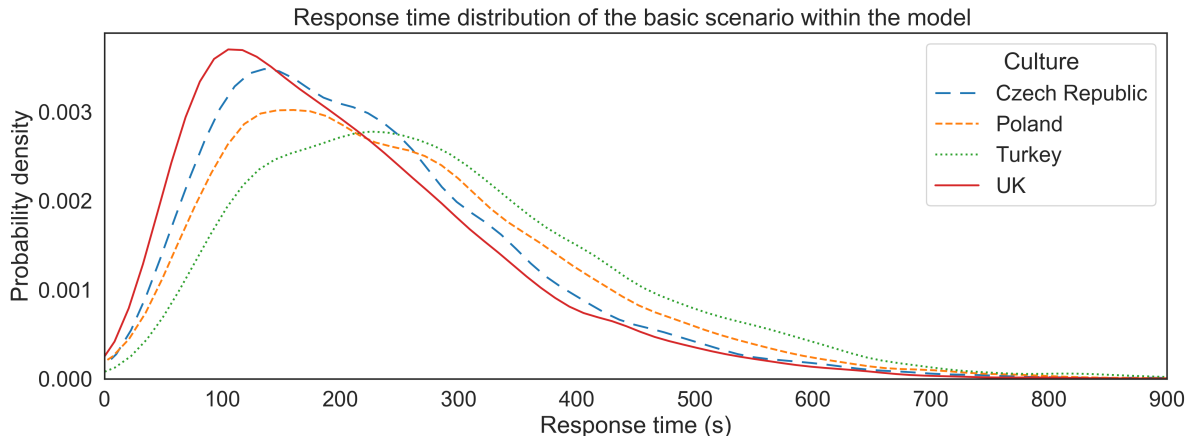


Figure 5.10: Response time distribution per country in the model

Besides the response time distributions, the number of people evacuated over time have been compared. In the BeSeCu project (Galea et al., 2015), the people evacuated over time has only been measured in the Turkish trial. In order to find the influence of response time distributions on the total evacuation time, a simulation was run by Galea et al. (2015). In this simulation, the response time distributions of all four countries were implemented in a library evacuation of the Turkish library. This was done with the EXODUS model, which has proven to accurately represent occupant behaviour during evacuations (Galea et al., 1998; Galea, 1998; Gwynne et al., 1998; Weckman et al., 1999) . The outcomes of the trial data and the simulation are shown in figure 5.11.

For the model in this study, the basic scenario has been considered, however with 100 occupants in the building. This has been done, so that it is similar to experiment done in BeSeCu (Galea et al., 2015). These outcomes can be seen in figure 5.12. The lines show the averages over 60 runs.

By comparing the figures, again, similar behaviour can be observed. In both figures it takes some time before the first people have been evacuated, after which the lines gradually increase. As well as in the comparison for the response time distributions, the exact outcomes are not the same. This is caused by the same reasons as already explained above.

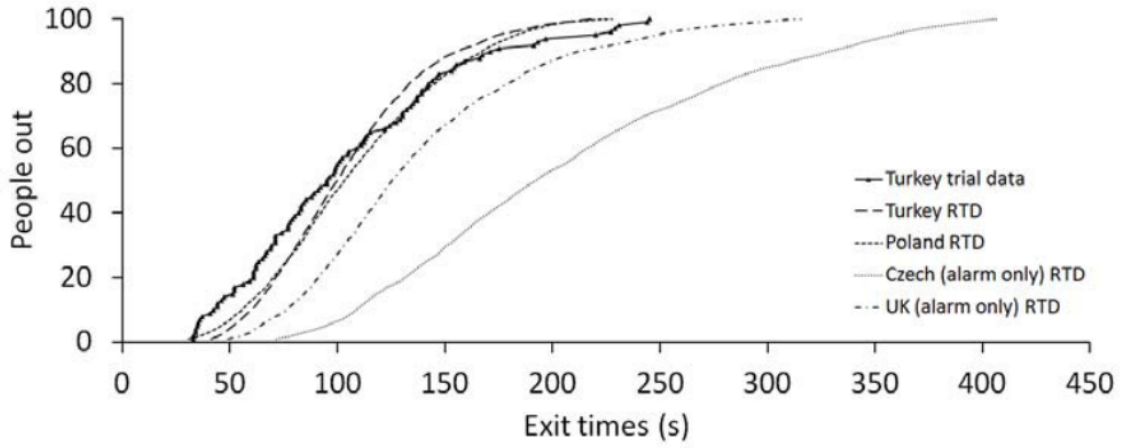


Figure 5.11: People evacuated over time per country for BeSeCu simulations(Galea et al., 2015)

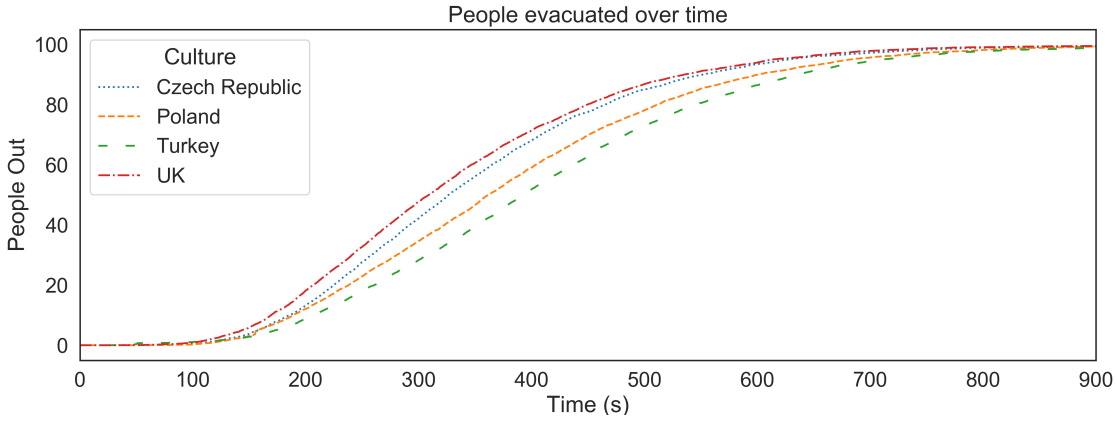


Figure 5.12: People evacuated over time per country in the model

5.8. Summary

This chapter has provided an answer to sub-question 3 *"How can cultural response-phase behaviour be modelled with an agent-based model in order to measure the response time and total evacuation time?"*. It has been explained how each of the occupant states have been modelled: normal state, response state, evacuating state and evacuated state. All agents within the model interact with each other, which causes adaptive and emergent behaviour during all states. The focus in the model lies an the response state, therefore this state has been modelled in more detail.

Response phase behaviour is split up in three parts: the initial response itineraries, adjustment of response itineraries during the response phase and finalising response tasks. The questionnaire data was used as input for these three parts of the response phase. These inputs vary for each country, causing different behaviours. The initial response itineraries have been based on the received cues and setting. Adjustment of response itineraries happened due to cues and finalising of response tasks consists of collecting belongings and performing affiliative behaviour.

After the model was developed, it was successfully validated and verified. The validation has shown different orders of magnitudes for the response and evacuation time among the model and the outcomes of the BeSeCu project (Galea et al., 2015). The two outcomes did however show similar behaviour for the response time distributions and the people evacuated over time. As the only similar type of research is the BeSeCu project (Galea et al., 2015), it was not possible to validate the model with any other data. Therefore, the obtained results should only be used within the context of this study. The overall model behaviour and the effect of influential factors does seem valid, however the exact quantitative outcomes have not been validated.

6

Model Results

In this chapter the results of the experiments are discussed, which provides an answer to sub-question 4: *"What effects can be identified, through simulations, of cultural response-phase behaviour on response time and total evacuation time?"*. The chapter consists of three parts: the Overall model behaviour, including cultural comparisons, sensitivity testing and the Influence of cues, setting and affiliation on model outcomes. As discussed in chapter 3, the average response time, average evacuation time and Evac 95 were considered as model outcomes.

6.1. Overall model behaviour

Figure 6.1 provides an overview of how average response time of visitors is correlated with the outcome parameters. A linear relationship is observed between the average response time and the average evacuation time. Therefore it can be stated that the response times of visitors directly affect their evacuation times. This relationship is not as clear for the total evacuation time, as total evacuation times are more scattered. This could be caused by few visitors taking longer to find their friends and the exit. Therefore, the moment in time has been observed during which 95 percent of the population has evacuated (Evac 95). This outcome is also considered during the rest of this chapter, instead of the total evacuation time. Evac 95 and the average response time show a somewhat linear relationship as well.

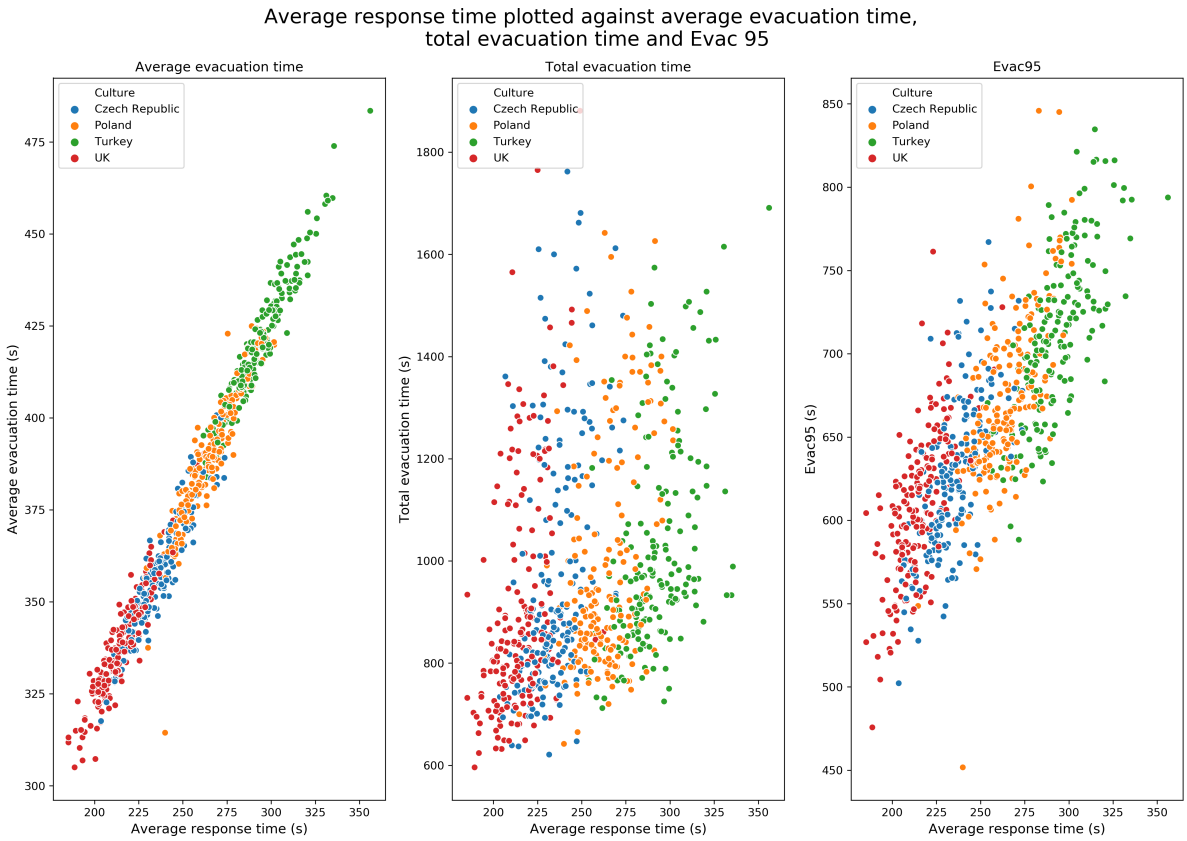


Figure 6.1: The average evacuation time, total evacuation time and Evac 95 plotted against the average response time

The four countries can be more easily compared, by inspecting how their evacuation times were built up, figure 6.2provides an overview. In this figure, the response time has been split up into the notification time and the time used to perform response tasks. The response tasks time takes up the biggest portion of the evacuation time, followed by the movement time and notification time. Interestingly, Czech Republic, Poland, Turkey and the UK differ on the response tasks time, while notification times are quite similar for all four countries. This indicates that differences between the countries in emergent response behaviour do not affect notification times.

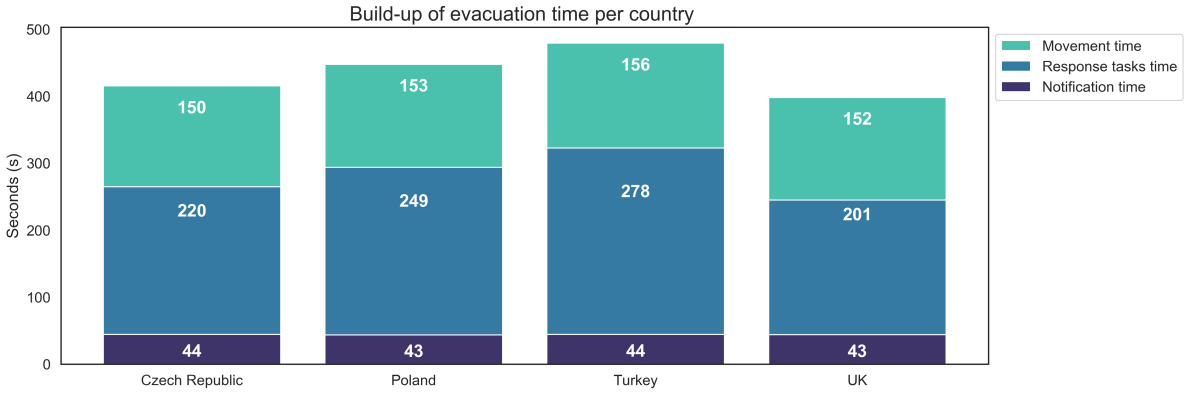


Figure 6.2: Build-up of evacuation time, for each visitor, per country

The violin plots in figure 6.3, show distributions per country, for the average response time, average evacuation time and Evac 95. A One-way ANOVA test has shown significant differences for all four countries for the average response time, the average evacuation time and Evac 95.

The average response time is highest in Turkey (M=290.79, SD=24.27), followed by Poland (M=262.79,

SD=20.48), Czech Republic (M=234.80, SD=14.39) and the UK (M=214.02, SD=34.63). The results of the One-way ANOVA test were as follows: F(3, 764) = 579.26, p=0.000.

Similary, the average evacuation time is highest in Turkey (M=416,79, SD=28.98), followed by Poland (M=385.13, SD=29.93), Czech Republic (M=355.60, SD=15.37) and the UK (M=336.39, SD=19.90). The results of the One-way ANOVA test were as follows: F(3, 764) = 396.48, p=0.000.

Evac 95 is highest in Turkey (M=707.98, SD=55.27), followed by Poland (M=667.00, SD=67.39), Czech Republic (M=626.11, SD=45.52) and the UK (M=606.19, SD=46.85). The results of the One-way ANOVA test were as follows: F(3, 764) = 130.53, p=0.000.

A post-hoc Games-Howell test shows that the outcomes of for each of the cultures vary significantly, with all p-values being 0.000.

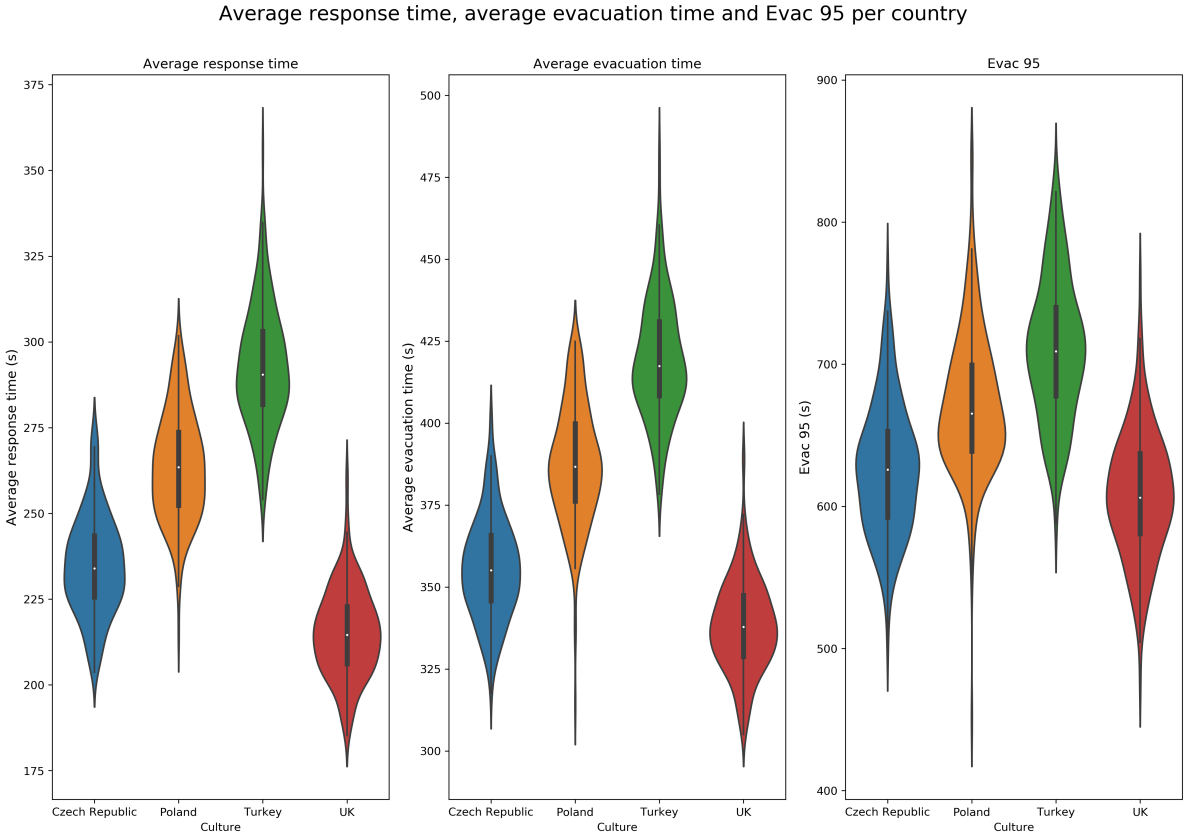


Figure 6.3: Violin plots per country for the average response time, average evacuation time and Evac 95

A closer look can be taken on the response times by inspecting the minimum and maximum times per country in Appendix C.1 and the response time distributions in figure 6.4.

Figure C.1 shows the minimum response times observed during each of the experiments. These are on average between 20 and 40 seconds. It can be observed that the minimum response times for the UK are more concentrated and on average lower compared to those of the other three countries. The figure also shows the maximum response times observed for each of the countries. The averages hereof are between 700 and 900 seconds, with again the UK showing the smallest time and Turkey the highest time.

The distribution plot indicates what causes the differences in the average response times. It can be explained by the steepness of the line and the spread of the graph. The figure shows that response times of the UK have the highest incline for relatively low response times, this is followed by Czech Republic. The response times of Poland and Turkey are both more distributed. The higher probabilities for increased response times for these countries, causes higher average response times. Additionally, figure 6.4 shows the distribution of evacuation times. This distribution plot shows similar behaviour, as Turkey clearly has the lowest number of low response times and it's distribution is more to the right, in comparison to the other countries.

These distributions clearly relate to the model input for the total number of tasks performed. The box plots in figure 4.1 show similar distributions, as clearly the UK performs less and Turkey performs more tasks in comparison to the other countries. Additionally, the box plot shows a larger spreading for the number of tasks in Turkey, compared to Czech Republic, Poland and the UK. This is directly translated into the response times.

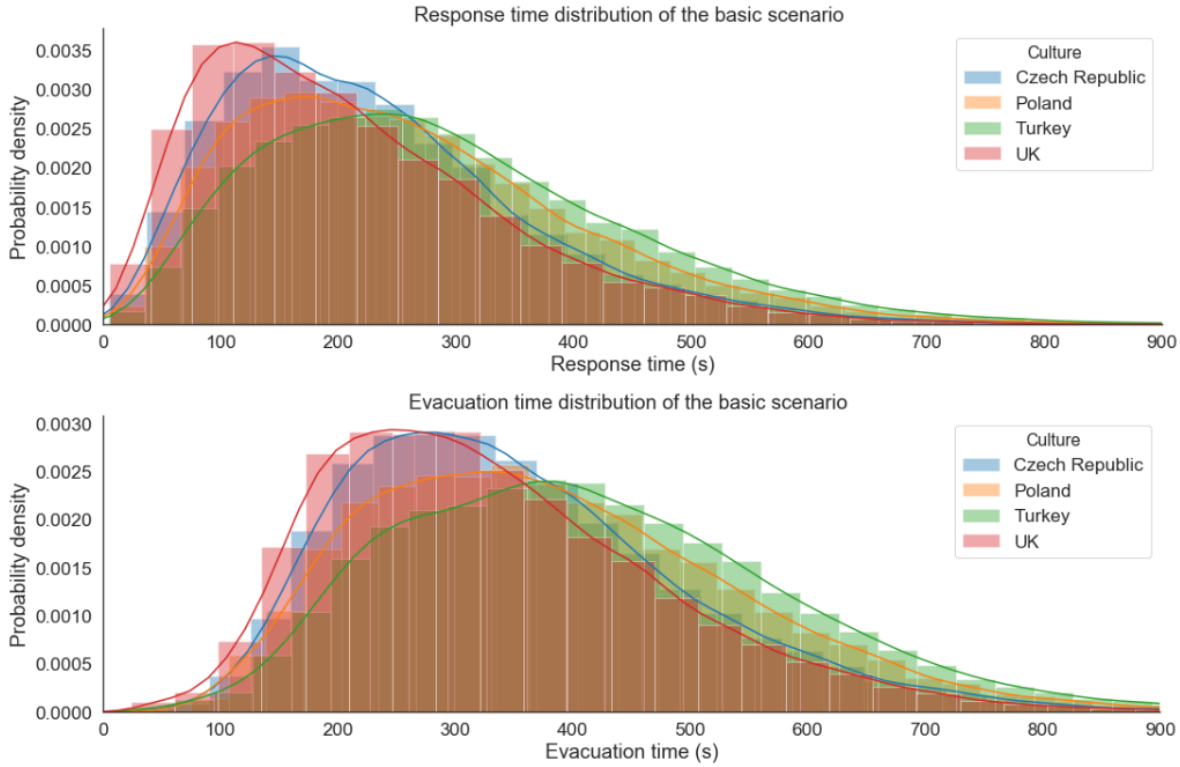


Figure 6.4: Distributions of the response and evacuation times of all visitors over all scenarios.

6.2. Sensitivity testing

As there is is always uncertainty present within a model, the effect of each of the input variables on the outcomes has been analysed. For the average evacuation time and response time, these results can be seen in figure 6.5. Figure C.2 shows similar relationships between the variables for Evac 95. This figure can be found in appendix The titles of each of the sub-figures describe which parameter has been adjusted and within which ranges. A darker colour in the plot indicates a higher parameter value.

The first sub-figure shows the chances of having friends within the building, also interpreted as the number of friend groups. The figure depicts combinations of high response times, evacuation times and / or Evac 95 correlating with a high chance of having friends inside the building. Outside of these high values for all outcomes, the figure shows that a higher number of friend groups in the building causes slightly lower average evacuation times and Evac 95.

The upper right figure shows that a high number of staff causes lower response time, evacuation time and Evac 95. Whenever the number of staff is relatively low, the average times show an increase.

In the lower left sub-figure, it is visible that the number of visitors does not highly affect the outcomes. Only relatively low response and evacuation times can be found for the situations with relatively few visitors within the building. Furthermore, the outcomes are more scattered, whenever there are less visitors present within the library.

The lower right figure shows that familiarity does not influence the average response time and Evac 95. It does however influence the average evacuation time, where a higher familiarity causes lower average evacuation times.

Besides testing how one parameter influences the outcomes, combinations of 2 parameters have been tested. These figures can be found in appendix C.1. Two intersting effects have been observed.

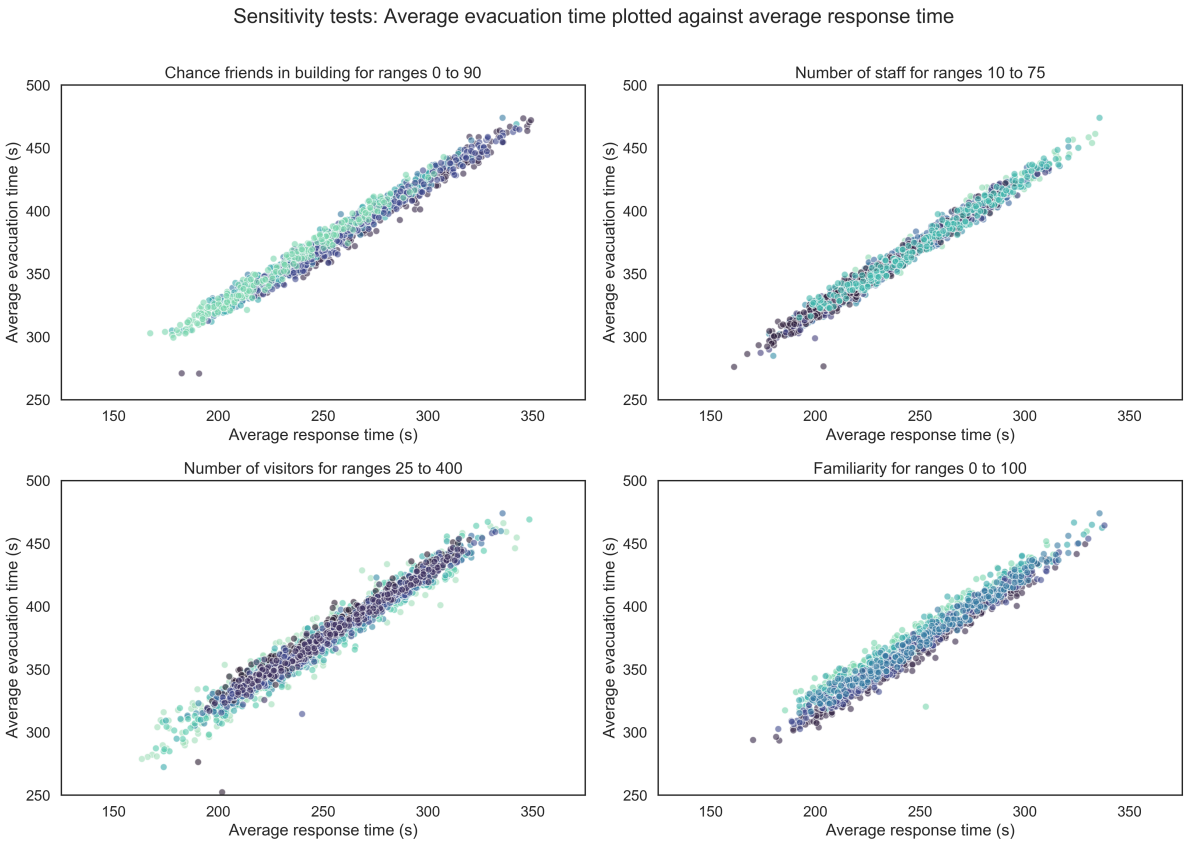


Figure 6.5: Influence of model input parameters on the average response time and average evacuation time

Firstly, the combination of familiarity and chance friends in building. For a high chance friends in the building, it has been found that a familiarity value above 0 causes big decreases in the evacuation time. This can be traced back to how the model was built, as knowledge sharing causes friend groups to make more efficient decisions on their exit destination. Additionally, it has been found that a higher familiarity score is not necessarily beneficial, whenever there is a higher number of staff present within the building. If more visitors are informed by staff member, they will already be informed about the nearest exit. Thus familiarity scores between 25 and 100 in cause similar evacuation times in combination with a high number of staff members present.

6.3. Cultural differences for the influences of Cues, Setting and Affiliation on model outcomes

This section discusses how cues, setting and affiliation affect the model outcomes. For the cues, being informed by a staff member and fire, have been analysed. For the setting, it has been analysed how the chance of being in a closed off space/ not around others influences the outcomes. For affiliation, the number of friend groups in the building have been analysed.

Correlations have been calculated for each of the influential factors in combination with each of the model outcomes. Pearson's r correlation tests have been used to find out if these observed correlations are significant.

6.3.1. Cues

Informed by staff

For the first cue, it was analysed how informing by staff members influences the model outcomes. A positive relationship was found between the number of staff members in the building and the percentage of visitors informed by a staff member. Especially when there are relatively few staff members in the

building, each newly added staff member causes a high in crease in the number of informed visitors. This effect levels out whenever the number of staff members in the building increases and a high percentage of the visitors is informed. This is depicted in figure 6.6.

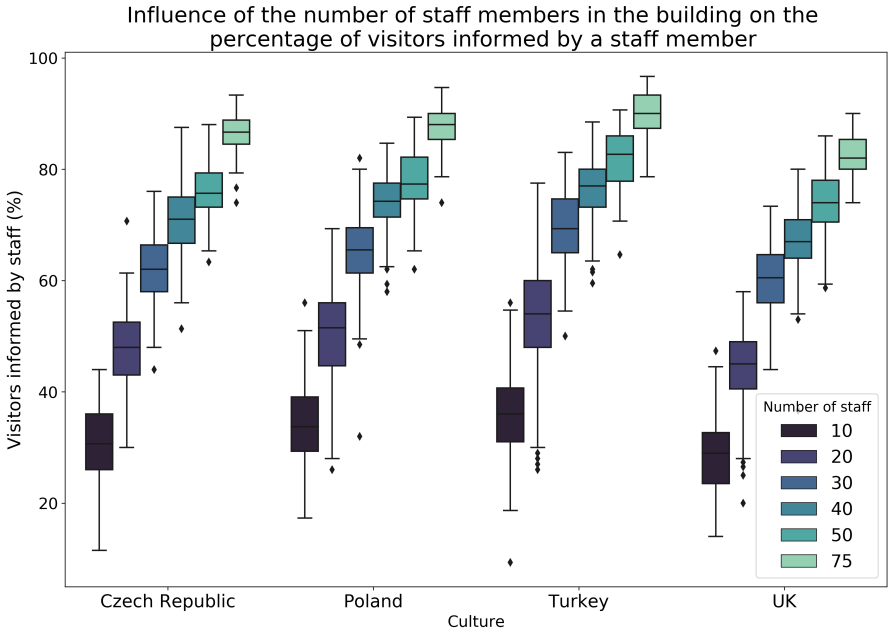


Figure 6.6: The effect of number of staff members in the building on percentage of visitors informed by a staff member

Figure 6.7, shows how informing of staff members influences the average response time. The figure shows the percentage of visitors informed by a staff member, with the corresponding average response times. A correlation can be found, where the average response times decreases, whenever the percentage of people informed increases. This effect is highest for Czech Republic (correlation = 0.57) and lowest for Turkey (correlation= 0.4).

