The Effectiveness of Evacuation Alarms in Multi-Hazard Environments

Robin Magnusson & Claude Pagnon Eriksson

Division of Fire Safety Engineering |
Faculty of Engineering | Lund University

The Effectiveness of Evacuation Alarms in Multi-Hazard Environments

Robin Magnusson & Claude Pagnon Eriksson

Lund 2019

Title
The Effectiveness of Evacuation Alarms in Multi-Hazard Environments

Titel
Effektiviteten av Utrymningslarm i Anläggningar med Flera Faror

Authors
Robin Magnusson & Claude Pagnon Eriksson

Report 5588
ISRN: LUTVDG/TVBB--5588--SE

Number of pages: 51 (excluding Appendixes)
Illustrations: by Robin Magnusson & Claude Pagnon Eriksson

Keywords
Evacuation, evacuation alarms, auditory alarms, alarm perception, perceived urgency, multi-hazard.

Abstract
The aim of this thesis is to investigate the effectiveness of using specific alarms for each hazard versus the effectiveness of using a single alarm for all hazards in multi-hazard facilities. The research was conducted by disseminating online questionnaires containing audio files of different alarms to occupants of multi-hazards facilities and conducting interviews with safety experts working at multi-hazard facilities. Responses show variability concerning the perceived urgency of an alarm and what respondents associate with that alarm. Each of the alarms were perceived as both 'not urgent' and 'very urgent' at least once by different respondents, however a trend was observed, suggesting that there might be other factors affecting the perceived urgency than those identified in the literature, for example the pulse pattern. As for the meaning, it could range from a hazard (such as radiation) to a computer error or a reversing truck for the same alarm. The results also indicated that alarms that were perceived as more urgent were also more often associated to a hazard as opposed to alarms that were perceived as less urgent that were more often considered as less hazardous. Responses indicated that people having experienced a real emergency situation preferred the use of multiple alarms more than the people with no experience. Based on the responses, it is recommended that the number of alarms used at a multi-hazard facility should depend on the number of evacuation responses rather than on the number of hazards.

Brandteknik
Lunds tekniska högskola
Lunds universitet
Box 118
221 00 Lund

www.brand.lth.se
Telefon: 046 - 222 73 60

Division of Fire Safety Engineering
Faculty of Engineering
Lund University
P.O. Box 118
SE-221 00 Lund
Sweden

www.brand.lth.se
Telephone: +46 46 222 73 60

Acknowledgements

This Master's Thesis is the final stepping stone in acquiring our Master of Science Degree in Risk Management and Safety Engineering and Bachelor's Degree in Fire Safety Engineering at Lund University. This project has been interesting and challenging and we would like to thank the following for their help:

Enrico Ronchi at the Division of Fire Safety Engineering at Lund University – for being an enthusiastic and supportive supervisor throughout the writing process.

Fredrik Jörud at ESS – for suggesting the research topic and providing helpful information.

Marina Giampietro at ESS – for helping us with the dissemination of the questionnaire.

Stefan Wiklund at MAX IV – for taking the time to meet us and give us a tour of MAX IV as well as helping us with the dissemination of the questionnaire.

Valentin Algoet, *Saverio La Mendola* and *Oriol Rios* at CERN – for providing useful information and comments for the questionnaire.

Further, we would like to thank those who participated in the interviews and everyone else who helped us with the questionnaire dissemination in some way and, of course, those who answered the questionnaire. Finally, we would like to thank our friends and family for their support along the way.

Robin Magnusson & Claude Pagnon Eriksson, Lund 2019.

Summary

Evacuation alarms are used to make building occupants aware of a danger and to make them understand that they should evacuate. In certain environments, occupants may be exposed to many different hazards. Some of these so-called multi-hazard facilities use different auditory alarms for different types of hazards as opposed to using one alarm for all types of hazards. However, limited research has been conducted to evaluate the effectiveness of both options. Earlier studies have shown that alarms may be misinterpreted and that the perceived urgency of an alarm can be modified by altering certain acoustics properties such as frequency or pulse rate. Therefore, the aim of the thesis is to investigate the effectiveness of using specific alarms for each hazard versus the effectiveness of using a single alarm for all hazards in multi-hazard facilities, resulting in the following research questions:

- Is the urgency of an alarm interpreted differently by different people?
- Do different people associate alarm signals to the same hazards, or do they interpret the alarms differently?
- Is there a relationship between the perceived urgency of an alarm and the interpretation of that alarm?
- What are the respective views of safety experts and other occupants of multi-hazard facilities on having multiple alarms?

This study comprises a literature study, a questionnaire study and interviews. The literature study focuses on human behaviour in evacuations and models relevant to evacuation situations, evacuation alarms and how their meaning and urgency are perceived, as well as the role of safety culture. To collect data an online questionnaire with audio files of different alarm sounds was designed and disseminated to the occupants at three multi-hazard facilities. Fifty-four people responded to the questionnaire. In addition to this, interviews were held with five safety experts currently working in different multi-hazard facilities.

The results lead to the following conclusions:

- People generally interpret the urgency of each alarm differently from each other, although some trends can be observed for certain alarms. For instance, the intermittent alarm with a pulse pattern of increasing frequency (like a “slow whoop”) received the highest mean perceived urgency. This suggests that there may be more factors affecting the perceived urgency of an alarm than those identified in the literature.
- The meaning of different alarms is interpreted differently. An unknown alarm can be intuitively associated to different scenarios, ranging from hazards to minor technical errors, depending on the listener. This highlights the importance of training.
- Alarms that have a higher perceived urgency are more often associated to a hazard, requiring evacuation, while alarms with a lower perceived urgency are more often associated with situations not requiring an evacuation.
- The conclusion that can be drawn about the opinions of interviewees and questionnaire respondents on the use of one alarm or several alarms is that these vary amongst both groups and that no option is clearly preferred by the majority. However, the respondents that had experienced a real emergency situation preferred the use of multiple alarms to a

greater extent than those without previous experience. Further, a recurring idea is that alarms should not be based on the hazard that triggers them but on the type of evacuation response that is required. This implies that the number of alarms used at a multi-hazard facility should depend on the number of necessary evacuation responses and not on the number of hazards present.

Sammanfattning

Utrymningslarm används för att varna människor i en byggnad för en fara och för att få dem att förstå att de ska utrymma. Det finns vissa anläggningar inom vilka människor kan utsättas för olika typer av faror. I dessa anläggningar finns två olika alternativ för larmanvändning, vissa använder olika ljudlarm för olika typer av faror medan vissa har ett och samma larm för alla faror. Det finns dock få studier som utvärderar effektiviteten av båda alternativen. Tidigare studier har visat att larm kan misstolkas och att deras brådskande karaktär, ”urgency”, kan regleras genom att ändra akustiska egenskaper såsom ton och pulsfrekvens. Syftet med detta examensarbete är därmed att undersöka effektiviteten av att använda olika larm för olika faror gentemot effektiviteten av att använda ett larm för alla faror i berörda verksamheter. Följande frågeställningar identifierades:

- Uppfattas larms ”urgency” olika av olika personer?
- Associerar olika personer larm med samma faror eller tolkar dem larmen olika?
- Finns det ett samband mellan uppfattad ”urgency” och tolkningen av larmens betydelse?
- Vilka åsikter och synpunkter har säkerhetsexperter samt personer som befinner sig i anläggningar med flera faror om användningen av flera larm?

Detta examensarbete utgörs av en litteraturstudie, en enkätundersökning och intervjuer. Teori om människors beteende vid utrymning och utrymningsmodeller ingår i litteraturstudien, tillsammans med teori kring säkerhetskultur samt utrymningslarm och hur deras betydelse och ”urgency” uppfattas. Datainsamling gjordes genom att skicka ut en webbenkät med ljudfiler på olika larm till personer på tre olika anläggningar med flera faror. Femtiofyra personer svarade på enkäten. Utöver detta hölls även intervjuer med fem säkerhetsexperter som jobbar på olika liknande anläggningar.

Följande slutsatser kunde dras från resultaten:

- Överlag uppfattar personer larmens ”urgency” på olika sätt för varje larm, trots detta har några trender identifierats. Till exempel erhöll det intermittenta larmet med ett pulsmönster med stigande ton det högsta medelvärdet för uppfattad ”urgency”. Detta pekar på att det kan finnas andra faktorer som kan påverka ”urgency” än de som identifierades i litteraturen.
- Larmens betydelse tolkas också olika. Om en person inte har lärt sig ett larm kan det intuitivt associeras med olika saker, såsom faror eller mindre tekniska fel. Tolkningen varierar alltså beroende på lyssnaren vilket också understryker vikten av träning.
- Utrymningslarm med en ”urgency” som uppfattas som hög associeras i större utsträckning med en fara som kräver utrymning. Medan utrymningslarm med en ”urgency” som uppfattas som låg oftare tolkas som larm för situationer som inte kräver utrymning.
- Utifrån intervjuerna och enkätsvaren kan slutsatsen dras att åsikterna om dem olika alternativen för larmanvändning varierar inom båda svarsgrupperna och inget alternativ föredras av majoriteten. Däremot visar enkätsvaren att dem som hade erfarenhet av en verklig nödsituation föredrar användning av flera utrymningslarm i större utsträckning än respondenterna utan tidigare erfarenhet. Utöver detta identifieras den återkommande synpunkten att larmen inte ska vara kopplade till specifika faror utan att dem ska vara styrda av de olika typer av responser som krävs. Detta innebär att antalet utrymningslarm

som används i en anläggning med flera faror bör bero på antalet nödvändiga responser vid utrymning och inte på antalet faror som finns i anläggningen.

Table of Contents

1 Introduction

Evacuation alarms can play a major role in helping to save people's lives in emergencies as they can alert them that an event out of the ordinary is going on. This means that research on how people interpret evacuation alarms is important. This way alarms can then be designed to be more effective, prompting a faster and safer evacuation for building occupants. In multi-hazard environments, such as nuclear and radiation research facilities or laboratories, the occupants can be exposed to several hazards including (but not limited to) fires, radiation and hypoxic conditions. To cope with these different hazards, some facilities have dedicated evacuation alarms for the specific threats.

Research experiments (Benthorn & Frantzich, 1999) done with shoppers in an IKEA store has shown that people generally have difficulties interpreting alarms with a ring signal, possibly because it is not clear what the alarm is referring to, leaving some to perceive it as a general warning and others thinking that it is simply a ring signal for something like a telephone. What the study by Benthorn and Frantzich shows is that the sound of the alarm affects how the listener perceives what the alarm is refereeing to. Today little information can be found on how the evacuation alarms affect how the occupants at multi-hazard facilities perceive the risk.

Different alarm signals or sounds can have an impact on the occupants' perceived level of urgency. According to Edworthy (2011) it is important that alarms are hazard-matched, meaning that more hazardous situations have more urgent alarms. The author has shown, through her research, that the urgency of an alarm can be altered by changing parameters including pitch, rhythm and loudness (Edworthy J. , 2011). If the perceived level of urgency is high it can potentially lead to a faster evacuation time. It is therefore interesting to study how different signals are interpreted in multi-hazard environments, particularly since there are so many different alarm sounds that are used today. A fire alarm in Sweden can sound differently from a fire alarm in France. The sound of the alarm can also vary depending on the building in which it is used.

This Master Thesis investigates how people in multi-hazard facilities perceive the urgency and meaning of different non-verbal auditory alarms. Literature on human behaviour in evacuations and evacuation scenarios was studied as well as literature on alarms and safety culture. In addition to the literature study an online questionnaire was designed and sent out to several multi-hazard facilities to collect data. Interviews were also held with safety experts to get their opinion on the use of a single alarm versus multiple alarms.

1.1 Aim and objective

The aim of this study is to investigate the effectiveness of multiple alarms in multi-hazard facilities versus the effectiveness of using a single alarm for all hazards. In other words, the overall aim is to determine whether it is more effective to have one single alarm regardless of the hazard or if it is more effective to have different alarms specific to each hazard.

The objective is to answer the following research questions:

- Is the urgency of an alarm interpreted differently by different people?
- Do different people associate alarm signals to the same hazards, or do they interpret the alarms differently?
- Is there a relationship between the perceived urgency of an alarm and the interpretation of that alarm?
- What are the respective views of safety experts and other occupants of multi-hazard facilities on having multiple alarms?

1.2 Delimitations

In this thesis certain conscious choices have been made that delimit the scope of the study. Focus lies on non-verbal auditory evacuation alarms, hence visual alarm signals such as flashing lights or verbal warning messages are not the focus of the study. The type of facility that is studied is multi-hazard facilities and therefore the result could vary for other types of facilities and should not be generalized without taking this into account. Another delimitation of the thesis is that eight different alarms and three hazards (fire, radiation and low oxygen level) are studied in the questionnaire. There are many more alarms and hazards that could have been studied; however, this delimitation was done to keep the questionnaire short.

1.3 Limitations

The thesis is limited by several factors that are difficult to control. A limitation with the study is that the reliability of the conclusions from the results depend on the number of respondents to the questionnaire. It is not easy to determine the response rate prior to sending out the questionnaire, making it difficult to decide how many people it should be sent to. Also, one of the facilities to which the questionnaire was intended to be sent to could not disseminate it within the timeframe of this study. This resulted in the questionnaire responses all being from multi-hazard facilities in Sweden as well as the responses being fewer than initially expected. When the potential effects of culture on alarm perception was studied the assumption was made that the respondent's nationality reflected the time spent in Sweden which may have been misleading.

A limitation to take into account is that some of the respondents to the questionnaire may be people that are interested in the topic and are more knowledgeable. Their answers can differ from the rest and it can be difficult to identify them, making it complicated to know how their responses have an impact on the result. The quality of the results can also be affected by different types of biases as well as the design of the questionnaire. Finally, the results are discussed mainly based on descriptive statistics.

1.4 Methodology

An initial literature study was performed before writing a project plan and initiating the work. The thesis work process consisted of several steps, illustrated in Figure 1, the first being the definition of the aim and objectives of the thesis as well as formulating the research questions that were to be answered.

The second step was to do a more comprehensive literature study to collect information relevant to the studied subject. This included the following fields: human behaviour in evacuations including risk perception, theory about auditory alarms and safety culture. Furthermore, literature about surveys and questionnaires was also examined. All the literature was found online and consisted of journal articles, reports of earlier studies and books, amongst other sources. Literature was found by searching with keywords and by looking at references used in reports relevant within the studied fields.

The third step in the work process was to design the online questionnaire, improve it based on feedback and disseminate it to the chosen multi-hazard facilities. Since the design of the questionnaire was an important part of this study it is described in more detail later in the report. The next step was interviewing safety experts to collect additional data which was followed by the final step of analysing the results from the questionnaire and interviews and drawing conclusions for the study. Both qualitative and quantitative methods were used for the analysis of the results.

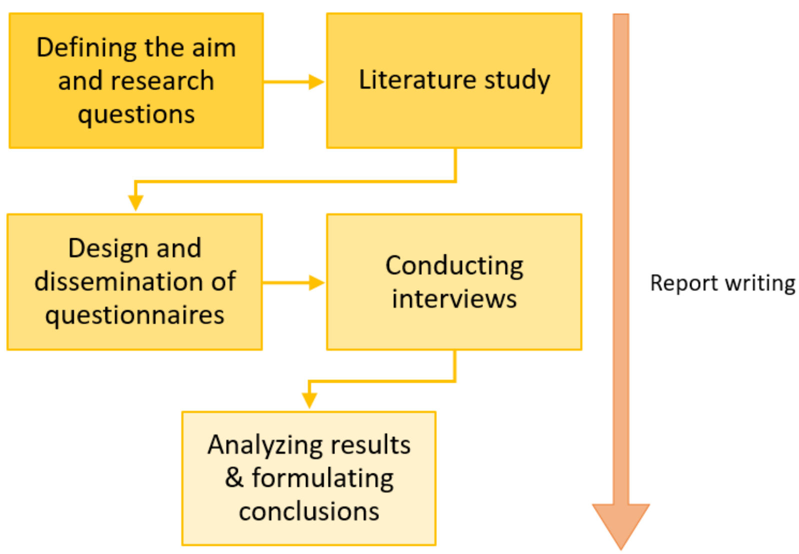


Figure 1. Illustration of the overall work process.

2 Human Behaviour in Evacuations

Although many studies (Benthorn & Frantzich, 1999; Canter, Breaux, & Sime, 1980; Proulx & Sime, 1991) have been conducted in the evacuation research area, there is still much to learn about human behaviour in emergency situations. There is room for more research as the field is vast and humans' behaviours as well as the nature of risks evolve along with the world. Further studies are also needed because there are still divided opinions on some subjects, an example of this is that different evacuation alarms are used in different countries and there is no general agreement on a standard universal fire alarm. Parts of the research on human behaviour in evacuation scenarios will be brought up in this chapter to get an understanding of how alarms among other factors can impact the evacuation of a building.

