Knowledge Visualisation Criteria for Supporting Knowledge Transfer in Incident Management Systems

by

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ABSTRACT

During an incident, which is critical in nature, sense-making by the individuals involved are essential in ensuring an optimal response to the incident. The incident management systems employed to manage the allocation of resources to an incident allow for the visualisation of the incident and its constituents, and this visualisation supports sense-making by improving knowledge transfer. Knowledge visualisation contains pitfalls that can be avoided by implementing knowledge visualisation criteria. The purpose of this study is to identify the knowledge visualisation criteria that optimise the knowledge transfer by visual artifacts in incident management systems like emergency medical or fire-response systems. This study used the design science research (DSR) methodology and was conducted in the context of critical incident response management. A review of the existing literature was done to identify an initial set of knowledge visualisation criteria. The initial set was evaluated by content experts (using questionnaire driven interviews) and usability experts (using questionnaire driven interviews, usability testing with eye tracking and a survey) in the context of an emergency incident management system. The main contribution of this study is a validated set of knowledge visualisation criteria to guide knowledge transfer in incident management systems.

KEYWORDS: Knowledge; visualisation; knowledge visualisation; knowledge transfer; sense-making; user experience; incident; incident management system; emergency; first responders; critical period

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Finally, I would like to thank my God for providing me with determination, insight and endurance required to complete this study. I owe everything to Him.

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Terms

DV – Data Visualization

IV – Information Visualization

KV – Knowledge Visualization

KVC – Knowledge Visualization Criteria

IMS – Incident Management System

OED – Oxford English Dictionary

DSR – Design Science Research

SUS – System Usability Scale

KM – Knowledge Management

KMS – Knowledge Management System

FCM – Firebase Cloud Messaging

SMS – Short Message Service

UCD – User Centered Design

Incident – An event or happening which is critical in nature and can lead to damage or fatalities.

Mobile Application – A software program designed to operate on a smart mobile device (smart phone).

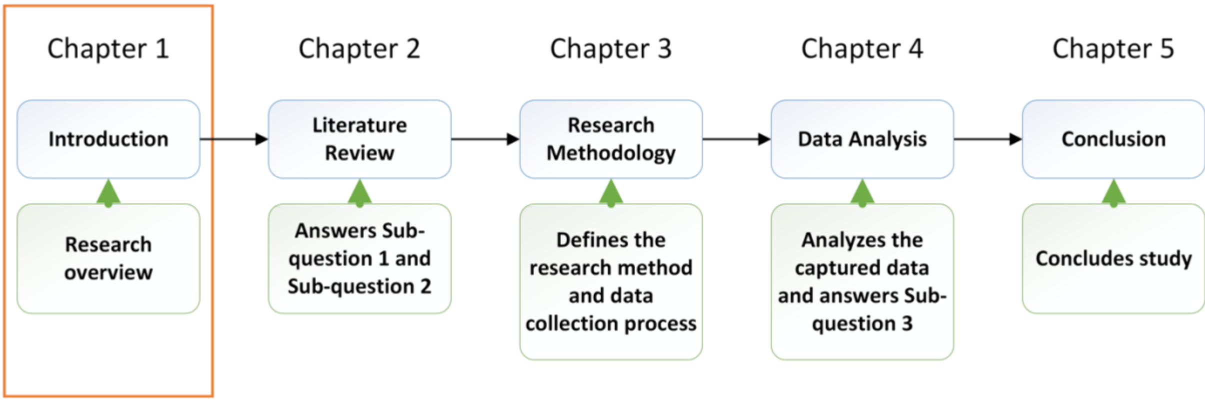
Publications

Quintus van Wyk, Towards Knowledge Visualization Evaluation Criteria for Incident Management Systems, September 26 – 28, SAICSIT 2017 Postgraduate Symposium, 2017, Thaba Nchu, South Africa

Quintus van Wyk, Judy van Biljon & Marthie Schoeman, Visualization Criteria: supporting knowledge transfer in Incident Management Systems, March 6 – 8, ICTAS 2019, 2019, Durban, South Africa, ISBN 978-1-5386-7365-2/19/

CHAPTER 1
Introduction and research overview

Chapter Content



1.1 Introduction

Emergency incidents, which are critical in its nature, may lead to the damaging of items such as property and infrastructure in the environs of the incident (Stein, 2004; Spiekermann, Kienberger, Norton, Briones, Weichselgartner, 2015; Allgren, Rouleau & de Rond, 2018). Such incidents may also result in injuries to individuals involved in the incident, as well as fatalities (Stein, 2004). In order to minimise these consequences as much as possible, the response to such incidents should be effective, efficient and resourceful (Luokkala & Virrantaus, 2014). Managing an incident comprises directing the various components of the incident, including the responders, communication and any allocated resources (Perry, 2003; Anderson, Compton & Mason, 2004; Hossain & Kuti, 2010), and is crucial to influencing the outcome of an incident (Perry, 2003).

The two principal and most vital pieces of information provided to the responders about an incident include the location and the type of incident. This information will assist the responders to decide on and prepare for the type of response required to resolve the incident in order to ensure the best possible outcome. Providing the responders with details regarding the incident and its context should assist the responders in their sense-making processes, thus leading to the making of more informed decisions. Optimised sense-making may be achieved by the responders through the transfer of knowledge about the incident to them utilising the technology incorporated into an incident management system (IMS).

The aim of this study was to determine the knowledge visualisation criteria (KVC) for knowledge visualisation (KV) in relevant academic literature and how such criteria apply to IMSs. This chapter serves as an introduction to the study. Section 1.2

presents the background to incidents and their context, the concept of KV and the way to achieve knowledge transfer while section 1.3 contains the rationale. Section 1.4 discusses the problem statement that motivated the study, the research question, research sub-questions and research objectives. The research outline is then discussed in section 1.5 with the research method being explained in section 1.6. The anticipated contribution of the study is discussed in section 1.7 and the assumptions and limitations of the study in section 1.8. Finally, the thesis structure is outlined in section 1.9.

1.2 Background

During an emergency (or critical) incident in which damage to property and/or the environment or even fatalities may occur, anxiety of those involved in the incident often arises (Stein, 2004; Sandberg & Tsoukas, 2015; Allgren, Rouleau & de Rond, 2018). The emergency responses may influence the outcome of the incident (which comprise elements of a disordered nature), either negatively or positively (Stein, 2004; Sandberg & Tsoukas, 2015). The response to an incident may include the allocation of incident experts, such as paramedics, firefighters and incident management staff as well as resources to assist these experts (Allen, Karanasios & Norman, 2014). The allocation of the appropriate resources (by means of disaster operations) to the incident may assist in lessening the impact of the incident (Galindo & Batta, 2013).