Note. Significance: * p < 0.05, ** p < 0.01

Figure 6.7: The effect of being informed by a staff member on average response time

These differences can be traced back to the model input, in which Czech Republic has showed the highest decrease in the number of response tasks reported after being informed by a staff member. The increasing order of the countries is similar for the correlations and for the number of tasks performed (section 4.4).

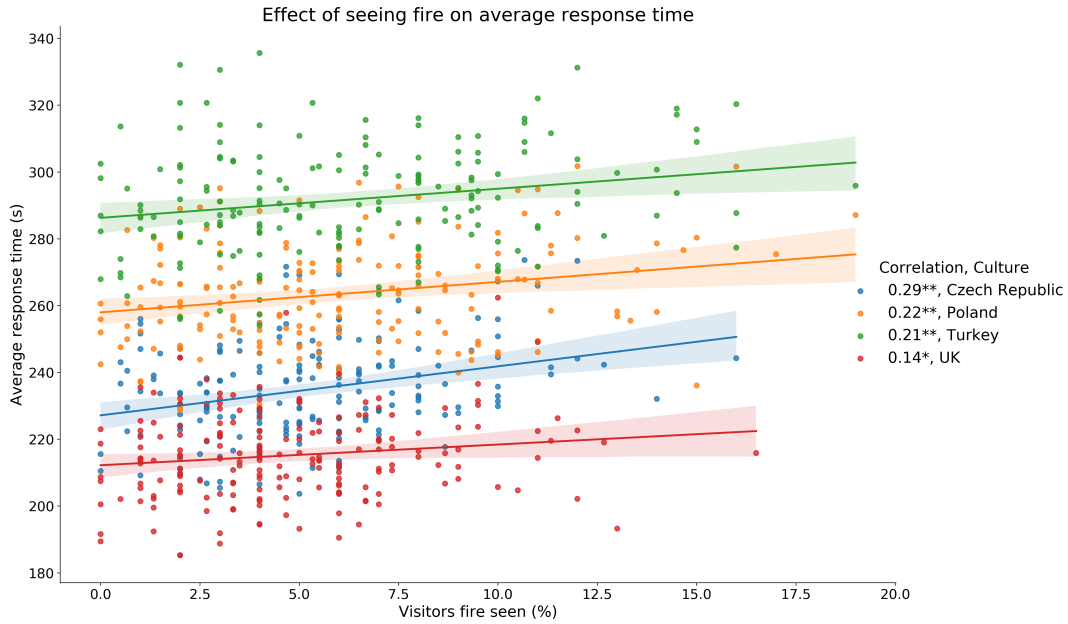
A similar influence of the cue on the average evacuation time is depicted in appendix C.9. While the correlation in this figure stays the same for Czech Republic, there are slight increases for each of the other countries. Figure C.10 shows similar results, however herein the correlations are lower, as Evac 95 times are more distributed.

Seeing fire

Figure 6.8 shows how seeing fire influences the average response time. In this figure is shown that response times slightly increase, for all countries, if more people have seen fire. This effect is highest for Czech Republic (correlation = 0.29) and lowest for the UK (correlation = 0.14).

The cause of these higher response times cannot be traced back to the number of tasks performed after seeing fire, to affiliate behaviour or to the collection of belongings. Therefore it is likely caused by changes in the types of tasks performed. All countries report a high likelihood of calling an alarm number. Additionally, by inspecting figures in section 4.9.1, it can be observed that Czech respondents are most likely to fight fire, while Britain respondents are least likely to do this. Fighting fire can take a long time, minimally 30 to 70 seconds. This causes a high delay in the response time. The observed cultural differences for likelihood to perform this task, could cause differences in the correlations observed.

Furthermore, Evac 95 (figure C.11) of Poland is most influenced by this cue (correlation = 0.20). The cue does however not significantly affect Evac 95 for the UK.



Note. Significance: * p < 0.05, ** p < 0.01

Figure 6.8: The effect of seeing fire on average response time

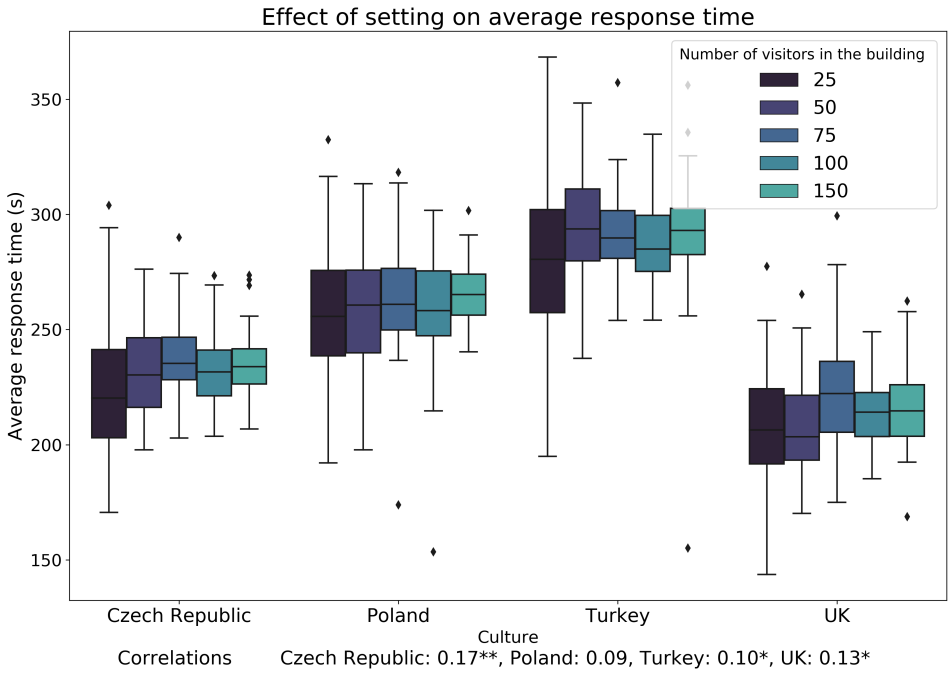
6.3.2. Setting

Figure 6.9 shows small effects from setting on the average response time for Czech Republic and the UK. For Poland and Turkey, no significant correlations have been found between the setting an average response time. What is noticeable, is how the response times become less divided when comparing the outcomes of 25 visitors inside the building to those with more people inside the building. Comparable effects have been found for the average evacuation time and Evac 95 times in figures C.16 and C.17.

Based on the way the model is developed, it would be expected that response times decrease whenever more people are present in the building. If more people are present, chances increase of

being informed by another visitors, or seeing others evacuated, which cause a decrease in the response time. This effect has however not been found while analysing the effect of the setting on notification time, as visible in figure C.15.

Therefore, the observed effects of setting on response time can only be traced back to what has been observed in figure 6.5. Which shows a slightly higher response time when more people are present in the building. This could be explained by the possibility to perform more response tasks and the of more clogging.



Note. Significance: * p < 0.05, ** p < 0.01

Figure 6.9: The effect of setting on average response time

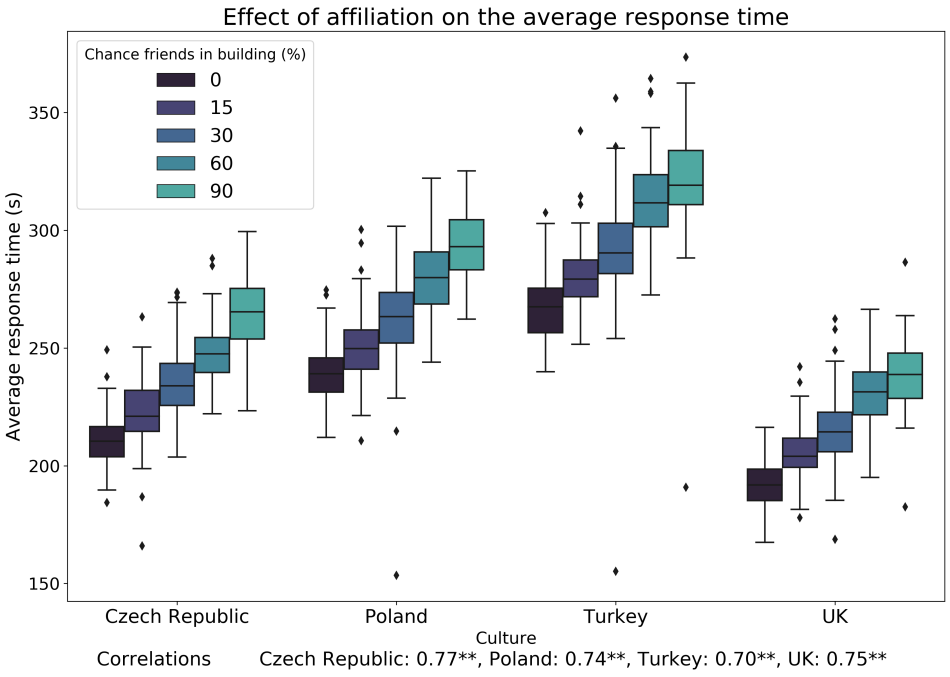
6.3.3. Affiliation

In figure 6.10 it shows that Czech Republic, Poland, Turkey and the UK are all highly influenced by affiliation. The figure depicts how the response time increases whenever there are more friend groups in the building. The medians show increases of about 50 seconds between no-one in the building having friends, and 90 percent of the occupants having friends. Similarly, as for being informed by a staff member, Czech Republic is most influenced by this parameter and Turkey is least influenced.

The high effect on Czech visitors is related to the likelihood of showing affiliative behaviour, as shown in table 4.4. This table shows that Czech visitors are most likely to wait for their friends before evacuation, which causes a high increase in the response time. The same effects as for the response time are observable for the effect of affiliation on the average evacuation time in figure C.14.

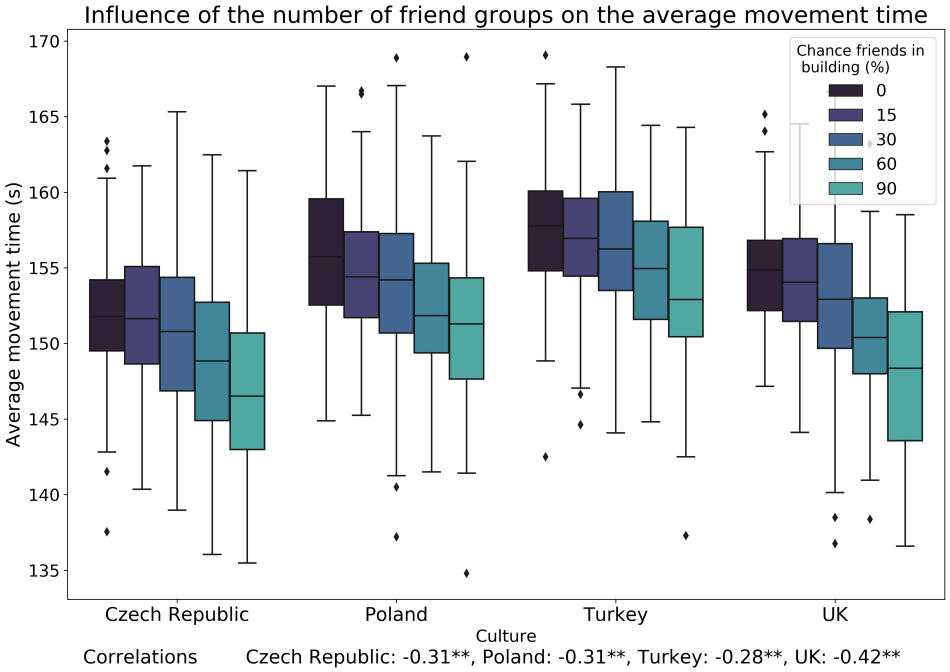
Figure C.13 shows the effect of affiliation on the Evac 95 times. The effects on Evac 95 are smaller, compared to those on the average response time. Furthermore, Turkey is not anymore the country least affected by affiliation, but it was replaced by the UK, which showed in the questionnaire to have the lowest likelihood to wait for friends (Table 4.4).

This relatively smaller effect on Evac 95, is caused by smaller evacuation movement times, when evacuating in groups (see figure 6.11). These evacuation movement times decrease, due to increased knowledge on the nearest exit. Which, in its turn, causes a decrease of the average evacuation time and Evac 95.



Note. Significance: * p < 0.05, ** p < 0.01

Figure 6.10: The effect of affiliation on average response time



Note. Significance: * p < 0.05, ** p < 0.01

Figure 6.11: The effect of affiliation on average movement time

6.3.4. Overview of correlations between cues, setting, affiliation and model outcomes

Figure 6.1 provides an overview of all the correlations found in this section. All factors do influence each of the model outcomes to some degree for at least two countries.

Affiliation and being informed by a staff member have the highest overall influence on the outcomes. Both of these factors mostly affect the average response time and average evacuation time. The effect on Evac 95 is considerably smaller. Seeing fire and the setting show a relatively low influence on each outcome.

The figure shows that all model outcomes of Czech Republic are significantly influenced by each influential factor. Additionally, average response times of Czech Republic show the highest correlation for each influential factor, in comparison to the other countries. For Turkey this is all outcomes are also significantly influenced by each factor, except for the effect of setting on average response time. The average response time and average evacuation time of Poland are also not influenced by the setting. For the UK, seeing fire does not influence the average evacuation time and Evac 95.

Table 6.1: Correlations per country between cues, setting, affiliation and outcomes

Influencing factor	Outcome variable	Czech Republic	Poland	Turkey	UK
Cue: Informed by staff	Average response time	-0.5755**	-0.4820**	-0.4007**	-0.4365**
Cue: Informed by staff	Average evacuation time	-0.5713**	-0.5326**	-0.4391**	-0.4744**
Cue: Informed by staff	Evac95	-0.2679**	-0.233**	-0.1800**	-0.1943**
Cue: Fire Seen	Average response time	0.2944**	0.2213**	0.2148**	0.1439*
Cue: Fire Seen	Average evacuation time	0.2463**	0.2074**	0.2436**	0.1400
Cue: Fire Seen	Evac95	0.1781*	0.2021**	0.2169*	0.0376
Affiliation	Average response time	0.7739**	0.7363**	0.7044**	0.7528**
Affiliation	Average evacuation time	0.7058**	0.6862**	0.7034**	0.6946**
Affiliation	Evac95	0.3479**	0.3106**	0.3039**	0.2624**
Setting	Average response time	0.1678**	0.0872	0.1034	0.1318*
Setting	Average evacuation time	0.1356*	0.0581	0.1116*	0.1644**
Setting	Evac95	0.2802**	0.1470**	0.1535**	0.2140**

Note. Significance: * $p < 0.05$, ** $p < 0.01$

6.4. Summary

This chapter has provided an answer to sub-question 4: *"What effects can be identified, through simulations, of cultural response-phase behaviour on response time and total evacuation time?"*.

Firstly, the overall model behaviour has been analysed. It has been found that the total evacuation times are highly scattered, therefore Evac 95 has been considered for further analysis. A linear relationship has been found between the response time and the average evacuation time and Evac 95, whereby evacuation times increase whenever the response time increases. The outcomes have shown significant differences among the countries for their response times, average evacuation times and Evac 95. British people were fastest to respond (M=214.02, SD=34.63), followed by Czech Republic (M=234.80, SD=14.39), Poland (M=262.79, SD=20.48) and Turkey (M=290.79, SD=24.27). This resulted in lowest average evacuation time for UK (M=336.39, SD=19.90), followed by Czech Republic (M=355.60, SD=15.37), Poland (M=385.13, SD=29.93) and Turkey (M=416,79, SD=28.98).

A sensitivity analysis has shown that all input parameters influence the model outcomes. This has shown the importance of considering uncertainties in the model input.

Thirdly, the effect of cues, setting and affiliation on response time and evacuation time was analysed. All influential factors have shown to significantly influence model outcomes for each country. This has shown that affiliation has the highest influence on both response times and evacuation times for all countries. Whereby a higher number of friend groups leads to higher response and evacuation times. The response time of Czech visitors is most influenced by affiliation (correlation = 0.7739) and the response time of Turkish visitors is least influenced (correlation = 0.7044).

Being informed by a staff member has also shown to highly affect the model outcomes. When more people are influenced by a staff member, this leads to lower response and evacuation times. This effect is again highest for Czech Republic (correlation = -0.5755) and lowest for Turkey (correlation = -0.4007).

Seeing fire has a somewhat smaller effect on the model outcomes. It has been found that response and evacuation times increase whenever visitors have seen indication of fire and/or smoke. This effect on the response time is largest for Czech Republic (correlation = 0.2944) and lowest for UK (correlation = 0.1439).

The setting has shown to have the smallest effect on the model outcomes. A higher number of people around, led to higher model outcomes. The response times have only been significantly influenced for Czech Republic (correlation = 0.1678) and the UK (correlation = 0.1318). Setting does however significantly influence Evac 95 for all countries.

7

Conclusion and Discussion

This thesis has answered the question *" How does Culture, in combination with cues, settings and affiliation, influence response-phase behaviour and time and total evacuation time ? "*.The question has been answered by developing a questionnaire and an agent-based model. The purpose of the questionnaire was to find cultural differences in response-phase behaviour among Czech Republic, Poland, Turkey and the UK in a library situation. Additionally, it found out how each of these cultures is influenced by cues, setting and affiliation. An agent-based model was developed to simulate library evacuations in the four countries and to find out how cultural differences in response-behaviour influence the response and evacuation time. This chapter will discuss the results, strengths, limitations, possibilities for future research and implications of this research and it finishes with a conclusion.

The results section consist of two parts: results obtained through the questionnaire and results obtained through the model. Besides the BeSeCu project Galea et al., there does not exist any other research on the influence of cultures on response-phase behaviour in a building. Therefore the exact results cannot be extensively reflected upon. However, it is embedded in literature through evacuation and psychological theories.

7.1. Questionnaire results

By analysing the results of the questionnaire, the first and second sub question have been answered. Respectively *"What similarities and differences can be found among response-phase behaviour of library visitors from Czech Republic, Poland, Turkey and the UK during an evacuation?"* and *"What are the effects of cues, setting and affiliation on the observed cultural response-phase behaviours?"* Firstly, significant differences were found in the questionnaire results for the total number of tasks reported by the four countries, Czech Republic, Poland, Turkey and the UK. Additionally, the questionnaire shows a significant difference for the number of information and action tasks reported for the countries. This is in line with the outcomes of the BeSeCu project (Galea et al., 2015), which also found significant difference in the number of tasks performed for the four countries. The BeSeCu project (Galea et al., 2015) did however not find similar numbers for the performed tasks, which can be explained by the different measurement used.

The observed differences in the number of response tasks could be substantiated by cultural theories, such as Hofstede's national culture theory. Each of the countries score differently on Hofstede's cultural dimensions and thus are expected to show different behaviours (Hofstede et al., 2010). There are no theories available which connect cultural aspects with the number of tasks performed. One could however speculate on relationships by comparing the questionnaire results with the cultural dimension scores of each country and the descriptions of these dimensions.

The UK deviates from the other countries in both the number of information tasks performed and the Uncertainty avoidance and Individualism scores. This could indicate a possible connection between Uncertainty Avoidance and Individualism and the number of information tasks performed. The UK performs a relatively low number of information tasks compared to Czech Republic, Poland and Turkey, additionally the UK scores low on uncertainty avoidance. According to Hofstede et al. (2010), cultures with a high uncertainty avoidance try to avoid unstructured situations. My interpretation therefore it

that a high uncertainty avoidance, leads to performing more information tasks in order to overcome unstructured situations. The UK scores relatively high on the Individualism dimension. In individualist societies, people are expected to take care of themselves and not necessarily of the larger group (Hofstede et al., 2010). From this I interpret that individualist cultures might be less inclined to use communication for information gains during an evacuation.

As the action tasks are quite different in their nature, no general connection is assumed between the performed number of action tasks and any of the cultural dimensions. In order to connect the action tasks to the cultural dimensions, one would need to delve deeper into the exact tasks and how often these were reported.

For 10 out of the 15 identified types of tasks, significantly different chances have been found between the four countries for performing these tasks. The tasks which did not show significant differences were providing information (3), packing belongings and changing footwear / glasses / clothing. The following tasks have the overall highest likelihoods of being performed: Look around and see what is happening, pack items in close vicinity, seek information through a member of staff and seeking information through conversations with others nearby. These four tasks also all come back in the first 5 tasks which Czech Republic, Poland and Turkey would perform in their itineraries. The UK shows a slightly different sequence of itinerary tasks, as they are not as likely to seek information through people nearby. Speculative connections could also be made between the performed task types and cultural dimensions. For example Turkish and Polish respondents are most likely to *Seek information through a member of staff*. Simultaneously, these two cultures score relatively high on the power distance dimension. In cultures with a high power distance, subordinates are expected to be told what to do (Hofstede et al., 2010). Therefore I interpret that visitors from a high power distance culture might be more likely to look up to staff members to tell them how to behave. Speculatively, there are no clear connections observable between chances of performing action tasks and any of the cultural dimensions.

The cues have shown to influence the chances of performing each of the types of tasks. This is in line with empirical observations and theories. McConnell et al. (2010) has observed behaviour during the 9/ 11 ramp and has found that the perception of cues influenced occupant activities. Lindell and Perry (2012) describes that cues initiate three pre-decision processes, which influences the perceptions of the threat. These perceptions produce a behavioural response. Reneke's Evacuation Decision Model (EDM) (Reneke, 2013) describes that cues influence risk perception, which influences the state and behaviour of an occupant. Lovreglio, Ronchi, and Nilsson (2016) has expanded the EDM by Reneke by including behavioural uncertainty and differentiating impacts of cues based on an evacuee's demographics and personal characteristics.

In contradiction to this, cues are not very likely to affect the number of tasks performed. Where only the number of tasks performed by Czech Republic and Poland are significantly influenced after they are informed by a staff member. A side note has to be made here, that two extra tasks became available for the fire scenario: call alarm number and fight the fire. Especially the first task has a very high likelihood of being performed by all countries, which thus causes a relative increase in the number of tasks performed. It can be concluded that cues do not necessarily influence the number of different tasks being performed, however it does influence which tasks are being performed.

The analysed setting, being in a closed off space/ not around others, has shown to have a small impact on the information tasks performed. For most of the tasks, only small percentile changes have been observed in comparison to the basic scenario.

The limited influence could be explained by how the setting has been defined and by the fact that respondents have only been asked to choose their information tasks for this scenario. As described by McConnell et al. (2010) the types of cues which an occupant received depends highly upon the setting, which in its turn determines the response tasks. As cues have not been taken into account for this question, an important element of what causes different behaviour in different settings is missing. Samochine et al. (2005) has observed influences of settings in retail stores. Herein it is described that the type of behaviour before the incident, also influences the response behaviour. This has not been incorporated in question on the setting either. For conatining the lengthiness of the questionnaire, respondents have only been asked to choose their new information tasks, whereas the action tasks could also be influenced.

For the affiliative behaviour, significant differences have been found in the basic scenario among the four countries for chances of waiting for friends or colleagues when they are in close proximity. Where Czech Republic is most likely to wait for a friend/ colleague, followed by Turkey, Poland and the

UK. A possible explanation for these differences could be found within the Individualism dimension. In collectivist societies, people are very loyal to their in-group members, their friends or colleagues (Hofstede et al., 2010). The dimension scores show a relatively high score for the UK on individualism, which lead to a lower likelihood of waiting for friends. The chances of searching for friends / colleagues do not show any significant differences for the four countries in the basic scenario. An interesting finding that after seeing fire, both of these affiliative behaviours do show significant differences among the countries. It has been found that seeing fire causes an overall negative effect on the likelihood to perform affiliative behaviour. Again, in a fire scenario it is found that the UK, with a high individualism score, is less likely to perform affiliative behaviour compared to the other countries.

7.2. Model Results

Through the development of the model, the third sub question has been answered *"How can cultural response-phase behaviour be modelled with an agent-based model in order to measure the response time and total evacuation time?"*. The analysis of the model data, provided an answer to the fourth sub question: *"What effects can be identified, through simulations, of cultural response-phase behaviour on response time and total evacuation time?"*. These results are further discussed below.

The first finding from the model is that the countries all have significantly different values for the average response time, the average evacuation time and Evac 95. Furthermore, a positive linear relationship is found between the average response time and the average evacuation time and Evac 95. The results indicate that Turkey is slowest during both the response phase and the total evacuation. This is followed by Poland, Czech Republic and the UK. This order follows the similar order as for the number of tasks observed in the questionnaire. It could thus be a direct result of the behavioural input used for the model.

These outcomes do however not correspond with the outcomes of the BeSeCu experiments (Galea et al., 2015), which report the smallest response time for Turkey and the largest response time for Czech Republic. A simulation run during the BeSecu Project (Galea et al., 2015) reported Czech Republic to be slowest, followed by UK, Poland and Turkey. These differences can be explained by the different behaviours observed (number of tasks performed) in the questionnaire compared to those during the BeSeCu experiment (Galea et al., 2015).

By combining the findings of the questionnaire and model it can be concluded that higher number of response tasks possibly leads to higher response times and total evacuation time. This corresponds with other evacuation research(Averill et al., 2005; Day et al., 2013; Proulx and Pineau, 1996), which all found that an increased number of tasks contributes to an increased response time. By delving deeper into the response time distributions, it was found that the maximum response times for all four countries are not that different. The minimum response times are more concentrated for the UK, while these are more spread out for the other three countries. Based on these insights, the biggest differences in average response times must have been caused by occupants with a somewhat low to medium response time per country, and thus not by the slowest visitors.

Secondly, the input variables were analysed for its effects on the model outcomes. Familiarity is discussed first, the other input parameters are discussed together with its corresponding cues, setting and affiliation. Familiarity negatively influences the average evacuation time, as a higher familiarity causes lower evacuation times. This corresponds with research by Richardson et al.(2019) and Horiuchi et al.(1986). Richardson et al.(2019) argues that the evacuation time is strongly impacted if familiarity drops below a certain threshold. Horiuchi et al.(1986) has found that familiarity influences the actions after noticing the fire, criteria for selecting escape routes and the ability to effectively reach an exit.

Thirdly, the effects of cues, setting and affiliation have been analysed in combination with cultural behaviours.

The first cue, being informed by a staff member causes a decrease in average response time and evacuation time. This is in line with previous research discussed in section 7.1. Not all countries are equally influenced by this cue, as it has the highest effect on response time for Czech Republic and the lowest effect on UK. These differences among the countries can be roughly explained by looking at Hofstede's Power Distance dimension (Hofstede et al., 2010). The UK has a lower score for this dimension in comparison to the other countries. A low Power distance score indicates that people from a society are less likely to obey powerful members of the society (Hofstede et al., 2010). This could be interpreted in the evacuation situation, as people with a low power distance being less likely to try

decrease their response time after being informed by a staff member.

The second cue, seeing fire and/or smoke, causes an increase in the response and evacuation times. This is in line with 9/11 ramp research by Gershon et al. (2012), which has observed an increased response and evacuation time after seeing fire. It is however not in line with findings by Choi et al. (2018), which found that seeing smoke, causes an increased level of perceived risk, which leads to starting evacuation movement in an accelerated speed.

In contrast to the findings of the questionnaire, the setting has shown to positively affect the average response time for Czech Republic and the UK and average evacuation time for Czech Republic, Turkey and the UK. Furthermore, it affects Evac 95 of all four countries. Although the effects are relatively small, this type of relationship was not expected. It could be explained by the way in which the setting was measured. As it was not measured in the model how many people were separated from others, however a proxy was used in which the number of visitors in the building was considered. This higher number of visitors could cause an increase in evacuation times (Kim et al., 2019). Additionally, it could explained through the performed response tasks. In the model, some response tasks would immediately end if there is no-one around, thus causing a lower response time if there is fewer people around.

Affiliation significantly influences the average response time, average evacuation time and Evac 95 for all four countries. When the response time is relatively low, an increase in the number of friend groups has shown to cause a decrease in the evacuation time. This is observed up to an average response time of about 300 seconds, after which the groups cause both higher response and evacuation times. While visually observing the simulation, it has been seen that unusually high response times and evacuation times were reached when two friends had a hard time to find each other within the building. From this can be concluded that friends do evacuate more effectively when they can easily reach each other, however this is not the case when it takes a longer time for them to come together. The observed decrease in evacuation time is not fully in line with affiliative research, however these can be reflected upon by taking into account the exit-choices and research on group behaviours. In the model, friends were able to make a better exit choice, as more knowledge was available on the nearest exit. According to van der Wal et al. (2017) group members will also evacuate more effectively due to social contagion. The increased response times are in line with research on affiliative behaviour by Liu et al.(2020) and Meacham(1999). They describe how affiliation causes a high delay during the evacuation. The cultural comparisons have shown that Czech Republic, Poland, Turkey and the UK all show an increase in the response time, when the number of friend groups increases. No major differences have been found between the countries on how it influences the model outcomes.