2.1 Evacuation process models

The evacuation of a building can be regarded as a process which consists of several intervals during which different actions are taken by the evacuating occupants. Figure 2 illustrates how evacuation alarms affect the evacuation time. It is a schematic drawing of an evacuation timeline based on an illustration from SFPE´s *Guide to Human Behaviour in Fire, 2nd Edition* (SFPE, 2019, pp. 21-22). The timeline shows how the evacuation process, in this example during a fire scenario, starts with a fire ignition followed by detection of the fire. The detection could be either due to occupants receiving cues, such as seeing or smelling the fire, or detection by a fire detector which then alerts the occupants. In this example the alarm is triggered after the fire has been detected, this time varies depending on the type of detection. Once the alarm sounds, the occupants perceive and interpret what the alarm means before making a decision. Hence the alarm's design can have an impact on the occupants' interpretation of the alarm and the time it takes for them to decide what they will do.

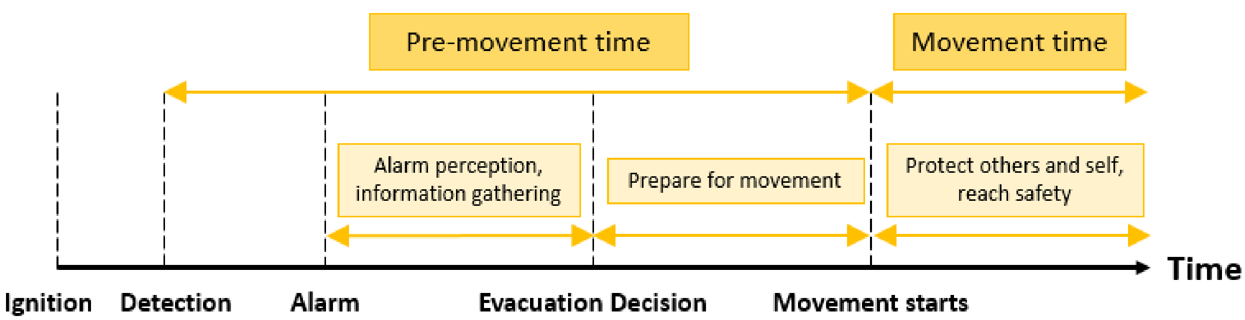


Figure 2. An evacuation timeline describing steps in a building evacuation, starting with the fire ignition and ending with occupants moving out of the building and reaching safety. Based on illustration in (SFPE, 2019).

If the alarm does not give the occupants enough information, the time between the alarm and the decision to evacuate is also used to gather additional information which the decision later is based upon. The time from the decision to evacuate to the actual evacuation movement starts is when occupants perform actions to help protect themselves and others and where they complete preparatory actions such as collecting personal belongings (SFPE, 2019, pp. 21-22). As they start to move towards safety, the occupants continue taking actions to protect themselves and others until safe place has been reached and the movement time has ended (Nilsson, 2015, pp. 33-34). The time ranging from the fire detection to the movement initiation is called the pre-movement time (SFPE, 2019; Nilsson, 2015).

While the evacuation timeline model in Figure 2 provides a simple model for the process of evacuating a building over time, it does not, however, capture all the possible occupant behaviours during an evacuation. Another model that could be used to better explain the response behaviour during and evacuation is the behavioural sequence model, depicted in Figure 3 and based on an illustration from Canter, Breaux and Sime (1980, p. 134). The model consists of the three nodal points *interpret*, *prepare* and *act*, each of which further contains different behaviour sequences explaining human behaviour in fire.

The behaviour sequence model starts with occupants receiving initial information, cues, about the fire, e.g. by smelling smoke or hearing an alarm. After receiving the initial cues from the fire, the occupants often ignore the information, or they choose to look for more information during the *interpretation* step. Canter, Breaux and Sime (1980, p. 134) came to the conclusion that during the initial step occupants often experience uncertainty due to the scarcity of available information. This is why the occupants consistently need to investigate and explore in order to find more information about the fire (Tong & Canter, 1985, p. 261). The effectiveness of an alarm, the information it provides, and its urgency could be used to reduce the need for information-gathering. During the *preparation* step of the behaviour sequence the occupants may act in accordance to the role-rule model, explained in further detail later on, meaning that the occupants involved in the evacuation are influenced by their own and other's "roles" in a context (Canter, Breaux, & Sime, 1980, p. 134; Tong & Canter, 1985, p. 261). The last sequential step is that of *action*, which depends on the previous steps and can either be to evacuate, fight, warn or wait.

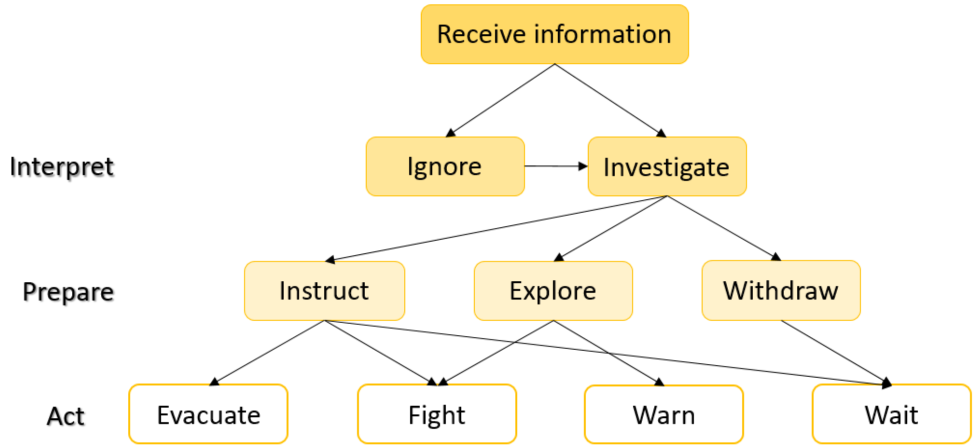


Figure 3. The behavioural sequence model explains occupants' behaviour during an evacuation, from receiving the first cues from a fire to performing some sort of action. Based on an illustration in (Canter, Breaux, & Sime, 1980).

It is important to understand the evacuation process and behavioural sequence models when studying the role of alarms and their effectiveness in emergency situations. The time between the alarm and the evacuation decision steps in the timeline in Figure 2 is the part where alarms can influence the evacuation. During this time the occupants are trying to process the information that they receive and the more information the alarm provides about the fire, the quicker the occupants can make the decision to evacuate. Something which then also could reduce the total evacuation time in an evacuation scenario. In a similar way this can also be seen in the behaviour sequence model, Figure 3. As stated earlier, the initial steps in this model are associated with uncertainty as information often is scarce, making occupants investigate. By using alarms that communicate more information to the occupants, the need to investigate or the time it would take could be reduced and the occupants could take action quicker.

2.2 Role-rule model and Biases

The role-rule model, as mentioned earlier, illustrates an impact on occupants' behaviour and on the evacuation process. The model explains how people's role in a particular situation, which comes with a set of expectations, can affect how people act as they will act according to the rules associated to that role (Canter, Breaux, & Sime, 1980, p. 134; Tong & Canter, 1985, p. 261). Proulx (2007, p. 1) further explained the importance of this theory in evacuations as she stated that occupants' response to fire alarms is governed by their perceived role in that specific building. The author exemplified this by comparing an evacuation scenario in a home to a scenario in an assembly building. When looking at the assembly building, when the fire alarm activates, the occupants that associate themselves with the role of being visitors might not respond to the alarm if no other cue is given to them. This could be due to them following the rules they believe that visitors have, which is waiting for instructions from employees and not acting until they are told so. Furthermore, it is more probable that occupants do respond to the fire alarm if they are employees at the assembly building because their role involves taking responsibility according to the rules associated with that role.

In a similar way occupants can be expected to have a high sense of responsibility and to respond when a fire alarm starts in their own home (Proulx, 2007, p. 1). This would be due to them acting according to the rules of having the role as the owner of that home. The core of the role-rule model is that occupants' response in an evacuation scenario depends on which role they are associating with in that specific scenario, and the rules that go with that particular role. Since occupants in assembly buildings have been shown to often ignore alarms and wait for staff it is very important to carefully design alarms in such facilities if they are to have any effect.

As described above the role-rule model can greatly impact the evacuation process, additionally there are several other types of cognitive biases that also can influence the occupants' behaviour during an evacuation. For example, anchoring is a bias that describes how occupants interpret a fire alarm as a false alarm due to focusing too much on previous experiences with false alarms in the building (Kinsey, Gwynne, Kuligowski, & Kinateder, 2019). Another bias that the authors present is the bandwagon bias which explains how people tend to base their beliefs or actions on what the general public is doing or believing. This could lead to occupants evacuating or not evacuating depending on the behaviour of the people around them, something that can have both positive and negative effects.

Confirmation bias is an additional issue that can affect behaviour, this bias could for example lead to an occupant unconsciously deciding to believe that a fire alarm is a false alarm and thereby not evacuating (Kinsey, Gwynne, Kuligowski, & Kinateder, 2019). Occupants interpret or look for information that fits their agenda, they try to confirm their own point of view by being selective with the available information. One last example of a bias affecting occupants' behaviour during evacuations is the optimism bias. This bias causes occupants to have an optimistic view of their own level of risk compared to others. Occupants could for example choose not to evacuate directly as a result of taking too lightly on their own risk in an evacuation situation, whereas they still could recognize others as being at risk (Kinsey, Gwynne, Kuligowski, & Kinateder, 2019).

2.3 Risk perception

An important concept when talking about how humans behave in fires and other dangerous situations that require evacuation is 'risk perception'. Risk perception is subjective, meaning that risks are perceived differently from person to person, depending on many factors including past experience, values and other background factors. One person may feel like getting on a plane, which potentially could crash, is unacceptable while another person could think that the same risk is acceptable and would be willing to get on the plane. In this example the two people have very different perceptions of the same risk. For a person who has experienced an emergency caused by a risk, the perceived risk has been shown to be higher than for a person with no experience of that risk (Knuth, et al., 2015, pp. 594, 595).

In evacuation scenarios, the subjective risk perception of an individual is a factor that can influence how that individual will make a decision to take protective action (Tancogne-Dejean & Laclémence, 2016, p. 17) – such as evacuating when the risk is perceived as high (Kinateder, Kuligowski, Reneke, & Peacock, 2015, p. 14). Consequently, when the perceived risk is low it can lead to delayed evacuation. As shown in the evacuation process model in Figure 2 when the alarm sounds in an evacuation scenario people perceive the alarm. Depending on how the occupants perceive and interpret the alarm it can then have an impact on the occupants' risk perceptions. For example, if an alarm signal is interpreted differently by occupants it could lead to the risk itself being perceived differently too. An alarm that seems very urgent to person A may leave them with a perception that the risk is high. However, the same alarm can be interpreted as moderately urgent by person B who may then think that the risk is lower. This could also be valid for the other way around. If person A and B have different risk perceptions based on their situational awareness before hearing an alarm, it could be a factor that affects how the alarm is perceived. For example, a higher level of perceived risk of the surroundings, e.g. when a person is in a multi-hazard environment, could lead to perceiving a potential alarm as more urgent and could prompt a faster evacuation.

There are however cases when people have not evacuated even though they have perceived the risk as high (Kinateder, Kuligowski, Reneke, & Peacock, 2015, p. 14). This could be because they do not estimate the cost of evacuating to be worth it, trust that others will help them or because they simply have no means to act, for example due to mobility impairment (Kinateder, Kuligowski, Reneke, & Peacock, 2015, pp. 15, 16).

Although the complexity of risk perception makes it difficult to understand exactly how and when risk perception undermines an evacuation process it is clear that it has an impact (Tancogne-Dejean & Laclémence, 2016, p. 17). By making sure that occupants receive accurate information about the risk they are facing it can modify their risk perception, hopefully resulting in a risk perception closer to reality. This can for example be done by using alarms that accurately represent a hazard. The perception of evacuation alarms and how to design alarms and urgency into alarms is presented in the next chapter.

3 Evacuation alarms

As presented in the previous chapter, evacuation alarms could play a major role in a situation where evacuation is necessary by acting as a cue for building occupants. In a multi-hazard environment, there are many hazards which can trigger the need for an evacuation. Fire may be one of the hazards, but there are different types of malfunctions, accidents or other types of events that can lead to hazards such as exposure to radiation, chemical leaks, toxic gases, low oxygen levels, explosions, etc. The list can be long and depend on the facility. This chapter will begin with exploring different types of alarms and explaining which alarms this thesis focuses on. Next, alarm perception and understanding which is connected to the presented human behaviour theories will be discussed. And later, studies about alarm design and urgency will be presented.

3.1 Alarm types

There are several different ways of alerting someone when their attention is required. These alerts are called alarms and their design can vary as well as their purpose. They can be used to alert people of non-emergency situations like indicating that the microwave is done, that it is time to wake up or that someone is at the door. This study however focuses on alarms that are used in emergencies to initiate a reaction from the people in a potentially dangerous situation, like a fire alarm. These are called here evacuation alarms. There are also alarms that indicate when quick action is required in near-emergency situations like in hospitals or in aircrafts. It can be an alarm that indicates when a patient’s heart rate is too slow or an alarm that warns aircrafts that they are on a collision path. These are not evacuation alarms, however much of the literature on these types of alarms and how to design them can be applicable to evacuation alarms as they are used in similar situations: when some kind of danger or hazard is present.

Evacuation alarms can be auditory, i.e. you can hear them, either verbal (such as a spoken message) or non-verbal. It can also be a combination of both, for example when an alarm consists of a sound or tune to get someone’s attention and followed by a spoken message. Alarms can also be visual with the help of flashing lights or displays that show pictograms or text. A study by Chan & Ng (2009) has shown that auditory and visual warning signals lead to different perceptions of a hazard depending on combinations of colours, flash settings and types of sounds. Finally, there are also alarms that emit vibrations and these are particularly useful for people who are hearing impaired and are asleep (NFPA, 2019).

3.1.1 Verbal evacuation alarms

Verbal evacuation alarms are a very useful type of auditory alarm, often used in public buildings, as they can convey a lot of information to the occupants of a building (Nilsson, 2015, p. 38). An important advantage that voice messages have is that no learning is required to understand the meaning of the alarm as the message explains itself (Edworthy J. , 2011, p. 291). Learning is however required for non-verbal alarms, which becomes more difficult to do when many different alarms are used and have to be learned. A verbal evacuation alarm message should include a call for attention followed by the cause for the alarm and finally instructions on what to do (Nilsson, 2015, p. 39). Theoretically any message-length could be designed into a verbal alarm telling occupants all they need to know. This is however not ideal as there are limits when designing voice alarms. The length of the alarm should be limited, otherwise the entire message will not be as easily understood or remembered (Nilsson, 2015, p. 42).

Although voice alarms may be very useful, there are some cases when it could be favourable to use non-verbal auditory alarms instead. In multi-hazard facilities the architecture of buildings may not be a good acoustic environment for voice messages. Tunnels are challenging as the sounds echo, hindering the understanding of the message (Nilsson, 2015, p. 40). In some nuclear research facilities, the people working with particle accelerators are in tunnels. Additionally, some problems may need immediate action and in that case verbal alarms may take too long time to convey the message (Edworthy J. , 1994, p. 202). Further, in environments that use multiple voice alerts for different situations the response has been shown to decrease (Edworthy J. , 1994, p. 203). This suggests that using many different voice alarms may not be an adequate solution to promote fast and safe evacuation.

This shows that verbal-auditory alarms may not be the most appropriate type of alarm for multi-hazard environments when different alarms are used for different hazards. The use of non-verbal alarms is common in the facilities studied in this thesis. It is therefore interesting to investigate how these non-spoken auditory alarms can be designed to convey different messages, how people interpret them and what hazards alarms are associated to. The following sections will thus be about non-verbal auditory alarms.

3.2 How people perceive and react to evacuation alarms

In order for occupants to make the decision to evacuate they must receive some cues and information about the danger that requires evacuation. Omori, Kuligowski, Butler and Gwynne (2017, p. 1642) present that an old misconception is that people would panic during an evacuation situation, which wrongly lead to the belief that it was better not to give occupants any information about the emergency.

Proulx and Sime (1991) also argue against the restriction of information to the public and reject claims that it would cause a panic. They studied five different types of warning messages and how they impacted how fast an underground train station was evacuated. The conclusion was that warnings that included information about the danger and instructions on what to do (i.e. verbal auditory warnings in the form of voice messages) prompted a faster and safer evacuation than a warning that just included a ringing bell – which was often ignored or misinterpreted (Proulx & Sime, 1991). It is argued that withholding information that could help occupants make a well-informed decision can have devastating consequences because they will spend valuable time searching for an explanation instead of immediately leaving the premises (Proulx & Sime, 1991; Omori, Kuligowski, Butler, & Gwynne, 2017, p. 1642). The time spent searching for more information is illustrated in the evacuation process timeline in Figure 2 described in the previous chapter.

It is quite common for people to misinterpret certain alarms and not understand that they mean ‘danger, evacuate’. Several studies have shown that auditory alarms which do not include a spoken message are frequently perceived as something else (Benthorn & Frantzich, 1999; Proulx & Laroche, 2003). In one study (Benthorn & Frantzich, 1999, p. 314) roughly a third of the participants interpreted the fire alarm (ringing bell) as something else than a warning, like a telephone. The lower sound level may however have impacted their interpretation.