When an incident occurs, there are certain elements at play which are of profound importance in the incident response. For example, when a fire ignites in a forest, the surrounding environment has a significant impact on how the fire will spread and the damage that will be caused. The weather, for example, has a direct influence on the fire, either because of a strong wind fanning the flames (which not only increases the danger further but causes the fire to spread at a rapid pace) or because of rain which might obstruct access to fighting the fire due to mud slides or flooding. The location of the fire is also vital for the response teams as placing the firefighters in the correct location to counter the spread of the fire will make a significant difference to the outcome.

An awareness of these extraneously involved elements may ensure that adequate response resources are allocated to the incident (Allen, Karanasios & Norman, 2014; Barton, Sutcliffe, Vogus & DeWitt, 2015; Abu-elkheir, Hassanein & Oteafy, 2016;

Allgren, Rouleau & de Rond, 2018). Such awareness depends on a specific flow of information from the IMS (Wu, Convertino, Ganoe, Caroll & Zhang, 2013; Reuter, Ludwig & Pipek, 2014). An IMS is a system which assists incident experts to manage the experts and resources allocated to an incident (Anderson, Compton & Mason, 2004; Kim, Sharman, Rao, Upadhyaya, 2007; National Fire Protection Association, 2013; Rose, Murthy, Brooks & Bryant, 2017).

When using an IMS (or any information system) to transfer knowledge about these elements listed above, it is also important to make sure that the knowledge transferred is accurate and that it denotes exactly all the elements present (Bai, White & Sundaram, 2012). Providing knowledge which is flawed due to misrepresentation may result in the recipient of the knowledge being provided with flawed understanding of the incident and its surroundings. In order either to avoid or to address this problem the components responsible for the transfer of the knowledge should be designed and implemented in accordance with certain principles.

It is essential that these principles are based on the transfer of knowledge in view of the fact that the IMS is used for the purpose of transferring knowledge. As an IMS utilises visual components to represent the incident and its surrounding environment (Wu et al., 2013) it follows that a more specific focus would be that of the principles of knowledge visualisation. Different visualisations exist, namely, data (Hornbæk & Hertzum, 2011; Azzam, Evergreen, Germuth, Kistler, 2012; Valkanova, Jorda & Vande Moere, 2015), information (Ware, 2004; Munzner, 2009; Jones, 2015) and KV (Eppler & Burkhard, 2004; Masud, Valsecchi, Ciuccarelli, Ricci & Caviglia, 2010; Marchese & Banissi, 2013; van Biljon & Renaud, 2015a; Grainger, Mao & Buytaert, 2016; Yaacob, Ali, Liang, Rahim, Maarop & Ali, 2018). While these three concepts overlap in respect of certain properties they, nevertheless, each represent different notions (Chen, Ebert, Hagen, Laramee, Van Liere, Ma, Ribarsky, Scheuermann & Silver, 2009). In view of the fact that knowledge visualisation was the type of visualisation on which this study focused it was explored in detail.

When designing visualisations with the goal of transferring knowledge certain concepts must be taken into account (Eppler & Burkhard, 2004). In addition, guidelines must be followed or specific criteria adhered to in the design of such a visualisation in order to ensure effective knowledge transfer (Renaud & van Biljon, 2017). This study focused on identifying the criteria pertaining to knowledge visualisation in IMSs. It is important to note that each information system (or, indeed, any system which makes use of visualisations) exists within a unique context while the information system is also designed to achieve unique goals. These two factors in turn influence the way in which the criteria and/or guidelines of knowledge visualisation are applied and followed.

1.3 Rationale

The aim of this study was to explore how the knowledge transfer of an incident and its surrounding environment may be achieved through an IMS. Knowledge visualisation is utilised in this knowledge transfer (Eppler & Burkhard, 2004; Kernbach, Eppler & Bresciani, 2015; Renaud & van Biljon, 2017; Yaacob, Liang & Mohamad, 2017). This research study endeavoured to identify the criteria which inform the design of a visualisation to ensure that the visualisation facilitates knowledge transfer in the context of an IMS.

The reason for achieving knowledge transfer in this context (of a critical incident and the IMS utilised) is to enable the individuals who should respond to the incident (as a first responder – see Figure 2.6) to make an informed decision in their response and to have adequate insight into the incident. This transfer of knowledge empowers (Ryan, 2016) the responders in their reaction to the incident.

The study incorporated elements of Information Visualisation (IV) and KV in identifying KVC. Information visualisation is an interactive visual representation (Eppler & Burkhard, 2004) of condensed information (Hornbæk & Hertzum, 2011), while KV is a visualisation method aimed at achieving knowledge creation and knowledge transfer (Burkhard, 2005; Renaud & van Biljon, 2017). IV is related to the human computer interaction (HCI) field (Hornbæk & Hertzum, 2011; Patterson et al., 2014) while KV is a sub-section within the knowledge management (KM) arena (Eppler & Burkhard, 2004), thus this study was located at the intersection of HCI and KM.

The IMS utilised in this study followed the process of activator, operator and responder with the operator contacting the activator to obtain knowledge in relation to the elements surrounding the environment of the incident. Once this knowledge has been captured it is relayed to the pre-identified responders via a dedicated mobile application. This mobile application utilises visual artifacts to convey the said knowledge to the responder in order to assist the responder to make an informed decision regarding the response required.

While this study resulted in a set of KVC for IMS the KVC which were identified may be further explored in relation to the application on various types of information systems which require knowledge transfer.

1.4 Problem Statement and Research Questions

The following questions arise: If awareness (or knowledge) regarding the incident and the surrounding elements are to be transferred from the site of the incident to the responders to the incident, which is the best method to use to do this? Are there specific criteria with which the components of an IMS must comply in order to optimise the transfer of the said knowledge from the activator to the responder?

Table 1.1 – Research Questions and Research Objectives

Main Research Question			
What are the knowledge visualisation criteria which optimise the knowledge transfer by visual artifacts in incident management systems?			
Sub-questions		**Action**	**Output**
1.	What are the visualisation components of an incident management system?	Literature review	List of items defining the visual artifacts that exist in an incident management system.
2.	What knowledge visualisation criteria exist?	Literature review	List of knowledge visualisation criteria.
3.	How do the knowledge visualisation criteria apply to an incident management system?	Literature review, questionnaire driven interviews, eye-tracking, System Usability Scale questionnaire	List of incident management system's specific knowledge visualisation criteria.
Main Research Objective			
The purpose of this research study is to establish a set of criteria to optimise an incident management system's visual artifacts to be used as knowledge visualisation artifacts to support knowledge transfer. The anticipated end result of this study is to have established			

the criteria for the evaluation of the visualisation artifacts in incident management systems and also how these criteria relate to knowledge visualisation.	
Research Sub-objectives	
1.	To use existing academic literature to establish the visual artifacts that exist in incident management systems.
2.	To establish what knowledge visualisation criteria exist based on the existing academic literature.
3.	To determine how the knowledge visualisation criteria established in answering sub-question 2 apply to the visual artifacts in an incident management system, as determined in the answer to sub-question 1, to achieve knowledge transfer.