As has been discussed in the model validation (section 5.7.2) and in section4.11), the outcomes of both the model and the questionnaire do not perfectly reflect occupant behaviour during an evacuation. Therefore the obtained results should only be used within the context of this study. The behaviour of the outcomes and the effect of different factors do seem valid, however exact quantitative outcomes have not been validated.

7.3. Strengths, limitations and future research

This is one of the first studies, to the knowledge of the author, which analyses in detail how response behaviour is influenced by cultures and how these cultural behaviours are affected by cues, setting and affiliation. There are separate studies which looked into factors which influence response behaviour and the effects of cultures on response behaviour. However, no studies have combined these two aspects and especially not in as much detail as in this study. In this study, an approach has been introduced to study these aspects, which could be applied to other contexts as well. It could be applied to other environments, but also to other cultures and influential factors of the response phase.

Other strengths can be found in the survey development. Firstly, an extensive literature research has been performed to identify all types of response tasks in a library situation. This literature research consisted of the analysis of 15 articles in which 22 response tasks have been identified.

Secondly, a strength can be found in the sample of respondents which filled out the questionnaire. With 105 respondents per country, this is a relatively large number of respondents. Additionally, these respondents have been selected such that for each country similar ratios are present of males/females and age groups. By meeting these requirements a representative sample of the library population has been found for Czech Republic, Poland, Turkey and the UK.

Furthermore, an agent-based model has been developed in this research in order to study the

effects of response behaviour, on the response and evacuation times. This has not yet been developed in as much detail, by taking into account the effects of culture, cues, setting and affiliation. The response phase has been modelled extensively by considering three processes: the decision on an initial response itinerary, the adjustment of response tasks and the finalisation of the response phase.

Additionally, the model is based on behavioural data, which makes the outcomes more powerful and reliable. Through the questionnaire, microscopical behaviours have been measured for all four countries, within different scenarios. These measurements have all been used as direct input to the model.

Besides the observed strengths, this research also has its limitations. One of the main limitations of this research is the simplification of overall evacuation behaviour. While focusing on the response phase and the influence of culture, cues, setting and affiliation herein, many aspects have not been taken into account. First of all, only two cues and one type of setting have been considered, while there exist many more. Secondly, factors have been neglected, such as social influence, emotions, risk perceptions and knowledge sharing (Bosse et al., 2013; Lerup et al., 1980; Liu et al., 2020; Lovreglio, Ronchi, and Nilsson, 2016; Nicolas et al., 2017; Nilsson and Johansson, 2009; Van Minh et al., 2012). Also group behaviour and queuing during the evacuation movement have not been considered (Levine et al., 2005; von Schantz and Ehtamo, 2015).

Furthermore, the approach used for describing response phase behaviour has been simplified. Firstly, this has been done for the decision-making process. In this research, the response itineraries have been pre-defined and these have been adjusted due to cues, setting and affiliation. Although this approach is far more elaborate than most, this assumes that building occupants from the same cultures all respond in similar ways (Kuligowski, 2013), thereby it might overgeneralise how societies behave. It also assumes that the tasks performed only have a limited feedback effect on the response behaviour (Lovreglio, Ronchi, and Nilsson, 2016). Research has shown, however, that individuals are likely to interpret cues differently (Mileti and Sorensen, 1990) and that their response behaviour is the result of an extensive decision-making process (Blumer, 1986). Secondly, in both the questionnaire and the model, building occupants had the ability to perform each response task only once. In reality however, people may perform a specific task multiple times during the response phase (Galea et al., 2015). Due to restrictions in the questionnaire software, there was no possibility to measure these recurrences and thus this had to be simplified.

Another limitation can be found in the approach to collect data on response phase behaviour through a questionnaire. The responses of the respondents indicate self-reported behaviour and these may not fully reflect the actual behaviour during an emergency evacuation (Shiwakoti, Tay, et al., 2020; Shiwakoti, Wang, et al., 2020). Furthermore, respondents might have answered the questions in a socially desirable way, which is described in literature as social desirability bias (Fisher, 1993; Grimm, 2010). This could mean for example that respondents pose themselves as being more helpful to others, than they are in real life.

The risk of overfitting the questionnaire data is another limitation. Overfitting means that data used as model input might depend too much on irrelevant instances of the questionnaire data (Bramer, 2007; Schaffer, 1991). The probabilities of performing tasks, as reported in the questionnaire, have been directly used as model input and input for the decision trees. A minimum threshold has been considered for the probability trees of 4 respondents performing tasks in the same order. This is a number which is arbitrarily chosen and few changes in responses could possibly cause different results. No sensitivity analysis has been performed to analyse how these small behavioural changes would affect the model outcomes.

Another limitation of the model itself is that all of the response tasks have been modelled based on assumptions of the modeller. No literature is available on how different task types have been modelled and thus the modeller had to made assumptions. While modelling these tasks, an evacuation video database by van der Wal (2020) has been consulted, however these videos did not always show clear response behaviours.

Both the limitations and strengths provide opportunities for future research.

Firstly, the simplifications as described above can be addressed. While it is impossible to make a perfect model, and models are always simplifications of the real world, extra aspects could be added to improve the validity of the research. All of the aspects described as being neglected or simplified can be improved within the model and the approach taken to describe behaviour, in order to achieve more realistic results.

Secondly, empirical experiments can be performed in order to validate and/or improve the data which has now been collected through the questionnaire. By conducting empirical experiments, it can be overcome that people might not actually behave as they would think they do and it can overcome social desirability biases. This also provides opportunities for overcoming the risks of overfitting the survey data for model input. Another opportunity for overcoming the overfitting of questionnaire data, is to open up the questionnaire again and achieve an increased number of responses for each country. By collecting more data, thresholds for the decision trees can be increased which causes lower chances of overfitting. Furthermore, a sensitivity analysis could be performed to inspect how small changes in response behaviour could influence the model outcomes and to adjust for this.

Thirdly, more research can be performed on the exact behaviour which people show during each of the response tasks. It could be done by observing people during empirical experiments or by collecting and inspecting more evacuation videos.

Besides overcoming the shortcomings, the strengths of the research provide extra opportunities for future research as well. One of the possibilities for future research is to use the questionnaire data, supplemented with extra data, to analyse correlations between performed tasks and cultural values. As discussed in sections 2.2.1 and 2.4.3, cultural behaviour can be explained through cultural dimension values. If any correlations can be found between these two, this poses opportunities for making predictions of response behaviour within other cultures.

This brings us to the next possibility for future research, which is to apply the methods of this research to other countries. As relatively little research has been done on evacuation behaviour in non-western countries, there is still a lot to achieve. This thesis has provided an elaborate approach which can be applied to any other country and in any other environment

While this thesis has inspected each of the cultures and their behaviour independently of each other, it would be interesting to see what would happen when different cultures are mixed during an evacuation. This is also slightly more realistic in a university library, as many universities educate people from all over the world. To analyse this, more insights would be needed on how people from different cultures interact with each other and how this influences in-group and out-group behaviour.

Another possibility for future research, is to implement policies in the model in order to test how these influence the response and evacuation times for each of the cultures. By doing this, the most optimal policies for each culture can be identified. Related to this is another opportunity, which is to analyse how each of the task types has influenced the evacuation and response times. An analysis can be done, to see how adjustments of these tasks could possibly improve or worsen the evacuation times. Policies can be further developed and tested to play into these findings.

7.4. Implications

This research has two theoretical implications. First of all, this research has provided an approach to research the influence of cultures, in combination with cues, setting and affiliation, on response phase behaviour, response time and evacuation time. This approach includes both a questionnaire and a model. Both the questionnaire and the model can be used to gain more insights in cultural and response behaviour. The overall approach, the questionnaire and the model could all be applied, to gain knowledge on other cultures and other types of buildings.

Additionally, the research has produced multiple findings. It has been found that Czech Republic, Poland, Turkey and the UK all have significantly different response phase behaviour during a library evacuation. This has been found for both the number of tasks being performed and the probabilities of performing different types of tasks. It has been found that response phase behaviour of Czech Republic, Poland, Turkey and the UK are all influenced by seeing fire and by different degrees of affiliative behaviour. However, the degrees to which they are influenced, differ per country. These findings acknowledge the importance of performing cross-cultural research for evacuation behaviour, as findings discovered within one culture cannot be directly applied to another culture.

Besides the theoretical implications, the research adds value for policy makers and emergency planners. As discussed above, it acknowledges the importance of performing cross-cultural research for evacuation behaviour. This thesis shows the need for policy makers and emergency planners to discuss effects of culture during evacuations and how to respond to this. The research has shown which types of response tasks are influenced by cultures and how different influential factors affect evacuation outcomes. This research can therefore be used concretely as a starting point for discussions among

stakeholders.

Additionally, the developed questionnaire and model have provided insights into specific response behaviours for library evacuations in Czech Republic, Poland, Turkey and the UK. These insights could be used to improve overall library evacuations, but also evacuations in any other context in Czech Republic, Poland, Turkey and the UK.

In order to practically apply this research for evacuation planning, it would need to be expanded further. First of all, the effect of each of the response tasks on the evacuation outcomes needs to be analysed. Based on this, policies can be developed around the task types which most negatively influence the evacuation times per country. These policies could be developed around the alarm system used or the training provided to staff members and first responders. The alarm message could for example be altered, so that it includes a message to not perform specific types of tasks. The staff members and first responders could be trained to provide clear instructions to building occupants so that they will be instructed to not perform certain tasks. These developed policies can be implemented and tested in the model developed in this research. The most optimal policies per country can be further implemented in practice.

7.5. Conclusion

The influence of cultures on response-phase behaviour has been understudied, data found in one country is frequently being applied to other countries. Furthermore, limited research has been performed on how cues, setting and affiliation are experienced differently in different cultures. Therefore, this study has answered the following research question: *" How does Culture, in combination with cues, settings and affiliation, influence response-phase behaviour and time and total evacuation time ? "*. To answer this question, an approach has been developed which includes the development of a questionnaire and an agent-based evacuation model. This approach has been applied to a case-study of library evacuations in Czech Republic, Poland, Turkey and the UK.

The questionnaire results show that there are significant differences in the number of response tasks being performed. In which Turkey performs the highest number of response tasks, followed in a decreasing order by Poland, Czech Republic and the UK. Furthermore, it has been found that response behaviour in all countries is influenced by cues, setting and affiliation.

The model results show that evacuations within Czech Republic, Poland, Turkey and the UK have significantly different response and evacuation times. It has been found that affiliation and being informed by a staff member highly affect response and evacuation times, while the setting and seeing fire do not. The exact degrees to which these factors influence evacuation and response times, differ per country.

This research also has some limitations. These limitations can be found in the simplification of evacuation behaviour, the method to collect behavioural data through a survey, possibly over fitting of data and the limited knowledge available for modelling response tasks. Future research can cope with these limitations by extending this research with other influential factors, conducting empirical evacuation experiments, and studying what behaviour is performed exactly during the different task types. Furthermore, future research poses opportunities for studying response behaviour in other cultures and environments, studying environments with mixed cultures and developing adequate evacuation policies.

Overall, this research provides a new approach to study the effect of cultures, in combination with cues, setting and affiliation, on response-phase behaviour and response and evacuation times.

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A

Appendix: Questionnaire setup and results

The developed questionnaire is described below and can be accessed through https://tudelft.fra1.qualtrics.com/jfe/form/SV_8GlM2LfcfVaTCke. Furthermore, additional results of the questionnaire are depicted in this appendix.

A.1. Questionnaire setup

You are being invited to participate in a research study titled ”Response-phase behaviour during a library evacuation”. The purpose of this study is to find similarities and differences in evacuation behaviour among building occupants. It will take you approximately 10 minutes to complete. The data will be used for the development of a simulation model. Your participation is entirely voluntary and you can withdraw at any time.

We believe there are no known risks associated with this research study; however, as with any online related activity the risk of a breach is always possible. To the best of our ability your answers in this study will remain confidential. Any risks will be minimised by anonymising the data and storing it on SURFdrive.

Additionally, the anonymised data will be shared through a scientific publication and stored in a data repository used for scientific research.

This study is conducted by Elvira Van Damme from the TU Delft. For any questions or comments, feel free to contact her (e.r.i.vandamme@student.tudelft.nl).

How old are you?

What is your nationality?

- Czech
- Polish
- Turkish
- UK

Where do you live?

- Czech Republic
- Poland
- Turkey

- UK

Have you ever visited a public library?

- Yes
- No

Next, you will be provided with an evacuation scenario description. Please imagine yourself in this scenario and answer the questions.

Imagine visiting a public library, as in the picture. You are sitting down at a desk, while working on a personal computer or reading a book. You are sitting here by yourself and there are no acquaintances of yours present in the library. From the place where you are sitting, you can see some other people working or walking around the library. Then, suddenly an alarm is sounding. Others around you seem calm. You haven't seen any unusual events and you don't have any information on why this alarm went off or what is going on.

The alarm sounds like this (please make sure your sound is on):

What would be your reaction after hearing the alarm? Please describe briefly

---

Below, a list of actions is given in a random order. Which of the following actions would you do after hearing the alarm? Please select all of the actions which you would do by clicking on them.

- Phone someone to seek information
- Seek information through electronic media
- Seek information through conversations with other people nearby
- Move to another location to seek information
- Look around to see what is happening
- Seek information through a member of staff (building security/ reception)
- Phone someone to provide information
- Actively provide information and / or instructions to others nearby

- Actively search for others in the building, to provide information and / or instructions
- Ignore the alarm
- I would not do any of these actions

At some point in time, you decide to leave the library. People around you are still calm and behaving orderly. Which of the following actions would you do before leaving? Please select all of the actions which you would do by clicking on them.

- Work-related duties, such as shutting down work station, locking files, tidying desk etc .
- Pack personal and work items in close vicinity, such as laptop, documents, phone, keys etc
- Collect and put on coat
- Change footwear/ glasses/ clothing
- Physically assist others (help others put on coat or collect items)
- Collect emergency equipment (flash lights, water etc)
- I would not do any of these actions

What would be the sequence in which you perform your previously selected actions? Please drag and drop the actions in the right sequence .

Next, six new evacuation scenarios will be given. Overall the situation is similar as before, to which we will refer from now as the basic scenario. However, some elements will be changed.

Scenario 1: While you hear the alarm, a staff member in an orange vest comes up to you. The staff member tells you to leave the building. For the rest, the scenario is similar to the basic scenario: - You

are still sitting on your place - People around you are behaving calmly and orderly - There are no acquaintances of you present in the library Below, your previously selected actions from the basic scenario

are shown. Are there any actions that you wouldn't do in the new scenario? Please select these actions. Are there any of the actions that you did not select in the basic scenario, which you would do now?

Please select these actions.

What would be the sequence in which you perform all actions in the scenario where you are informed by a staff member? Please drag and drop the actions in the right sequence.

Scenario 2: You are walking around the library when you start hearing the alarm. This means that your personal belongings (bag, coat, laptop, etc) are not with you, but these are still at the spot where you were sitting earlier. For the rest, the scenario is similar to the basic scenario: - People around you are

behaving calmly and orderly - There are no acquaintances of you in the library - You haven't seen any unusual events and you don't have any information on the cause of the alarm You can choose to either

leave the library without your personal belongings or to walk back to collect your belongings. Would you collect your belongings before leaving?

- Yes
- Only if I can reach my personal belongings in a short amount of time (such as 1 to 2 minutes)
- No

Scenario 3: Now, when you hear the alarm, you are not in close proximity to others. This can be because there is no one sitting near to you, or you may be in a closed off space (e.g. office). For the rest,

the scenario is similar to the basic scenario: - You are still sitting on your place - There are no acquaintances of you in the library - You haven't seen any unusual events and you don't have any information on the cause of the alarm

Which of the following actions would you do ?

- Phone someone to seek information
- Seek information through electronic media
- Move to another location to seek information
- Look around to see what is happening
- Seek information through a member of staff
- Seek information through a member of staff (building security/ reception)
- Ignore the alarm

Scenario 4: You are in the library together with your friend or colleague. You are sitting next to each other. For the rest, the scenario is similar to the basic scenario: - You are still sitting on your place -

People around you are behaving calmly and orderly - You haven't seen any unusual events and you don't have any information on the cause of the alarm Would you wait for your friend/colleague so that

you can leave the building together?

- Yes
- No

Scenario 5: You are in the library together with your friend or colleague. However, you are not in close distance to each other and you are not sure where your friend is. For the rest, the scenario is similar

to the basic scenario: - You are still sitting on your place - People around you are behaving calmly and orderly - You haven't seen any unusual events and you don't have any information on the cause of the alarm Would you search for your friend before leaving the building?

- Yes
- Only if I can find my friend within a relatively short amount of time (such as 1 to 2 minutes)
- No

Scenario 6: While you hear the alarm, you see fire and/or signs of smoke. For the rest, the scenario

is similar to the basic scenario: - You are still sitting on your place - People around you are behaving calmly and orderly - There are no acquaintances of you present in the library

Below, your selected actions from the basic scenario are shown. Are there any actions that you wouldn't do in the new scenario? Please select these actions. Are there any actions that you did not select in the basic scenario, which you would do now? Please select these actions.

- Fight the fire (Newly available action)
- Call alarm number (Newly available action)

What would be the sequence in which you perform all actions in the scenario where you see signs of fire or smoke? Please drag and drop the actions in the right sequence.

Scenario 6.1: You are in the library together with your friend or colleague and you have seen fire and/or signs of smoke. You are sitting next to each other. For the rest, the scenario is similar to the basic scenario: - You are still sitting on your place - People around you are behaving calmly and orderly Would you wait for your friend/colleague so that you can leave the building together?

- Yes
- No

Scenario 6.2: You are in the library together with your friend or colleague and you have seen fire and/or signs of smoke. However, you are not in close distance to each other and you are not sure where your friend is. For the rest, the scenario is similar to the basic scenario: - You are still sitting on your place - People around you are behaving calmly and orderly Would you search for your friend before leaving the building?

- Yes
- Only if I can find my friend within a relatively short amount of time (such as 1 to 2 minutes)
- No

Scenario 6.3: You are walking around the library when you start hearing the alarm and you see fire and/or signs of smoke. This means that your personal belongings (bag, coat, laptop, etc) are not with you, but these are still at the spot where you were sitting earlier.

For the rest, the scenario is similar to the basic scenario: - You are still sitting on your place - People around you are behaving calmly and orderly - There are no acquaintances of you present in the library You can choose to either leave the library without your personal belongings or to walk back to collect your belongings. Would you collect your belongings before leaving?

- Yes
- Only if I can reach my personal belongings in a short amount of time (such as 1 to 2 minutes)
- No

Almost finished! One more page with questions after this. What is your gender?

- Male
- Female
- Non-binary / third gender
- Prefer not to say

What is the highest level of education you have completed?

- Up to High school
- College
- Masters degree
- Doctorate or Professional degree

How frequently do you visit a public library?

- Never
- 1-5 times a year
- 6-10 times a year
- 1-3 times a month
- 1-2 times a week
- 3-7 times a week

Last questions!

When visiting a public library, are you usually there by yourself or with others?

- By myself
- With 1 or 2 other people
- With 3 or more people

Have you received any formal fire emergency training before?

- Yes
- No

In how many fire drills or emergency evacuations have you participated during the last 5 years?

- None
- 1 -2
- 3-5
- More than 5

A.2. Questionnaire results; task adjustment

Table A.1: Tasks adjustment after being informed by staff

	% Not				% Yes			
	Czech Republic	Poland	Turkey	UK	Czech Republic	Poland	Turkey	UK
Phone someone to seek information	28.57	40	16.67	12.5	4.08	9	8.05	3.09
Seek information through electronic media	28.57	33.33	16.67	14.29	1.02	5.88	8.64	5.1
Seek information trough conversations nearby	27.08	38.33	20.75	16.67	10.53	8.89	13.46	14.49
Move to another location to seek information	23.08	23.53	27.78	34.78	7.58	7.95	9.2	4.88
Look around and see what is happening	21.25	13.33	16.22	24	20	20	9.68	10
Seek information through a member of staff	35.71	34.38	16.9	5.41	10.2	12.2	14.71	13.24
Phone someone to provide information	12.5	28.57	18.75	25	3.09	8.16	7.87	5.15
Actively provide information to others nearby	19.05	29.63	20	15.38	8.33	7.69	7.06	9.78
Actively search for others to provide information	30	25.93	10.53	5.88	5.88	5.13	8.14	5.68
Work-related duties	23.08	21.21	19.61	31.25	2.17	4.17	3.7	0
Pack personal and work items in close vicinity	13.92	12.5	21.52	21.54	3.85	12	15.38	5
Collect and put on coat	12.82	12.12	33.33	20.41	4.55	2.78	1.33	12.5
Change footwear/ glasses / clothing	0	50	33.33	25	3.06	3.03	1.01	2.15
Physically assist others	30.77	22	14.29	26.32	10.61	7.27	14.29	3.49
Collect emergency equipment	14.29	17.86	24.39	25	2.2	5.19	9.38	2.35

Table A.2: Tasks adjustment after seeing fire

	% Not				% Yes			
	Czech Republic	Poland	Turkey	UK	Czech Republic	Poland	Turkey	UK
Phone someone to seek information	57.14	0	22.22	12.5	2.04	4	8.05	3.09
Seek information through electronic media	28.57	33.33	37.5	28.57	1.02	2.94	2.47	4.08
Seek information trough conversations nearby	27.08	35	26.42	33.33	1.75	4.44	17.31	8.7
Move to another location to seek information	33.33	29.41	11.11	39.13	9.09	4.55	10.34	3.66
Look around and see what is happening	17.5	18.89	24.32	20	8	13.33	9.68	10
Seek information through a member of staff	30.36	37.5	19.72	27.03	2.04	9.76	5.88	7.35
Phone someone to provide information	37.5	0	31.25	0	0	6.12	6.74	3.09
Actively provide information to others nearby	28.57	14.81	20	7.69	4.76	7.69	14.12	5.43
Actively search for others to provide information	40	22.22	21.05	23.53	8.24	1.28	6.98	4.55
Work-related duties	46.15	42.42	25.49	31.25	1.09	0	5.56	1.12
Pack personal and work items in close vicinity	21.52	27.5	22.78	29.23	3.85	4	3.85	0
Collect and put on coat	15.38	36.36	26.67	36.73	4.55	1.39	1.33	5.36
Change footwear/ glasses / clothing	28.57	33.33	16.67	33.33	1.02	1.01	0	2.15
Physically assist others	28.21	28	10.2	26.32	9.09	10.91	8.93	8.14
Collect emergency equipment	28.57	21.43	26.83	35	3.3	5.19	9.38	3.53
Call alarm number					47.62	57.14	36.19	33.33
Fight the fire					20.95	18.1	18.1	4.76

B

Appendix: Model details and Input

B.1. Description situations

Table B.1: Description of all situations and corresponding questionnaire scenarios

Situation	Description	Corresponding questionnaire scenarios
1	In this situation, the building occupant has not seen any fire, he/she has not been informed by staff and he/she is not in a space with no-one nearby.	Basic scenario
2	In this situation, the building occupant has not seen any fire, he/she has not been informed by staff and he/she is in a space with no-one nearby.	Basic scenario + Scenario 3
3	In this situation, the building occupant has not seen any fire, he/she has been informed by staff and he/she is not in a space with no-one nearby.	Scenario 1
4	In this situation, the building occupant has not seen any fire, he/she has been informed by staff and he/she is in a space with no-one nearby.	Scenario 1 + Scenario 3
5	In this situation, the building occupant has seen signs of fire and/or smoke, he/she has not been informed by staff and he/she is in a space with others nearby.	Scenario 6
6	In this situation, the building occupant has seen signs of fire and/or smoke, he/she has not been informed by staff and he/she is in a space with no-one nearby.	Scenario 6 + Scenario 3

B.2. Example: Response tasks process for a Czech Visitor

Below an example will follow of a Czech visitor, which is in situation 1, the basic situation. The corresponding decision tree can be seen in figure B.13. Based on the probabilities within the tree, the following sequence has been selected for this visitor: ”Look around and see what is happening, Seek information through conversations with other people nearby, Seek information through a member of staff”.

The chances of performing remaining tasks can be seen in table B.2. Based on the probabilities in table B.2, the following response tasks are added to the sequence: ”Physically assist others, Collect and put on coat”. This will result in the following itinerary of initial response tasks: ”Look around and see what is happening, Seek information through conversations with other people nearby, Seek information through a member of staff, Physically assist others, Collect and put on coat”.

After performing the first three response tasks, the itinerary is as follows: ” Physically assist others, Collect and put on coat”. At this point in time, the Czech visitor is informed by a staff member. the

visitor pauses his tasks, to listen to what the staff member has to say. Afterwards, the visitor removes from his itinerary ” Collect and put on coat”. The remaining itinerary is” Physically assist others”.

After finishing the last task, the visitor decides to look for his friend, with whom he came together to the library. The visitor and his friend are not together, and he is not sure where his friend is. After searching for his friend for 1.5 minute, he has not yet found his friend. He decides to terminate the search, and starts evacuation movement

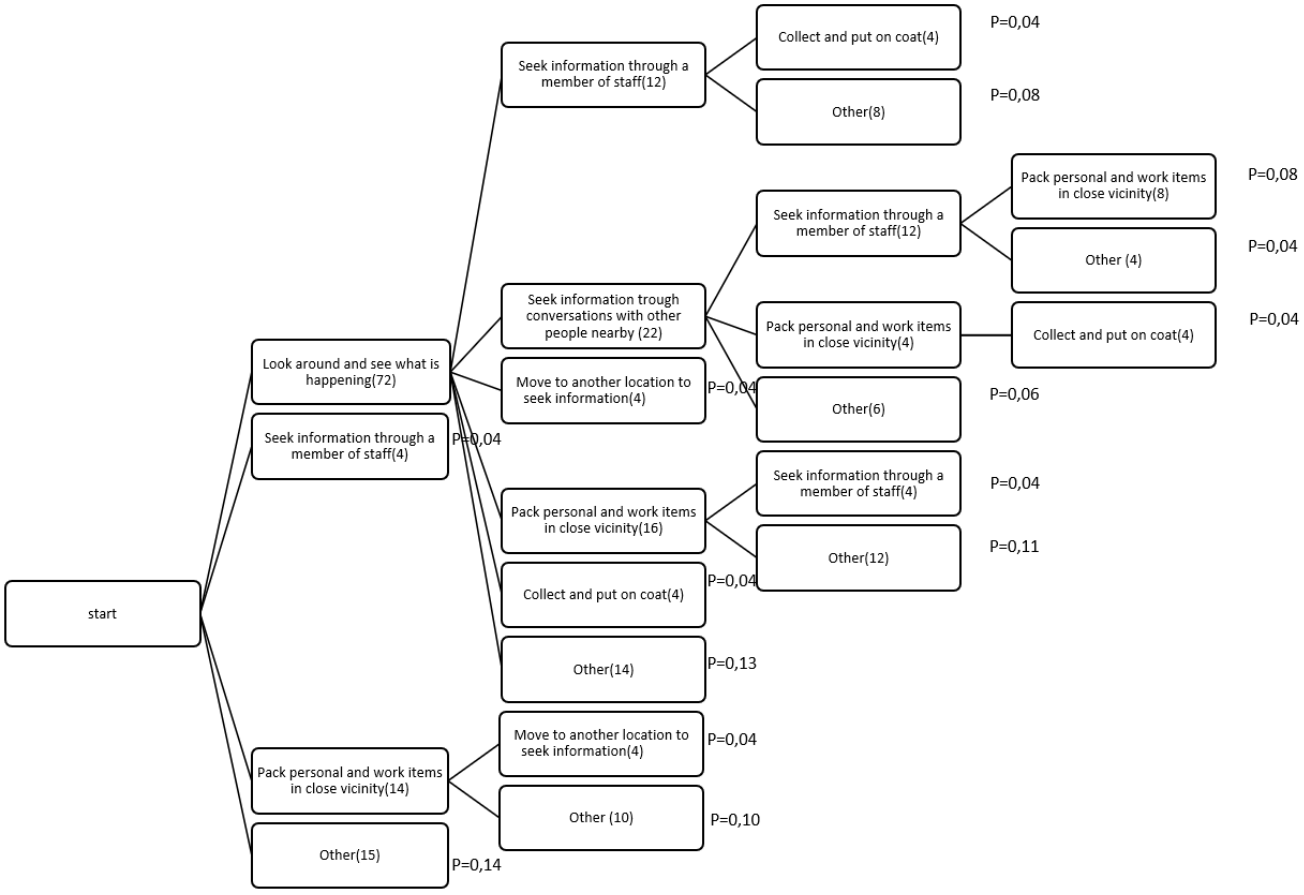

Figure B.1: Example: Decision Tree for Czech visitors in the Basic scenario

Table B.2: Example: Chances of performing remaining tasks for Czech visitors in the basic scenario

TaskType	Remaining chances (%)
Phone someone to seek information	7
Seek information through electronic media	7
Seek information trough conversations with other people nearby	25
Move to another location to seek information	30
Look around and see what is happening	8
Seek information through a member of staff	23
Phone someone to provide information	8
Actively provide information to others nearby	20
Actively search for others in the building to provide information	19
Work-related duties	8
Pack personal and work items in close vicinity	30
Collect and put on coat	30
Change footwear/ glasses / clothing	7
Physically assist others	37
Collect emergency equipment	13

B.3. Submodels

B.3.1. Modelling of response tasks of visitors

In this section is described how the response tasks have been modelled. All response tasks and its corresponding model procedures can be found in table B.3.