Another study (Proulx & Laroche, 2003) also showed that participants often had trouble correctly identifying a fire alarm. The Temporal-Three pattern (T-3) was one of the fire alarms used in the study and, although as much as 71 % of the participants had heard the sound before, only 6 % of the participants associated it with a fire or evacuation alarm (Proulx & Laroche, 2003, pp. 74-76). Many thought that it was something like an alarm clock or a telephone instead. The other two fire alarms investigated in the study were the Slow Whoop and the Bell. The Slow Whoop was only correctly identified by 23 % and the Bell by 50 % (Proulx & Laroche, 2003, p. 76).

According to Proulx (2007, p. 6) we should not stop using evacuation alarms because, even though they are not always understood as expected, they are a very effective way of warning people and getting their attention. The alarm is one of the puzzle pieces of cues that an occupant can receive. If an occupant has heard an alarm and later sees smoke, they are more likely to understand the seriousness of the situation (Proulx, 2007, p. 6). Something that could undermine this however is frequent false-alarms. False-alarms that occur too often can cause people to lose confidence in the alarm and start to ignore it, thinking that there is no danger. This, in turn, leads to people not acting when a real emergency occurs because they do not trust the alarm (Proulx, 2007, p. 4). This behaviour could be explained by some of the biases presented in section 2.2.

Culture is another factor which can influence how people perceive and react to alarms. Unfortunately, literature on how culture can influence human's behaviour in fires is scarce. This factor is particularly interesting in this study as the multi-hazard facilities from which the questionnaire participants come from, gather people from a lot of different nationalities and cultures. A recent study (Almejmaj, Skorinko, & Meacham, 2017) has compared the general population of Saudi Arabia and the U.S. and their self-reported perception and response time to fire alarms. The results from the online survey showed that culture had a significant effect on the self-reported alarm recognition time and response time. The U.S. participants were more likely to recognize and react to the alarm, possibly due to the fact that a higher percentage of them (89.5 % versus 35.4 % of the Saudi participants) had experience with fire drills (Almejmaj, Skorinko, & Meacham, 2017, p. 4).

Another study (Andrée & Eriksson, 2008), comparing students from campuses in Australia and Sweden, supports that there can be some differences in how people perceive alarms partly due to culture. The fire alarm was more often associated with a serious situation by the Australians, namely 48 % of them, than the Swedes (Andrée & Eriksson, 2008, p. 50). Only 21 % of the Swedish students thought the alarm indicated a real emergency.

3.3 Designing alarms

Knowing that people react (and too often *do not* react) in many different ways to alarms, as described in the previous section, leads to recognizing the need for good alarm design. The alarm design will affect how people perceive and interpret the alarm. In other words, their perception and understanding of the hazard that the alarm refers to relies partly on how the alarm sounds.

Palmgren and Åberg (2010) studied a selection of 10 evacuation alarms based on international standards to find characteristics which distinguished alarms that were good at getting people's attention. According to their study an important characteristic was that an alarm should vary between at least two frequencies, i.e. two different pitches as seen in Figure 4. Before Palmgren and Åberg's study, Edworthy and Meredith (1994, p. 447) were already arguing against having alarms with a continuous tone because it is easier for our cognitive system to detect change instead of consistency in the form of constant pitch.

Apart from finding that a good attention-getting alarm should vary between two frequencies, Palmgren and Åberg (2010, p. 34) also found that it should be continuous, meaning that there are no silent pauses in the sound as illustrated with the yellow sound pattern in Figure 4. They also concluded that the pulse rate should be at least 1 Hz (Palmgren & Åberg, 2010, p. 38), which means that the pulse should be repeated after 1 second or shorter time.

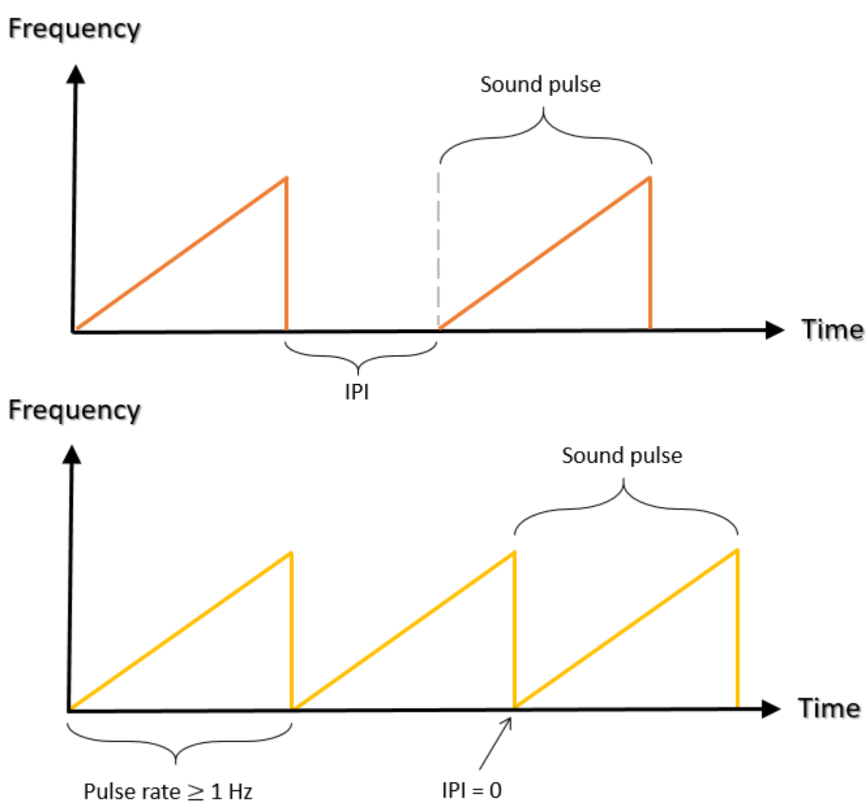


Figure 4. Schematic drawing of two different sound patterns varying between two frequencies. IPI (inter pulse interval) is the 'pause' between sound pulses. IPI is 0 s for a continuous sound as seen in the yellow sound pattern. Illustration adapted from (Palmgren & Åberg, 2010, p. 4).

Edworthy has described some important features of the alarm philosophy one should have when designing alarms (2011, p. 290). Standardization of alarms is one of them and helps to reduce the number of alarms that are used. This is important in a facility with many alarms, as it would be inappropriate to have different sounds indicating the same scenario. Standardization between facilities would also diminish the need to learn different alarms for the same scenario. Moreover, one of the biggest problems with alarm design is to take into account the fact that alarms should be easy to learn and this depends on the type of sound used (Edworthy J. , 2011, p. 291). Edworthy also underlines the importance of hazard matching (2011, p. 290), also called urgency mapping which will give more information to the respondent about the situation.

Finally, there are four criteria that should be met for an effective alarm (Nilsson, 2015, p. 36): (1) the fire alarm's meaning must be obvious, (2) the alarm must be reliable, (3) the alarm must indicate the location of the fire and (4) the alarm must inform occupants on how to act. Criteria 3 and 4 can be difficult to achieve without the use of a voice message alarm. Criteria 2 echoes back to false alarms which was presented in the previous section. If the alarm is not perceived as reliable the ones who hear it are more likely to ignore it and do nothing (Proulx, 2007, p. 4).

As has been described there are many factors that play a role in how a good alarm is designed, whether it be more technical acoustic properties or principles on how to form and use them. This multitude of factors makes it difficult to find the 'perfect alarm', particularly when there is a need for many different alarm sounds to indicate different urgency levels of a situation.

3.4 Alarm urgency

Proulx and Laroche (2003, p. 80) argue that an alarm sound itself (without the help of other cues or voice messages) cannot convey a sense of urgency that will trigger a general evacuation. This is however based on a study in public buildings and it is feasible that the situation is different in multi-hazard facilities where many hazards are present and many different alarms may be present. In that case there could be the need to design alarms to convey different urgency levels depending on the hazard. The perceived urgency of alarms can be altered by changing different acoustic properties (Haas & Casali, 1993; Haas & Edworthy, 1996).

A study showed that when the perceived urgency of an alarm increased, the detection time decreased (Haas & Casali, 1993, p. 544). Factors that affect the urgency are the length of inter-pulse intervals (IPI) as illustrated in Figure 4 and the pulse level or 'loudness'. The shorter the IPI, or pause between sound pulses, the higher the urgency. Alarms with an IPI of 0 seconds were perceived as the most urgent ones (Haas & Casali, 1993, p. 548). This finding was also supported by another study (Haas & Edworthy, 1996, p. 196). The pulse level affected urgency in the way that a louder signal conveyed a higher urgency (Haas & Casali, 1993, p. 544). This however does not mean that alarms should be made as loud as possible to be perceived as urgent. There are downsides to having too loud alarms. Alarms may be switched off because their loudness is too disturbing and thereby rendered useless (Edworthy J. , 1994, pp. 204-205; Haas & Edworthy, 1996, p. 193).

In another study, by Haas and Edworthy (1996, p. 195), it was showed that alarms with a frequency of 500 Hz and 800 Hz were rated as more urgent than alarms at 200 Hz. This suggests that higher frequencies may convey more urgency. This however does not mean that the best alarms have the highest frequency – there is a limit to how high the frequency should be. In a study on the awakening effectiveness of different alarms it was shown that sleeping people were at least 4 to 12 times more likely to wake up to an alarm with a frequency of 520 Hz compared to the alarm of 3100 Hz (Bruck & Thomas, 2008, p. 412). Also hearing loss of the high frequencies is common as people age making it difficult for some to hear sounds above 2000 Hz (Bruck & Thomas, 2008, p. 412).

Table 1 is a summary of the acoustic properties presented in section 3.3 and 3.4 for an attention-getting and urgent alarm:

Table 1. Acoustic properties of an urgent and attention-getting alarm versus a less urgent and attention-getting alarm.

More urgent and attention-getting	*Less* urgent and attention-getting
Varies between 2 or more frequencies	Constant tone / single pitch
IPI = 0 s (continuous sound)	Long IPI
Pulse rate ≥ 1 Hz	Pulse rate ≤ 1 Hz
High pulse level (volume)	Low pulse level (volume)
High frequency	Low frequency

The above characteristics can be used to develop alarms that can convey different levels of urgency which is helpful in places where there can be people who do not know the meaning of an alarm. Although the specific cause of the alarm is not known, the urgency of the sound can provide the listener with some information about the situation, this is called urgency-mapping (Edworthy J. , 1994, p. 206). For those who work in a certain environment and are aware of the hazards, their situational awareness will have an impact on how they perceive the urgency of an alarm. If they are performing a critical action or a difficult phase of an activity their reaction to an alarm will depend on the fact that they were in that particular situation (Arrabito, Mondor, & Kent, 2004, p. 822).

4 Safety culture

Safety culture can affect what the general safety atmosphere looks like in a facility, including how well safety procedures are respected and the importance that is given to drills and training etc. Safety culture could play an important part in how occupants react to different alarms, possibly due to the amount of time spent learning the meaning of the alarms or due to alarms being taken seriously. This is why considering safety culture can help to get an understanding of how occupants perceive alarms.

There is no single definition of safety culture, but a range of different definitions can be used. Instead of handpicking one of the many definitions, different descriptions of the term are presented to get a broad idea of what safety culture is referred to in this study. Akselsson (2014, p. 137) defines safety culture as the safety part of an organisational culture which consists of three layers, see Figure 5, based on Schein's (2004, p. 25) model of organizational culture. Akselsson (2014, p. 137) explains how the innermost layer, the core of safety culture, includes more or less unconscious collective beliefs and assumptions about safety and how to act and think about safety. The inner and outer layers can be seen as manifestations of the core whereby the inner layer entails more conscious attitudes and values (Akselsson, 2014). The outer layer is made up of artefacts, for example personal protective equipment and security management, and of the behaviour of the people involved. Both the inner and outer layers can be studied to understand the core of safety culture. The inner layer can be studied questionnaires and interviews, while the outer layer is easily observable (Akselsson, 2014, p. 137). The Health and Safety Laboratory (HSL, 2002, p. 2) has made a review of the literature on safety culture which shows that many other definitions also included the beliefs, attitudes, values and behaviour of the members that govern commitment to safety. Cooper (2000, pp. 113-114) has also reviewed some of the literature on safety culture definitions which again showed the same notions as well as norms and practices.

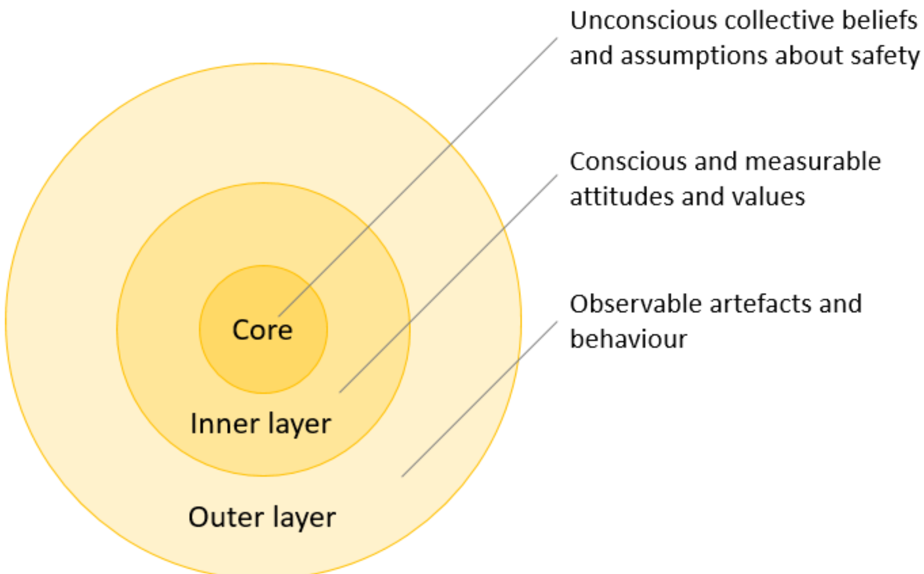


Figure 5. Definition of safety culture described by including the core, inner layer and outer layer. Based on an illustration in (Akselsson, 2014).

Ek (2014, p. 58) carried out a literature study and an interview study at Swedish nuclear power plants and discovered factors, methods and components affecting safety culture in different ways. The author concludes that to accomplish a change in the behaviour and attitudes of people, training and education play a central role. Likewise, Reason (1997, pp. 196, 218-219) also explains the importance of constant learning, to increase safety and improve the safety culture. Even though Reason's type of learning is focused on reactive learning (after an incident or accident) and Ek focuses on proactive training and education (before incidents or accidents can happen), the training and education can and should still be based on previous experiences to increase the perceived relevance for the participants. Thereof the similarity between Ek's view on training and education and Reason's (1997, pp. 196, 218-219) learning culture. The training, education and learning part of safety culture can be of significance in order for occupants to get accustomed with the alarms that are present in their facility. Furthermore, in multi-hazard environments where several types of alarms are used this could become even more important as the occupants need to learn to recognize more than one alarm. Ek (2014, p. 58) further explains how feedback and observations also are important parts of the work for a positive safety culture, since it allows to create a dialog with employees that can lead to increased safety in behaviours and operations. This suggests that a positive safety culture is important for learning alarms and responding to them appropriately.

5 Data collection methodology

In this chapter the methodology for the data collection is presented. The data collection comes from questionnaire answers as well as answers from short interviews with safety experts. This chapter includes theory on how to design questionnaires correctly to avoid certain biases and sources of error. This is followed by a section explaining how the content of the questionnaire was chosen, particularly focusing on the alarms that were studied. Practicalities such as questionnaire dissemination and to what population sample it was sent are then described. Later, the methodology for the interviews is also presented.

In order to collect data on how different evacuation alarms are perceived and interpreted it was decided that a questionnaire would be an efficient tool to use. Holding experiments with participants and making them listen to recorded audio files was also discussed but later discarded. It was thought to be easier to reach out to many participants with an online questionnaire sent by e-mail than gather the same number of people to perform an experiment in a particular place. An online questionnaire gives the participants more flexibility to answer the questions when they have time, thus hopefully increasing the amount of responses.

5.1 Questionnaire software and dissemination

To conduct this survey and answer the research questions a questionnaire software which fitted the needs of the current study, was chosen. Several online survey software were initially tried out in order to find one that fulfilled the requirements to build a complete questionnaire. Some of the requirements and characteristics that were sought were the abilities to: embed audio in the questionnaire without opening a new tab or window, randomize question order and to include different types of questions (open questions, multiple choice, rating scales). Cost was also a deciding factor as several software had a free version with limitations and different levels of paid versions, ranging from low to high costs. After reviewing various online survey software, Google Forms was found to be the best choice for this study as it satisfied most of the needs and was user friendly, both for creators and respondents.

Since this thesis focuses on studying alarm signals in multi-hazard environments there was a need to reach out to a specific population. The population that was sought was people that currently work, study or conduct research at a facility where many different hazards are present, i.e. in multi-hazard environments. The following three facilities were initially chosen as they qualified to the prerequisite of being multi-hazard: European Spallation Source (ESS) and MAX IV both in Lund in Sweden and Conseil Européen pour la Recherche Nucléaire (CERN) located on the border between Switzerland and France, near Geneva. At ESS the questionnaire was sent to people working in some of the accelerator buildings. In MAX IV the individuals working in one of the accelerator areas, optics and experimental hutches and/or chemistry labs received the questionnaire. Finally, at CERN the questionnaire should have been disseminated to those who work in the Large Hadron Collider (LHC) or the large experiment caverns, unfortunately this could not be done within the time frame of the study and no answers from CERN were received.