Figure 1.1 presents the research sub-objectives from a diagrammatic perspective and how the various components of the research objectives relate to each other.

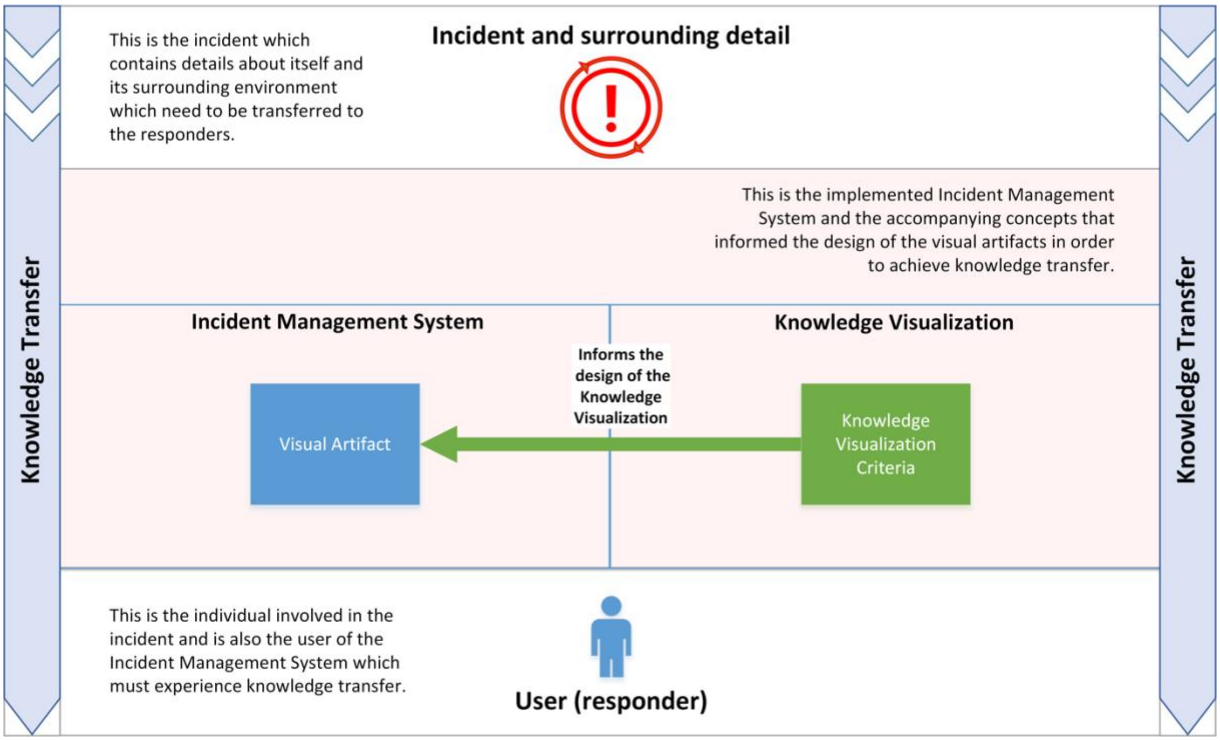


Figure 1.1 – Research Objectives

1.5 Research Outline

The study commenced with a literature review aimed at establishing the criteria for knowledge visualisation. The literature review focused on incidents, sense-making during incidents, IMSs, data, information and knowledge and their visualisation counterparts and culminated in the identification of a set of KVC. The IMS utilised in the study was evaluated by content experts to determine whether the criteria were applicable to the IMS and was also evaluated against the criteria by usability experts to ascertain whether it complied with the criteria. The usability of the responder interface of the IMS was also assessed by the usability experts by means of usability tasks and the completion of a survey.

1.6 Methodological Approach

The research conducted during this study was iterative in nature. Design science research (DSR) was deemed appropriate for the purposes of the study as advocated by (Hevner, March, Park and Ram, 2004) for an iterative study where a knowledge artifact is designed.

1.6.1 Design Science Research

The approach followed in the study involved exploring existing literature to identify and develop a set of criteria for knowledge visualisation in IMSs, to evaluate these criteria and then to evaluate a specific IMS against the criteria. While the IMS was originally developed (before the commencement of this study) based on human centred design principles the results from the evaluation of the IMS suggested that minor changes could be implemented to improve the interface. Accordingly, it was decided that iterative development would be the norm for the study. DSR was deemed to be a fitting methodology for this approach as it allows for the recurrent steps of building and evaluating concepts (de Villiers, 2005).