Table B.3: Task description and corresponding model procedures

Task	Model procedure
Phone someone to seek information	phone-seek-info
Seek information through electronic media	Electronic-media-seek-info
Seek information trough conversations with other people nearby	seek-info-coversation
Move to another location to seek information	seek-info-other-location
Look around and see what is happening	scan-environment
Seek information through a member of staff	seek-info-professional
Phone someone to provide information	phone-share-info
Actively provide information to others nearby	actively-provide-info-nearby
Actively search for others in the building, to provide information	actively-search-people-provide-info
Work-related duties	shut-down-work-action
Pack personal and work items in close vicinity	pack-belongings-nearby-action
Collect and put on coat	take-coat-action
Change footwear/ glasses / clothing	change-footwear-clothes-action
Physically assist others	physically-assist
Collect emergency equipment	collect-emergency-equipment
Call alarm number	call-alarm-number-action
Fight the fire	fight-fire

For six response tasks, no further explanation is needed on the modelling. As these tasks only take a certain amount of time, during which visitors are not moving or interacting with others. These tasks with the corresponding time ranges can be seen in table B.4. It will cost the visitor a random amount of time between these two ranges to finish the tasks. All of the response task times have been based on the task times as described in a paper by Vistnes et al. (2005). Below, explanations are provided of how the other response tasks have been modelled.

Table B.4: Time per response task task

Task type	Time range (s)
Phone someone to seek information	16 - 34
Seek information through electronic media	12 - 28
Look around and see what is happening	6 - 10
Phone someone to provide information	16 - 34
Change footwear/ glasses / clothing	5 - 35
Call alarm number	16 - 34

Seek information trough conversations with other people nearby

For this response task, the visitor checks if there is any other visitor in the nearby distance (within a radius of 20 meters). If there is no-one around, it will take the visitor 4 to 10 seconds to realise this and after this time, the task will be ended. If there is anyone in the nearby distance. the visitor will choose this other visitor as his/her conversation-buddy and calculate the shortest route towards the conversation buddy. While walking towards its' conversation-buddy, there are three things which can cause the recalculation of the path or the decision on the conversation-buddy. Firstly, a visitor cannot conversation with a conversation-buddy which has evacuated. So whenever the conversation-buddy has evacuated, the visitor will try to find a new evacuation-buddy. Secondly, the visitor reaches the original destination where the conversation-buddy was located whenever the path was calculated and the conversation-buddy is not there. In this case the visitor will either recalculate a path towards the conversation-buddy or, if there is another visitor closer , he/ she will set this other visitor as his/her conversation-buddy. Thirdly, the visitor will see any other visitors nearby, while his/her buddy is further away. In this case, the visitor will change his conversation-buddy to the other visitor which is located closer. Whenever the visitor reaches his/her conversation-buddy he/she will conversation with the buddy for about 7 to 13 seconds. The full process can also be seen in figure B.2.

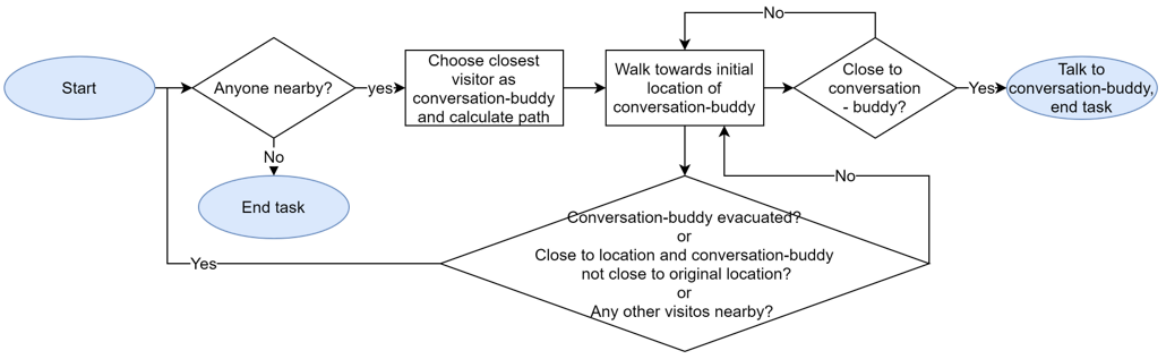

Figure B.2: Process: Seek information trough conversations with other people nearby

Move to another location to seek information

For this task, the visitor will move to another location in the building in order to gain more information on the nature of the alarm. Whenever this task starts, the visitor will choose a destination within 40 meters to go and visit, a route will be calculated and the visitor will follow this route. Whenever the visitor reaches his/her destination he/she will take 2 to 8 seconds to look around. During this task the visitor will visit between 1 and 4 places before the task ends. The process can be seen in figure B.3

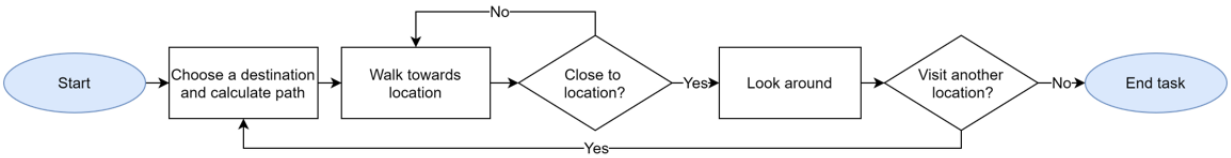

Figure B.3: Process: Move to another location to seek information

Seek information through a member of staff
During this task the visitor will try to find a member of staff in order to gain more information on the nature of the alarm.

If there is no staff-member nearby, the visitor will move to a random location within a certain radius. While walking towards this destination, the visitor is constantly looking around to see if there is a staff-member nearby. If the visitor does not see any staff-members on its way to his/her destination, he/she will continue walking towards the destination. When the visitor has reached his/her destination he/she will look around for 2 to 5 seconds. While the visitor does not see any staff members around, he/ she will visit 2 to 5 places before he/she gives up the search for a staff member.

If the visitor sees a staff member at any point in time, he/ she will consider this staff member as his/her new conversation-buddy. The visitor will calculate a path towards the new buddy and follow this path. While following the path, the visitor can still choose another staff member as his/her conversation-buddy, if this other staff member is located closer at any point in time.

When the visitor reaches a staff member, he/she will talk to the staff member for 5 to 11 seconds and afterwards end this task. The process can be seen in figure B.4.

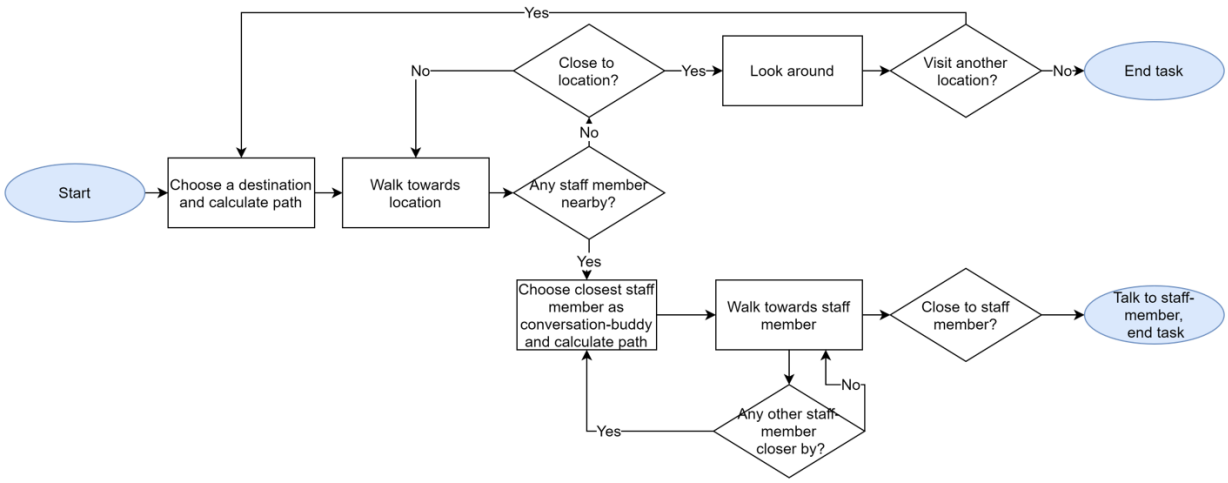

Figure B.4: Process: Seek information through a member of staff

Actively provide information to others nearby
During this task, a visitor wants to inform any other visitor with the knowledge that he/she has already gained. To start the task, the visitor will look around if there are any other visitors nearby. If there is no-one nearby, the visitor will look around for 4 seconds and end the task.

If there are others around, the visitor will choose the closest visitor as his/her conversation-buddy and calculate a path. While walking towards its' conversation-buddy, there are three things which can cause the recalculation of the path or the decision on the conversation-buddy. Firstly, a visitor cannot conversation with a conversation-buddy which has evacuated. So whenever the conversation-buddy has evacuated, the visitor will try to find a new evacuation-buddy. Secondly, the visitor reaches the original destination where the conversation-buddy was located whenever the path was calculated and the conversation-buddy is not there. In this case the visitor will either recalculate a path towards the conversation-buddy or, if there is another visitor closer , he/ she will set this other visitor as his/her conversation-buddy. Thirdly, the visitor will see any other visitors nearby, while his/her buddy is further away. In this case, the visitor will change his conversation-buddy to the other visitor which is located closer. Whenever the visitor reaches his/her conversation-buddy he/she will conversation with the buddy for about 4 to 10 seconds.

The visitor will inform 1 to 3 other visitors in the nearby surroundings, whereby he/she will not inform a visitor which he/she has informed during any earlier point in time.

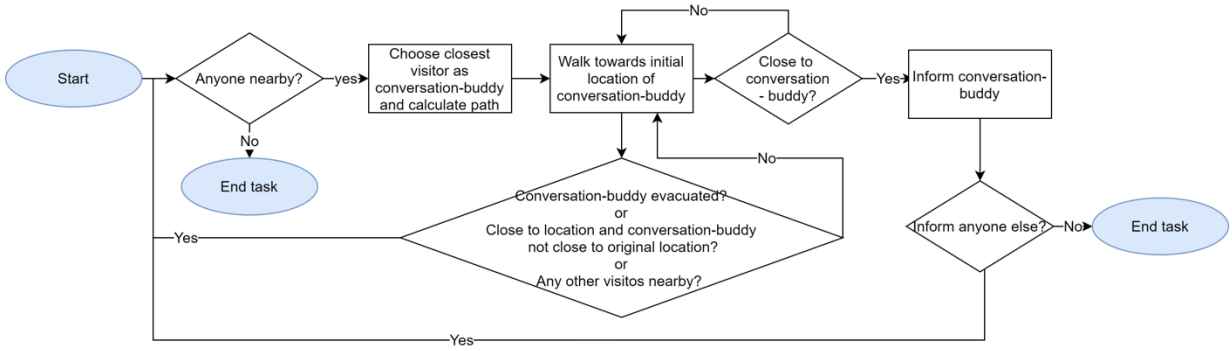

Figure B.5: Process: Actively provide information to others nearby

Actively search for others in the building to provide information
This task is built up in the similar way as ”Seek information through a member of staff”.

If there is no visitor nearby, the visitor will move to a random location within a certain radius. While walking towards this destination, the visitor is constantly looking around to see if there is another visitor member nearby. If the visitor does not see any visitors on its way to his/her destination, he/she will continue walking towards the destination. When the visitor has reached his/her destination he/she will look around for 2 to 5 seconds.

If the visitor sees another visitor at any point in time, he/ she will consider this visitor as his/her new conversation-buddy. The visitor will calculate a path towards the new buddy and follow this path. While following the path, the visitor can still choose another visitor as his/her conversation-buddy, if the conversation-buddy has been evacuated or if there is another visitor located closer by. However, if the conversation-buddy has evacuated and the visitor does not see anyone else nearby he/she will stop the search.

When the visitor reaches the conversation-buddy, he/she will inform the conversation-buddy for 4 to 10 seconds. Afterwards, the visitor can move to another place, another conversation-buddy or end the task. The visitor will inform 2 to 4 other visitors in total or go to 2 to 4 places to see if there is anyone around to inform. The process can be seen in figure B.6

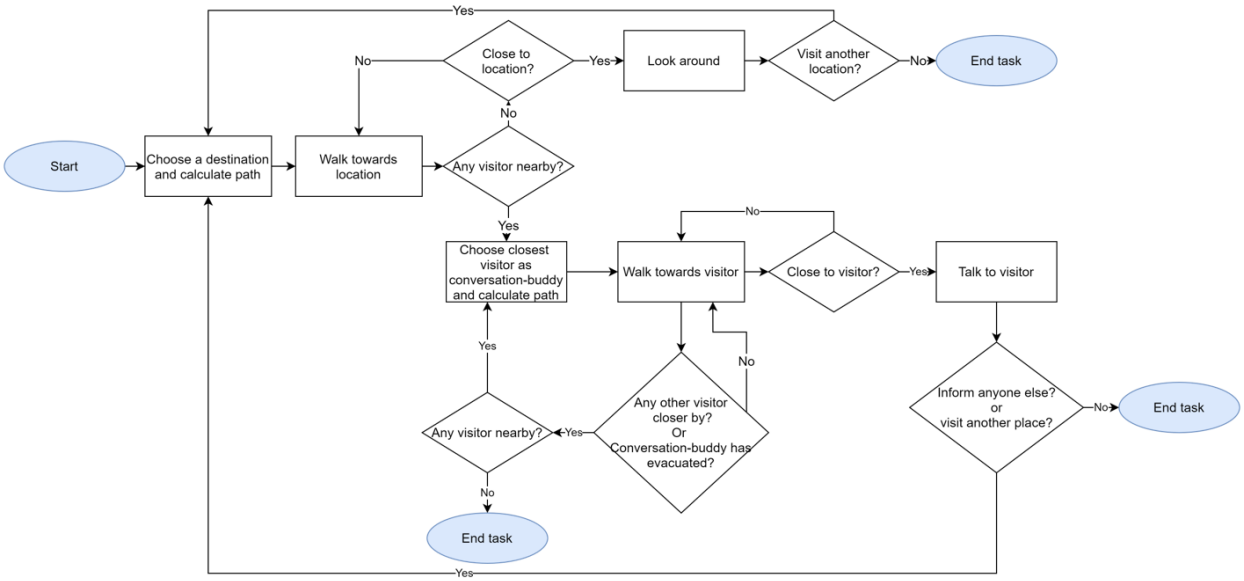

Figure B.6: Process: Actively search for others in the building to provide information

Work-related duties, *Collect and put on coat* and *Pack personal and work items in close vicinity*
These three tasks will follow a similar process. It is assumed that the visitor will need to be present

at his / her sitting place in order to perform these tasks. Therefore, there will be checked if the sitting place is within a distance of four meters from the visitor. If this is true, the visitor will perform the task. This means that it will take 9 to 21 seconds to do ”Work-related duties”, it will take 6 to 8 seconds to ”Collect and put on coat” and it will take 16 to 34 seconds to ”Pack personal and work items in close vicinity”.

If the visitor is not near his/her sitting-place it will be checked whether the visitor will go back to do these tasks. This will be done based on the chances in tables 4.3 and 4.8. These chances will be different in the two situation where someone has or has not seen any signs of smoke and/or fire. There are three possible outcomes of this check. Firstly, the visitor can decide not to return to his/her sitting-place, this will end the task. Secondly, the visitor can decide to return to his/her sitting-place and perform the tasks. Thirdly, a visitor will try to reach his/her sitting place within a certain amount of time (maximum 50 to 150 seconds). If it is reachable within these time ranges, he/she will perform the action. If the visitor does not reach his/her sitting place within these time limits, he/she will end the task. The process can be seen in figure B.7.

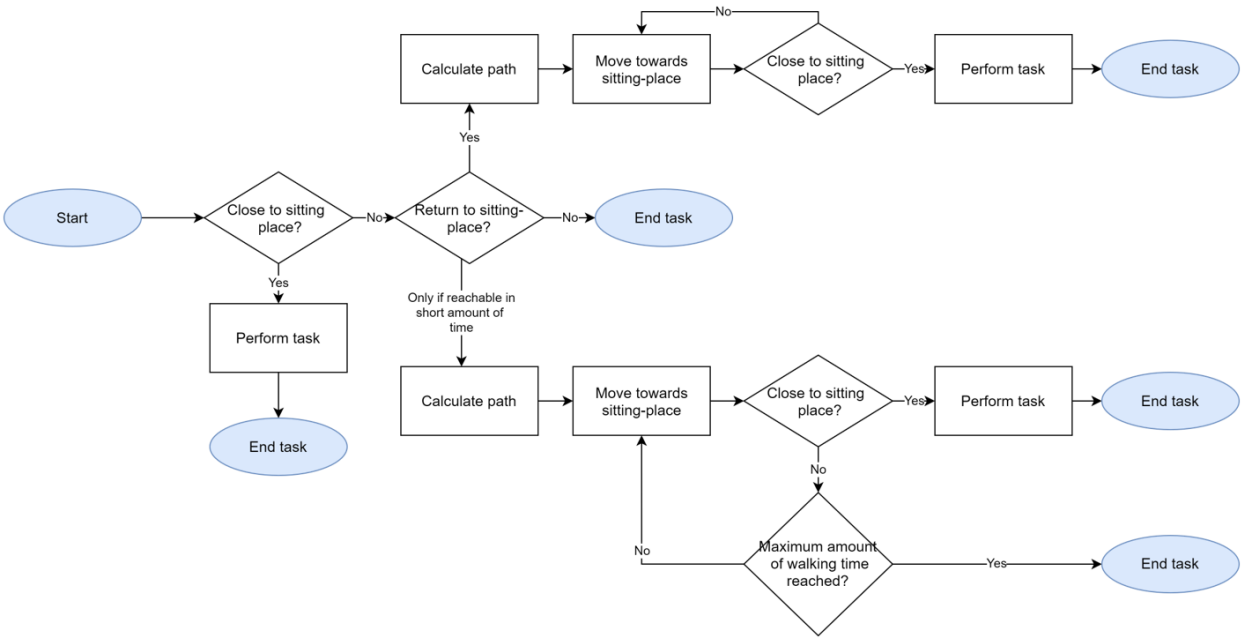

Figure B.7: Process: Work-related duties, Collect and put on coat and Pack personal and work items in close vicinity

Physically assist others

For this action, the visitor will look around to see if there are any visitors nearby which are in need of assistance. If this is not the case, the visitor will take 6 to 10 seconds to realise this and end the task afterwards. If there is anyone nearby, who is in need of help, the visitor will calculate a path and move towards this person (conversation-buddy). If the person in need has moved locations, a new path will be calculated towards the new location. Furthermore, if the person in need has been evacuated before he/she is reached, the visitor will end the task. Whenever the visitor reaches the person in need, it will take 16 to 18 seconds to provide help. The process can be seen in figure B.8.

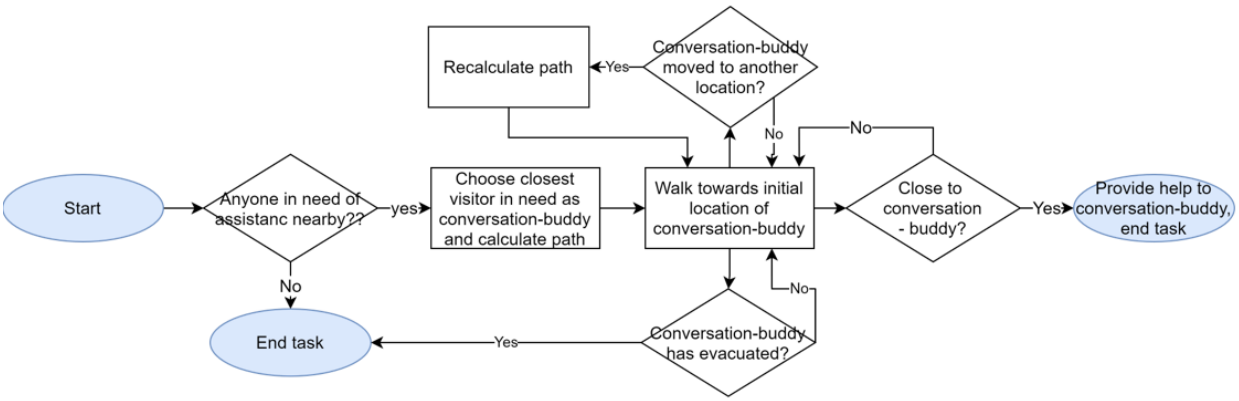

Figure B.8: Process: Physically assist others

Collect emergency equipment

For this task it is assumed that visitors who perform this task, know where the emergency equipment is located in the building. When performing this task, the visitor will calculate the path towards the emergency equipment location and follow this path. Once the visitor is close, it will take 11 to 29 second to collect the equipment. The process can be seen in figure B.9.

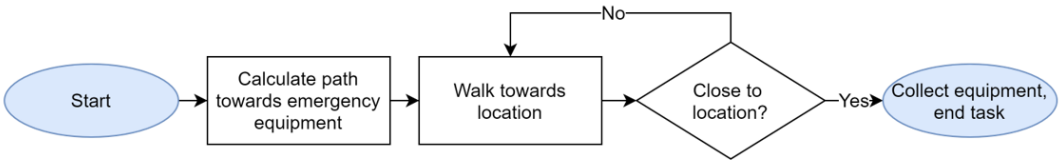

Figure B.9: Process: Collect emergency equipment

Fight the fire

For this task, visitors will calculate a path toward the fire area. They will follow this path until they have reached it. Then they will take 30 to 70 seconds to try and fight the fire. The process is depicted in figure B.10.

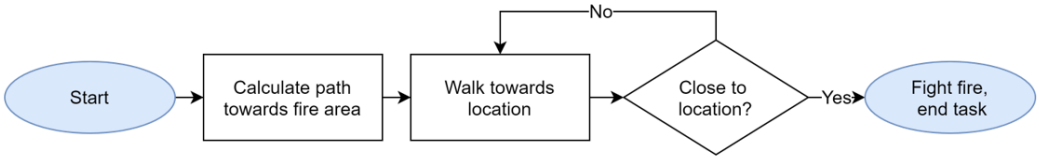

Figure B.10: Process: Fight the fire

B.3.2. Modelling of response tasks of staff

Phone someone to seek information and *Look around and see what is happening* and *Move to another location to seek information*

These tasks have been modelled exactly in the same way as they have been for the visitors. Therefore, these will not be discussed again here.

Seek information through another member of staff

During this task, the staff member will look around if there is another staff-member nearby. If there is no-one nearby, the staff member will look around for 10 seconds and afterwards end the task. If there are any staff members nearby, the nearest person will be chosen as the conversation-buddy. The staff-member will calculate the path towards his/her conversation-buddy and follow this path. If at some point in time, the conversation-buddy has evacuated, or has moved destinations, the staff member will

check if there is still another staff member nearby and pick this person as his/her conversation-buddy. Of there is no other staff-member nearby, the task will be ended.

Whenever the staff member approaches his/her conversation-buddy, they will talk for 4 to 10 seconds and afterwards end the task. The process can be seen in table B.11.

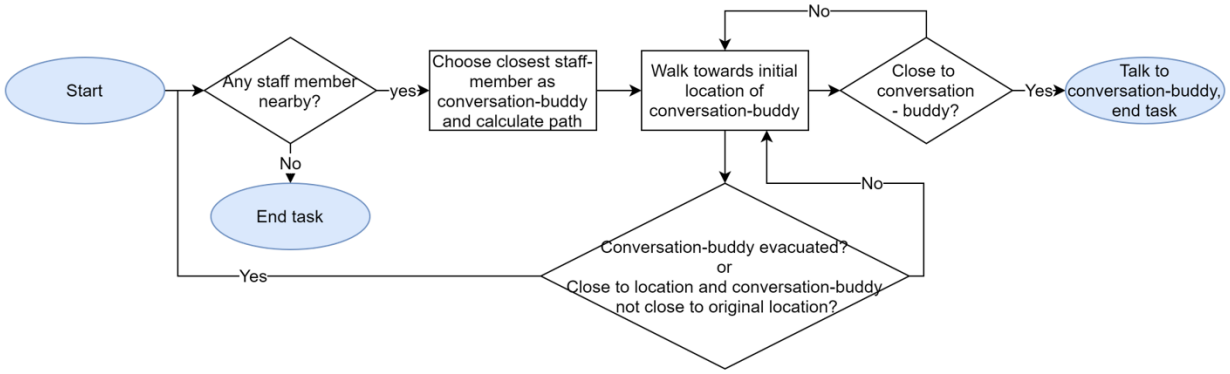

Figure B.11: Process: Seek information through another member of staff

Evacuate visitors

During this task, the staff member will inform any visitor to leave the building. To start the task, the staff member will look around if there are visitors nearby. If there is no-one nearby, the staff member ends the task. If there are others around, the staff member will choose the closest visitor as his/her conversation-buddy and calculate a path.

While walking towards its' conversation-buddy, there are three things which can cause the recalculation of the path or the decision on another conversation-buddy.

Firstly, a staff member cannot conversation with a conversation-buddy which has evacuated. So whenever the conversation-buddy has evacuated, the staff-member will try to find a new conversation-buddy.

Secondly, the staff member reaches the original destination where the conversation-buddy was located, whenever the path was calculated, and the conversation-buddy is not there. In this case the visitor will either recalculate a path towards the conversation-buddy or, if there is another visitor closer, he/ she will set this other visitor as his/her conversation-buddy. Additional to this, if the staff-member notices that the conversation-buddy is walking away from him/her and has a higher walking-speed, the staff-member will stop following this conversation-buddy and seek another one. This is because it will be very hard for the staff-member to reach the conversation-buddy in this situation.

Thirdly, there is a situation in which the conversation-buddy is already talking to another staff-member. It will be useless to also approach this visitor. Therefore, the staff member will look around to see if there is another visitor nearby.

If any of the above three situations occur and there is no visitor nearby, the staff member will end the task.

Whenever the staff-member has reached his/her conversation-buddy, he/she will inform the conversation-buddy for 3 to 8 seconds. The conversation-buddy will be informed about the closest exit as well and will adjust tasks or adjust the notification time where this is deemed appropriate.

While doing this, all surrounding visitors will be informed at the same time with the same information.

After finishing informing the conversation-buddy, the staff-member will look around for a new conversation-buddy. This conversation-buddy can only be a visitor to which he/she has not spoken yet.

The staff member will keep going through this full process until there are no other visitors nearby which he/she has not informed yet. The whole process is depicted in figure B.12.