To increase the chances of getting a higher amount of total number of responses on the survey, students from Kemicentrum (KC, housing the chemistry faculties) at Lund University, Sweden, were also included in the population. Here the target population were those who had spent time in the laboratories during their education. Even though the students cannot entirely be equated with individuals from the three other facilities, the laboratories at KC still qualify as multi-hazard environments due to the fire risk and the use of different hazardous chemicals. Therefore the students were included in the scope of the study.

Contacts at each of the facilities helped with the e-mail dissemination to employees. Before sending out the questionnaire some of the contacts working with safety, such as Health and Safety Officers, were given the opportunity to comment and give valuable feedback on a test version of the questionnaire. This included providing helpful information about the facilities in order for the questionnaire to be relevant to the respondent.

5.2 Theory on questionnaire design

After deciding to conduct an online questionnaire, time was spent searching literature about surveys and how to design them in the best possible way to reduce errors in the data. Some aspects that were taken into account while designing the survey are presented below.

To avoid respondent fatigue, which occurs when the participant loses his/her motivation, it was decided that the questionnaire should be rather short, limiting the number of questions (Ben-Nun, 2008, p. 743; Krosnick & Presser, 2009, p. 31). Other solutions used to deal with survey fatigue were using simply formulated questions and keeping the number of open-ended questions to a minimum (Ben-Nun, 2008, p. 743).

A past study (Assael & Keon, 1982) has shown that non-sampling error contributes the most to total survey error. Non-sampling error is caused by response error and non-response error. Non-response error is due to participants in a sample not answering the questionnaire. To minimize the number of non-respondents the participants were informed about the length of the questionnaire and what its purpose was in the e-mail to motivate them. The first questions of the questionnaire were mainly about demographics as these questions are deemed easier to answer because they do not require much reflection. This way more respondents might be willing to continue with the survey due to minimal respondent burden in the beginning (Krosnick & Presser, 2009, p. 47).

Response error, when the respondent simply gives a ‘wrong’ answer (on purpose or inadvertently) was reduced by following general advice for question design (Krosnick & Presser, 2009, p. 3): using simple words and syntax, avoiding ambiguous meanings and leading questions. Avoiding response error due to someone not answering seriously and giving ‘wrong’ answers on purpose can be tricky. Since there are not really any wrong or right answers in a questionnaire about perceptions of sound it can be misleading to dismiss answers that differ from the expected norm. However, if respondents were straight-lining (choosing the same answer over and over again) or giving senseless or absurd answers to questions which were very clear the validity of their data was reviewed.

The effect of asking questions in a certain order was discussed. Answers can be biased by the context in which a question is asked; the preceding questions may influence the respondent’s attitudes or state of mind (Oldendick, 2008, p. 664). Randomization, varying the question order for each respondent, is a method that can be used to minimize question order effects (Oldendick, 2008, p. 665). Unfortunately, this could not be done in the chosen questionnaire software (Google

Forms) in a satisfactory manner as certain sections of the questionnaire needed to remain in a logical order. To manually incorporate some randomization to the questions, two different questionnaires were done, A and B, with the exact same questions, but the order in which the alarms were presented was different as well as the order in which the risks were presented. Respondents were asked to answer questionnaire A if they were born on a date with an even number (such as the 4th or 18th) or answer questionnaire B if they were born on a date with an odd number (such as the 13th or 25th).

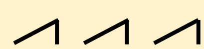
5.3 Questionnaire content and choice of signals

The content of the questionnaire was carefully tailored to collect data that could be used to answer three of the previously presented research questions: (1) Is the urgency of an alarm interpreted differently by different people? (2) Do different people associate alarm signals to the same hazards, or do they interpret the alarms differently? (3) Is there a relationship between the perceived urgency of an alarm and the interpretation of that alarm?

The questions used in the questionnaire can be seen in Appendix A.

A total of eight evacuation alarms were used in the questionnaire. To collect data for the research questions connected to urgency, four alarms that can be used as evacuation alarms were chosen based on the factors presented in section 3.4 in Table 1. The four different alarms were selected for their different acoustic characteristics in order for them to have different expected levels of urgency based on the literature on how to design urgent alarms. The alarms were assigned a letter which were later used in the questionnaire as the name of each alarm. The letters were randomly chosen to be K, R, X and V to avoid any bias due to the name of the alarm. The alarms were not named A, B, C and D or 1, 2, 3 and 4 as it was thought that this would affect the respondents' answers as they might think A or 1 is 'best' or something similar. To make it easier to remember the alarms, they were given names associated to their sound. Table 2 summarizes the chosen alarms' properties.

Table 2. Designated names, acoustics properties and pulse pattern of alarms K, R, X and V.

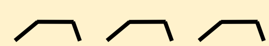
Alarm	Name	Frequency	Sound pattern	Pulse rate	Pulse pattern
K	Beeping	544 Hz	Intermittent (IPI > 0)	1,14 Hz	
R	Constant	340 Hz	Continuous (IPI = 0)	N/A	
X	Alternating_1	800-1000 Hz (varies between two)	Continuous (IPI = 0)	4 Hz	
V	Slow Woop	500-1200 Hz (varies between two)	Intermittent (IPI > 0)	0,3 Hz	

Respondents were asked to listen to each alarm, write down which hazard they associated with the alarm and rate how urgent they felt the alarm was on a 7-point scale ranging from - 3 to + 3 with - 3 being not urgent and + 3 being very urgent. A 7-point scale was used as a review of studies on optimal scale length concluded that it is often the most favourable length (Krosnick & Presser, 2009, p. 20).

A new set of four alarms were used in the second part of the questionnaire. This part of the questionnaire focused on collecting data to answer the second research question: if people interpret alarms differently and associate the sounds to different hazards. In this part respondents were asked to imagine that they were facing a hazard and then listen to the four alarms and choose the ones they felt were the most appropriate for that hazard. The three hazards used in the questionnaire were 'fire', 'low oxygen level' and 'exposure to radiation'. These were chosen because the respondents were expected to have enough knowledge to understand the dangers associated with these hazards.

This second set of four alarms were recordings of alarms presently used in some of the facilities. Hence, they were not chosen based on their acoustics properties but on the fact that they are actually used. These alarms were, similar to the four other alarms, also given random letters: N, Q, Y and F. Alarms N and Y are used as oxygen deficiency hazard (ODH) alarms, which is the same as the low oxygen level hazard, in two of the facilities: CERN and ESS respectively. Alarm Q, used at KC, is a mechanical fire bell alarm, this is an evacuation alarm commonly used in Swedish public buildings (Palmgren & Åberg, 2010, p. 7). Alarm F, from CERN, is also an evacuation alarm but with a different sound from the mechanical bell. The alarms' sound patterns and pulse patterns can be found in Table 3.

Table 3. Designated names, sound pattern and pulse pattern of alarms N, Q, Y and F.

Alarm	Name	Sound pattern	Pulse pattern
N	Quick oscillation	Continuous (IPI = 0)	
Q	Bell	Continuous (IPI = 0)	Mechanical bell
Y	Alternating_2	Continuous (IPI = 0)	
F	Rise & Fall	Intermittent (IPI > 0)	

The final part of the questionnaire included an open answer question about the respondents' personal opinions on multiple evacuation alarms to partly answer the fourth research question: "What are the respective views of safety experts and other occupants of multi-hazard facilities on having multiple alarms?". Further data for this question was collected through interviews with safety experts as described in the next section.

5.4 Interviews

As a complement to the questionnaire answers, interviews with safety experts were conducted. These interviews were semi-structured with open answers in order to give the respondent more freedom to respond with their own opinion and experiences. The persons that were interviewed were people working at multi-hazard facilities, having enough experience within the safety sector to be regarded as safety experts for this study. All five interviewees worked in nuclear research facilities. The interviews were done in order to get a perspective from people who have experience with multiple alarms as well as give them the chance to develop their arguments in a way that cannot be achieved through a questionnaire.

Questions used in the interviews were based on the questions in the survey with more focus on the respondents' expertise and experience. They were informed in the beginning of the interview that they would remain anonymous. The interview was done over the phone or a similar means of communication. Questions that were used to guide the interview can be found in Appendix B.

6 Results and Analysis

In this section the results from the data collection from the questionnaire and the interviews are presented and analyzed.

6.1 Results from the questionnaire

The following sections treat the results from the questionnaire which was sent out to three multi-hazard facilities.

6.1.1 General information about the population of respondents

The online questionnaire was sent out to staff at the following three facilities: Kemicentrum (KC), MAX IV and ESS. The number of responses received from each respective facility was 14, 18 and 22. This means that a total of 54 answers were analyzed, however there are some cases when a few answers could not be included in the results as the answer could not be interpreted. An example of this is when a respondent answers a country when asked for their date of birth. The questions and layout of the questionnaire can be found in Appendix A.

From the 54 respondents, 18 were female and 34 were male. Two respondents did not wish to answer the question. The gender distribution of the respondents is illustrated in Figure 6 below.

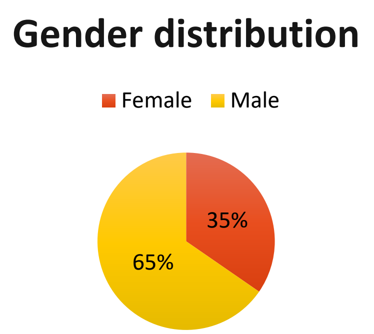


Figure 6. Gender distribution of the 52 respondents who answered the question.

The age distribution of the respondents ranged from 20 to 62 years of age, with a mean of 37,4 and a standard deviation of 11,3. There were 4 answers which could not be included in the distribution either because they did not wish to answer or because the answer was not relevant for the question. There are no big differences between the age categories, see Figure 7, apart from the 60-69 age category in which there is only one respondent who was 62 years.

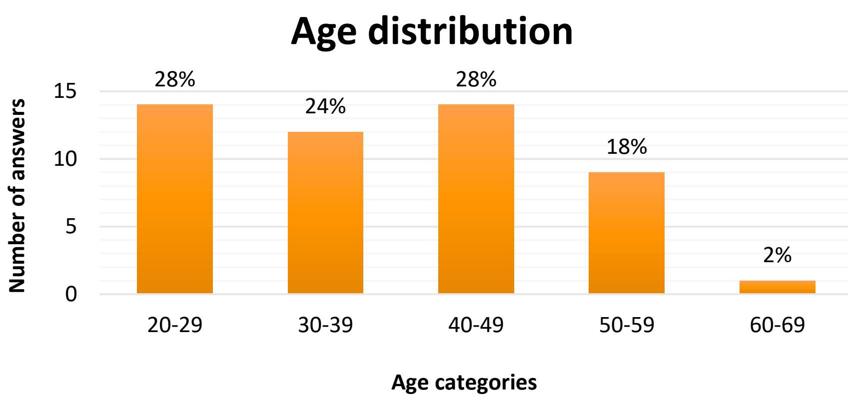


Figure 7. Age distribution of the 50 respondents who answered the question.

Most of the respondents were Swedish, namely 71 %, as can be seen in Figure 8. This is not surprising as the questionnaire was sent only to facilities in Sweden. However, it is not uncommon to find people from other nationalities in the facilities that are studied, e.g. guest researchers, exchange students or expatriates. This explains why 29 % of the respondents who answered the questionnaire were from other countries. There were two respondents who did not wish to answer the question. The nationalities that were chosen apart from Swedish are not represented individually because there were very few answers for each nationality. The category included respondents from 8 countries: Brazil, China, France, Germany, the U.K., Iceland, Italy and Russia.

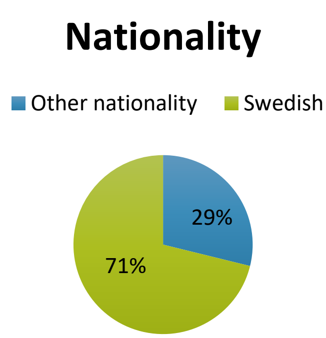


Figure 8. The nationality of the 52 respondents who answered the question divided into Swedish and Other nationality.

The respondents were asked about their occupation at the facility at which they worked or studied, see Figure 9. All of the 14 respondents from KC were students, including PhD students. The remaining 40 respondents from MAX IV and ESS were mainly engineers/technicians (28%), Health and Safety officers (19%) or researchers (17%). In the category 'Other' there were amongst others assistants, administrators and occupations on a management and leadership level.

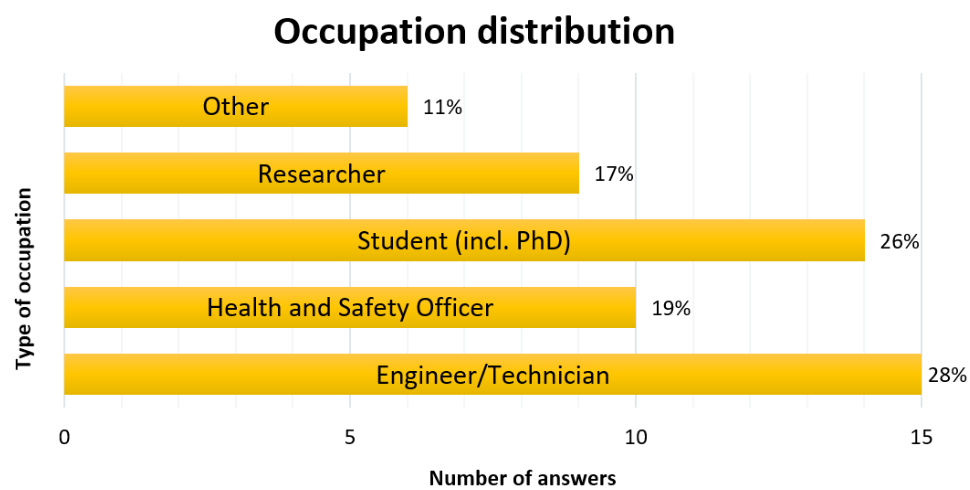


Figure 9. Distribution of the respondents' occupation.

To avoid the analysis of invalid or irrelevant data some questions were asked to check that the respondents' answers could be included in the results. When asked if they could hear the sound in the test video, all of the respondents answered yes. When asked about hearing impairment, only two mentioned that they had some kind of hearing impairment, however it was judged that these respondents were still able to hear the alarms in the questionnaire well enough.

6.1.2 Interpretation of the alarms' urgency and meaning

The respondents listened to four alarms (K, R, X and V) and were asked which hazard they associated each alarm with. As the questions were open, i.e. no options were presented, many different answers were given and these are presented in Figure 10. Each alarm received 54 answers.

Equipment alarm includes answers that are of a technical nature for example: "technical error", "machine failure" and "computer error". It also includes several answers about the sound being an alarm for a door that should be closed or a vehicle alarm: "some door isn't closed properly", "door not being closed", "reversing truck" and "forklift". The *Hazard* category contains hazards such as "fire", "gas leak", "aerial attack" and "radiation". All the answers in this category imply that evacuation is required when the alarm is heard. *Emergency* is a category for answers that indicate that the respondent associated the alarm with an urgent situation but that did not require evacuation. Such as a medical emergency: "respiratory issues", "ambulance" or "cardiac arrest". But also a situation connected to crime: "burglar alarm", "crime" or "break-in". The category *No hazard* includes answers like "no hazard", "no idea", "doorbell?" and "end of phone call?".

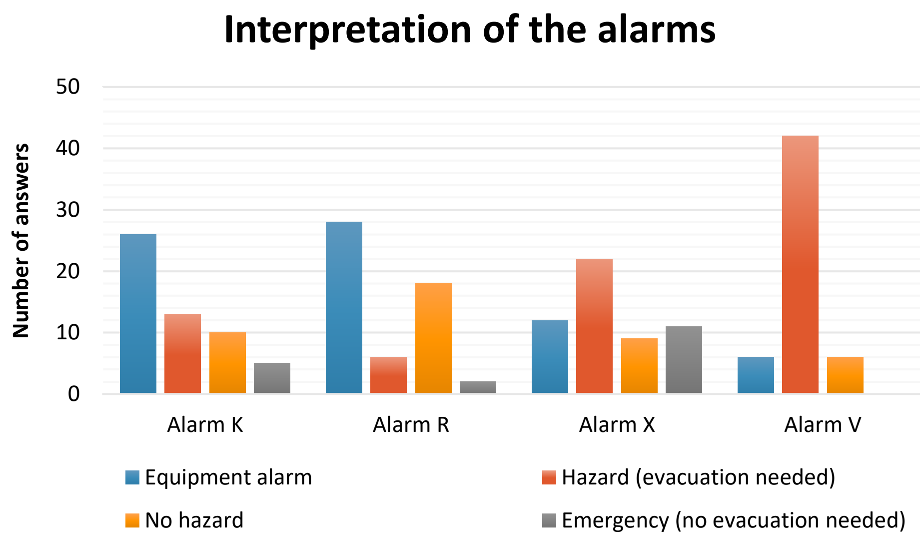


Figure 10. The distribution shows how each alarm (K, R, X and V) was interpreted. There were 4 categories of interpretation.