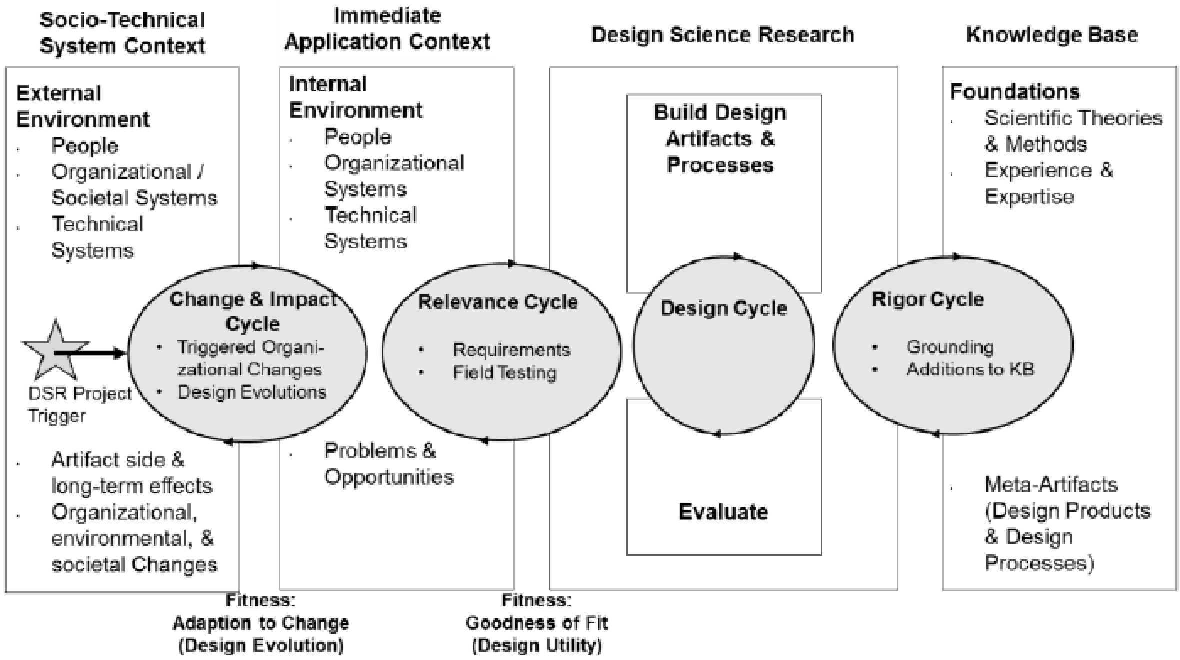


Figure 1.2 – Four Cycle Design Science Research Model (Drechsler & Hevner, 2016)

The four-cycle view model depicted in Figure 1.2 was the method which directed this research study. The literature on knowledge visualisation was reviewed to identify the criteria required to design an effective visualisation. Appropriate criteria were identified and abstracted from the literature and established for the purposes of the study. These criteria were then utilised to identify how and the extent to which the criteria applied to the IMS used in this study by means of questionnaire-driven interviews which were conducted with content experts. The data capturing strategies used included interview-driven questionnaires, usability tasks accompanied by eye-tracking and a survey utilising a System Usability Scale (SUS) questionnaire. The extent to which the IMS complied with the criteria which had been identified was evaluated by interviewing (questionnaire-driven) usability experts as well as their participating in usability tasks on the IMS interface with eye-tracking. Content experts were interviewed (questionnaire-driven) with the intention of determining how the set of criteria which had been identified applied to the responder interface of the IMS.

1.6.2 Literature Review

The literature review conducted in the study focused on first establishing the definition of a critical incident and the life-time of such an incident. The influences that play a role during the life-time of an incident and that affect the sense-making of the individuals involved in an incident were identified and the way in which individuals who are exposed to these influences experience them was then discussed. This sense-making process and the influences on it was then linked to the role an IMS plays as a technological influence on sense-making during an incident, thus paving the way for the introduction of knowledge visualisation. Data, information and knowledge were then deliberated upon as was the way in which they relate to each other. These three were explored as visual components with the focus on knowledge visualisation. In section 2.3.3 in the literature review the criteria were developed (identified, analysed and synthesised).

1.6.3 The Incident Management System

At the time of the study the researcher was involved in the development and maintenance of an IMS serving multiple clients in South Africa with each client having different objectives in respect of utilising the IMS (more details in section 3.2.3). The IMS was developed based on the general principles of user centred design (Abras, Maloney-krichmar & Preece, 2004; Garrett, 2010; Lanter & Essinger, 2017). The IMS was developed before the commencement this study, the developer had not been exposed to the academic field of knowledge visualisation before the IMS development and thus the visualisation was based on basic User Centred Design (UCD) principles. The researcher has access to, and influence over the development of all the components of the system, thus giving him the opportunity to alter the system where required. However, this advantage was employed only under the protocols implemented by the company which owned the system. This IMS was already being provided to clients as a functioning system and with an ongoing maintenance and improvement policy. Thus, any changes suggested by the results of the research would be beneficial to the system itself and the clients using it.

1.6.4 Data Capturing Strategies

The study used various data capturing strategies to assist in answering the research question, namely, interviews, a survey and usability tasks.

1.6.4.1 Interviews

In the study two different fields or groups of expertise were consulted, namely, usability expertise and emergency content expertise. Utilising these two expertise areas required the collection of data from the two groups and, thus, separate questionnaire-driven interviews were conducted with the participants from the two different fields. First content experts were required to complete the questionnaire (in an interview setting) in order to ascertain the extent to which the criteria of knowledge visualisation, which had been identified, were applicable to an IMS. The usability experts were then interviewed (similar to the content experts) in order to establish the extent to which the current implementation of the IMS under investigation complied with the criteria.

1.6.4.2 Usability Tasks with Eye-tracking

Eye-tracking was done while the usability experts performed usability tasks on three sample incidents on the responder mobile interface in order to evaluate transfer of knowledge by this interface. The participants were provided with three tasks – each of which involved evaluating different incident types – on the mobile interface of the responder application. The time required to complete each task was recorded as was the feedback from the participants in respect of whether they were of the opinion that there was sufficient information to enable them to make an informed decision. The content experts did not participate in the usability tasks because of logistical difficulties involved in their coming to the laboratory (availability of the experts was another contributing factor for not having the content experts participate in the usability tasks).

1.6.4.3 Survey (System Usability Scale Questionnaire)

The usability experts also completed a questionnaire on the System Usability Scale (SUS) (Brooke, 1996) to establish how the IMS current responder mobile interfaces rated on the scale. The SUS was chosen as it allows for the easy collection of a participant's rating of a product and has been tested and proven to be a robust tool (Bangor, Kortum & Miller, 2008).

1.7 Research contribution

This study is novel in having an explicit focus on knowledge visualisation in the fields of IMS, more specifically the study's contribution is significant in the following ways:

1. A **theoretical contribution** in the form of a set of general KVC synthesised from the existing literature. One of the goals of this study was to identify KVC

(which achieves knowledge transfer) as discussed in the literature. This led to the demarcation of clear and concise descriptions of KVC which was then used during the remainder of this study. This set is presented in Table 2.3.

2. A second **theoretical contribution** in the form of a validated set of IMS specific KVC. This set was developed from the KVC synthesised in point 1 above but underwent evaluation during the data collection process. While the original KVC from point 1 may have been be applicable to all information systems it may also have been applicable only to varying degrees according to the system in relation to which it is was applied. The new set of KVC focused on the prioritisation of the original KVC identified applied to IMSs from the perspective of both the high-level (management) and low-level (implementation) users involved. This new set of KVC for IMSs is presented in Table 4.5.
3. The literature review conducted for the purposes of the study provided an insight into an incident and how it may last over various periods. The study makes a third **theoretical contribution** by expanding on the concept of an incident and the way in which it influences the sense-making process of the individuals involved by illustrating the allocation of periods in relation to the timeline of an incident's existence. Diagrams were used to illustrate this concept (Figures 2.1 and 2.2).
4. A final **theoretical contribution** was the diagram depicting the factors which contributed to the creation of a KV artifact (Figure 2.14). The diagram was synthesised from the academic literature on KV (the What, Why, For Whom, Context) and combined with the original set of KVC.
5. The results presented in Chapter 5 indicated that the IMS achieved knowledge transfer, thus providing the **practical contribution**: namely, a validated IMS that achieves knowledge transfer but with some known limitations.
6. The study also offered suggestions for improvements to the IMS responder application interface. When implemented these suggestions should ensure an improved IMS interface for the responder group of the IMS used for the purposes of this study. This may be regarded as another **practical contribution** of the study.