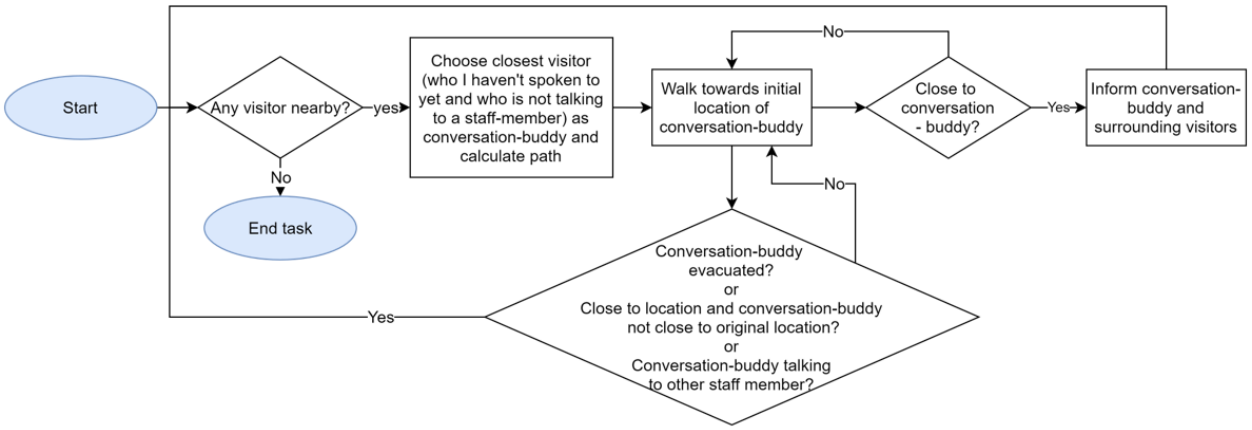

Figure B.12: Process: Evacuate visitors

B.4. State variables

Table B.5: Extra state variables used in the model for staff and visitors

Variable name	Static / Dynamic	Explanation	Values ranges/ units
response-activity-time-left	Dynamic	The time left to perform a response task. This is only used when there is no more interaction/ movement during a task	0 - 70 s
notification-time-countoff	Dynamic	The remaining time left before starting the response state	0- 96
people-informed	Dynamic	List of other agents which an agent has informed	Agent IDs
conversation-buddy	Dynamic	Other agent which is being approached to inform or seek information	Agent ID
conversationing-time-left	Dynamic	The remaining time left of speaking to another agent	Seconds
response-task-finished-check?	Dynamic	Indicates if a response task has been finished	True / False
task-only-run-once?	Dynamic	Indicates if a response task needs to be run only one time in order to set a timer	True / False
first-response-task?	Dynamic	Indicates if the first response task is currently being performed	True / False
all-response-tasks-finished?	Dynamic	Indicates if all response tasks from the list have been finished	True / False
number-of-places-to-visit	Dynamic	The number of places to look for information during a response task	1-5 places
number-of-places-visited	Dynamic	The number of places visited to look for information during a response task	0 - 5 places
scan-environment-counter	Dynamic	The time left to look around / interact during a respone task	0 - 14 seconds
looking-around-seek-info?	Dynamic	Indicates if an agent is standing still to look around	True / False
recaculated-path-ticks-time	Dynamic	Provides time when path was recalculated last time	seconds
response-tasks-added	Dynamic	The extra response tasks added during task adjustment	List of tasks
buddy-walking-away	Dynamic	Indicates the ID of an agent which was walking away while being approached	Agent ID

Table B.6: Extra state variables used in the model for visitors

Variable name	Static / Dynamic	Explanation	Values ranges/ units
time-searching-for-belongings	Dynamic	The amount of time that a visitor is already searching for his / her belongings	seconds
stop-searching-for-belongings -after-short-time?	Dynamic	Indicates if a visitor will stop searching for belongings after a certain amount of time	True / False
maximum-time-to-search-for-belongings	Dynamic	The maximum time spent to search for belongings	50-150 s
time-searching-for-friend	Dynamic	The amount of time that a visitor is already searching for his / her friend	Seconds
stop-searching-for-friend-after-short-time?	Dynamic	Indicates if a visitor will stop searching for friend after a certain amount of time	True/ False
maximum-time-to-search-for-friend	Dynamic	The maximum time spent to search for a friend	Seconds
evacuating-with-friend?	Dynamic	Indicates if two friends are evacuating together	True / False
friends	Static	List of friends	Agent IDs
last-time-conversationing-with-staff	Dynamic	Moment in time when visitor was last conversationing with a staff member	seconds
emergency-equipment-destination	Dynamic	While collectig emergency equipment, this patch is used as the destination	Patch value
number-of-people-to-inform	Dynamic	The number of people a visitor will need to inform during a specific task	1-3 visitors
number-of-people-informed	Dynamic	The number of people a visitor has already informed during a specific task	0- 3 visitors

B.5. Verification: Logging of response tasks

Table B.7: Logs of behaviour for ten visitors

Visitor	Ticks Time	Event	Current Response Tasks List
25	52	Setup Response Tasks Basic	[scan-environment actively-provide-info-nearby physically-assist seek-info-coversation]
30	57	Setup Response Tasks Basic	[scan-environment seek-info-other-location physically-assist actively-search-people-provide-info]
35	88	Setup Response Tasks Basic	[physically-assist actively-search-people-provide-info seek-info-professional seek-info-coversation]
35	105	Informed by staff	[physically-assist actively-search-people-provide-info seek-info-professional seek-info-coversation] –>[physically-assist seek-info-coversation]
40	86	Setup Response Tasks Basic	[pack-belongings-nearby-action seek-info-other-location seek-info-coversation collect-emergency-equipment]
45	106	Setup Response Tasks Basic	[scan-environment actively-provide-info-nearby actively-search-people-provide-info physically-assist]
45	112	Informed by staff	[scan-environment actively-provide-info-nearby actively-search-people-provide-info physically-assist] –>[scan-environment actively-provide-info-nearby physically-assist phone-share-info]
50	83	Setup Response Tasks Basic	[scan-environment pack-belongings-nearby-action seek-info-professional actively-search-people-provide-info actively-provide-info-nearby]
55	68	Setup Response Tasks Basic - Closed Space	[scan-environment seek-info-other-location pack-belongings-nearby-action physically-assist phone-seek-info]
55	117	Fire seen	[pack-belongings-nearby-action physically-assist phone-seek-info] –>[pack-belongings-nearby-action phone-seek-info take-coat-action]
55	215	Informed by staff	[pack-belongings-nearby-action phone-seek-info take-coat-action] –>[pack-belongings-nearby-action take-coat-action]
60	37	Setup Response Tasks Basic	[scan-environment pack-belongings-nearby-action seek-info-coversation take-coat-action phone-share-info]
60	57	Informed by staff	[phone-share-info] –>[phone-share-info]
65	96	Setup Response Tasks Basic	[scan-environment pack-belongings-nearby-action actively-search-people-provide-info phone-seek-info]
70	110	Setup Response Tasks Basic	[pack-belongings-nearby-action phone-seek-info physically-assist scan-environment take-coat-action]

B.6. Probability Trees

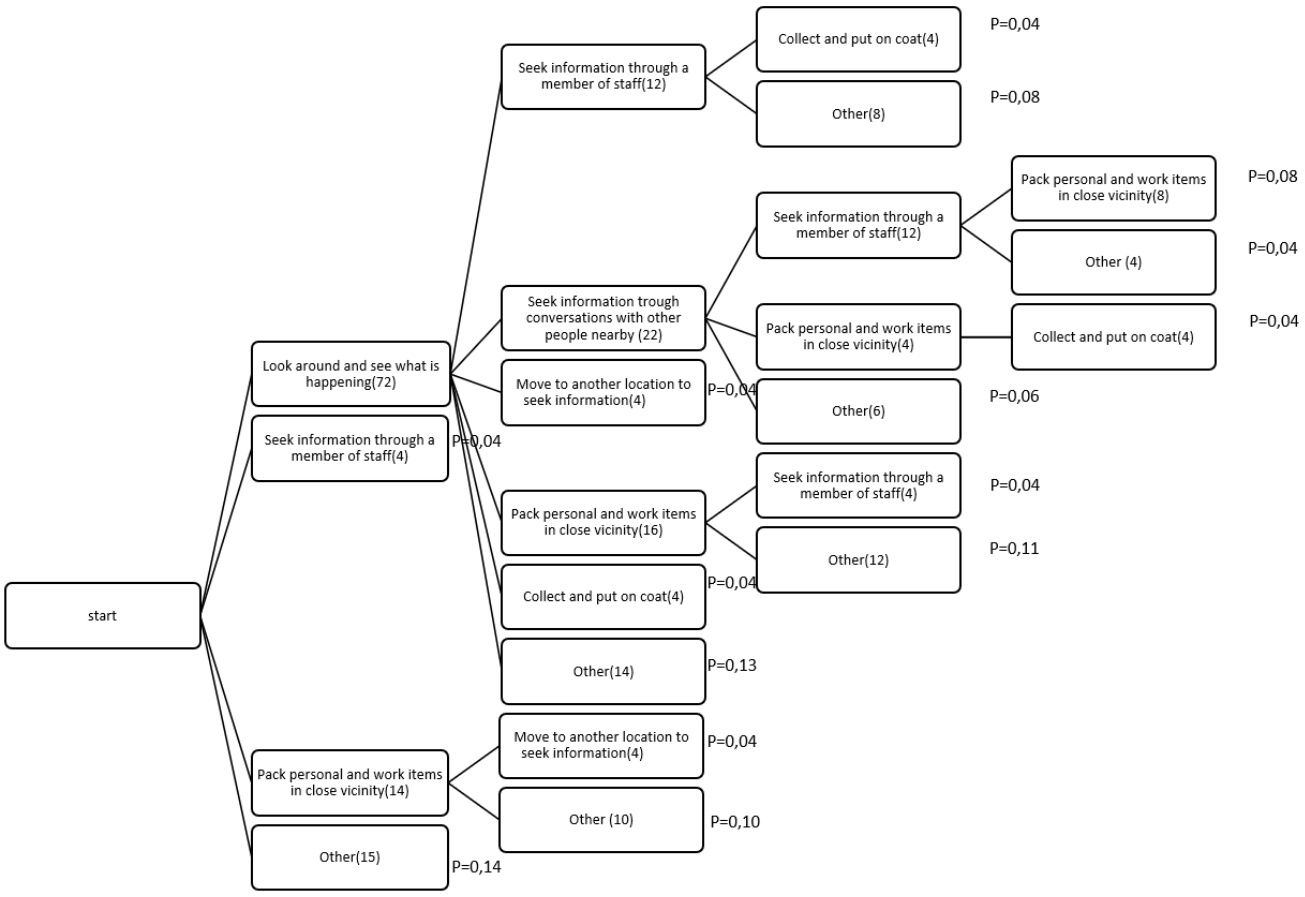

Figure B.13: Probability tree for Czech Republic Basic scenario (situation 1)

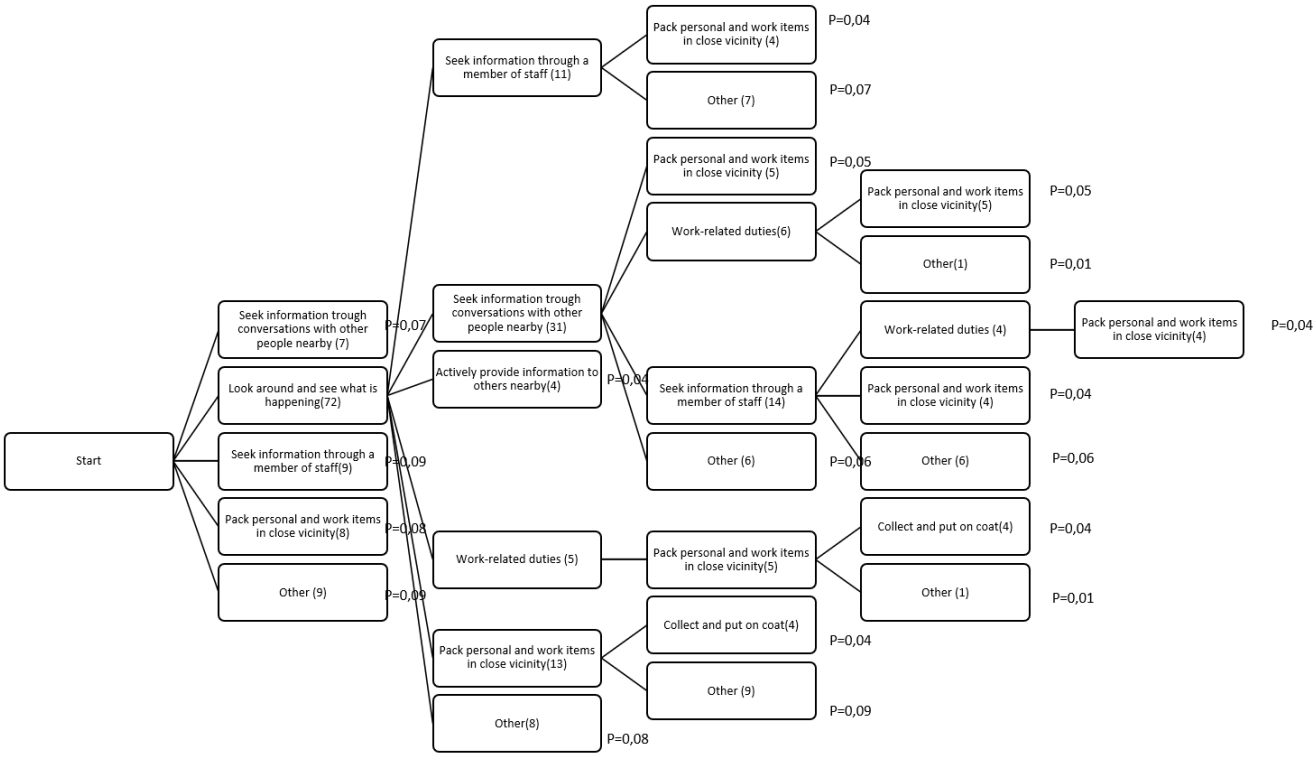

Figure B.14: Probability tree for Poland Basic scenario (situation 1)

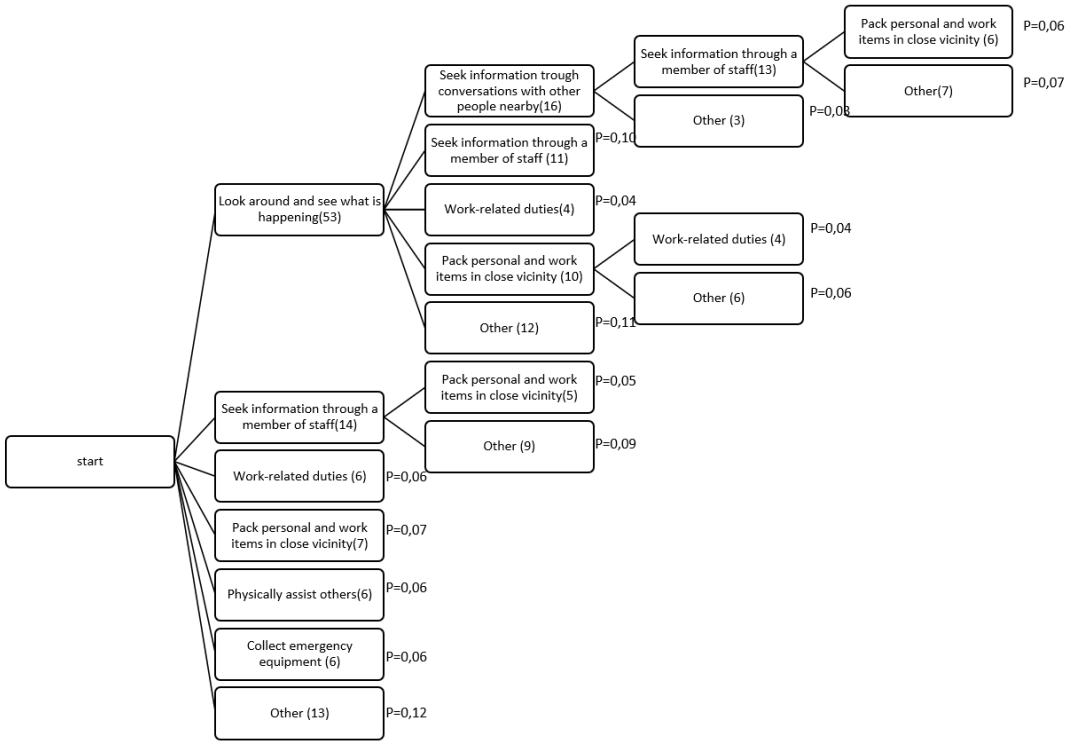

Figure B.15: Probability tree for Turkey Basic scenario (situation 1)

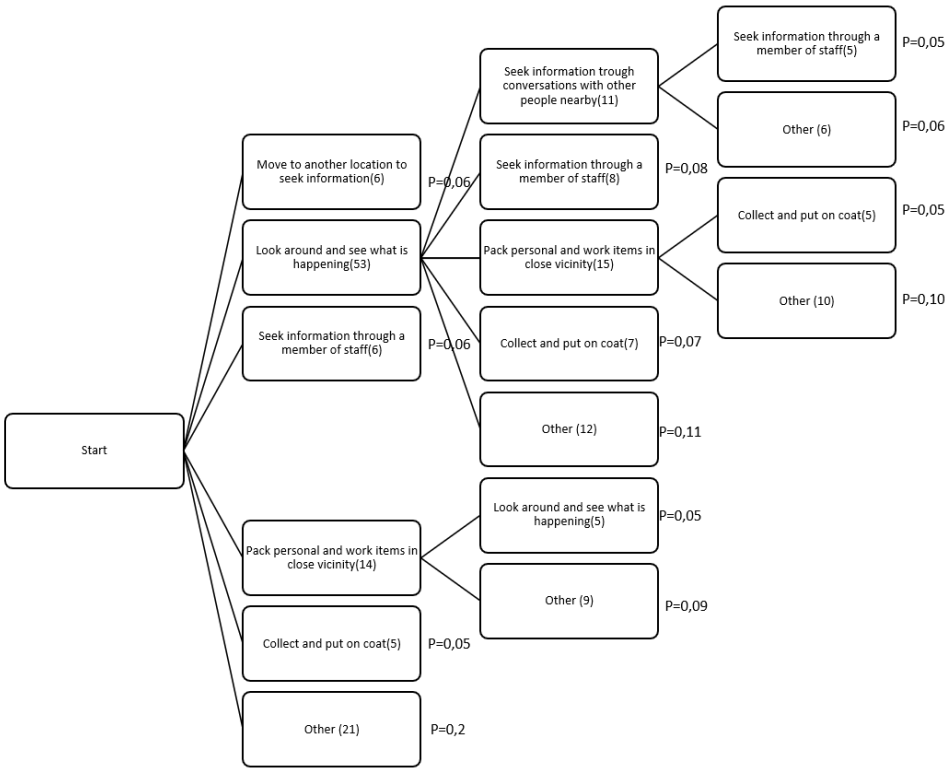

Figure B.16: Probability tree for UK Basic scenario (situation 1)

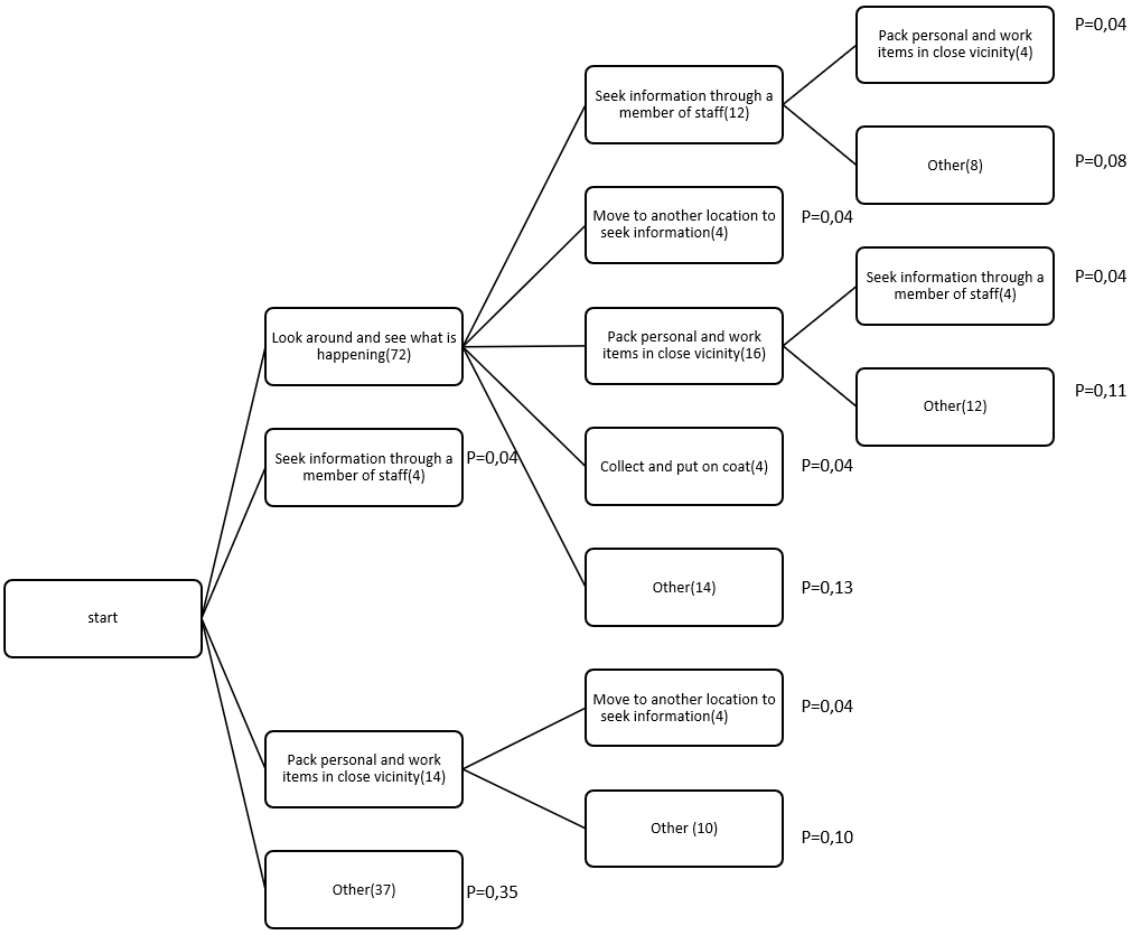

Figure B.17: Probability tree for Czech Republic Closed space (situation 2)

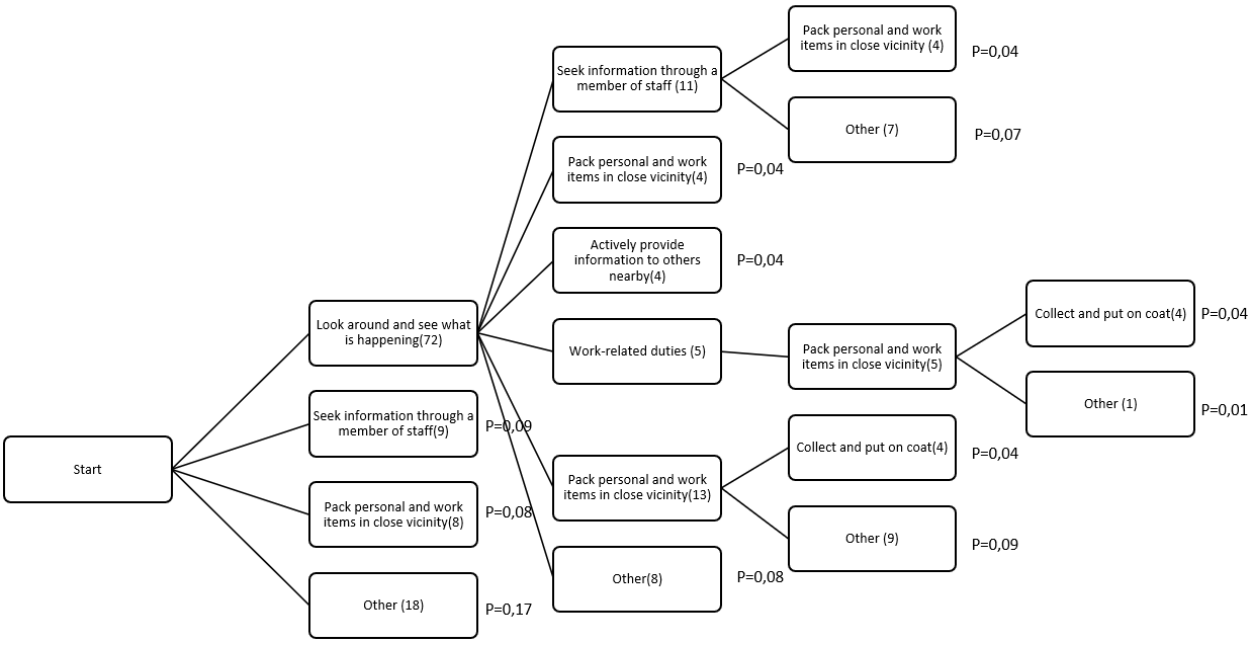

Figure B.18: Probability tree for Poland Closed space (situation 2)

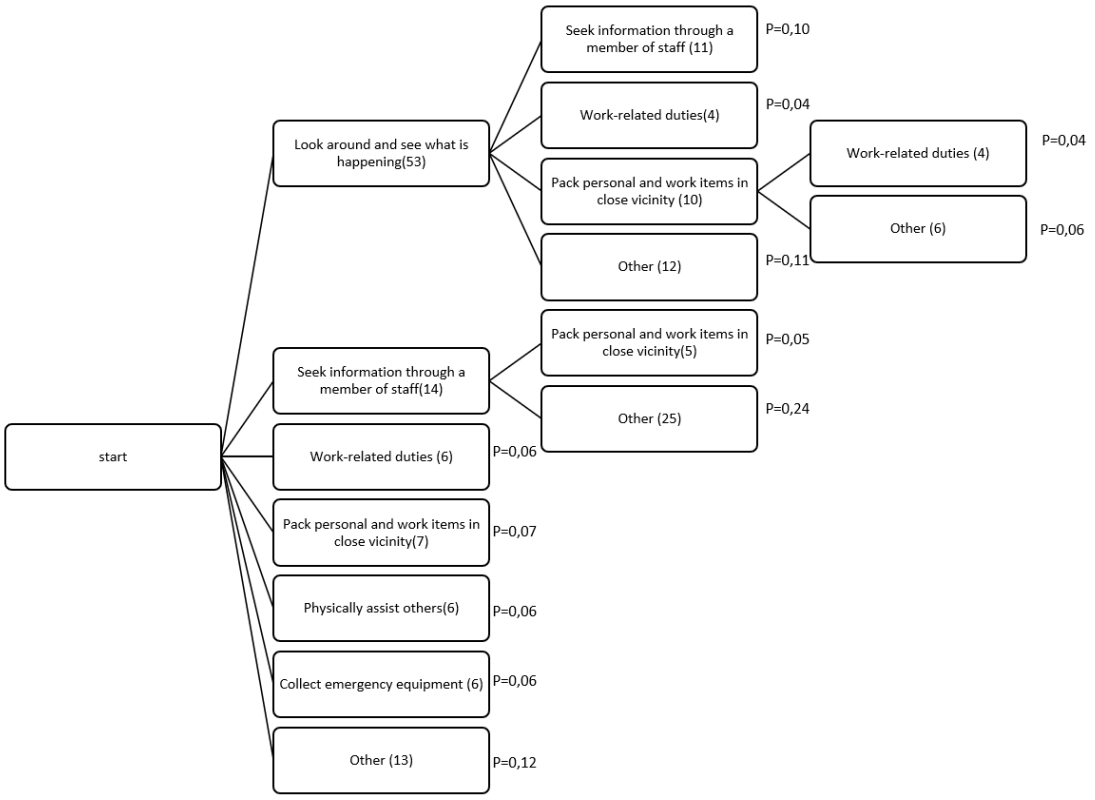

Figure B.19: Probability tree for Turkey Closed space (situation 2)

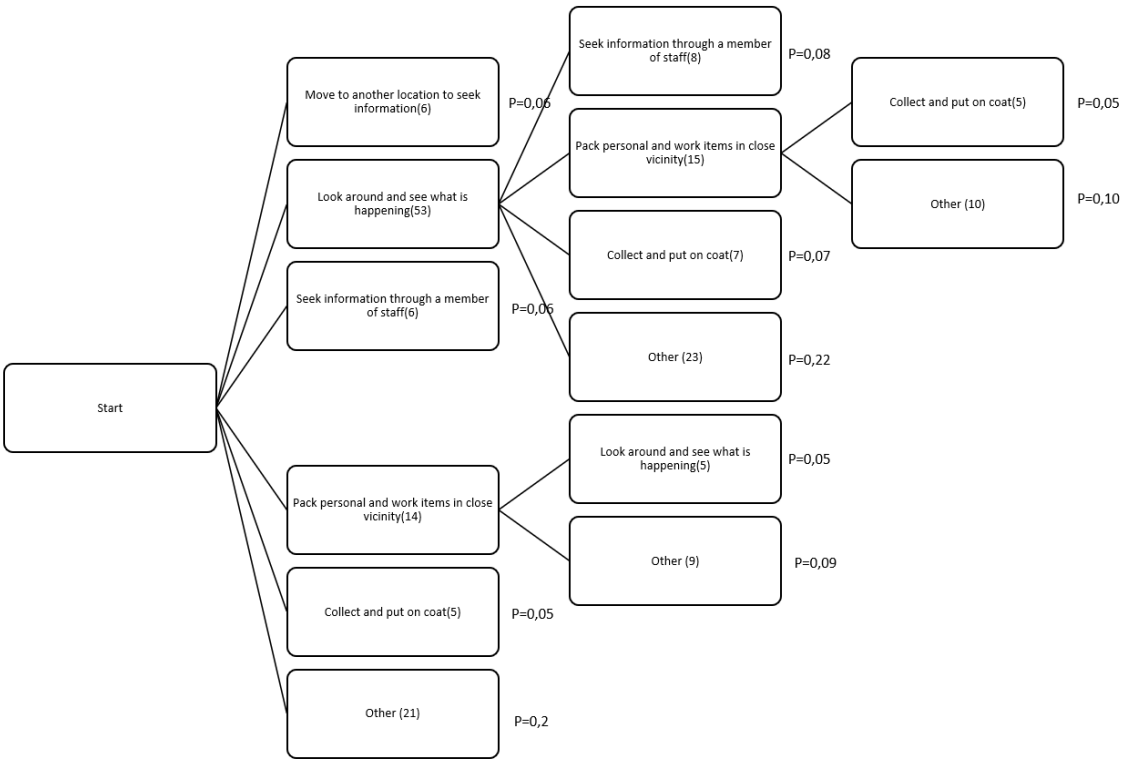

Figure B.20: Probability tree for UK Closed space (situation 2)

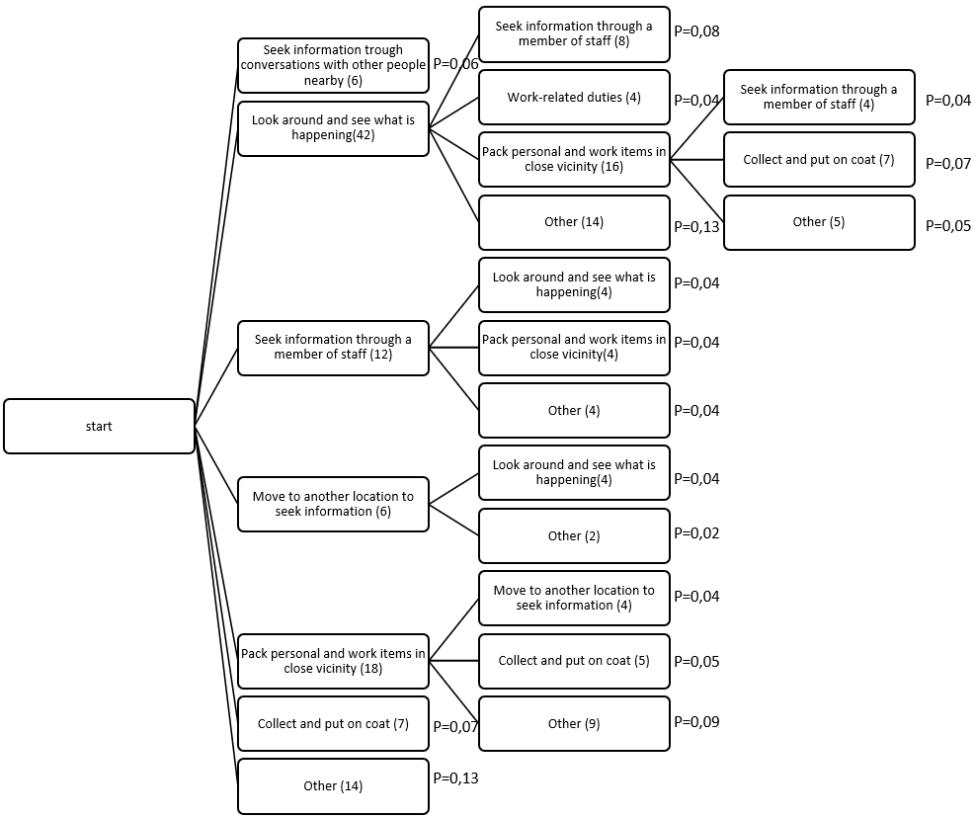

Figure B.21: Probability tree for Czech Republic Informed by staff (situation 3)