Alarm K (Beeping) and R (Constant) were more often interpreted as equipment alarms rather than evacuation alarms. However, alarm V (Slow Woop) was associated with a hazard in most cases, 42 out of 54 answers. As for alarm X (Alternating_1), the biggest category is *Hazard* but not to the same extent as alarm V, it had 22 answers associating the alarm with a hazard. Alarm K had 13 answers in the *Hazard* category. Alarm R was least interpreted as an alarm associated with a hazard with only 6 answers for that category.

Since the focus in this thesis lies on alarms that warn about hazards, the *Hazard* category was dissected for each alarm, revealing the different types of hazards that each alarm was associated to. In Figure 11 the components of each *Hazard* category from Figure 10 can be seen. For example, 13 answers for alarm K associated the alarm with a hazard, from these 13 answers 6 were *Other*, 5 were *Fire*, 0 were *Radiation* and 2 were *Gas hazard*. The category *Other* contains answers such as “aerial attack”, “urgent hazard”, “leave area” but also answers containing several hazards, e. g. “fire or hazardous leak”.

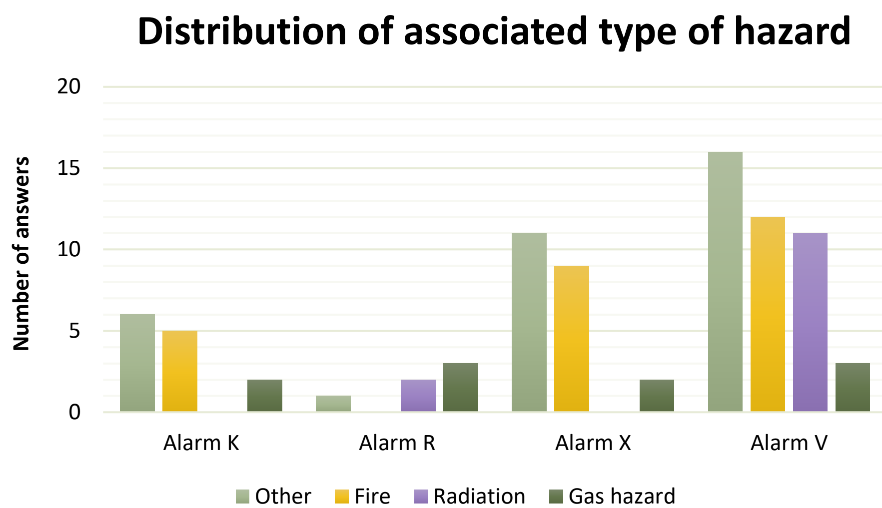


Figure 11. Distribution of the answers that associated an alarm with a hazard. Hazard types were divided into 4 categories.

What Figure 11 shows is that none of the alarms above have an obvious meaning. Without having learned the meaning of the alarms, the respondents' intuitive associations vary. For instance, those who associated alarm V with a hazard have answered different types of hazards: 16 *Other*, 12 *Fire*, 11 *Radiation* and 3 *Gas hazard*.

After they were asked what they associated an alarm with the respondents were also asked to rate the urgency of each alarm on a 7-point scale ranging from -3 (not urgent) to +3 (very urgent). The descriptive statistics in Table 4 below show that alarm V (Slow Woop) has the highest mean urgency 1,556 followed by alarm X (Alternating_1) with a mean of 1,444. Alarm K (Beeping) has a mean urgency of 0,148 meaning that it is only slightly urgent while alarm R (Constant) has the least urgent mean value, -0,759.

Table 4. Descriptive statistics for perceived urgency of each alarm rated on a 7-point scale from -3 to +3.

	Alarm K	Alarm R	Alarm X	Alarm V
Mean	0,148	-0,759	1,444	1,556
Median	0	– 1	2	2
Standard Deviation	1,559	1,873	1,550	1,410
Sample Variance	2,430	3,507	2,403	1,987
Minimum	– 3	– 3	– 3	– 3
Maximum	3	3	3	3
Sum	8	– 41	78	84

It is worth noticing that the maximum and minimum values of -3 and +3 have been chosen at least once for all four alarms showing that within each alarm perceived urgency ranges to each extremity. This variation is also illustrated in Figure 12 below.

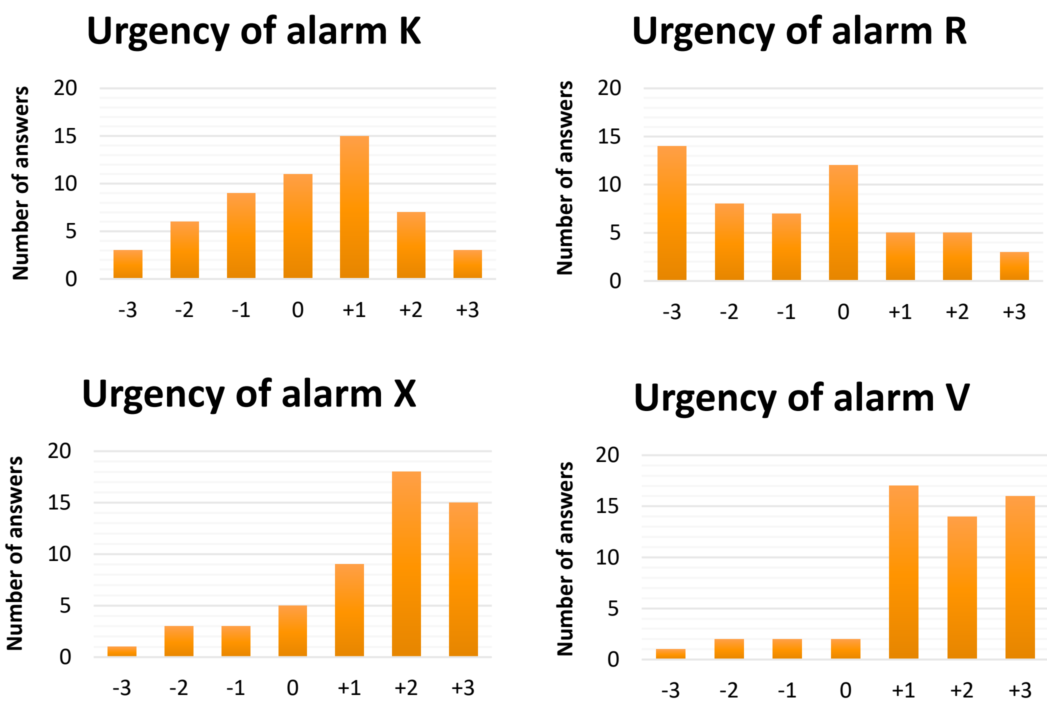


Figure 12. The distribution of perceived urgency for each alarm rated on a 7-point scale from -3 to +3.

Alarm V (Slow Woop) which has the highest mean urgency of the four alarms is also the alarm which most respondents associated with a hazard, see Figure 10. The second most urgent alarm, X (Alternating_1), follows this pattern as it has the second most responses associating it with a hazard. On the contrary, the two alarms R (Constant) and K (Beeping) were less often associated with a hazard, and these have lower mean urgency values. Alarm R, which has the lowest urgency mean of -0,759, is also the alarm which has the highest number of answers in the category *No hazard* as well as the lowest number of answers in the *Hazard* category. This indicates that the higher the perceived urgency of an alarm, the more likely it will be associated with a hazard.

6.1.3 Alarm choice for a certain hazard

The respondents were presented with three hazards; fire, low oxygen level and radiation. They were then asked to choose which of the four new alarms, N, Q, Y and F, sounded like an evacuation alarm for that particular hazard. First they could choose more than one option, see Figure 13, and in the next question they had to choose only one alarm, see Figure 14. Comparing Figure 13 and Figure 14 suggests that many respondents choose the same alarm when they have to choose a single alarm. The choices are more varied when respondents can choose multiple alarms.

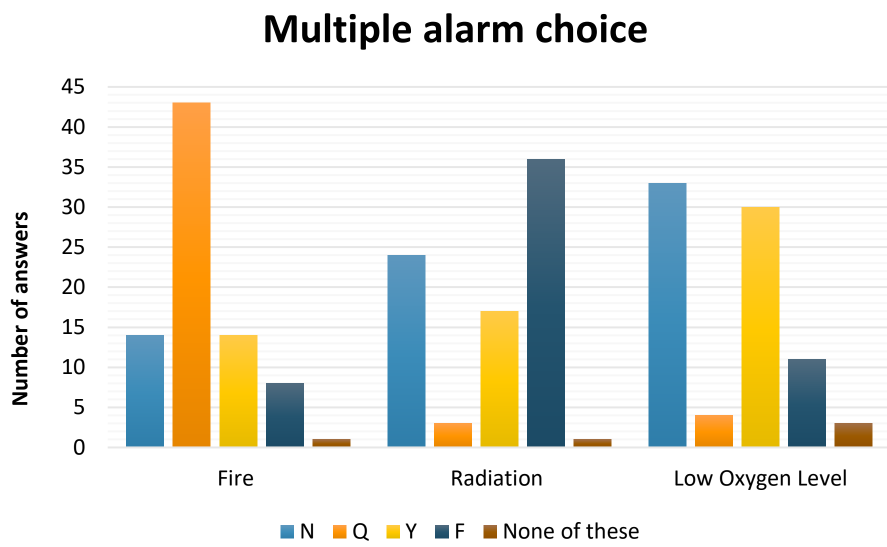


Figure 13. Distribution of the respondents' choice of alarm for each hazard with multiple choices possible.

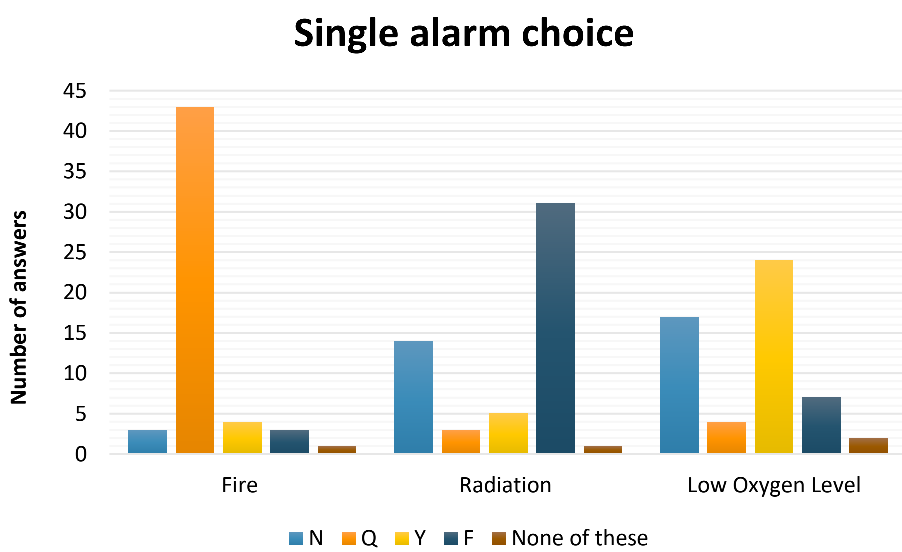


Figure 14. Distribution of the respondents' choice of alarm for each hazard with a single choice possible.

It is interesting to see that alarm N (Quick oscillation) and Y (Alternating_2) are the most chosen alarms for the low oxygen level hazard, 17 and 24 answers respectively in Figure 14, as both are actually used as ODH alarms at CERN and ESS. This suggests that the ODH alarms are correctly recognized by many. This could potentially be due to the respondents from ESS recognizing alarm Y which is used at their facility. However, the results show that the respondents from ESS are not the main contributors to alarm Y being the most chosen. In fact, 9 out of 14 respondents from KC and 8 out of 18 respondents from MAX IV respectively picked alarm Y, whereas only 7 out of 22 from ESS chose alarm Y.

For the radiation hazard alarm F (Rise & Fall) was the most chosen one with 31 answers in Figure 14. Furthermore, alarm Q (Bell) was the alarm that most agreed upon to represent a fire alarm, with 43 answers out of 54 answers. The most likely explanation for this is that alarm Q is a mechanical fire alarm bell which is commonly used in public buildings in Sweden. As 71 % of the respondents were Swedish this was thought to have an impact on this result, therefore answers for the fire hazard were compared for Swedish respondents and respondents from other nationalities. The comparison is presented for the single alarm choice in Figure 15.

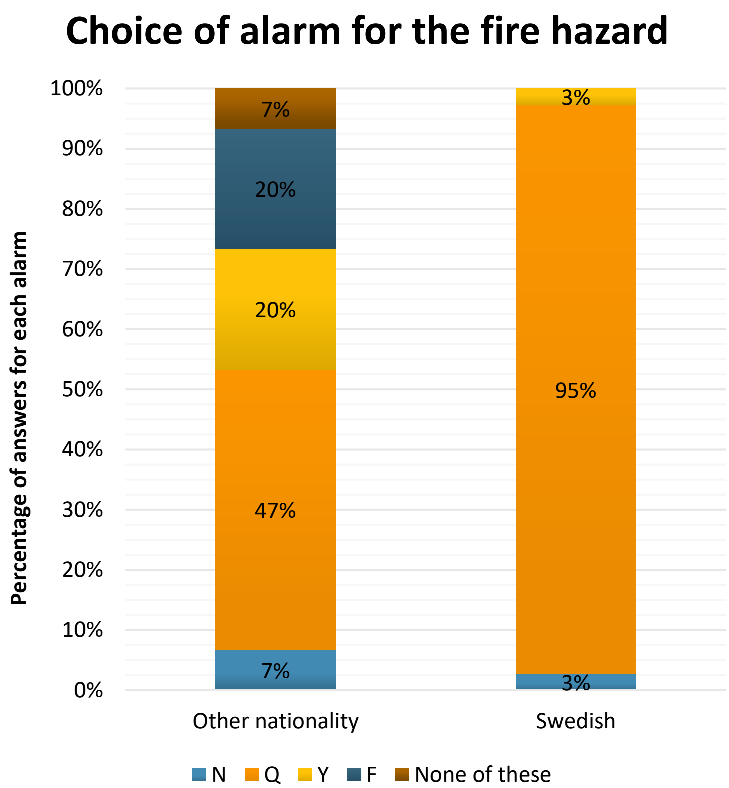


Figure 15. Distribution of the chosen alarms for the single choice question for the fire hazard. The sum of the parts is not exactly 100 % due to rounding up as certain values have an unlimited number of decimals.

Since Figure 15 shows that 95 % of the Swedish respondents chose alarm Q compared to 47 % of the respondents from other nationalities a statistical Z-test was done to confirm whether the difference is statistically significant. The statistical test, which can be found in Appendix C, show that the Swedish respondents choose alarm Q more than the other respondents with a statistic significance level of 2,5 %.

6.1.4 Respondents' opinions on having multiple alarms

In the final part of the questionnaire respondents were asked to give their opinion on the use of one alarm sound for different types of hazards and the use of specific alarms for each hazard. The answers were divided into four categories: *Several alarms*, *One alarm*, *Mixed opinion* and *No opinion*. Answers in the *Several alarms* and *One alarm* categories are those stating their preference for one or the other, for example: "I believe that each hazard should have its own alarm" and "One alarm signal for all hazards is the best solution". The category *Mixed opinions* contains answers that indicate that the respondent is not certain that one or the other is better, giving advantages and disadvantages for both options or saying that it depends on the situation. An example answer in this category is: "I think it depends on the situation. If you have a facility with only a limited number of trained personnel, specific alarms are probably better [...]. At larger facilities with lots of people [...] a general alarm might be better [...]". Finally answers that were left blank fell into the *No opinion* category. The distribution of the respondents' opinions can be seen in Figure 16.

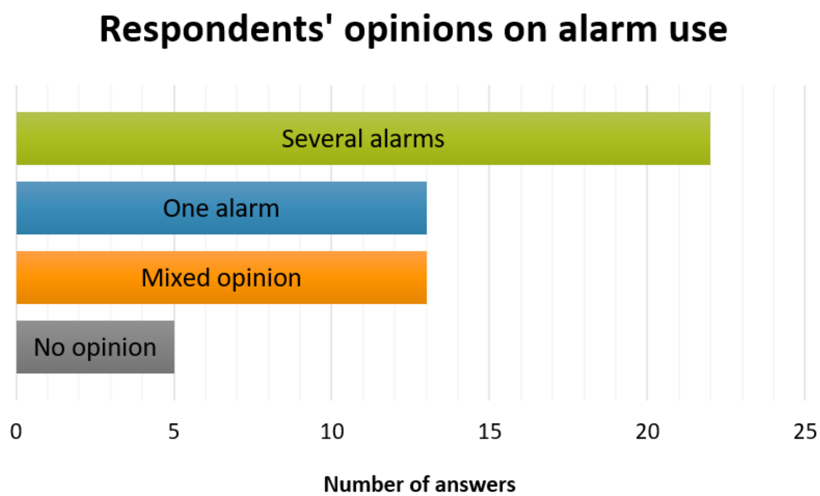


Figure 16. Distribution of the questionnaire respondents' opinions on the most appropriate alarm use.

Twenty-two of the respondents preferred the use of several alarms, making it the most frequent opinion. Further, the potential effect of previous experience on respondents' opinions was studied. They were asked if they had experienced any real emergency situations and 45 % of 53 respondents answered yes while 55 % answered no. One answer from the 54 respondents could not be analyzed for this question which is why the result is based on 53 answers. Figure 17 shows the differences in the distribution of opinions based on previous experience.