1.8 Scope, Assumptions and Limitations

This section discussed the scope of the study, the assumptions underpinning the study and the limitations of the study.

1.8.1 Scope

The scope of the study was as follows, namely, an IMS in the domain of both private and corporate clients as well as government institutions for the risk management of incidents. At the time of this study the IMS was being used by clients with a number of end users, and these users represented various domains such as corporate and business, government and private.

The data collection process involved seven content experts (individuals with vast experience in incident management and response) as well as eight usability experts (individuals with an academic background) from the Gauteng province of South Africa. The data capture process commenced on 9 April 2018 and concluded on 3 May 2018.

The interactions between responders during an incident was beyond the scope of the study and, in addition, the process of analysing and planning responses to an incident were also not covered in the study. In other words, these concepts were beyond the scope of the study and would have entail different areas of the study which were not included in the study. Furthermore, this detracted from the authenticity of the evaluation of the IMS as the focus of the study was primarily on KVC and its application to the visual components of the IMS.

1.8.2 Assumptions

One of the main assumptions underpinning the study was that the participants (both from the content expert group and the usability expert group) would know how to use a mobile application and how it functions. This was required if the participants were to give their opinions and evaluations with regard to the responder mobile application interface.

1.8.3 Limitations

In view of the fact that the study focused on the application of KVC to the mobile interface of an IMS the participants (incident and usability) were provided with sheets of paper containing screenshots of the mobile interface together with the list of criteria.

This was done for the following two reasons, namely, to evaluate the list of criteria according to the mobile interface using a single page and because evaluation on a physical mobile interface would complicate the process of providing the complementing criteria evaluation. Unfortunately, this completely eliminated the benefit of interactivity of the mobile application and, thus, the participants were only able to provide commentary on the static screenshots and what the researcher was able to convey to them regarding the application. This was particularly true in the case of the content experts as the usability experts experienced the interactivity of the simulation of the mobile application as implemented for the eye-tracking tests.

As the research was intended to utilise the expertise of the usability experts the number of participants in the usability group was limited by the available experts. Another factor curtailing the number of usability experts used in the study was the eye-tracking process which required participants to participate in the eye-tracking test at the usability laboratory on the Unisa campus.

Another limitation in this study was the eye-tracking data collection process. While there is technology and tools for eye-tracking on mobile interfaces, the researcher did not have access to mobile eye-tracking technology at the time of the study and, thus, he had to make use of alternative methods. In order to carry out the eye-tracking on the interfaces, the researcher took individual screenshots of the interfaces and set up a simulation on a browser-based system known as InVision. This system provides functionality to be able to set up interactivity over the screenshots to provide the participants with the experience a mobile application would provide without the mobile application actually being a developed software. This enabled the participants to interact with the mobile application simulation on a computer which had eye-tracking technology embedded, thus allowing for eye-tracking to be implemented on the responder mobile application interfaces.

1.9 Thesis Structure

The dissertation structure comprised five chapters, namely, Introduction and Research Overview, Literature Review, Research Methodology, Data Analysis and Results and Conclusion (in that order). Figure 1.3 presents a diagram indicating the flow of the chapters.

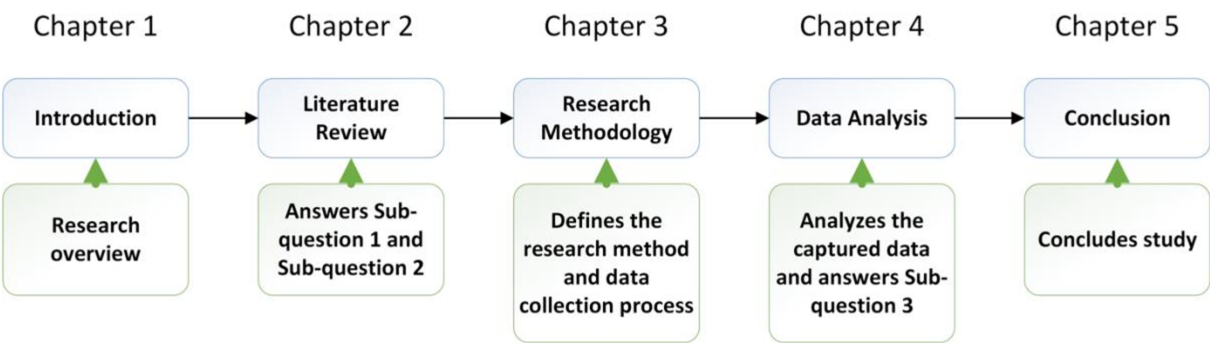


Figure 1.3 – Dissertation Flow

Chapter 1 contained an overview of the study. In addition, it discussed the research questions, the research to be conducted and how it would be done, the anticipated contributions of the study and the limitations of the study.

Chapter 2 comprised the literature review. The chapter first discussed the background to incidents and an incident's structure, then visualisation and, eventually, knowledge visualisation. The criteria for KV were also identified and discussed. Sub-questions 1 and 2 were answered in this chapter.

Chapter 3 detailed the research method utilised in the study. It also provided an overview of the IMS used in the study and presented the responder mobile application interfaces on which the eye-tracking and the questionnaires were based. The groups of participants as well as the questionnaires to be administered were also discussed in the chapter.

Chapter 4 discussed the results emanating from the interviews, the eye-tracking and any additional comments or suggestions expressed by the participants. Certain points of interest were identified, and the results of the eye-tracking data were presented in the form of gaze-plots on the interfaces. Sub-question 3 was answered in this chapter.

The study is concluded in the final chapter, Chapter 5 with the research objective being finalised, and the research questions revisited in light of the results of the study as a whole. The research questions were discussed together with their answers and suggestions made for further research.