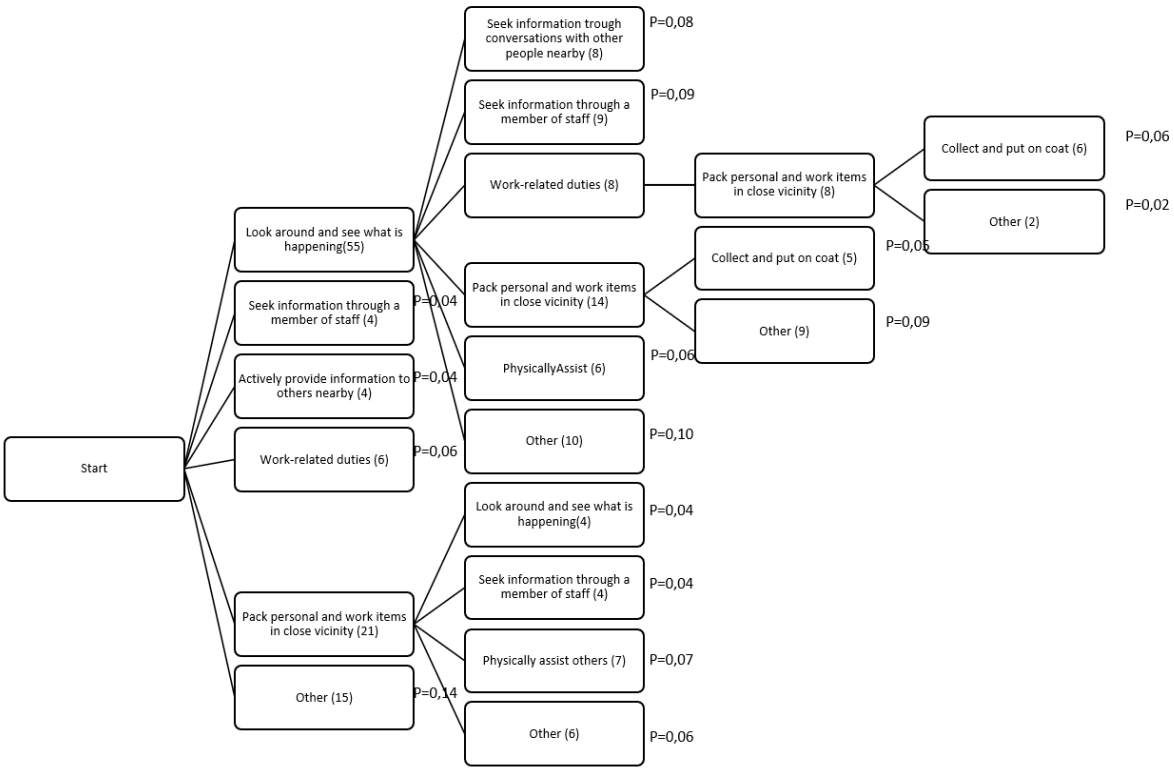

Figure B.22: Probability tree for Poland Informed by staff (situation 3)

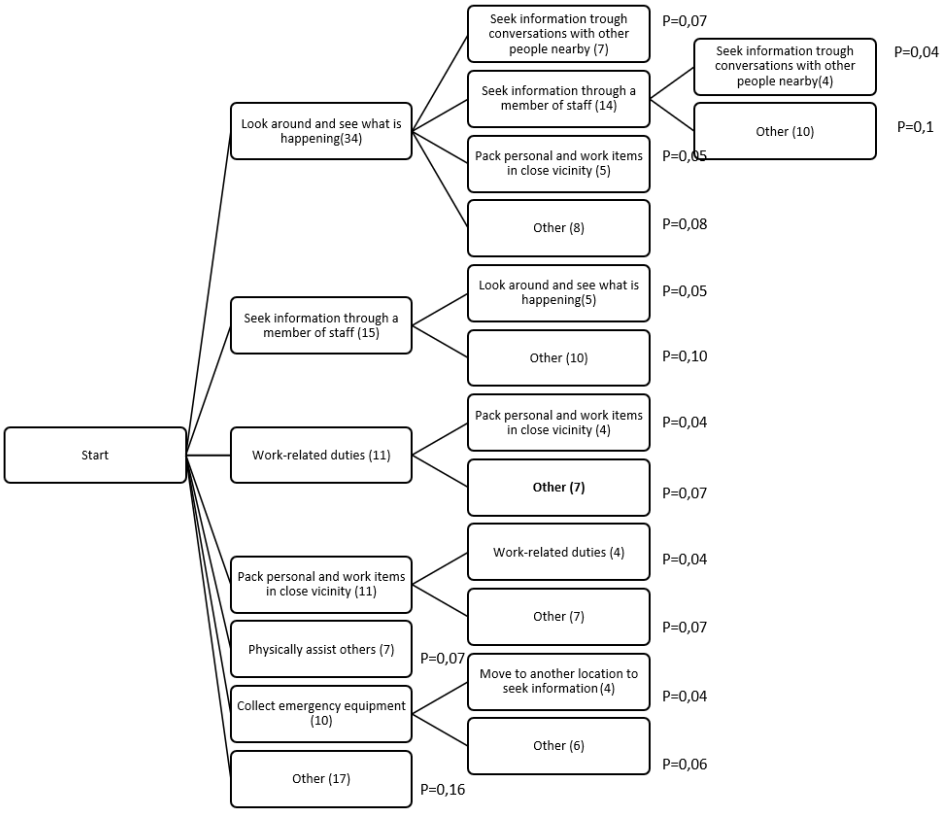

Figure B.23: Probability tree for Turkey Informed by staff (situation 3)

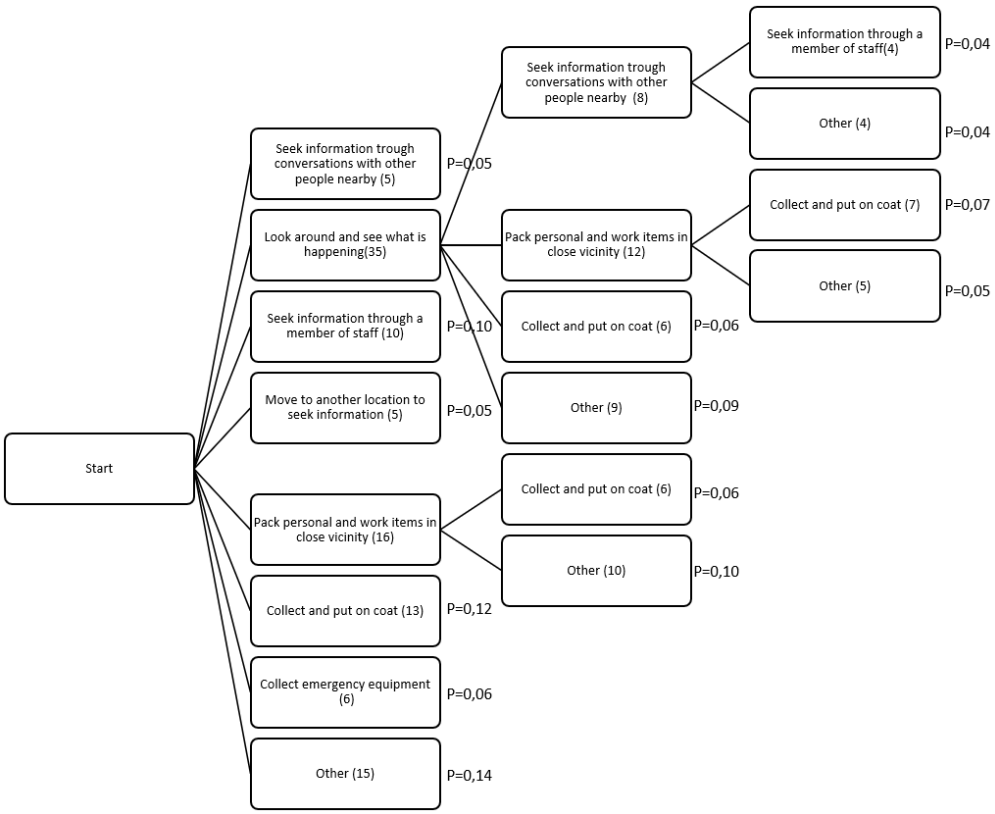

Figure B.24: Probability tree for UK Informed by staff (situation 3)

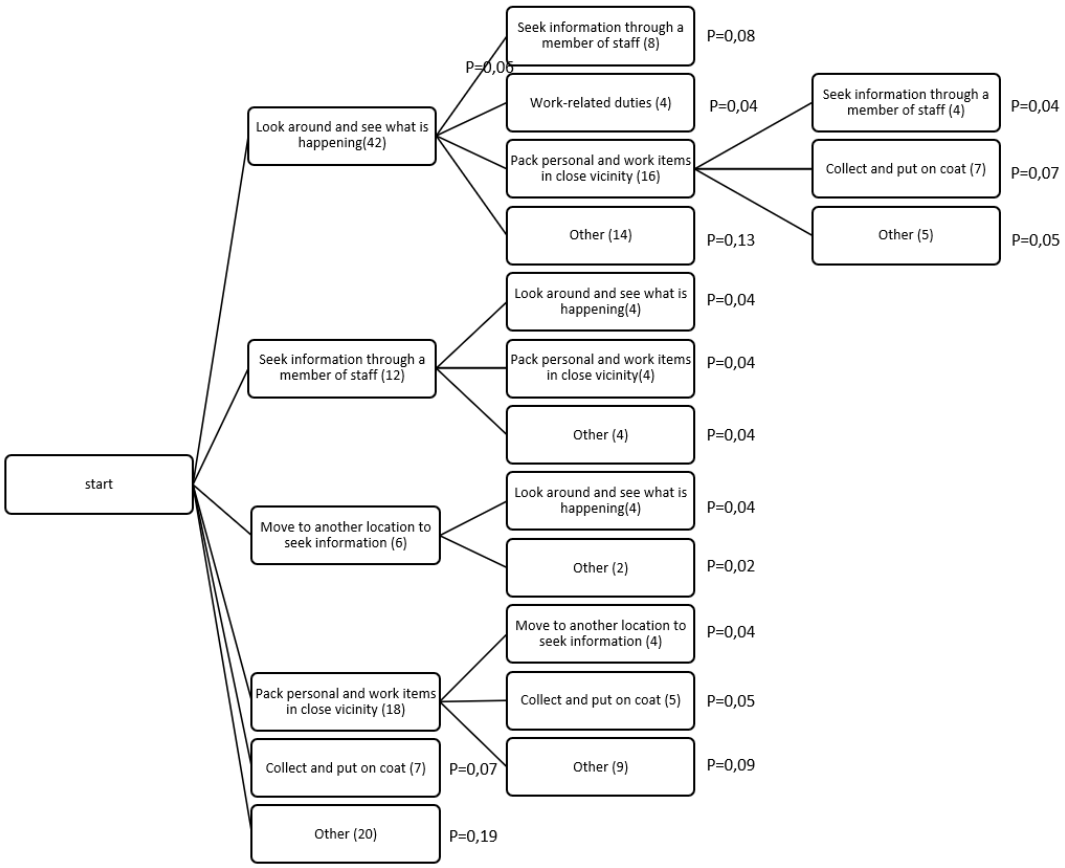

Figure B.25: Probability tree for Czech Republic Informed by staff, Closed space (situation 4)

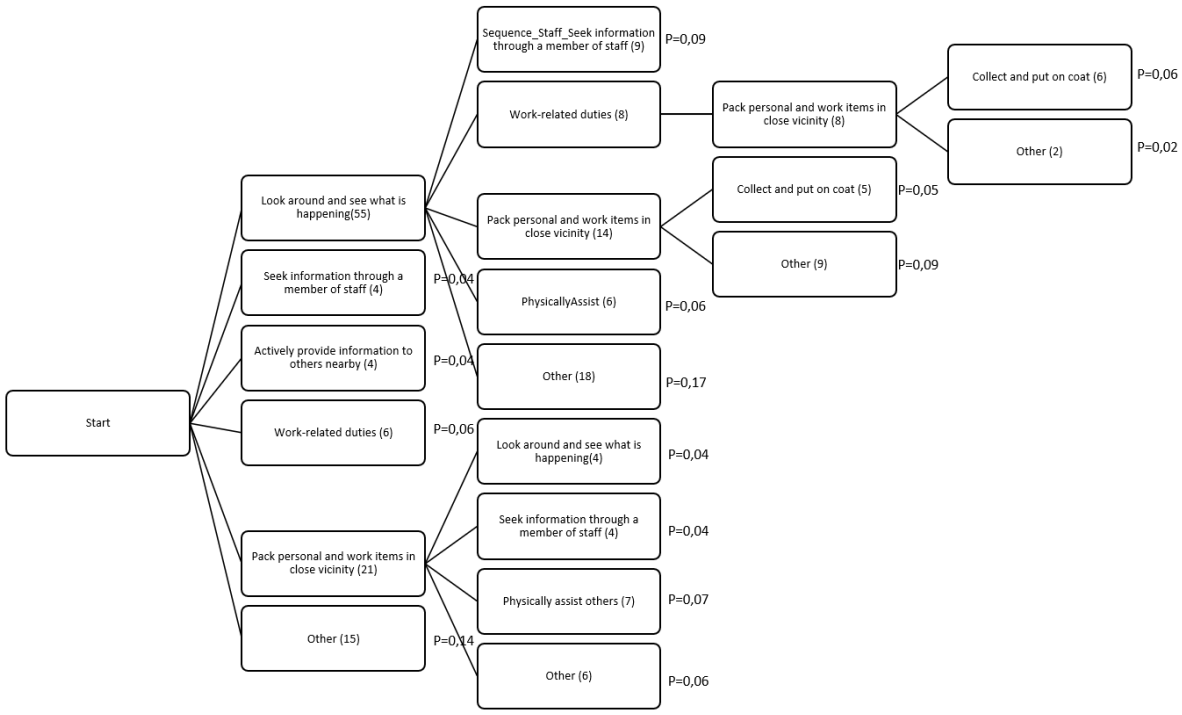

Figure B.26: Probability tree for Poland Informed by staff, Closed space (situation 4)

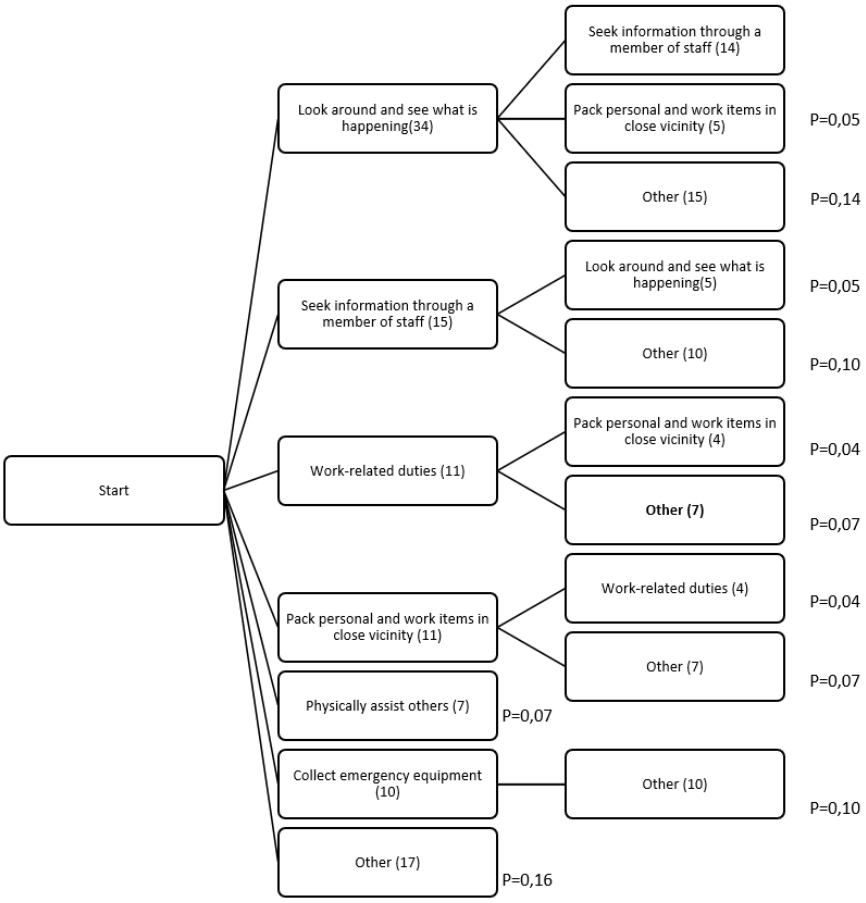

Figure B.27: Probability tree for Turkey Informed by staff, Closed space (situation 4)

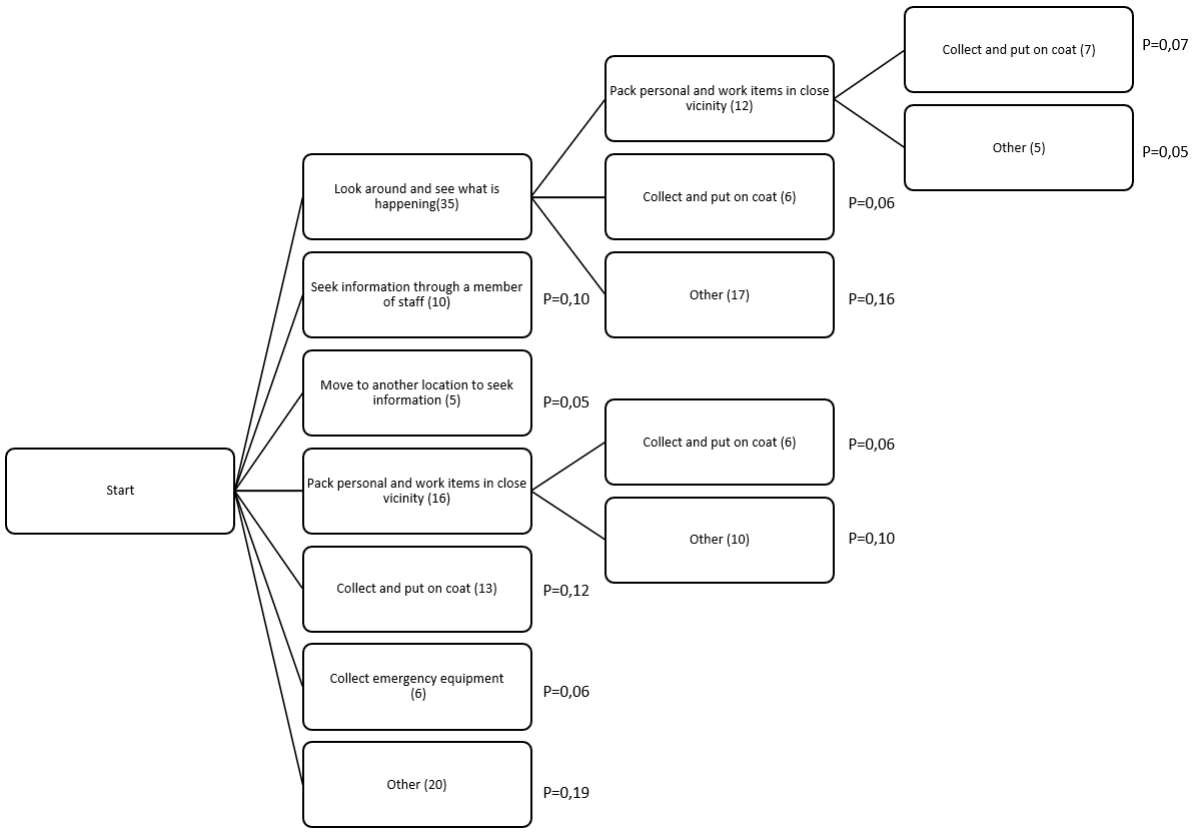

Figure B.28: Probability tree for UK Informed by staff, Closed space (situation 4)

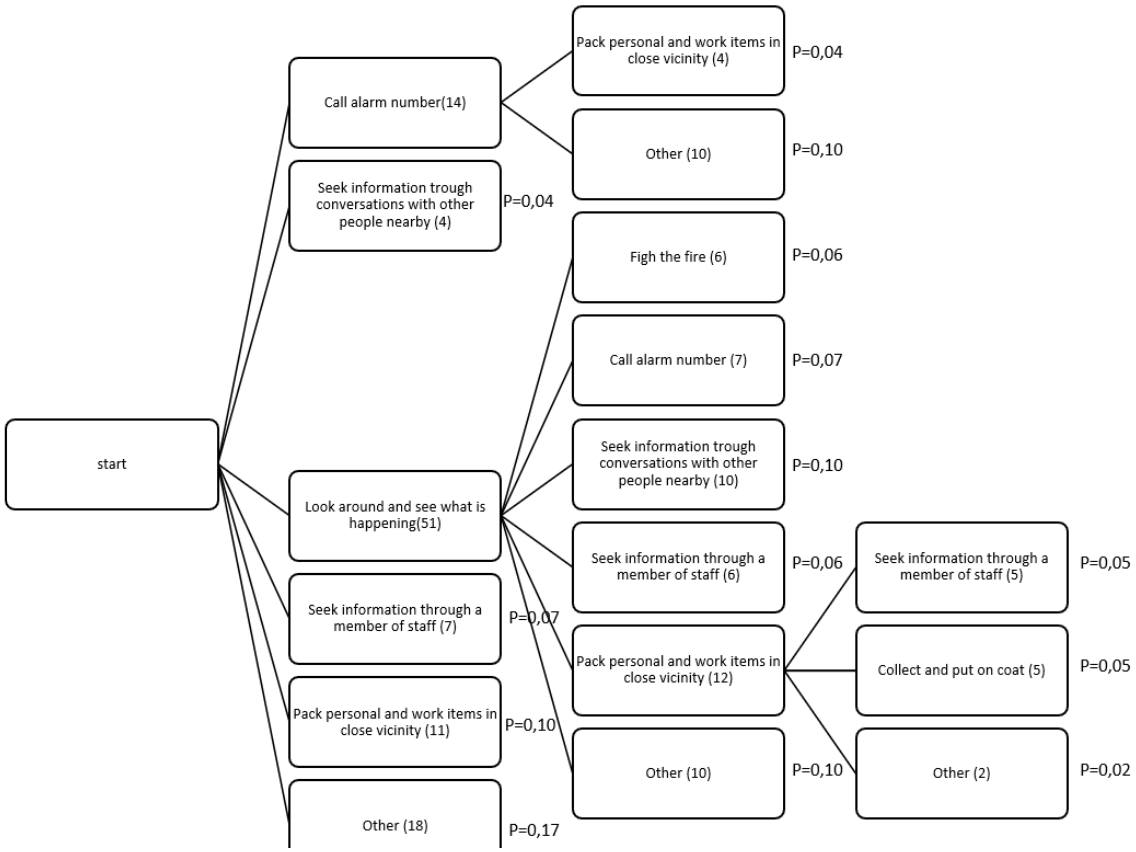

Figure B.29: Probability tree for Czech Republic Fire seen (situation 5)

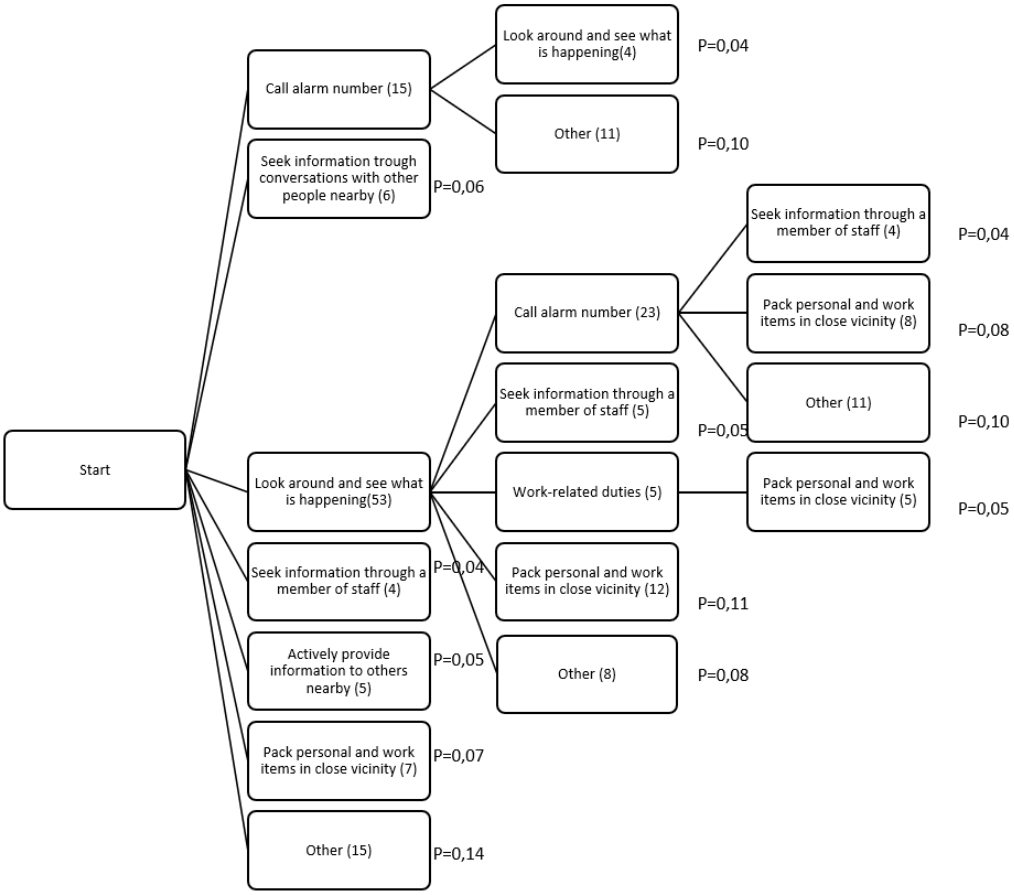

Figure B.30: Probability tree for Poland Fire seen (situation 5)

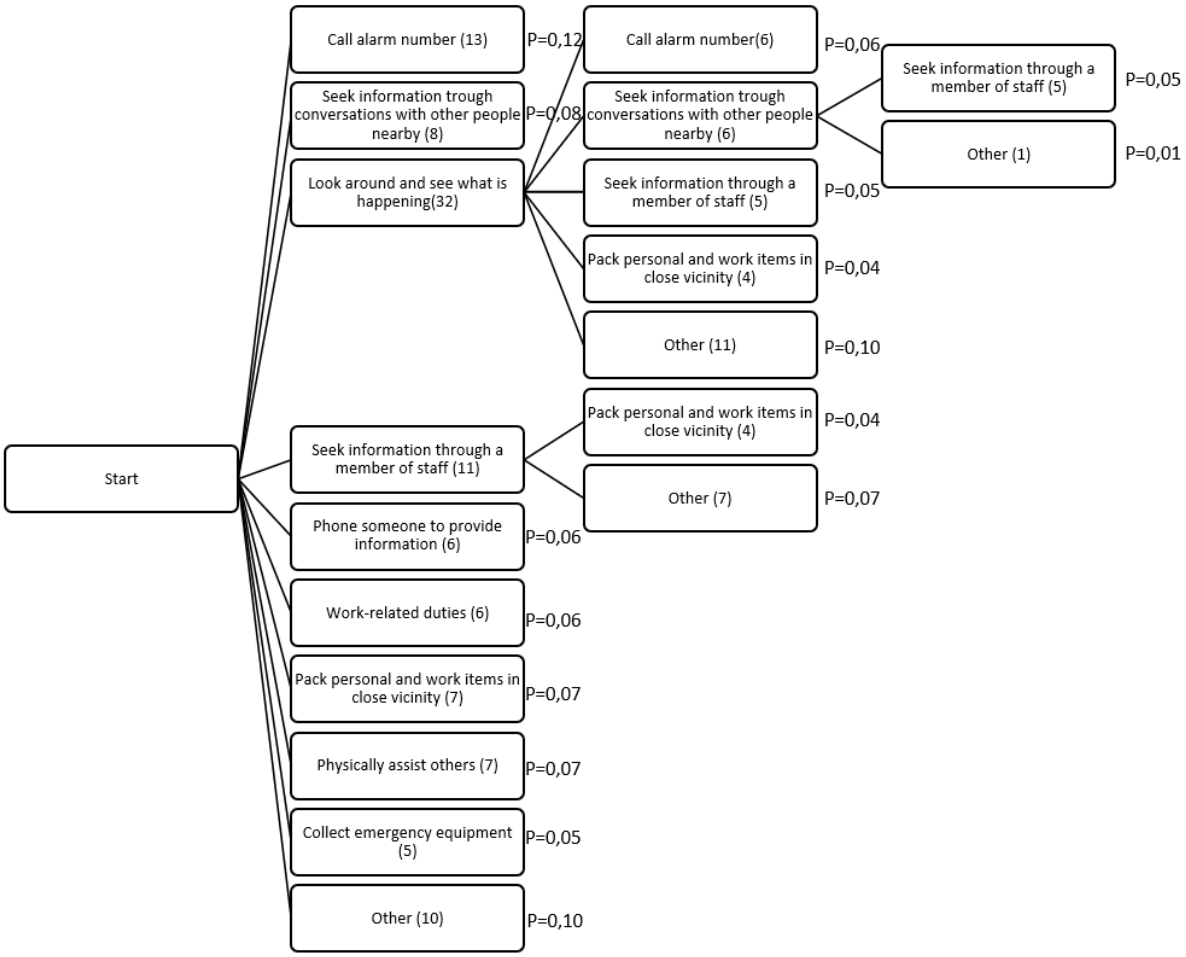

Figure B.31: Probability tree for Turkey Fire seen (situation 5)