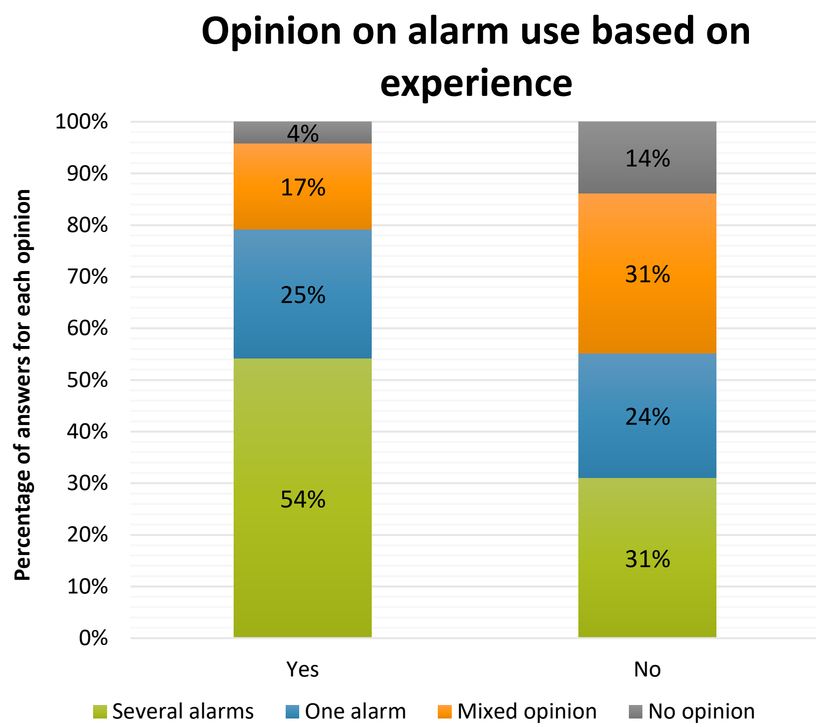


Figure 17. Distribution of respondents' opinions on alarm use based on whether they had previously experienced a real emergency situation. Those who had previous experience answered 'Yes' and those who did not answered 'No'.

A statistical Z-test was done to see if there was a difference between the proportion of respondents preferring several alarms that have previously experienced an emergency situation, 54 %, and those that have not, 31 %. The calculations can be found in Appendix C. The result from the test shows that those who have experienced an emergency more frequently prefer the use of several alarms with a statistical significance level of 5 %.

Respondents gave arguments as to why they preferred one or the other (one alarm or several alarms) and these have been summarized into arguments for and against the two options. An advantage of having one alarm is also the disadvantage of having several alarms and vice versa. Table 5 and Table 6 only contain arguments that respondents gave in their answers. This means that some of the arguments in the two tables will have been mentioned multiple times. Table 5 presents the synthesized arguments that respondents gave for and against the use of one alarm.

Table 5. Respondents' arguments for and against the use of one alarm.

Advantages	• Minimizes confusion as there is only one sound, leading to faster evacuation. • No need to think about the alarm's meaning. • Less training required to recognize and learn the alarms when there is only one.
Disadvantages	• Increases stress or confusion because occupants will not know the cause of the alarm. • Cannot communicate the type of response needed if there are different appropriate responses.

Table 6 presents the synthesized arguments that respondents gave for and against the use of several alarms.

Table 6. Respondents' arguments for and against the use of several alarms.

Advantages	• Minimizes confusion and stress as the different alarms will inform occupants on the cause of the alarm. • Can be used when different responses are necessary. E.g. local evacuation or general evacuation. • Possible to differentiate urgency levels of emergencies.
Disadvantages	• Less urgent alarms may be ignored or taken less seriously. • Too many alarms may lead to confusion, difficult to know how many are too many. • Increases risk of confusing alarms with other sounds, e.g. warning sounds from machinery. • Difficulties for occupants to remember or recognize alarms in stressful situations. • Training is required to learn and recognize alarms.

Another interesting finding from the arguments is that some of the respondents suggesting that several alarms is the better option thought that alarms should be associated to a response and not a hazard. The same train of thought was found for some of the respondents preferring one alarm. They argued that only one alarm is needed, regardless of the hazard, because only one response is needed: evacuation.

It was interesting to get an idea of the occupants' general feelings towards evacuations. Therefore, the respondents were asked to rate how confident they were that they knew what to do in an evacuation situation at their facility on a scale from 0 to 6. The results in Figure 18 show that the majority of the respondents rated their confidence level as a 4, 5 or 6. This means that they are positive that they know what to do in an emergency.

Figure 18. Distribution of the respondents' level of confidence in an evacuation situation, 0 being "not confident at all" and 6 being "very confident".

6.2 Results from the interviews

In this section the results and answers from the interviews with safety experts are presented. The answers will be presented together as a summary of the most interesting findings for this study and hence not all the questions will be presented in the text, for the interview questions see Appendix B.

To begin with, a brief overview of the interviewees is given to give an idea of the type of safety experts that were interviewed. Some general questions were asked in the beginning to get an understanding of their field of work and experiences. The interviewees' respective roles consisted of the following: Safety Officer, Official Fire Safety Officer, Group Leader Occupational Health and Safety, Fire Protection Engineer. They had all been working within the safety sector for 6 to 30 years and they had also been working at different facilities throughout the years, ranging from nuclear and fusion research facilities to the fire brigade. The respondents were all initially chosen based on their current place of work, which are multi-hazard facilities, and because they had enough experience within the safety sector to be regarded as safety experts for this study. All of the respondents were familiar with the issue of using several alarms for different kinds of hazards.

When asked if they knew if the urgency of the hazard had been considered when choosing the alarm sounds for their respective facility most replied that they did not know or that they did not think that it had been taken into consideration. The reason why they were unsure was that most of them had not been involved in choosing the evacuation alarms. Two respondents also mentioned how they do not find it logical to choose alarms based on urgency since there is no hazard that requires slow evacuation, rather all evacuations should be swift. Based on the interviewees' own experience on acoustic properties, three of them answered that they find the sound level or volume to be an important characteristic for the alarm to be interpreted as urgent and lead to an effective evacuation. One person also suggested that the sound level is more important than the pitch or tone of the alarm. Another interviewee also talked about the lack of standards regarding e.g. ODH alarms which means that the sound level and the inspection of alarm beacons are not regulated, amongst other factors. The three respondents also mentioned that it is important to take the background noise into consideration when designing alarms for the facilities since noisy machines and equipment can delay the evacuation of the occupants cannot hear the alarm clearly.

Another acoustic characteristic that was brought up by one person was that alarms with a continuous sound pattern are preferred over intermittent ones, as the latter could be interpreted more often as warnings rather than evacuation alarms. Further, the interviewee also said that the sound should be annoying. Another respondent mentioned how it is important to have clearly different sounds for alarms if several alarms are used in the building. This is to make it easier for occupants to differentiate between them and to know what has happened. One interviewee mentioned that acoustic alarms should be combined with voice messages for effective evacuation. The interviewee also explained how this was a challenge in their facility as the people working there are from different countries and speak different languages making voice messages ineffective for those that cannot understand them.

The interviewees were also asked to provide answers on their own opinion on having one single alarm for all types of hazards or several different alarms for different hazards, a question for which they presented different points of view. Arguments for having only one alarm proposed that if there are many different alarms it can be difficult for the occupants to learn each and every one of them, which hazard they are referring to and what the appropriate response is. Furthermore, if the alarms are not heard frequently it makes it even more challenging to learn the types of alarms present at the facility. It was suggested by one respondent that more responsibility could be put on the occupants in a way that would make the use of one alarm possible. The idea is that they should know what hazards are present in the area they find themselves in and when the evacuation alarm goes off they should know what to do based on the types of hazards present in that specific area. Also, in public buildings where occupants have no possibility to learn the alarms, there should only be a single evacuation alarm.

There were also arguments for having multiple alarms presented by the respondents. Someone mentioned that several alarms can be useful when different responses are required. However, this person mentioned that having several alarms should still be simplified, i.e. not having too many alarms. This could be done by having a few different alarms which are not connected to a specific hazard, but instead to the hazards' appropriate responses. Then, different hazards that require the same evacuation response could be linked to the same alarm, keeping the number of alarm signals to a minimum. Another argument for having multiple alarms is that when only one alarm is present there is a risk that people do their own "risk assessment", trying to figure out what hazard the alarm is referring to. This could lead to the occupants interpreting the alarm as the most frequently occurring hazard, e.g. a fire in some cases, or interpret it as a false alarm if it commonly goes off in error. The problem with this is that when it is not the most common cause of the alarm that has occurred, it could lead to the wrong evacuation response being chosen.

By having different alarms this can be avoided as the occupants would know exactly what hazard has occurred and how to respond. However, as pointed out by three of the respondents, there is a need of training to make people familiar with the buildings and alarms that exist. A problem mentioned by two respondents is that when drills and training are too frequent occupants do not react very quickly because they do not believe it is a real emergency. The downside of training is according to the respondents that it undermines that alarms' effectiveness.

7 Discussion

There have not been many studies on the effectiveness of using multiple alarms in multi-hazard facilities. The aim of this study has been to bring some clarity to the subject by looking at factors like people’s interpretation of alarm urgency and alarm meaning as well as advantages and disadvantages of using a single alarm for different hazards or using specific alarms based on hazards. This section aims to discuss the findings of the study and the limitations, delimitations and possible sources of error which may have impacted the result. Finally, the direction of possible future research is discussed.

7.1 Discussion of the results

The results from the questionnaire study were based on 54 respondents’ answers. Although it would have strengthened the reliability of the results to have more answers, it was still deemed that there were enough respondents to be able to get some meaningful results.

The sample of respondents seems to have been varied, which is positive as both men and women of varying ages and occupations responded to the questionnaire. The number of women that answered was lower than the number of men, but this is possibly due to the population that the questionnaire was disseminated to. The population from ESS and MAX IV is thought to have a higher percentage of men working there, thus the sample may reflect this. However, the population from KC is estimated to have a more equal gender distribution. There was one category within the age distribution which unfortunately only contained one respondent. This was the category of 60-69 years, which may be explained by the fact that many retire within this age category. Although there are not as many elderly people working in multi-hazard facilities as there are younger people, this age group should not be overlooked since they may be more vulnerable. Furthermore, 29 % of the respondents had a nationality other than Swedish, making it possible to study if the implications of culture and the time spent in a certain country had an impact on some of the results. This impact is discussed later on.

When asked what they associate an alarm with, respondents gave varying answers for the different alarms. Each alarm was associated to a hazard by some respondents, however the same alarms were also interpreted as equipment alarms, or not connected to a hazard at all by other respondents. This shows how the same alarm can be interpreted differently by differently people, which is in line with findings from other studies such as the ones by Benthorn & Frantzich (1999) and Proulx & Laroche (2003). Even within the category of respondents that had associated an alarm with a hazard, the type of hazard varied a lot, including fire, radiation or a gas hazard. This variation of interpretation may reduce the effectiveness of alarms in facilities where multiple alarms are used because the information that they are supposed to convey may not be understood by all. It is unlikely that the respondents had heard the four alarms (K, R, X and V) in the first part of the questionnaire before. This could be one of the reasons that the interpretations of the alarms in the questionnaire vary. Moreover, since the respondents have not heard the alarms before and learned their meaning it suggests that there is no intuitive interpretation of the four alarms shared by all respondents and that training could be an important factor to achieve a common interpretation of the alarms of a facility.

It was not only the alarms' meanings that were interpreted differently but also the urgency. For each alarm, at least one person interpreted the urgency as -3 and at least one person interpreted it as +3, showing that there were perceptions on both extremities. Situational awareness (Seppänen & Virrantaus, 2015, p. 113) and the subjectivity of risk perception can contribute to these inconsistencies. Based on their subjective risk perception, the respondents may have a different situational awareness when they are working with critical tasks exposing them to certain hazards than during lunchtime in the canteen. How urgent an alarm is perceived in those two situations can then vary due to situational awareness. Although many answers were different, the results indicate that the higher the mean urgency of an alarm was, the more respondents had associated it with a hazard. This suggested trend is somewhat expected because associating the urgency of the sound to the seriousness of the situation is thought to occur intuitively within the listener's mind. This supports Edworthy's (1994; 2011) arguments and calls for urgency mapping and hazard matching of alarms.

According to the acoustic properties identified in Section 3.3 and 3.4 which are summarized in Table 1, alarm X (Alternating_1) has the most number of properties making the alarm urgent. The three properties that alarm X possesses are variation between two frequencies, a continuous sound pattern and a pulse rate higher than 1 Hz. Because of this, alarm X was expected to be the most urgent alarm, however based on the result from the questionnaire this was not shown to be the case. Alarm V (Slow Woop), which 'only' had one of the urgent properties (variation between two frequencies) was therefore expected to have a low perceived urgency. However, it was the alarm with the highest mean perceived urgency and lowest standard-deviation. The mean urgency of alarm X was 1,44 and for alarm V, which has similar perceived urgency, it was 1,56. This could imply that there are other properties which have a greater effect on an alarm's urgency. One difference that has been identified is the pulse pattern of X and V. Alarm X has a continuous pulse pattern alternating between only two frequencies, as seen in Table 2, while alarm V has intermittent sound pulses consisting of an increasing frequency like a "slow whoop". This continuous increase in frequency may be a property that contributes to the urgency of an alarm and it would have been interesting to investigate it further.

When respondents were asked to choose the alarm they thought was more appropriate for a certain hazard (fire, radiation and low oxygen level) each of the four alarms (N, Q, Y and F) was chosen at least once for each hazard, once again indicating variation in how alarms are interpreted. However, some trends were observed, such as alarm Q (Bell) being the most popular alarm chosen for the fire hazard, N (Quick oscillation) and Y (Alternating_2) for the oxygen deficiency hazard (ODH) and F (Rise & Fall) for the radiation hazard. N and Y are actual ODH alarms which may suggest that there is either an intuitive association or that some kind of learning and training has taken place. One of the interviewees did mention that colleagues who were working in areas with ODH may be using alarms similar to those at previous facilities supporting the idea that previous training may be the reason that N and Y were chosen more often. As for alarm F, this is not a radiation alarm, but a general evacuation alarm. It is interesting that it was "incorrectly" preferred by the majority as a radiation alarm. It may possibly be due to an intuitive choice. Moreover, there is a possibility that choice by elimination occurred when the alarms were chosen. But this cannot be confirmed and respondents did have the possibility to choose 'none of these'. Since not so many answered ‘none of these’ it seems like choice by elimination may not have played an important role in the results.

Alarm Q (Bell) was shown to be the most popular alarm for the fire hazard. This was not surprising as many Swedes were expected to recognize it because it is widely used in public buildings in Sweden. It was assumed that those with a Swedish nationality have spent several years in Sweden, resulting in familiarity with specific alarms and evacuation procedures. Curiously, many of the respondents from other nationalities also chose alarm Q. But this could be explained by the fact that the questionnaire was disseminated to people working in Sweden and, regardless of their nationality, the respondents may have heard alarm Q in other public buildings in Sweden as they also may have lived several years in Sweden. Yet, the 53 % that did not choose alarm Q must be taken into account, it could be visiting researchers or exchange students who are not accustomed to that particular alarm or even people that simply did not recognize it. In facilities of this type where many different cultures and nationalities meet it is important to consider that everyone may not recognize the alarm, as several studies (Andrée & Eriksson, 2008; Almejmaj, Skorinko, & Meacham, 2017) have shown that cultural differences can affect alarm association and response. This is also relevant for spoken evacuation messages. As one of the interviewees mentioned the language of the spoken message may not be understood by everyone.

The results show that almost all of the respondents are confident that they know what to do in an evacuation situation at their facility, 49 out of 54 rated their confidence as a 4 or higher on a scale from 0 to 6 with 3 being neutral. This could mean that the majority of the occupants actually know what to do due to sufficient training or common sense, or it could mean that some of them have a false notion of security. One of the biases affecting human behaviour in evacuations, optimism bias, may contribute to the overestimation of their own confidence. However, it is also difficult to apply the results from a questionnaire to a real emergency situation. The respondents will not have been in the same state of mind when calmly filling out the questionnaire compared to a possibly more stressful emergency situation. Their self-reported confidence could therefore vary in different situations. Further sources of uncertainty due to the questionnaire being different from reality will be discussed later on.

7.1.1 One alarm versus several alarms

The purpose of using different alarms for different hazards is to provide the occupants with more information on what has happened in order to facilitate the evacuation process. Proulx and Sime’s study (1991) with underground train station evacuations led them to the conclusion that occupants evacuate in a more effective way when they are provided with adequate information, such as a voice message indicating what has happened and what they should do. This could indicate that using multiple alarms for the purpose of providing occupants with more information could be a good idea, however there is the important assumption that occupants all understand the different alarms.