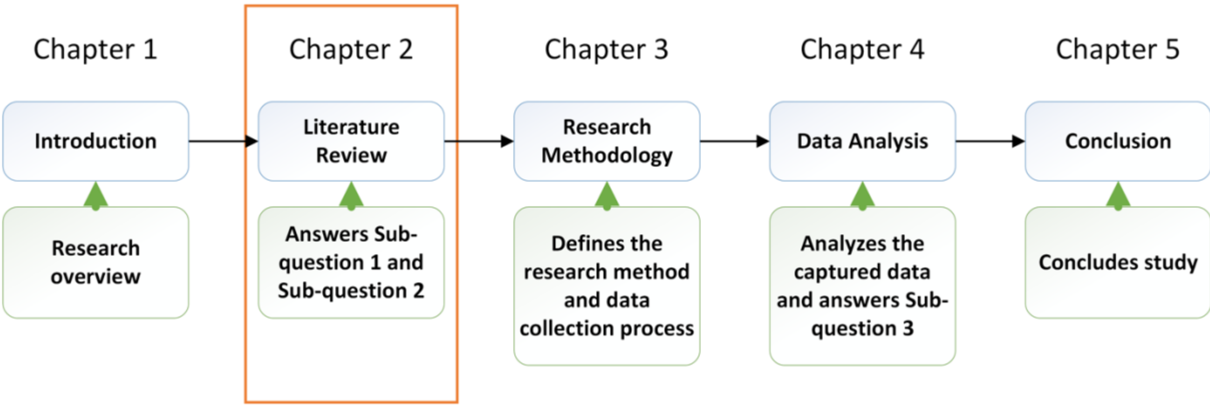
1.10 Summary

KV may be utilised in systems to achieve knowledge transfer between individuals or groups. While the concept of KV is well-defined in existing academic literature there are application pitfalls (Bresciani & Eppler, 2015) and, thus, guidelines on the use of KV are required. No relevant KV guidelines for IMS were found during the exploration of the relevant literature. The aim of the study was, therefore, to identify KVC from existing academic literature and to evaluate the KVC which had been identified in the context of IMSs.

The overview in Chapter 1 provides a roadmap on the way in which the study was conducted in finding KVC suited for IMSs. The following chapter, Chapter 2, contains the literature review which was conducted and during which the set of KVC was synthesised. Incidents are defined and discussed the concept of KV outlined. This resulted in the formulation of the set of KVC.

CHAPTER 2
Review of Literature

Chapter Content:



2.1 Introduction

Incidents which are critical in its nature may cause extensive damage to their surroundings and result in fatalities for the individuals involved (Allen, Karanasios & Norman, 2014). The of incident responders is to respond to an incident in order to minimise, or prevent, the damage and fatalities caused by an incident (Heverin & Zach, 2012; Stralen, 2015). During an incident certain influences impact on the individuals involved in the incident and this, in turn, has an effect on how the individuals understand and react to their environment. This process is termed sense-making (Weick, 1993; Stein, 2004; Mills, Thurlow & Mills, 2010; Dixon, Weeks, Boland & Perelli, 2017). While there are multiple factors that may impact on this sense-making process (Sandberg & Tsoukas, 2015) this study focused on that of technology in IMSs. KV may be employed in any visualisation method including technological methods (Burkhard, 2004; Bai, White & Sundaram, 2012; Marchese & Banissi, 2013).

This chapter explores the characteristics of an incident, the implementation of an IMS within the context of an incident, the role of KV during an incident and how KV fits into the incident response. Section 2.2 discusses the incident concept, its definition and the periods during which it exists. This section also discusses sense-making as a process that takes place in in the cognitive sphere of the individual involved in an incident and how the different factors which characterise an incident event influence this sense-making process. Incident management systems are also examined, how they contribute to the response to an incident and why an IMS is deemed to be an influence on sense-making. Awareness is then identified as the thread which links an incident and knowledge visualisation. Section 2.3 examines KV. It discusses data, information and knowledge as well as their visualisation counterparts, and then presents the criteria for knowledge visualisation. This is followed by a discussion on the constituents of the design of knowledge visualisation artifacts. Section 2.5 concludes Chapter 2.

2.2 Incidents and Their Operations Management

An incident should be seen as an entity which consists of multiple elements and with different periods through which it lasts. These periods are each unique in their own composition while they also differ in the way in which they influence the surrounding environment. The manner in which response is actioned during each of these periods may influence the final outcome of the incident as well as the extent of the collateral damage caused by the incident. Managing the response to these incidents plays a vital role in the effectiveness of the response. The utilisation of an incident management system is fundamental in this management process.

2.2.1 What is an Incident

The OED (Oxford English Dictionary) defines an incident as “[s]omething that occurs casually in the course of, or in connection with, something else, of which it constitutes no essential part; an event of accessory or subordinate character”. Thus, this definition indicates that an incident is an event that happens or exists for a period of time. The type of incidents which were the focus of this research study included disasters, crises and emergencies during which human lives and/or infrastructure are at risk. The OED defines these types as follows:

> Disaster – “Anything that befalls of ruinous or distressing nature; a sudden or great misfortune, mishap, or misadventure; a calamity”.
>
> Crisis – “A vitally important or decisive stage in the progress of anything; a turning-point; also, a state of affairs in which a decisive change for better or worse is imminent”.
>
> Emergency – “A juncture that arises or ‘turns up’; esp. a state of things unexpectedly arising, and urgently demanding immediate action”.

It is clear from the definition of an incident as ‘something that occurs’ that an incident has a starting point, a period during which it exists, and then a conclusion or end point. In other words, it may be considered as a temporal space (Powley, 2009). This view of an incident provides a structure along a timeline during which the incident exists.

Assigning an incident structure assists in understanding the categories that exist during the life-time of an incident and this, in turn, provides the opportunity to investigate the dynamics involved in each category while bringing to the fore different concepts that influence the performance of the actors participating in the response activities of the incident.

Stein (2004) introduced the notion of a 'critical period' of an incident, indicating that this critical period follows the incubation period of an incident and is the precursor to the aftermath of an incident. In short, he defines this as the period in which the disaster unfolds. He stresses that the introduction of a critical period is necessary in view of the fact that the phenomena that occur during the incubation period are distinct from those which occur during the critical period. The response to the critical period impacts directly on the severity of an incident.

A critical period starts with an event that is known as the 'triggering event' or 'precipitating event' and which invariably leads to a disaster if no counteractive action is taken (Stein, 2004). This period ends only when the dangers caused by the incident have been remedied and further catastrophes involving death or damage are less likely to occur. The ending of the critical period gives way to the following period known as the 'aftermath' during which further suffering and even fatalities caused by the incident may still occur but are not as probable as they were during the critical period. Although Stein (2004) identified the periods of an incident he did not provide a diagram to illustrate his ideas. Figure 2.1 was designed by the researcher and provides a perspective on the allocation of these periods in relation to the timeline of an incident's existence. This figure is known as the 'disaster sequence' and is based on the research conducted by Stein (2004).