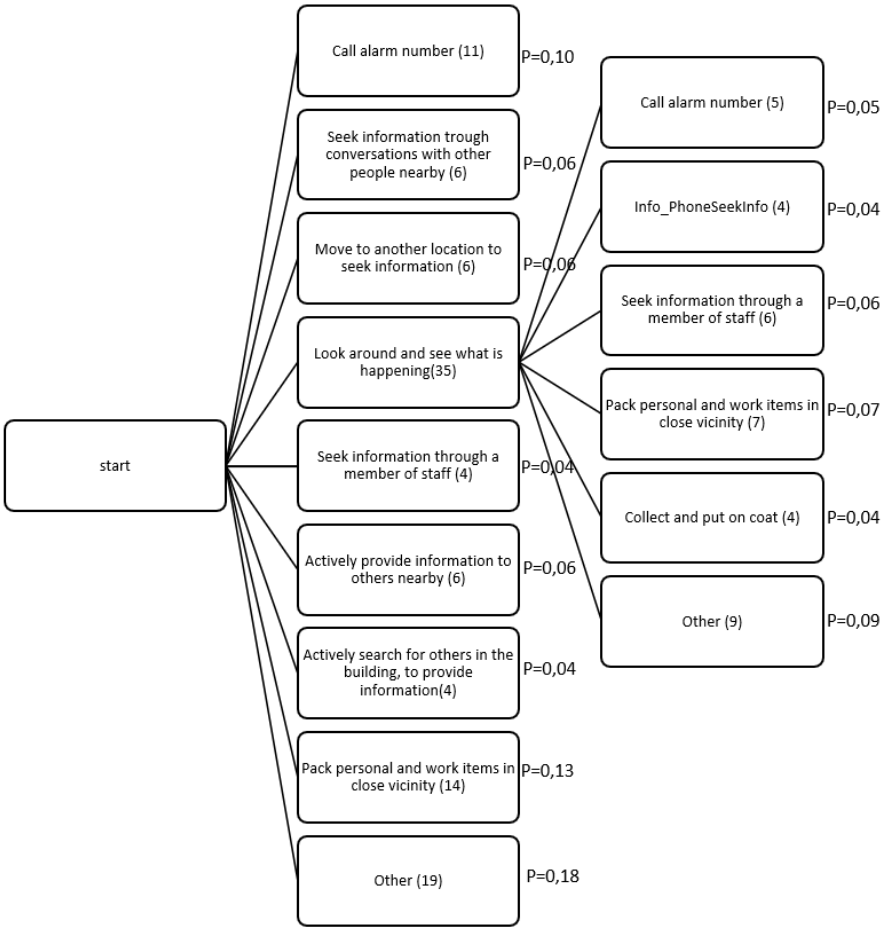

Figure B.32: Probability tree for UK Fire seen (situation 5)

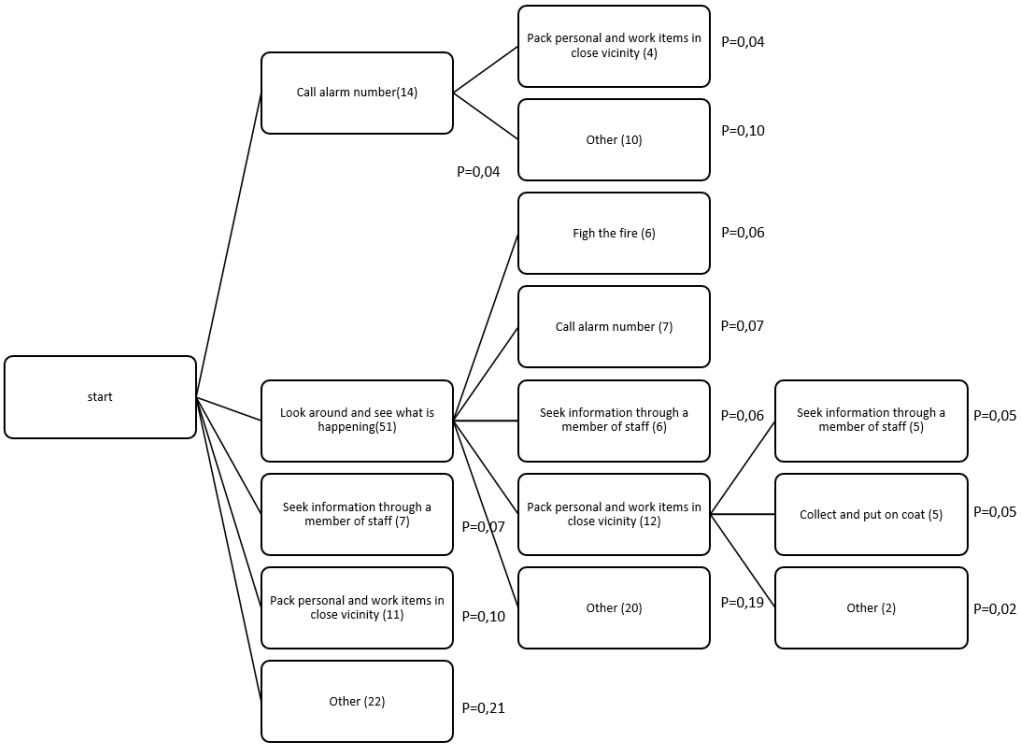

Figure B.33: Probability tree for Czech Republic Fire seen, Closed space (situation 6)

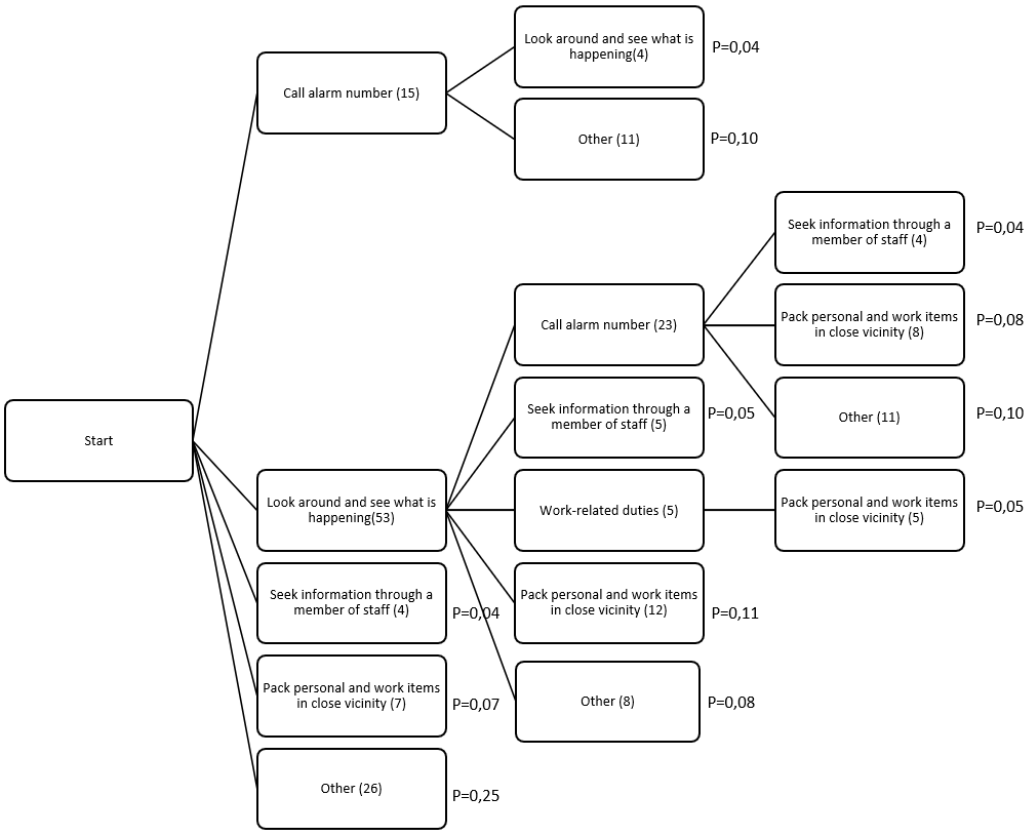

Figure B.34: Probability tree for Poland Fire seen, Closed space (situation 6)

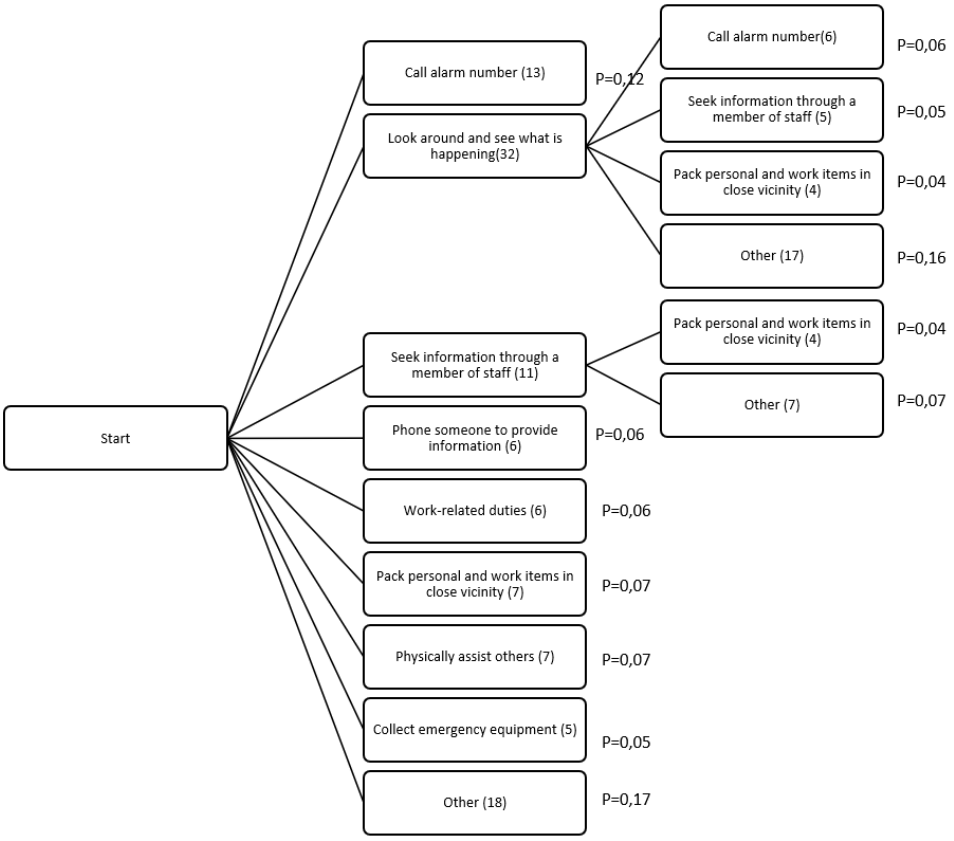

Figure B.35: Probability tree for Turkey Fire seen, Closed space (situation 6)

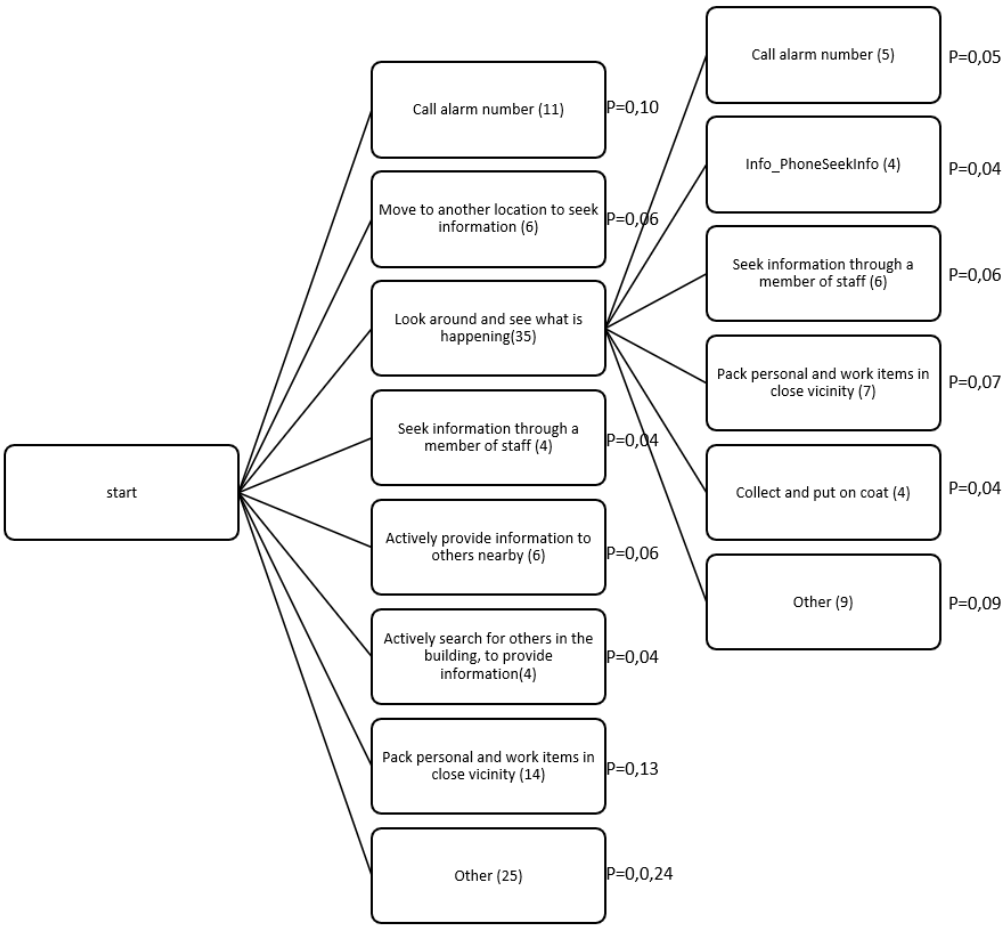

Figure B.36: Probability tree for UK Fire seen, Closed space (situation 6)

B.7. Remaining chances for performing response tasks

Table B.8: Remaining chances for performing response tasks in the basic scenario (situation 1)

Task Type	Czech Republic				Poland				turkey				UK			
	Freq. total	Freq. tree	Freq. left	**Remaning chance (%)**	Freq. total	Freq. tree	Freq. left	**Remaning chance (%)**	Freq. total	Freq. tree	Freq. left	**Remaning chance (%)**	Freq. total	Freq. tree	Freq. left	**Remaning chance (%)**
Phone someone to seek information	7	0	7	**7**	5	0	5	**5**	18	0	18	**17**	8	0	8	**8**
Seek information through electronic media	7	0	7	**7**	3	0	3	**3**	24	0	24	**23**	7	0	7	**7**
Seek information trough conversations with other people nearby	48	22	26	**25**	60	38	22	**21**	53	16	37	**35**	36	11	25	**24**
Move to another location to seek information	39	8	31	**30**	17	0	17	**16**	18	0	18	**17**	23	6	17	**16**
Look around and see what is happening	80	72	8	**8**	90	72	18	**17**	74	53	21	**20**	75	58	17	**16**
Seek information through a member of staff	56	32	24	**23**	64	34	30	**29**	71	38	33	**31**	37	19	18	**17**
Phone someone to provide information	8	0	8	**8**	7	0	7	**7**	16	0	16	**15**	8	0	8	**8**
Actively provide information to others nearby	21	0	21	**20**	27	4	23	**22**	20	0	20	**19**	13	0	13	**12**
Actively search for others in the building to provide information	20	0	20	**19**	27	0	27	**26**	19	0	19	**18**	17	0	17	**16**
Work-related duties	13	5	8	**8**	33	15	18	**17**	51	4	47	**45**	16	0	16	**15**
Pack personal and work items in close vicinity	79	48	31	**30**	80	48	32	**30**	79	38	41	**39**	65	29	36	**34**
Collect and put on coat	39	8	31	**30**	33	8	25	**24**	30	0	30	**29**	49	17	32	**30**
Change footwear/ glasses / clothing	7	0	7	**7**	6	0	6	**6**	6	0	6	**6**	12	0	12	**11**
Physically assist others	39	0	39	**37**	50	0	50	**48**	49	6	43	**41**	19	0	19	**18**
Collect emergency equipment	14	0	14	**13**	28	0	28	**27**	41	6	35	**33**	20	0	20	**19**

Table B.9: Remaining chances for performing response tasks in the Basic scenario, Closed space (situation 2)

Task Type	Czech Republic				Poland				turkey				UK			
	Freq. total	Freq. tree	Freq. left	**Remaning chance (%)**	Freq. total	Freq. tree	Freq. left	**Remaning chance (%)**	Freq. total	Freq. tree	Freq. left	**Remaning chance (%)**	Freq. total	Freq. tree	Freq. left	**Remaning chance (%)**
Phone someone to seek information	11	0	11	**10**	11	0	11	**10**	26	0	26	**25**	9	0	9	**9**
Seek information through electronic media	5	0	5	**5**	7	0	7	**7**	22	0	22	**21**	11	0	11	**10**
Move to another location to seek information	49	8	41	**39**	40	0	40	**38**	41	0	41	**39**	20	6	14	**13**
Look around and see what is happening	65	72	-7	**0**	68	72	-4	**0**	57	53	4	**4**	44	58	-14	**0**
Seek information through a member of staff	46	20	26	**25**	58	20	38	**36**	73	25	48	**46**	37	13	24	**23**
Phone someone to provide information	13	0	13	**12**	10	0	10	**10**	21	0	21	**20**	11	0	11	**10**
Actively search for others in the building to provide information	13	0	13	**12**	20	0	20	**19**	22	0	22	**21**	20	0	20	**19**
Work-related duties	13	5	8	**8**	33	5	28	**27**	51	4	47	**45**	16	0	16	**15**
Pack personal and work items in close vicinity	79	36	43	**41**	80	30	50	**48**	79	32	47	**45**	65	29	36	**34**
Collect and put on coat	39	4	35	**33**	33	8	25	**24**	30	0	30	**29**	49	17	32	**30**
Change footwear/ glasses / clothing	7	0	7	**7**	6	0	6	**6**	6	0	6	**6**	12	0	12	**11**
Physically assist others	39	0	39	**37**	50	0	50	**48**	49	6	43	**41**	19	0	19	**18**
Collect emergency equipment	14	0	14	**13**	28	0	28	**27**	41	6	35	**33**	20	0	20	**19**

Table B.10: Remaining chances for performing response tasks Informed by staff (situation 3)

Task Type	Czech Republic				Poland				turkey				UK			
	Freq. total	Freq. tree	Freq. left	**Remaning chance (%)**	Freq. total	Freq. tree	Freq. left	**Remaning chance (%)**	Freq. total	Freq. tree	Freq. left	**Remaning chance (%)**	Freq. total	Freq. tree	Freq. left	**Remaning chance (%)**
Phone someone to seek information	9	0	9	**9**	12	0	12	**11**	22	0	22	**21**	10	0	10	**10**
Seek information through electronic media	6	0	6	**6**	8	0	8	**8**	27	0	27	**26**	11	0	11	**10**
Seek information trough conversations with other people nearby	41	6	35	**33**	41	8	33	**31**	49	11	38	**36**	40	13	27	**26**
Move to another location to seek information	35	10	25	**24**	20	0	20	**19**	21	4	17	**16**	19	5	14	**13**
Look around and see what is happening	68	50	18	**17**	81	59	22	**21**	65	39	26	**25**	60	35	25	**24**
Seek information through a member of staff	41	12	29	**28**	47	17	30	**29**	64	29	35	**33**	44	14	30	**29**
Phone someone to provide information	10	0	10	**10**	13	0	13	**12**	20	0	20	**19**	11	0	11	**10**
Actively provide information to others nearby	24	0	24	**23**	25	4	21	**20**	22	0	22	**21**	20	0	20	**19**
Actively search for others in the building to provide information	19	0	19	**18**	24	0	24	**23**	24	0	24	**23**	21	0	21	**20**
Work-related duties	12	4	8	**8**	29	14	15	**14**	43	15	28	**27**	11	0	11	**10**
Pack personal and work items in close vicinity	69	18	51	**49**	73	33	40	**38**	66	20	46	**44**	53	28	25	**24**
Collect and put on coat	37	19	18	**17**	31	11	20	**19**	21	0	21	**20**	46	32	14	**13**
Change footwear/ glasses / clothing	10	0	10	**10**	6	0	6	**6**	5	0	5	**5**	11	0	11	**10**
Physically assist others	34	0	34	**32**	43	13	30	**29**	50	7	43	**41**	17	0	17	**16**
Collect emergency equipment	14	0	14	**13**	27	0	27	**26**	37	10	27	**26**	17	6	11	**10**

Table B.11: Remaining chances for performing response tasks Informed by staff, Closed space (situation 4)

Task Type	Czech Republic				Poland				turkey				UK			
	Freq. total	Freq. tree	Freq. left	**Remaning chance (%)**	Freq. total	Freq. tree	Freq. left	**Remaning chance (%)**	Freq. total	Freq. tree	Freq. left	**Remaning chance (%)**	Freq. total	Freq. tree	Freq. left	**Remaning chance (%)**
Phone someone to seek information	9	0	9	**9**	12	0	12	**11**	22	0	22	**21**	10	0	10	**10**
Seek information through electronic media	6	0	6	**6**	8	0	8	**8**	27	0	27	**26**	11	0	11	**10**
Move to another location to seek information	35	10	25	**24**	20	0	20	**19**	21	4	17	**16**	19	5	14	**13**
Look around and see what is happening	68	50	18	**17**	81	59	22	**21**	65	39	26	**25**	60	35	25	**24**
Seek information through a member of staff	41	12	29	**28**	47	17	30	**29**	64	29	35	**33**	44	10	34	**32**
Phone someone to provide information	10	0	10	**10**	13	0	13	**12**	20	0	20	**19**	11	0	11	**10**
Actively search for others in the building to provide information	19	0	19	**18**	24	0	24	**23**	24	0	24	**23**	21	0	21	**20**
Work-related duties	12	4	8	**8**	29	14	15	**14**	43	15	28	**27**	11	0	11	**10**
Pack personal and work items in close vicinity	69	18	51	**49**	73	33	40	**38**	66	20	46	**44**	53	28	25	**24**
Collect and put on coat	37	19	18	**17**	31	11	20	**19**	21	0	21	**20**	46	32	14	**13**
Change footwear/ glasses / clothing	10	0	10	**10**	6	0	6	**6**	5	0	5	**5**	11	0	11	**10**
Physically assist others	34	0	34	**32**	43	13	30	**29**	50	7	43	**41**	17	0	17	**16**
Collect emergency equipment	14	0	14	**13**	27	0	27	**26**	37	10	27	**26**	17	6	11	**10**

Table B.12: Remaining chances for performing response tasks Fire (situation 5)

Task Type	Czech Republic				Poland				turkey				UK			
	Freq. total	Freq. tree	Freq. left	**Remaning chance (%)**	Freq. total	Freq. tree	Freq. left	**Remaning chance (%)**	Freq. total	Freq. tree	Freq. left	**Remaning chance (%)**	Freq. total	Freq. tree	Freq. left	**Remaning chance (%)**
Phone someone to seek information	38	0	38	**36**	37	0	37	**35**	51	0	51	**49**	54	4	50	**48**
Seek information through electronic media	41	0	41	**39**	34	0	34	**32**	46	0	46	**44**	53	0	53	**50**
Seek information trough conversations with other people nearby	54	14	40	**38**	57	6	51	**49**	67	14	53	**50**	64	6	58	**55**
Move to another location to seek information	49	0	49	**47**	43	0	43	**41**	55	0	55	**52**	56	6	50	**48**
Look around and see what is happening	77	51	26	**25**	80	57	23	**22**	69	32	37	**35**	78	35	43	**41**
Seek information through a member of staff	59	18	41	**39**	55	13	42	**40**	74	21	53	**50**	62	10	52	**50**
Phone someone to provide information	39	0	39	**37**	42	0	42	**40**	47	6	41	**39**	55	0	55	**52**
Actively provide information to others nearby	51	0	51	**49**	53	5	48	**46**	58	6	52	**50**	57	6	51	**49**
Actively search for others in the building to provide information	53	0	53	**50**	46	0	46	**44**	50	0	50	**48**	57	6	51	**49**
Work-related duties	43	0	43	**41**	40	5	35	**33**	57	6	51	**49**	51	0	51	**49**
Pack personal and work items in close vicinity	73	27	46	**44**	67	32	35	**33**	68	15	53	**50**	60	21	39	**37**
Collect and put on coat	51	5	46	**44**	44	0	44	**42**	48	0	48	**46**	57	4	53	**50**
Change footwear/ glasses / clothing	43	0	43	**41**	34	0	34	**32**	40	0	40	**38**	56	0	56	**53**
Physically assist others	62	0	62	**59**	59	0	59	**56**	71	7	64	**61**	59	0	59	**56**
Collect emergency equipment	46	0	46	**44**	50	0	50	**48**	55	5	50	**48**	56	0	56	**53**
Call alarm number	50	21	29	**28**	60	38	22	**21**	38	19	19	**18**	35	16	19	**18**
Fight the fire	22	6	16	**15**	19	0	19	**18**	19	0	19	**18**	5	0	5	**5**

Table B.13: Remaining chances for performing response tasks Fire, Closed space (situation 6)

Task Type	Czech Republic				Poland				turkey				UK			
	Freq. total	Freq. tree	Freq. left	**Remaning chance (%)**	Freq. total	Freq. tree	Freq. left	**Remaning chance (%)**	Freq. total	Freq. tree	Freq. left	**Remaning chance (%)**	Freq. total	Freq. tree	Freq. left	**Remaning chance (%)**
Phone someone to seek information	38	0	38	**36**	37	0	37	**35**	51	0	51	**49**	54	4	50	**48**
Seek information through electronic media	41	0	41	**39**	34	0	34	**32**	46	0	46	**44**	53	0	53	**50**
Move to another location to seek information	49	0	49	**47**	43	0	43	**41**	55	0	55	**52**	56	6	50	**48**
Look around and see what is happening	77	51	26	**25**	80	57	23	**22**	69	32	37	**35**	78	35	43	**41**
Seek information through a member of staff	59	18	41	**39**	55	13	42	**40**	74	16	58	**55**	62	10	52	**50**
Phone someone to provide information	39	0	39	**37**	42	0	42	**40**	47	6	41	**39**	55	0	55	**52**
Actively search for others in the building to provide information	53	0	53	**50**	46	0	46	**44**	50	0	50	**48**	57	6	51	**49**
Work-related duties	43	0	43	**41**	40	5	35	**33**	57	6	51	**49**	51	0	51	**49**
Pack personal and work items in close vicinity	73	27	46	**44**	67	32	35	**33**	68	15	53	**50**	60	21	39	**37**
Collect and put on coat	51	5	46	**44**	44	0	44	**42**	48	0	48	**46**	57	4	53	**50**
Change footwear/ glasses / clothing	43	0	43	**41**	34	0	34	**32**	40	0	40	**38**	56	0	56	**53**
Physically assist others	62	0	62	**59**	59	0	59	**56**	71	7	64	**61**	59	0	59	**56**
Collect emergency equipment	46	0	46	**44**	50	0	50	**48**	55	5	50	**48**	56	0	56	**53**
Call alarm number	50	21	29	**28**	60	38	22	**21**	38	19	19	**18**	35	16	19	**18**
Fight the fire	22	6	16	**15**	19	0	19	**18**	19	0	19	**18**	5	0	5	**5**

C

Appendix: Model Results

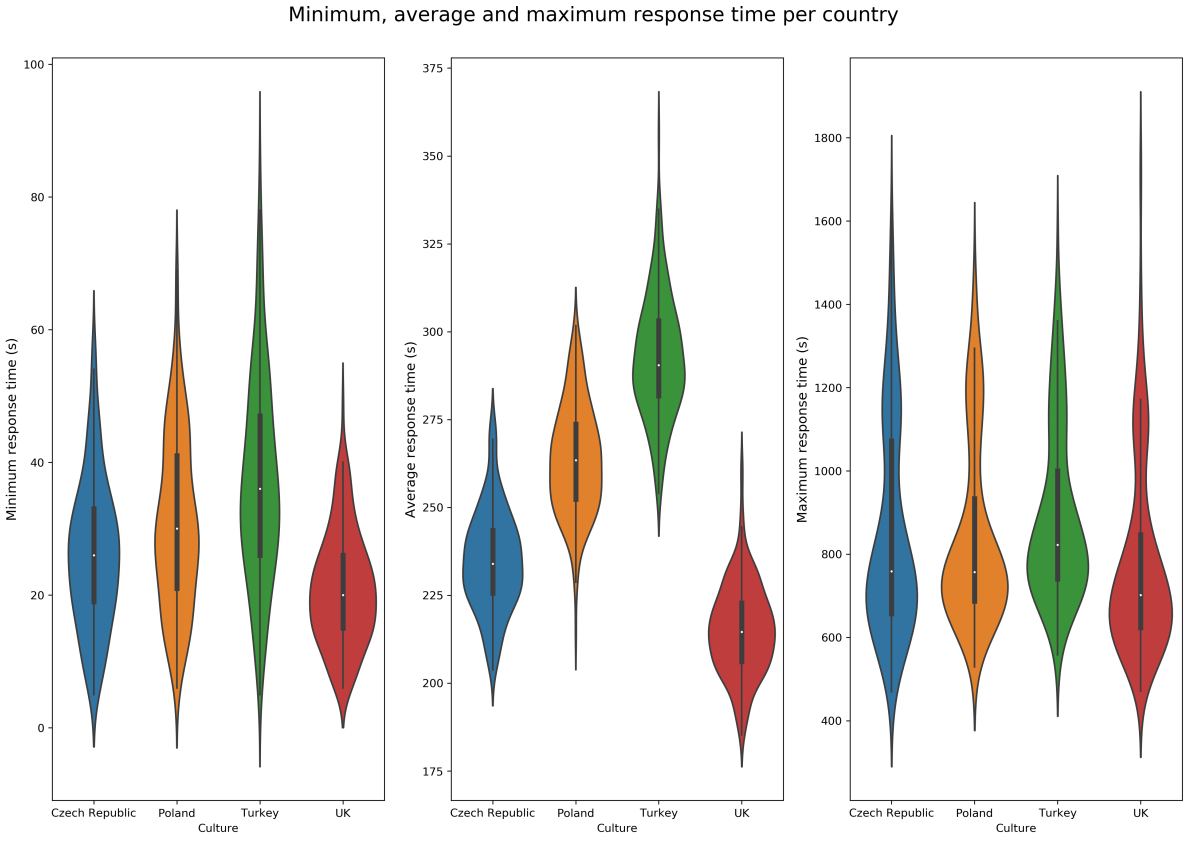

Figure C.1: Violin plots per country for minimum, average and maximum response time