As several of the questionnaire respondents and interviewees mentioned, training and drills are an important part for learning how to react to different alarms. If the different alarms are not recognized nor understood, the use of several alarms loses its purpose as the information that they should convey is not received. Adequate training and learning through feedback from drills, actual incidents or online and paper-based training can be seen as manifestations of a positive safety culture. Since these are important factors for the successful use of several alarms, a positive safety culture can be seen as a prerequisite for this. An interviewee mentioned the downsides of too much training; based on the interviewee's experience, alarms are often ignored or not taken seriously because occupants expect it to be a drill. This is called anchoring bias (Kinsey, Gwynne, Kuligowski, & Kinateder, 2019) which manifests itself by occupants interpreting the alarm as something else based on their experience. Rigos, Mohlin and Ronchi (2019, p. 2) also support this view, drills that are unannounced may lead to a cry-wolf effect reducing the perceived trustworthiness of alarms. Hence, they argue for the use of announced drills instead. Further, although they acknowledge that egress drills are very important, Gwynne et al. (2017) argue that there are some potential problems with the way that drills are conducted. If occupants are over-drilled they may become complacent or have a false sense of security due to egress scenarios that are unrealistically simple and that won't challenge their response. These arguments support the interviewee's concerns about inadequate training and drilling in evacuation response.

Another problem caused by anchoring bias was mentioned by another interviewee when arguing against the use of a single alarm. According to this person, when one alarm is used for many hazards the occupants will do their own assessment of what the alarm means based on previous experience. Thus, when false alarms are commonly occurring, many occupants will likely interpret any alarm as a false alarm.

Results show that the category with the most questionnaire answers for the respondents' opinion on alarm use is *Several alarms*. In addition to this, the results showed that those who had previous experience of a real emergency situation were more likely to think that several alarms was a good option. Further, as discussed earlier, the majority were confident that they knew how to react in an emergency. This is interesting as all three facilities do use several alarms today and these results indicate that many respondents are happy with it. There is however a large group of respondents who either prefer one alarm or have mixed opinions. This group cannot be overlooked as they make up the majority. However, many of those who preferred one alarm seem to have assumed that there was only one possible reaction: evacuate. It would have been interesting to follow up with the same question but tell them that there are two different evacuation responses possible to see if they still would have preferred one alarm.

One of the arguments given by questionnaire respondents as an advantage of using several alarms is that alarms of different urgency levels can be used to indicate the urgency of a hazard. This could, according to the respondent, lead to a more appropriate response based on that information. On the other hand, one interviewee argues that there is no point in having different levels of urgency for evacuation alarms because evacuation should always be swift. There is no need to differentiate between 'fast, medium or slow' evacuation. It could also be argued that one type of hazard, such as a fire, can have several urgency levels for e.g. based on the size of the fire or type of fuel, etc. In that case there would have to be alarms with urgency levels based on the hazard but also on the particular circumstances of that hazard, resulting in senselessly many alarms. This points to urgency of a situation being less important than the type of response required when designing evacuation alarms.

Interestingly, different respondents used the same argument for both using a single alarm and using several alarms. One argument was that using one alarm minimizes confusion. And the other argument was that the use of several alarms minimizes confusion. Some may prefer to have different alarms because they will feel less confused and more in control if they can receive information on what is happening based on the alarm sound. Instead, for others, having to keep up with different alarms only adds to the confusion because they would need to reflect and try to remember the different alarms instead of just having to consider a single one. They are not interested in knowing what caused the alarm and simply plan on evacuating. This shows that what is deemed to be confusing or not is a personal preference.

One of the interviewees argued that the occupants should react based on the hazards they are exposed to when they are in a particular place, e.g. in an area where the low oxygen level risk is present. This would reduce the amount of alarms used. The interviewee reasoned that a single alarm should be used throughout the building because experience has shown that it is difficult for visitors and even staff to learn the alarms when there are more than one. A difficulty with using only one alarm exists when occupants work in an area where many hazards can occur, e.g. a fire and low oxygen level. When one of the hazards becomes reality and triggers the alarm it won't be possible for the occupant to know which hazard the alarm is referring to. If different responses are required based on the hazard (e.g. putting on a breathing mask before evacuating, shutting off a certain machine, or instead staying inside and closing windows) this method is not suitable. However, if the response should be the same no matter what hazard then a single alarm would be the most appropriate option.

It is important to consider the effects of the role-rule model (Canter, Breaux, & Sime, 1980) when it comes to occupants that are not familiar with the building, this could be one-day visitors but also short-term guests that spend a few days at the facility. These persons cannot be expected to react to the alarms in the same way as the regular occupants. Certain routines may need to be implemented to ensure that guests and visitors know what to do in an emergency.

A recurring idea both from some interviewees and questionnaire respondents is the role that the alarm plays for the evacuation response, i.e. the actual purpose of the alarm. Also, several respondents who argued for the use of multiple alarms, for the use of a single alarm and those that had mixed opinions occasionally mentioned that alarms should rather be linked to a particular response and not necessarily to a hazard. Many of those that argued for one alarm only, assumed that there was only one appropriate response hence only requiring one alarm. There is a common point of view, found amongst all of the groups, which is that there should not be two different alarms when only one type of action is needed. Identifying the different evacuation responses that may be needed seems to be a good starting point for choosing alarms at a multi-hazard facility.

7.2 Uncertainties and sources of errors

Some of the uncertainties in the results come from delimitations, limitations and the methodology used in the study. Several aspects will be discussed as well as their possible effect on the results.

First of all, the problem with many questionnaire and interview studies is to know if the results are representative of the studied population. Non-sampling error due to non-response error may have an effect on the results. Unfortunately, there is no precise way of checking the response rate as it is not known how many people received the questionnaire. However, the response rate is thought to be low, this is based on the number of people having received the questionnaire, estimated to be at least three times as many as the number of respondents which was 54. It is possible that those who did not respond would have answered differently from those who did, contributing to non-response error. It is also possible that those who answered belonged to a group of people interested in the subject and that their answers differ from the rest of the population. It was assessed that interest in the subject should not had a big effect on the results as many of the questions are about perception, which is why the results can be used as an indication for the studied population.

It is not easy to project the experience of a real emergency situation or the sound of a real alarm into a questionnaire with recorded audio files. Sitting by a desk and filling out a form on the computer may not produce the same answers as an actual evacuation situation which is more intense. The way people *think* they will react can be different from their actions in a real emergency, this means that the results should be used with caution. One example is that some respondents might have over-estimated their confidence level.

A factor that has been both a limitation and a delimitation is the effect of volume on alarm perception. The volume of an alarm was mentioned as an important factor by three of the interviewees as well as three questionnaire respondents even though they were not asked about it. One of the delimitations of the study was to exclude volume from the studied urgency factor which is why the volume was held the same for all the alarm recordings the questionnaire. It is however difficult to control how respondents listened to the alarms, whether on a computer, on a phone, with or without headphones, and the default volume that each respondent has on their device. This could have led to systematic misinterpretation of the alarms' urgency if respondents kept the same volume while answering the questionnaire. Because the misinterpretation caused by having a lower volume is 'equal' for all alarms it does not affect the comparison of the alarms relative to each other. However it could explain why the urgency ratings are scattered for each alarm. It is thought that respondents that had a low volume may have rated the urgency lower and interpreted the alarms as evacuation alarms to a lesser extent than they would if they had heard the alarm in a real emergency situation when the sound is more striking.

Since interpretation is subjective there are some questions which may contain uncertainties. When respondents were asked to rate urgency on a scale from -3 to +3 they may have interpreted the scale differently from each other. This means that a "-2" does not have the same implication for different people and that two people perceiving an alarm as equally urgent might have given different answers, e.g. "-1" and "-2". The way the scale was interpreted could partly explain why alarm urgency ratings were so scattered as well the possible systematic misinterpretation due to different listening volume levels.

Another source of uncertainty comes from the subjective interpretation of all of the text answers for the questions where no predefined options were given. Some of those answers could possibly have been interpreted in different ways. It was deemed that it was better no to limit the respondents' answers by only using multiple-choice questions in order to collect more detailed information and see the bigger picture. Although efforts were made to be as objective as possible in the interpretations, it is impossible to completely eradicate subjectivity. One of the results that contains uncertainties is the distribution of the respondents' opinions on having one or several alarms. Some answers that were difficult to understand might have been wrongly interpreted.

7.3 Future research

It was initially expected that training would play an important role for the successful use of multiple alarms in a multi-hazard facility. This study did however focus more on the interpretation of alarms' meaning and urgency and not so much on how well occupants of the facilities recognize their alarms. It would therefore be interesting, in future research, to study if training with multiple evacuation alarms gives positive results; if there is a particular limit to the number of different evacuation alarms that can be remembered by individuals; and if there are particular acoustic characteristics that are easier to learn and recognize.

Since it is difficult to project the seriousness of an emergency situation onto a questionnaire it could be valuable to compare the results for some of the questions from this study with a more realistic research method. Evacuation drills or virtual-reality could be used to increase the authenticity of an evacuation experience, thus potentially yielding different results as well as allowing the possibility to control the volume of alarms.

As described earlier, the results showed that there seems to be yet another factor affecting how urgent an alarm sounds, this is the pulse pattern of an alarm. It seems like increasing frequency like a "slow whoop" might be contributing to a higher perceived urgency. Hence it would be interesting to investigate if this pulse pattern or other pulse patterns have an effect on perceived urgency and if there are additional factors that have not been identified.

8 Conclusion

This thesis' aim was to investigate the effectiveness of using specific alarms for each hazard versus the effectiveness of using a single alarm for all hazards in multi-hazard facilities. A literature study of human behaviour in evacuation, perception of alarms and reaction to evacuation alarms as well as safety culture helped to interpret the results. These results were obtained from a questionnaire being sent to staff at three different multi-hazard facilities and from interviews with five safety experts. The following research question could be answered based on the results:

Is the urgency of an alarm interpreted differently by different people?

The highest and lowest urgency rating was given to each of the four alarms in the questionnaire. Although some trends could be observed for some of the alarms, rating were generally scattered indicating that people interpret the urgency of an alarm differently from each other. One of the observed trends was that Alarm V (Slow Woop) had the highest mean perceived urgency and smallest standard deviation. This suggests that there might be other factors affecting the perceived urgency than those identified in the literature, for example the pulse pattern.

Do different people associate alarm signals to the same hazards or do they interpret the alarms differently?

Results showed that respondents' interpretation of the alarms' meanings were varied. None of the alarms were unanimously interpreted the same way. Even amongst those who associated an alarm as a hazard, the type of hazard mentioned varied a lot. This showed that there was no common intuitive interpretation of the alarms, however, some trends could be observed. Alarm R (Constant) was the alarm that was least frequently associated with a hazard while alarm V (Slow Woop) was most frequently associated with a hazard. However, 'hazard' was defined as many different types of hazards by respondents. Additionally, alarm Q (Bell) was associated with a fire alarm by most of the respondents, particularly the Swedish respondents as it is an alarm commonly used in public buildings in Sweden. As highlighted by both questionnaire respondents and safety experts, training would be necessary to achieve a common understanding when several alarms are used and to make sure that the information conveyed by the alarm is understood by everyone at the facility.

Is there a relationship between the perceived urgency of an alarm and the interpretation of that alarm?

When comparing how questionnaire respondents interpreted the meaning of the alarms and the mean of the urgency of each alarm, it was discovered that alarms that had a higher mean perceived urgency were also more often associated with a hazard, requiring evacuation. On the other hand, alarms with a lower mean perceived urgency were more often not associated with a hazard but rather with equipment warnings and emergency situations not requiring evacuation.

What are the respective views of safety experts and other occupants of multi-hazard facilities on having multiple alarms?

Twenty-two of the 54 respondents preferred the use of several alarms, however thirteen preferred one alarm and thirteen had mixed opinions. Although several alarms was the most frequent opinion, it does not constitute the majority making it difficult to draw any conclusion about the general opinion of the occupants other than them having varied opinions. As for the safety experts, they also followed this trend – some of them arguing for the use of one alarm and other for the use of several alarms. Those who argued for the use of several alarms underlined that there should not be too many and that each alarm should have a unique purpose. An important view which was common amongst many respondents and interviewees is that alarms should not be based on the hazard that triggers them but on the type of evacuation response that is required.

To summarize the conclusion of this thesis, it is still difficult to say whether a single alarm or several alarms is the best option for multi-hazard facilities. However, the thesis highlights certain advantages and disadvantages of both options, e.g. using one alarm for all hazards cannot communicate different evacuation responses while several alarms dedicated to specific hazards require respondents to learn and remember them. Also, it is concluded that training is an important factor for the successful use of multiple alarms. This is because results have shown that the intuitive interpretation of an alarm's meaning and urgency can vary a lot, although alarms that are perceived as urgent seem to be associated with a hazard more often than alarms of lesser urgency. Finally, if several alarms are to be used this should only be because different evacuation responses are required.

References

Akselsson, R. (2014). *Människa, Teknik, Organisation och Riskhantering.* Lund University, Faculty of Engineering, Department of Design Sciences.

Almejmaj, M., Skorinko, J. L., & Meacham, B. J. (2017, May). The effects of cultural differences between the U.S. and Saudi Arabia on emergency evacuation — Analysis of self reported recogntion/reaction times and cognitive state. *Case Studies in Fires, 7*, 1-7. doi:10.1016/j.csfs.2016.12.002

Andrée, K., & Eriksson, B. (2008). *Cultural differences in an evacuation scenario - A study comparing Australian and Swedish responses.* Lund University, Department of Fire Safety Engineering, Lund.

Arrabito, G. R., Mondor, T. A., & Kent, K. J. (2004). Judging the urgency of non-verbal auditory alarms: a case study. *Ergonomics, 47*(8), 821-840. doi:10.1080/0014013042000193282

Assael, H., & Keon, J. (1982). Nonsampling vs. Sampling Errors in Survey Research. *Journal of Marketing*, 114-123.

Ben-Nun, P. (2008). Respondent Fatigue. In P. J. Lavrakas (Ed.), *Encyclopedia of Survey Research Methods* (p. 743). Thousand Oaks: Sage Publications, Inc. doi:10.4135/9781412963947

Benthorn, L., & Frantzich, H. (1999). Fire Alarm in a Public Building: How do People EvaluateInformation and Choose an Evacuation Exit? *Fire and Materials, 23*(6), 311-315.

Bruck, D., & Thomas, I. (2008). Towards a better smoke alarm signal – an evidence based approach. In B. Karlsson (Ed.), *Proceedings of the 9th International Symposium of the International Association for Fire Safety Science*, (pp. 403-414). Karlsruhe, Germany.

Canter, D., Breaux, J., & Sime, J. (1980). Domestic, Multiple Occupancy, and Hospital Fires. In D. Canter (Ed.), *Fires and Human Behaviour* (pp. 117-136). Chichester, U.K: John Wiley & Sons, Ltd.

Chan, A. H., & Ng, A. W. (2009). Perceptions of implied hazard for visual and auditory alerting signals. *Safety Science, 47*(3), 346-352. doi:10.1016/j.ssci.2008.06.003

Cooper, M. D. (2000). Towards a model of safety culture. *Safety Science, 36*(2), 111-136.

Edworthy, J. (1994, August). The design and implementation of non-verbal auditory warnings. *Applied Ergonomics, 24*(4), 202-210. doi:10.1016/0003-6870(94)90001-9

Edworthy, J. (2011, July/August). Designing Effective Alarm Sounds. *Biomedical Instrumentation & Technology*, 290-294.

Edworthy, J., & Meredith, C. S. (1994, November). Cognitive psychology and the design of alarm sounds. *Medical Engineering & Physics, 16*(6), 445-449. doi:10.1016/1350-4533(94)90067-1

Ek, Å. (2014). *Beständiga förändringar av säkerhetskulturen.* Swedish Radiation Safety Authorithy.

Gwynne, S. M., Kuligowski, E. D., Boyce, K. E., Nilsson, D., Robbins, A. P., Lovreglio, R., . . . Roy-Poirier, A. (2017). Enhancing egress drills: preparation and assessment of evacuee performance. *Fire and Materials*. doi:10.1002/fam.2448

Haas, E. C., & Casali, J. G. (1993). The Perceived Urgency and Detection Time of Multi-Tone and Frequency Modulated Warning Signals. *Proceedings of the Human Factors and Ergonomics Society 37th Annual Meeting*, (pp. 544-548).

Haas, E. C., & Edworthy, J. (1996, August). Designing urgency into auditory warnings using pitch, speed and loudness. *Computing & Control Engineering Journal* , 193-198.

HSL. (2002). *Safety Culture: A review of the literature.* UK: Health and Safety Executive.

Kinateder, M. T., Kuligowski, E. D., Reneke, P. A., & Peacock, R. D. (2015). Risk perception in fire evacuation behavior revisited: definitions, related concepts, and empirical evidence. *Fire Science Reviews, 4*(1), 1-26. doi:10.1186/s40038-014-0005-z

Kinsey, M., Gwynne, S. M., Kuligowski, E., & Kinateder, M. (2019). Cognitive Biases Within Decision Making During Fire Evacuations. *Fire Technology, 55*(2), 465-485. doi:10.1007/s10694-018-0708-0

Knuth, D., Kehl, D., Hulse, L., Spangenberg, L., Brähler, E., & Schmidt, S. (2015). Risk perception and emergency experience: comparing a representative German sample with German emergency survivors. *Journal of Risk Research, 18*(5), 581-601. doi:10.1080/13669877.2014.910685

Krosnick, J. A., & Presser, S. (2009). Question and Questionnaire Design. In Wright, J. D., & P. V. Marsden (Eds.), *Handbook of Survey Research (2nd Edition).* San Diego, California: Elsevier.