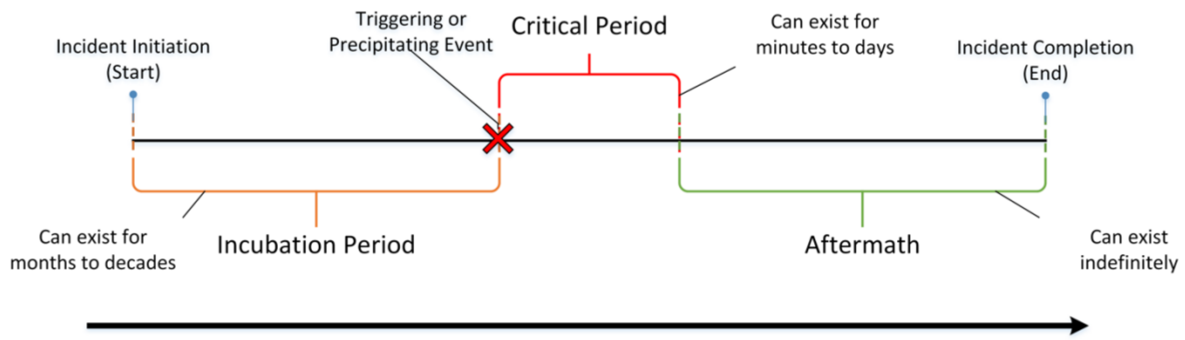


Figure 2.1 – The Disaster Sequence (Researcher's Original Work)

Stein (2004) uses three points to introduce the critical period as a different period to the well-established incubation period.

- First, the triggering event is viewed as a marking point at which there is, noticeably, a qualitative difference in the periods. This event is the initiation of catastrophic processes which result in a corresponding sense of urgency.
- Second, the duration of the critical period tends to be significantly shorter than that of the incubation period. Where the critical period may last from minutes to days the incubation period may last from months to decades.
- Third, the information produced during the critical period requires immediate attention as it represents the truth about the onset of the catastrophic processes. On the other hand, the long-term problems (that caused the incident) during the incubation period may be ignored without necessarily leading to disaster.

The fact that an emergency incident has a chronological existence with the periods as defined by Stein (2004) indicates that the incident may subsist as a liminal space (Allgren, Rouleau & de Rond, 2018). This space creates an environment in which the triggers of sense-making may occur for all those involved in the incident ((Lycett & Marshan, 2016; Allgren, Rouleau & de Rond, 2018) while it also influences the capacity of the sense-making during the critical period (Allgren, Rouleau & de Rond, 2018).

2.2.2 Sense-making

In view of the decision-making is externally driven whereas sense-making is an ongoing accomplishment which originates from the efforts to create order and make retrospective sense of what has occurred sense-making during an incident has been suggested as a preferred method, as opposed to decision-making, in the interests of contextual rationality (Weick, 1993). This means that, where decision-making collapses once the environment in which it occurred (the decision-making took place) changes or presents as something other than was originally assumed, sense-making continually adapts or re-evaluates as the environment evolves. This notion of sense-making has been further expounded on several researchers such Maitlis and Christianson (2014), Lycett and Marshan (2016) and Berthod and Müller-Seitz (2018), to name but a few. Weick (1993) refers to this collapse of the rational as a cosmology episode. Weick (1993) was of the belief that sense-making within an organisation may provide meaning and order in environments that impose contradictory demands (Weick, 1993).

An organisation may be defined as an entity characterised by the following criteria (Weick, 1993), namely, coordination by direct supervision, strategy planned at the top, little formalised behaviour, organic structure and plans being formulated intuitively by the person in charge. Weick (1993) maintains that organisations may provide sense-making in an environment which is characterised by ill-defined (or inconsistent) demands. Sandberg and Tsoukas (2015) agree that there is a strong link between sense-making and organising. They support this statement by demonstrating that the cause maps that are created in the actors' minds (the sense-making of their environment by means of chunking and organising experiences) converge once they the actors have negotiated consensus in the handling of their mutual task.

It is important to note that sense-making is not without its disadvantages and that it too, like decision-making, may collapse. Some of the causes of failed sense-making include social context and cues becoming ambiguous, because retrospection is then more difficult and plausibility strained (Sandberg & Tsoukas, 2015).

Sense-making is triggered by ambiguous events. There are five types of ambiguous events that may trigger sense-making, namely: major planned events, major unplanned events, minor planned events, minor unplanned events and hybrids of events (Sandberg & Tsoukas, 2015). Ambiguity occurs when information has multiple meanings, thereby inducing a search for meaning (Maitlis & Christianson, 2014; Stralen, 2015). Whereas uncertainty is binary in nature (right or not right) and results in a search for the correct answer, which leads to fidelity, ambiguity is multifaceted and limited in its fidelity. It should not be assumed that ambiguity and uncertainty are opposites on a spectrum but, rather that adding time as an intervention to uncertainty introduces a special case of ambiguity (Stralen, 2015).

The sense-making caused by an event is composed of a series of components which iterate in the following order, namely, creation, interpretation and enactment (Sandberg & Tsoukas, 2015). It would appear that that a limited amount of research has adopted the perspective of these three concepts as co-existing in the order listed above during sense-making. If executed correctly this type of sense-making may lead to either restored sense and restored action but, if not, it may lead to non-sense and no restored action. Figure 2.2 presents a diagram indicating the relations between these concepts. While Sandberg and Tsoukas (2015) provided a table detailing the influences on the event of an incident they did not, however, provide a diagram showing the relation of the influences to the event and the sense-making process. Figure 2.2 was based on the concepts of the 'sense-making perspective' from Weick's work as discussed by Sandberg and Tsoukas (2015).