C.1. Sensitivity analysis

C.1.1. Single parameter testing

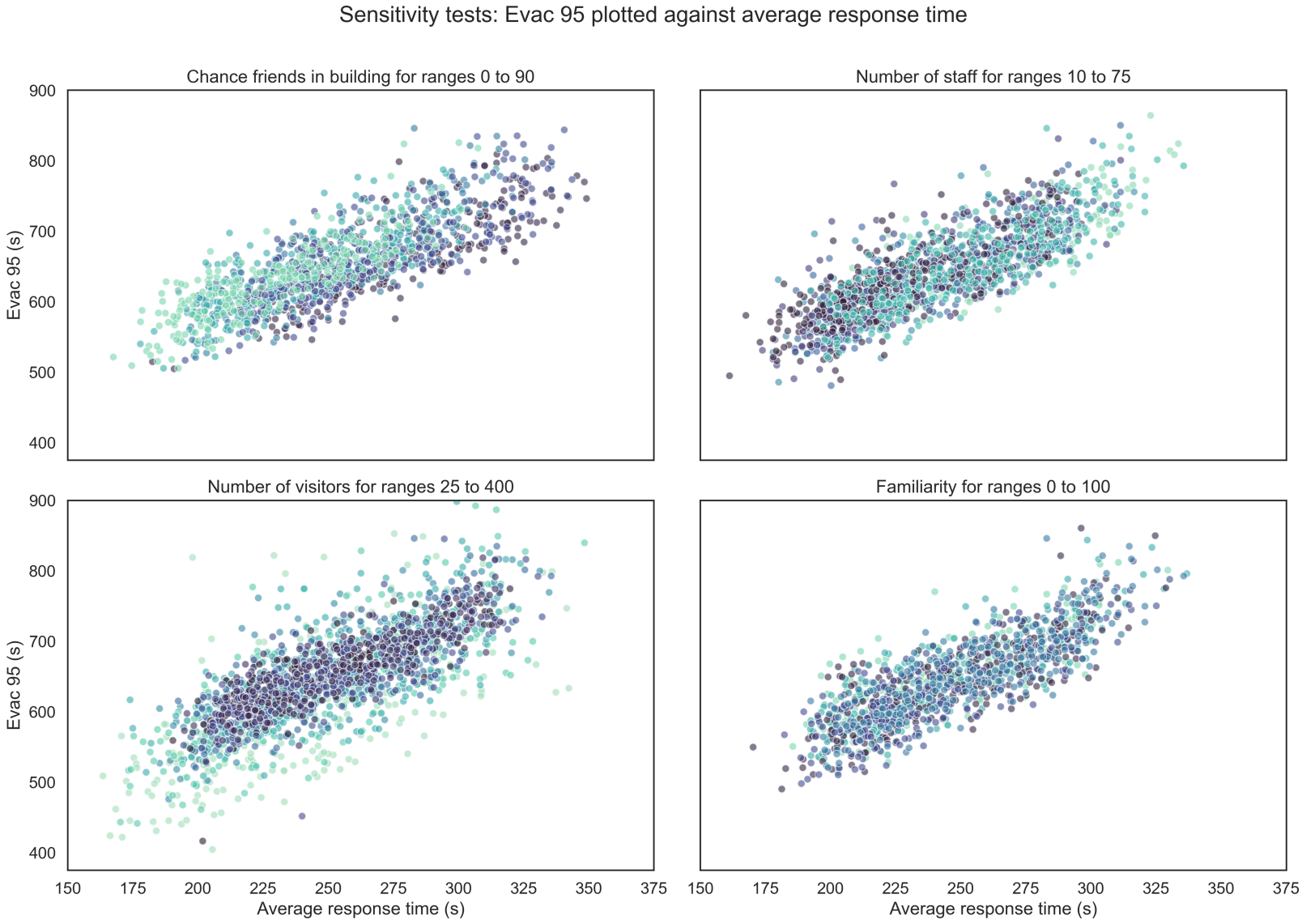

Figure C.2: Influence of model input parameters on Evac95

C.1.2. Double parameter tesing

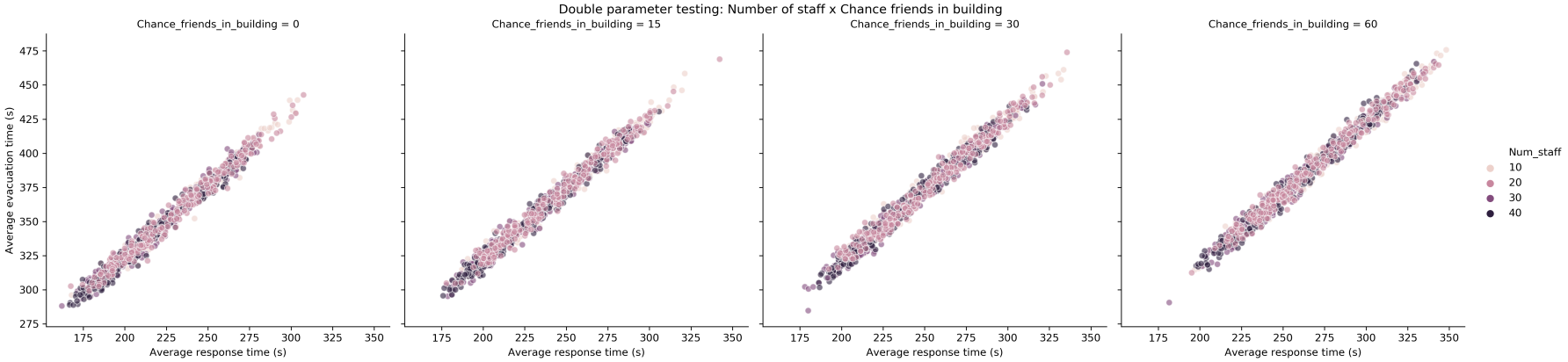

Figure C.3: Double parameter testing: Number of staff x Chance friends in building

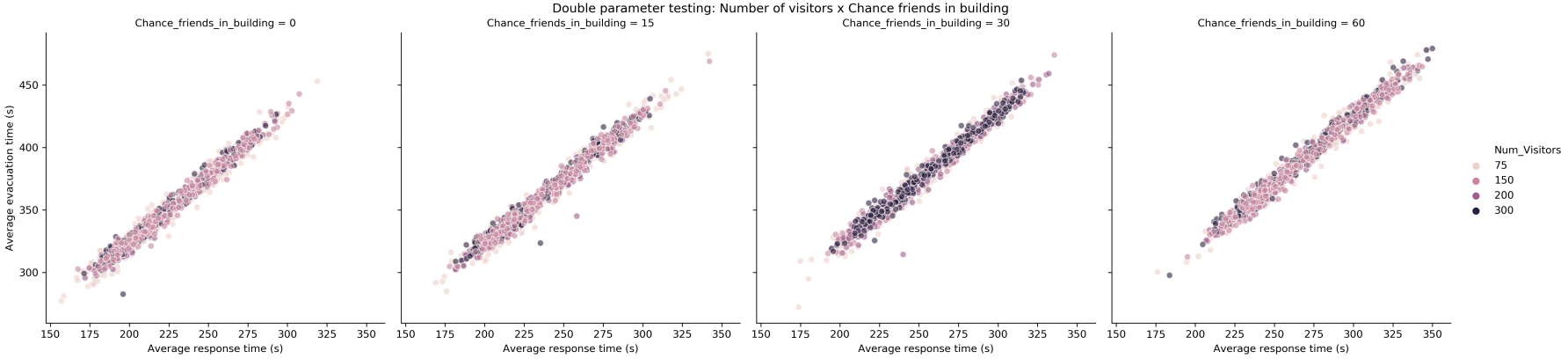

Figure C.4: Double parameter testing: Number of visitors x Chance friends in building

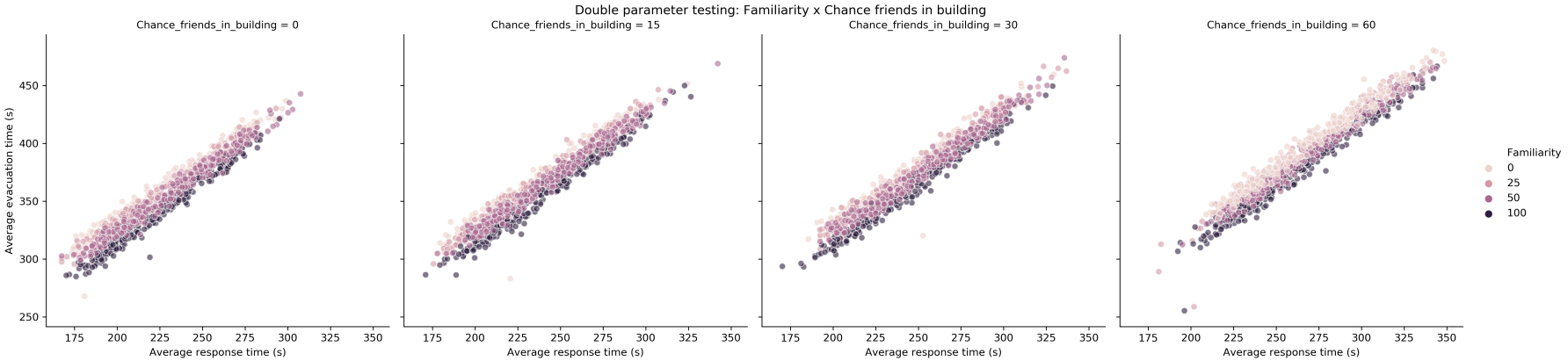

Figure C.5: Double parameter testing: Familiarity x Chance friends in building

Figure C.6: Double parameter testing: Number of staff x Number of visitors

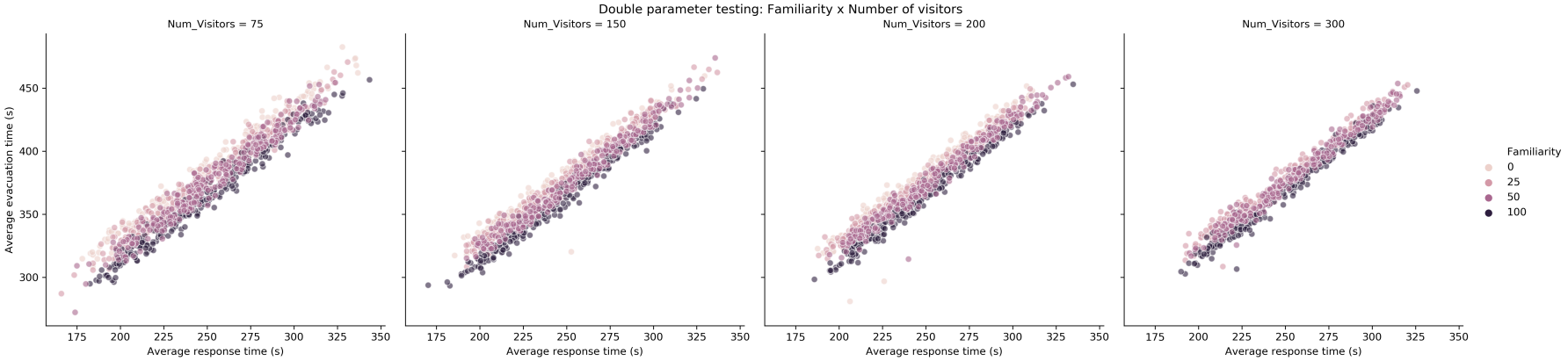

Figure C.7: Double parameter testing: Familiarity x Number of visitors

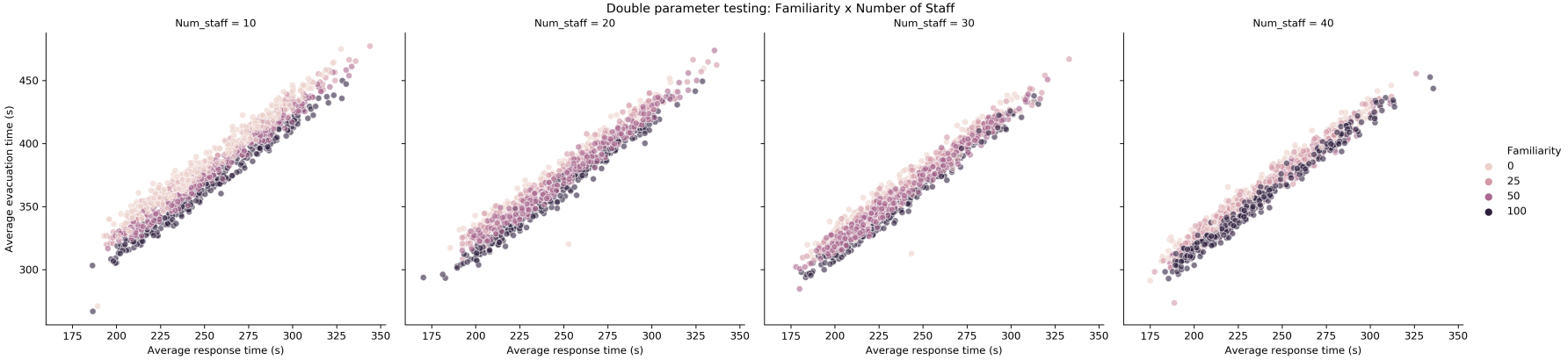

Figure C.8: Double parameter testing: Familiarity x Number of staff

C.2. Effect of cues, setting and affiliation on model outcomes

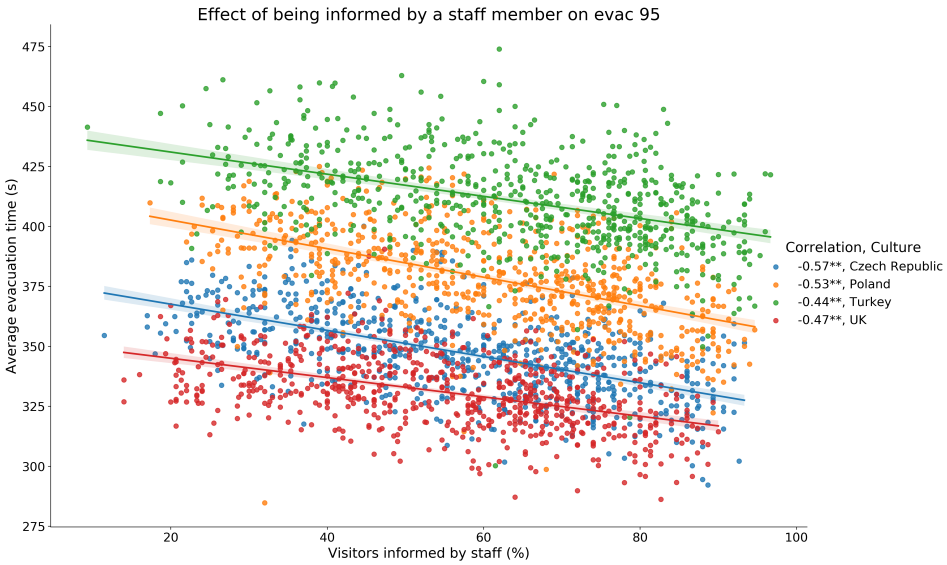

Figure C.9: The effect of being informed by a staff member on average evacuation time

Figure C.10: The effect of being informed by a staff member on Evac 95

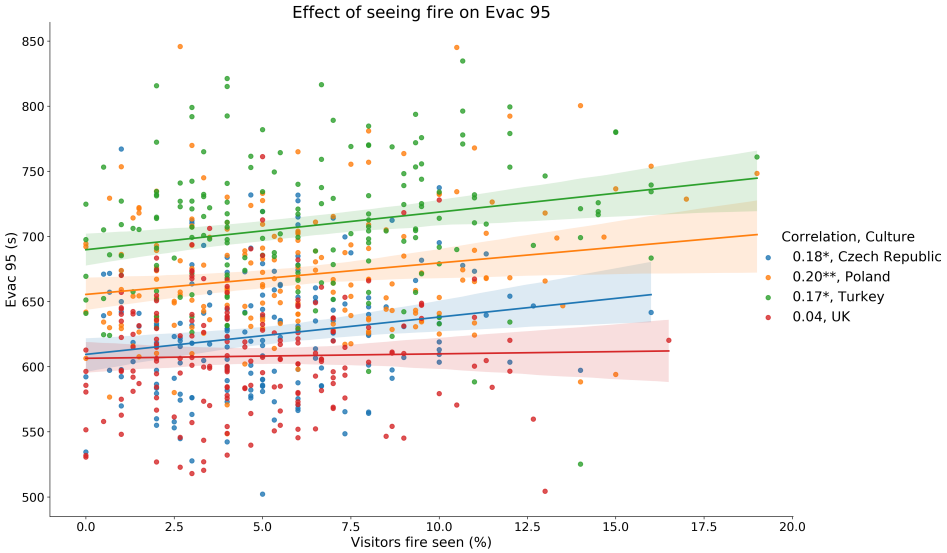

Figure C.11: The effect of seeing fire on Evac 95

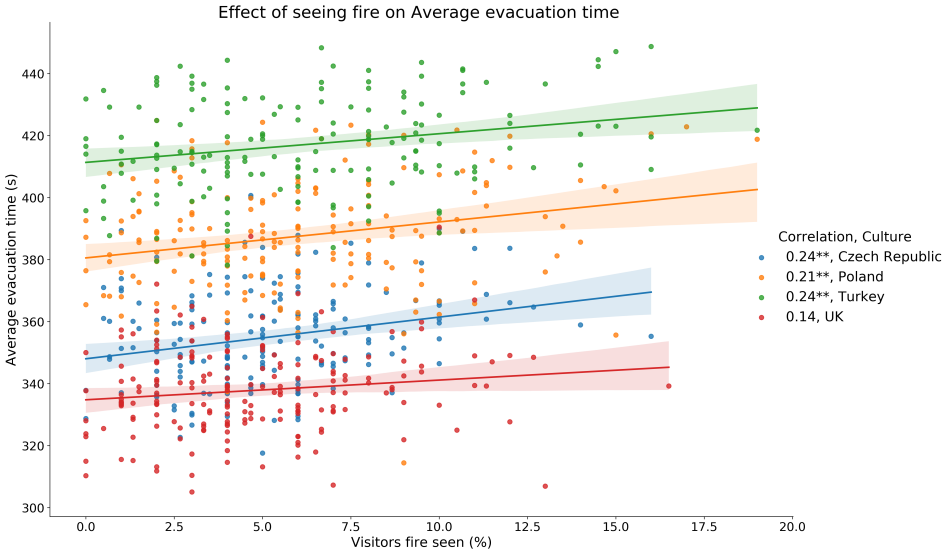

Figure C.12: The effect of seeing fire on average evacuation time

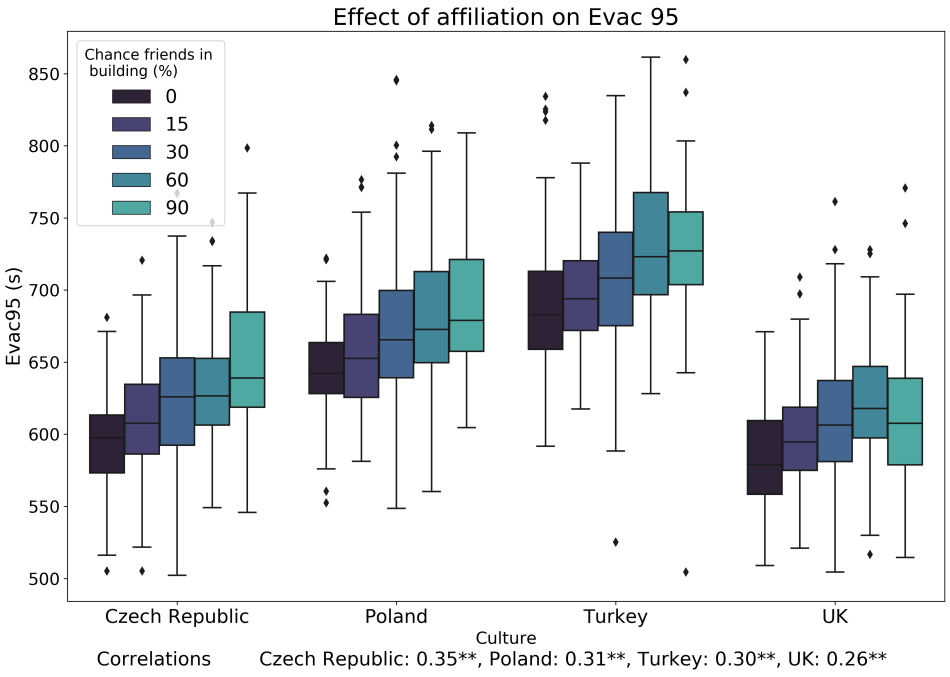

Figure C.13: The effect of affiliation on Evac95

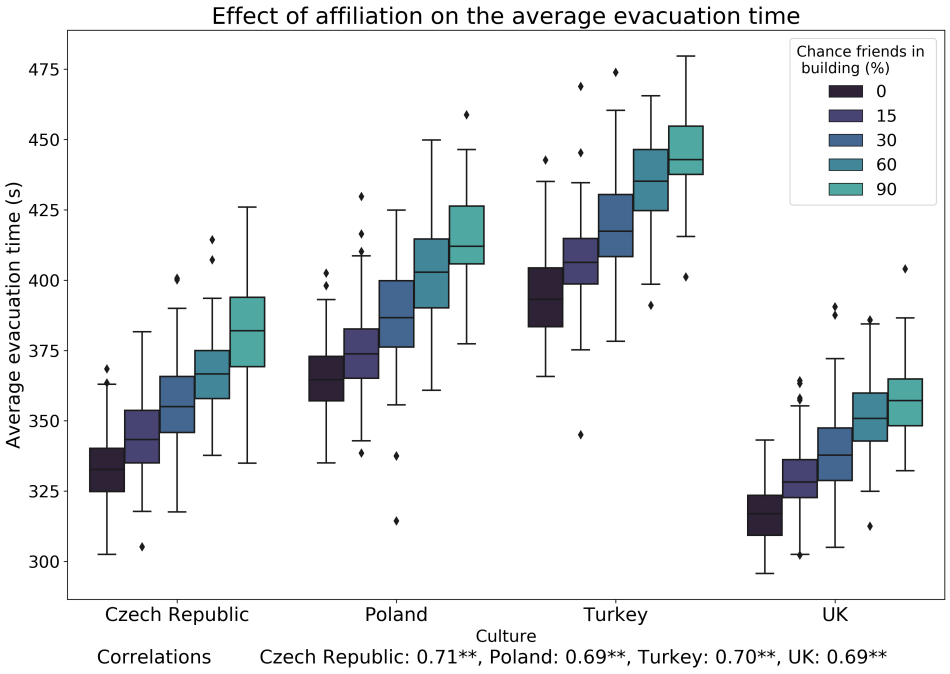

Figure C.14: The effect of affiliation on average evacuation time

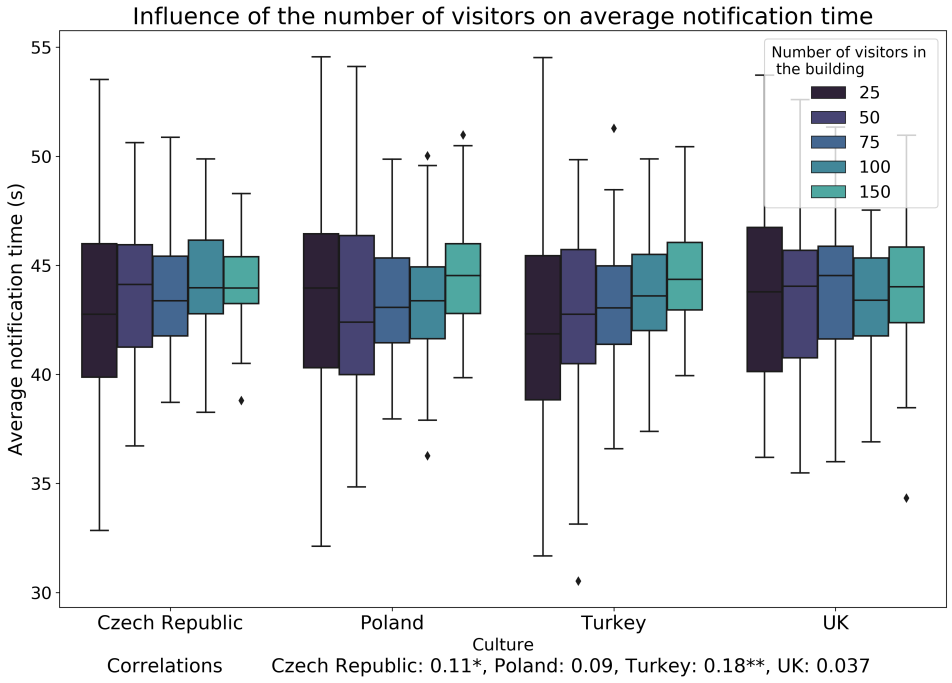

Figure C.15: The effect setting on average notification time

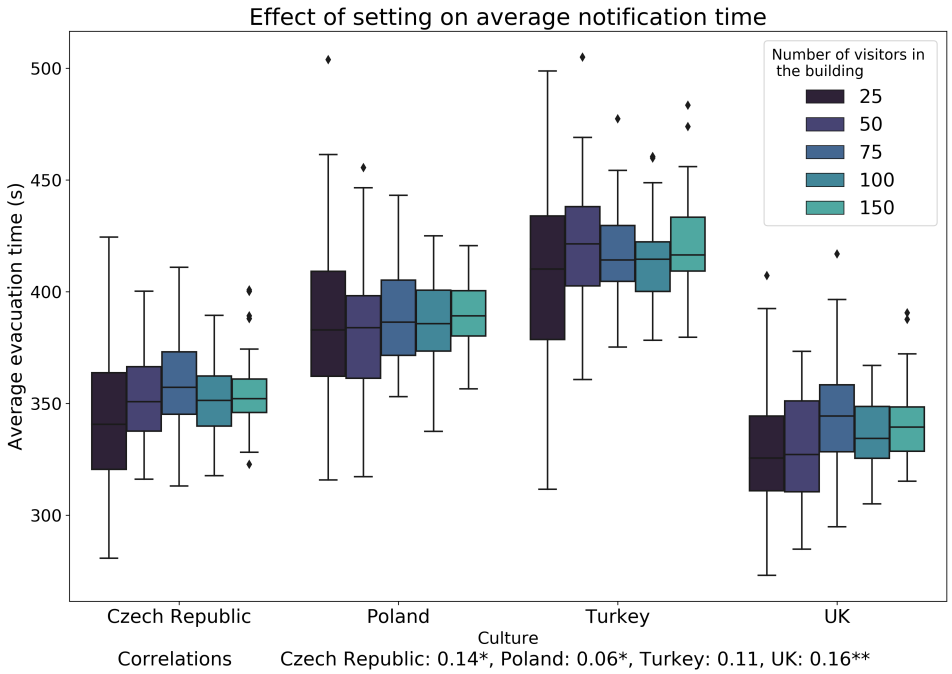

Figure C.16: The effect setting on average evacuation time

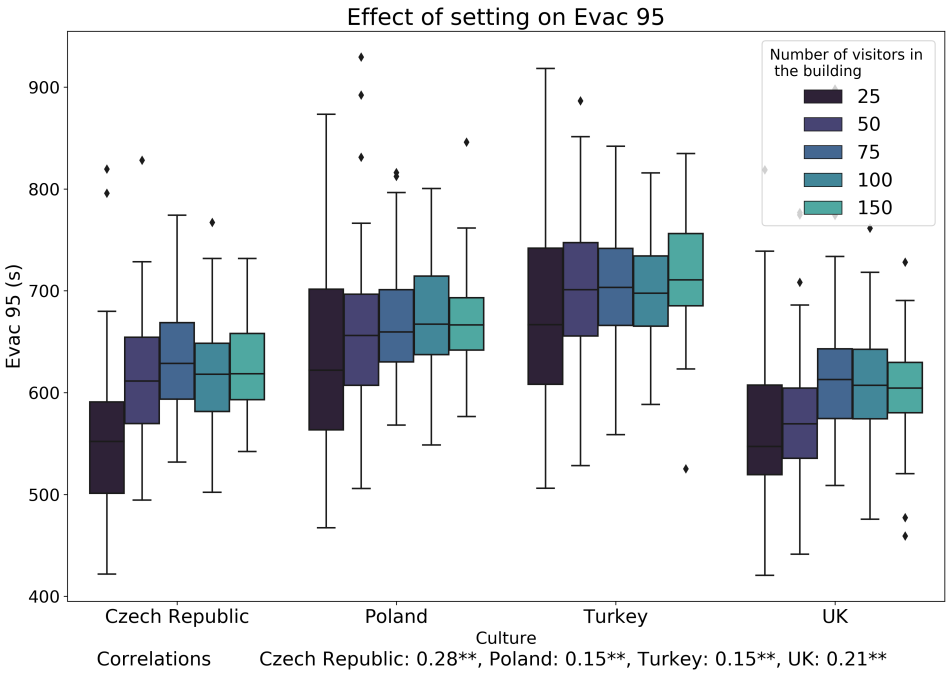

Figure C.17: The effect setting on Evac 95