NFPA. (2019, April 25). *People who are deaf or hard-of-hearing*. Retrieved from National Fire Protection Association Web site: https://www.nfpa.org/Public-Education/By-topic/People-at-risk/People-with-disabilities/Educational-materials/People-who-are-deaf-or-hard-of-hearing

Nilsson, D. (2015). Design of fire alarms: Selecting appropriate sounds. *Sound, Safety & Society*, (pp. 33-46). Lund.

Oldendick, R. (2008). Question order effects. In P. J. Lavrakas (Ed.), *Encyclopedia of survey research methods* (pp. 664-665). Thousand Oaks, California: SAGE Publications, Inc. doi:10.4135/9781412963947.n428

Omori, H., Kuligowski, E. D., Butler, K. M., & Gwynne, S. M. (2017). Human Response to Emergency Communication: A Review of Guidance on Alerts and Warning Messages for Emergencies in Buildings. *Fire Technology*(53), 1641–1668. doi:10.1007/s10694-017-0653-3

Palmgren, R., & Åberg, J. (2010). *Vilka ljud- och ljussignaler passar bäst som utrymningslarm?* . Lund University, Department of Fire Safety Engineering and Systems Safety.

Proulx, G. (2007). *Response to fire alarms.* NRCC.

Proulx, G., & Laroche, C. (2003, February). Recollection, Identification and Perceived Urgency of the Temporal-Three Evacuation Signal. *Journal of Fire Protection Engineering, 13*, 67-82. doi:10.1177/104239103032856

Proulx, G., & Sime, J. D. (1991). To Prevent 'Panic' In An Underground Emergency: Why Not Tell People The Truth? *Fire Safety Science*(3), 843-852. doi:10.3801/IAFSS.FSS.3-843

Reason, J. (1997). *Managing the Risks of Organizational Accidents.* Aldershot: Ashgate.

Rigos, A., Mohlin, E., & Ronchi, E. (2019). *The Cry Wolf Effect in Evacuation: a Game-Theoretic Approach.* Retrieved from https://arxiv.org/abs/1904.01963

Schein, E. H. (2004). *Organizational culture and leadership.* San Francisco: Jossey-Bass.

Seppänen, H., & Virrantaus, K. (2015). Shared situational awareness and information quality in disaster management. *Safety Science, 77*, 112-122.

SFPE. (2019). *SFPE Guide to Human Behaviour in Fire* (2nd ed.). Cham: Springer.

Tancogne-Dejean, M., & Laclémence, P. (2016, February). Fire risk perception and building evacuation by vulnerable persons: Points of view of laypersons, fire victims and experts. *Safety Science, 80*, 9-19. doi:10.1016/j.firesaf.2015.11.009

Tong, D., & Canter, D. (1985). The decision to evacuate: a study of the motivations which contribute to evacuation in the event of fire. *Fire Safety Journal, 9*(3), 257-265.

Appendix A

In this appendix an adapted version of the questionnaire sent out to respondents is presented. Note that there were two versions, A and B, in which the question order differed in some cases. Only one version is shown here.

Questionnaire about alarms

This study is part of a Master Thesis at the Fire Safety Engineering Department at Lund University, Sweden. The aim of this survey is to investigate the effectiveness of alarm sounds. The results will help to understand how people perceive alarm sounds.

- You will listen to a set of alarm sounds so you need to have headphones or speakers. You should also be in a quiet place.

- We recommend answering the questionnaire on a computer (smartphone works as well).

- The entire process should take about 10 minutes of your time.

- Answers you provide will be anonymous.

- If you wish to withdraw for any reason, close the tab/window and no data will be sent.

If you have any questions please send an email to Mr Robin Magnusson (bra14rma@student.lu.se) or Ms Claude Eriksson (bra14cpa@student.lu.se).

* Required

1. **What year were you born?** *

____

2. **What gender do you identify with?** *
   Mark only one oval.

   ◯ Female
   ◯ Male
   ◯ Prefer not to say
   ◯ Other: ________________________

3. **What is your nationality?** *
   If you have multiple nationalities, please chose the one you identify most with.

4. **Do you have any documented hearing impairment?** *
   Mark only one oval.

   ◯ Yes
   ◯ No

5. **If yes, please specify:**

____

____

6. **Where are you currently working/studying?** *

This includes having a full-time or part-time job, studying, being a guest researcher...
Mark only one oval.

- ◯ ESS *Skip to question 11.*
- ◯ MAX IV *Skip to question 7.*
- ◯ CERN *Skip to question 9.*
- ◯ Kemicentrum (KC) *Skip to question 13.*

MAX IV

7. **What is your main occupation here?** *

Mark only one oval.

- ◯ Researcher
- ◯ Health and Safety Officer
- ◯ Student
- ◯ Other: ____________________

8. **How many times have you been in an accelerator area / an optics hutch / an experimental hutch / a chemistry lab in the past year?** *

Mark only one oval.

- ◯ Not been there
- ◯ Once or twice
- ◯ Less than 3 times/month (or 36 times/year)
- ◯ More than 3 times/month (or 36 times/year)

Skip to question 15.

CERN

9. **What is your main occupation here?** *

Mark only one oval.

- ◯ Researcher
- ◯ Health and Safety Officer
- ◯ Student
- ◯ Other: ____________________

10. **How many times have you been in the Large Hadron Collider (LHC) and/or the large experiment caverns in the past year?** *

Mark only one oval.

- ◯ Not been there
- ◯ Once or twice
- ◯ Less than 3 times/month (or 36 times/year)
- ◯ More than 3 times/month (or 36 times/year)

Skip to question 15.

ESS

11. **What is your main occupation here?** *
Mark only one oval.

- Researcher
- Health and Safety Officer
- Student
- Other: ____________

12. **How many times have you been in the accelerator buildings (G01, G02 and/or G04) in the past year?** *
Mark only one oval.

- Not been there
- Once or twice
- Less than 3 times/month (or 36 times/year)
- More than 3 times/month (or 36 times/year)

Skip to question 15.

Kemicentrum

13. **What is your main occupation here?** *
Mark only one oval.

- Researcher
- Health and Safety Officer
- Student
- Other: ____________

14. **How many times have you been in the labs in the past year?** *
(It doesn't matter if it is the same lab or different labs as long as it is somewhere in KC)
Mark only one oval.

- Not been there
- Once or twice
- Less than 3 times/month (or 36 times/year)
- More than 3 times/month (or 36 times/year)

Skip to question 15.

Sound testing

Lower your volume before playing the video! The sound may be higher than you expect. This is a test video for you to adjust the volume to a comfortably high volume. When you have done that, please do not change the volume during the rest of the questionnaire.

Alarm TEST

15. **Could you hear the sound in the video clearly?** *

You should hear an alarm sound, adjust the sound until it is clearly audible. If the video does not work, try clicking on the YouTube logo.
Mark only one oval.

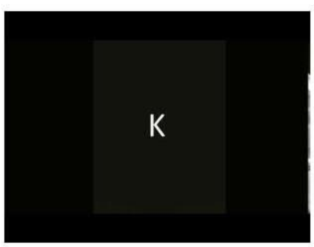
- ( ) Yes
- ( ) No *Stop filling out this form.*

Alarm urgency

You will now hear 4 different alarms, imagine that you are in the facility where you work/study when you hear the sounds. We will ask you questions after each sound. There is no 'correct' answer, choose what you feel is right.

Here we define 'hazard' as: 'a potential source of harm or adverse health effect on a person or persons'.

Alarm K



16. **What hazard do you associate alarm K with?** *

____

17. **How urgent is alarm K?** *

(not urgent = - 3 , very urgent = + 3)
Mark only one oval per row.

	- 3	- 2	- 1	0	+ 1	+ 2	+ 3
Urgency	( )	( )	( )	( )	( )	( )	( )

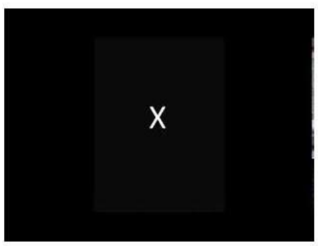
Alarm R

18. **What hazard do you associate alarm R with?** *

19. **How urgent is alarm R?** *
(not urgent = - 3 , very urgent = + 3)
Mark only one oval per row.

	- 3	- 2	- 1	0	+ 1	+ 2	+ 3
Urgency	◯	◯	◯	◯	◯	◯	◯

Alarm X



20. **What hazard do you associate alarm X with?** *

21. **How urgent is alarm X?** *
(not urgent = - 3 , very urgent = + 3)
Mark only one oval per row.

	- 3	- 2	- 1	0	+ 1	+ 2	+ 3
Urgency	◯	◯	◯	◯	◯	◯	◯

Alarm V

22. **What hazard do you associate alarm V with?**
*

23. **How urgent is alarm V?** *
(not urgent = - 3 , very urgent = + 3)
Mark only one oval per row.

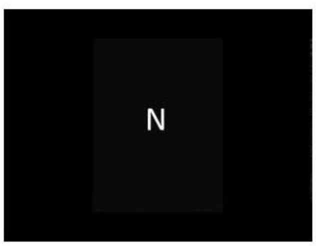
	- 3	- 2	- 1	0	+ 1	+ 2	+ 3
Urgency	◯	◯	◯	◯	◯	◯	◯

Alarm selection

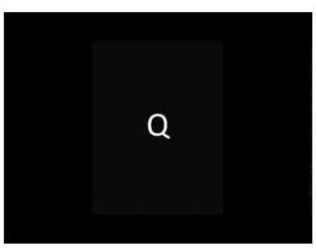
In this part you will imagine that different hazards have occurred at your facility. Choose the alarm(s) that you feel sound like an evacuation alarm for that specific hazard, again there is no 'correct' answer.

A fire has started in the building and evacuation is necessary. Listen to the following 4 alarms and answer the questions below.

Alarm N



Alarm Q



Alarm F

Alarm Y

24. **Which alarm(s) sound like a fire evacuation alarm?** *

You can choose more than one.
Check all that apply.

	N	Q	F	Y	None of these
Alarm	☐	☐	☐	☐	☐

25. **If you had to chose only one of the alarms for the above question, which would you chose?** *

Mark only one oval per row.

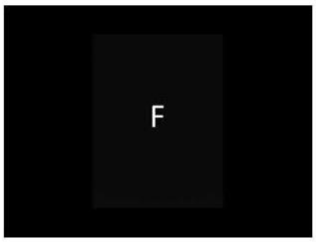
	N	Q	F	Y	None of these
Alarm	◯	◯	◯	◯	◯

Imagine that there is a sudden risk of being exposed to dangerous radiation levels and, thus, evacuation is necessary. Listen to the following 4 alarms again and answer the questions below.

Alarm N

Alarm Q

Alarm F



Alarm Y

26. **Which alarm(s) sound like a radiation hazard alarm?** *
You can choose more than one.
Check all that apply.

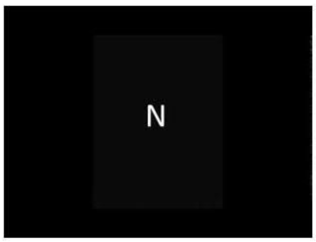
	N	Q	F	Y	None of these
Alarm	☐	☐	☐	☐	☐

27. **If you had to chose only one of the alarms for the above question, which would you chose?** *
Mark only one oval per row.

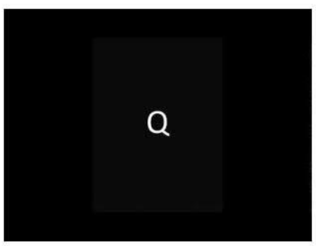
	N	Q	F	Y	None of these
Alarm	◯	◯	◯	◯	◯

Imagine that the oxygen level is dangerously low. Listen to the following 4 alarms again and answer the questions below.

Alarm N

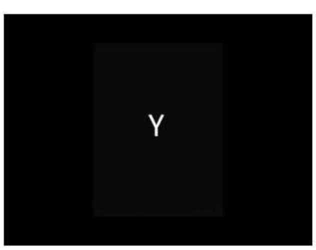


Alarm Q



Alarm F

Alarm Y



28. **Which alarm(s) sound like an oxygen deficiency hazard alarm?** *
You can choose more than one.
Check all that apply.

	N	Q	F	Y	None of these
Alarm	☐	☐	☐	☐	☐

29. **If you had to chose only one of the alarms for the above question, which would you chose?** *
Mark only one oval per row.

	N	Q	F	Y	None of these
Alarm	◯	◯	◯	◯	◯

Final Section

Great, now you are almost done! We only have a few last questions for you.

30. **What is your opinion on having one alarm for all types of hazards or having a specific alarm for each hazard?**
(e.g. one alarm sound for fire, another alarm sound for radiation and so on...) Even if you are unsure any comments are interesting for us!

31. **How confident are you that you know what do to in an evacuation situation in your facility?** *
Mark only one oval.

	0	1	2	3	4	5	6	
Not confident at all	◯	◯	◯	◯	◯	◯	◯	Very confident

32. **Do you have any previous experience with real emergency situations?** *
Mark only one oval.

◯ Yes
◯ No
◯ Other:

33. **Do you have any comments about the questionnaire? Feel free to tell us here:**

Appendix B

In this appendix the structure of the interview is presented with the questions that were asked to get an understanding of how the interviews were conducted. For the interview methodology see section 5.4.

The following questions were used as a guide during the interviews:

1. The answers you provide will be anonymous. We won't name you or the facility however we would like to know your title/role?
   a. Safety expert, safety officer…
2. Can we make an audio recording of the interview? We are the only ones who will listen to the recording and it will be deleted after the thesis is finished.
3. How many years have you worked within the safety sector?
4. In how many different places/facilities have you worked within the safety sector?
5. Do you use one or multiple alarms in your current facility?
6. Do you know if the urgency of a hazard has been considered when choosing the alarm sounds for the facility?
7. Are there any particular alarm sounds or characteristics (e.g. pitch, continuous) which you think are particularly effective - i.e. when occupants have reacted or evacuated quickly?
   a. E.g. certain alarm sound for radiation warning, fire alarm or toxic gases...?
   b. Based on your experience, are there any alarm sounds that could be improved at your facility to make occupants react more promptly?
8. Have you experienced real evacuation situations or false alarms?
   a. If yes, how did people react to the alarm? Anything in particular?
9. As a conclusion, what is your opinion on having different alarms for different hazards?
   a. One for all? It depends? Dedicated alarms for each hazard?

Appendix C

This appendix presents the calculations of statistical test that were made in the results section. To begin with the equations used for the test will be presented followed by the setup of the calculations for the different questions.

Z-test

Z-tests where used to compare proportions between two sample groups. For the z-test the following equations where used:

$$Z = \frac{p_1 - p_2}{\sqrt{P * (1 - P) * (\frac{1}{n_1} + \frac{1}{n_2})}} \quad where \quad P = \frac{n_1 * p_1 + n_2 * p_2}{n_1 + n_2}$$

Z was then compared to Z_α taken for different α values, determining the significance level. The null hypothesis, H_0, and alternative hypothesis, H_1, was setup depending on what was tested.

Effect of nationality when choosing alarm Q

The first test was done to see if there was any difference between Swedish respondents and respondents from other nationalities on the question where they were asked to choose one alarm for a fire hazard and they chose alarm Q.

H_0: $p_1 - p_2 = 0$
H_1: $p_1 - p_2 > 0$
$\alpha = 2{,}5\% \rightarrow Z_\alpha = 1{,}96$

p_1 = the proportion of the Swedish respondents that answered alarm Q.
p_2 = the proportion of the respondents from other nationalities that answered alarm Q.

$p_1 = 0{,}9459$
$p_2 = 0{,}4667$
$n_1 = 37$
$n_2 = 15$

$$P = \frac{37 * 0{,}9459 + 15 * 0{,}4667}{37 + 15} = 0{,}808$$

$$Z = \frac{0{,}9459 - 0{,}4667}{\sqrt{0{,}808 * (1 - 0{,}808) * (\frac{1}{37} + \frac{1}{15})}} = 3{,}97 > 1{,}96$$

This leads to the null hypothesis being rejected, with a significance level of 2,5%, meaning that the alternative hypothesis is accepted and statistical significance exists.

Previous experience with real emergency situations

The second test was performed in order to study if earlier experience with emergency situations had an impact on the question where the respondents gave answers based on their own opinion on having one alarm for all hazards or specific alarms for each hazard.

H_0: $p_1 - p_2 = 0$
H_1: $p_1 - p_2 > 0$
$\alpha = 5\% \rightarrow Z_\alpha = 1{,}64$

p_1 = the proportion of the respondents with previous experience that answered several alarms.
p_2 = the proportion of the respondents with <u>no</u> previous experience that answered several alarms.

$p_1 = 0{,}54$
$p_2 = 0{,}31$
$n_1 = 24$
$n_2 = 29$

$$P = \frac{24 * 0{,}54 + 29 * 0{,}31}{24 + 29} = 0{,}414$$

$$Z = \frac{0{,}54 - 0{,}31}{\sqrt{0{,}414 * (1 - 0{,}414) * (\frac{1}{24} + \frac{1}{29})}} = 1{,}69 > 1{,}64$$

This leads to the null hypothesis being rejected, with a significance level of 5%, meaning that the alternative hypothesis is accepted and statistical significance exists.