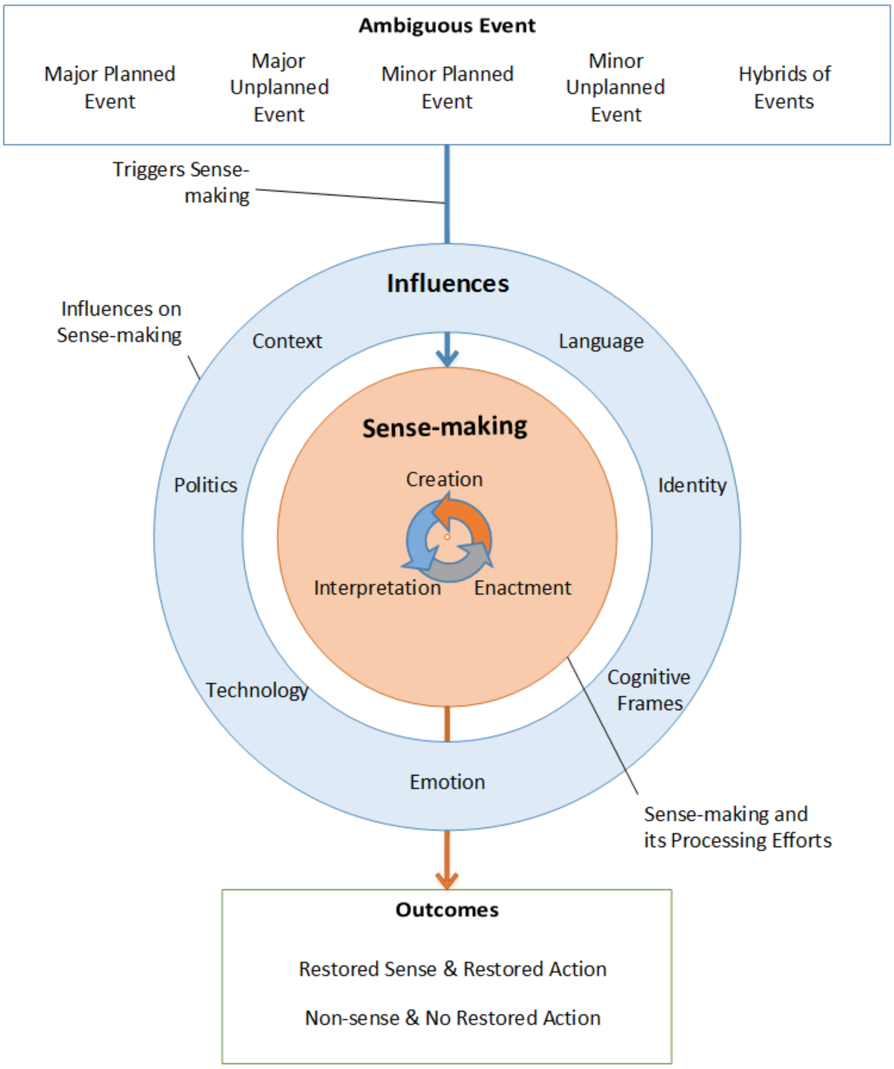


Figure 2.2 – The Sense-making Perspective (Researcher's Original Work)

2.2.3 Influences on Sense-making

According to Sandberg and Tsoukas (2015), sense-making never occurs in isolation but is, instead, influenced by certain factors that surround the sense-making process.

Their study identified seven major types of influences (see Figure 2.2), namely, the context in which the sense-making occurs, the politics that evolve during the sense-making process, the technology involved, the emotions of the actors involved, the cognitive frameworks of the actors, the identity developed by the actors and linguistic factors (Sandberg & Tsoukas, 2015). Although some of these influential factors are beyond the scope of this study a brief overview of emotions as an influential component is presented below.

The influence that emotions may exert on the sense-making process may be either positive or negative (Sandberg & Tsoukas, 2015). Some of the negative emotions identified include fear, anxiety and panic (Lycett & Marshan, 2016) although this does not necessarily mean these emotions are negative in all situations. If we consider anxiety, we may define the types of influence anxiety exercises on the sense-making perspective. Stein (2004), basing his work on Freud, indicated that a possible contrast between fear and anxiety is that anxiety exists in a situation in which the danger may be partly unknown, whereas fear is experienced when the danger is known. He went on to identify two types of anxiety, namely, neurotic anxiety and realistic or signal anxiety, with neurotic anxiety being accepted as pointless and enigmatic whereas realistic anxiety constitutes a reaction to danger (Stein, 2004).

From the perspective of anxiety as an emotional influence on sense-making Stein (2004) indicates that a tolerance of anxiety by the actor acts as the independent variable while the sense-making is the dependent variable. This provides an indication that the type of anxiety and the degree to which (in the case of realistic anxiety) such anxiety is experienced in sense-making steers the course of sense-making during the critical period of an incident (Stein, 2004). Figure 2.3, designed by the researcher, depicts a diagrammatic representation of anxiety in relation to the sense-making process as discussed above.

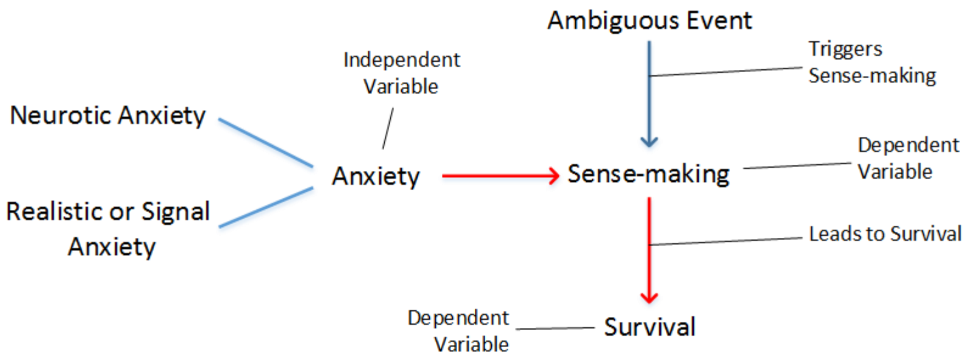


Figure 2.3 – Anxiety in Sense-making (Researcher's Original Work)

While anxiety is a single element deemed to influence sense-making in either a positive or negative manner, it serves as an example that all the entities exerting influence on the sense-making process may contribute to the type of sense-making outputs attained. While these factors may exert an influence on sense-making some of them may also be considered as triggers for sense-making during the unfolding of a crisis (Maitlis & Christianson, 2014; Lycett & Marshan, 2016).

It is important to note, as Wu et al. (2013) point out, that sense-making is a vital element of knowledge work. The process of sense-making finds critical patterns in the amorphous situation (the ambiguous event) by means of refined representations in relation to which information is tailored in service of the task/tasks at hand. This process may be augmented by means of support systems which have been found to stem from visualisation techniques (Wu et al., 2013). This leads into a discussion of the possible influence of technology on sense-making.

Technology is one of the influences present in the sense-making perspective while information and communication technologies have been found to influence sense-making in indisputable ways (Sandberg & Tsoukas, 2015; Berthod & Müller-Seitz, 2018; Seidel, Chandra Kruse, Székely, Gau & Stieger, 2018). Scott Finazzo provided a practical example when he indicated that, during his fire station's training to respond to shooting incidents (such as the Century 16 theatre shooting), it was found that unstructured communication methods by means of radio technology were in need of improvement (Finazzo, 2016). He indicated that, if all the departments responding to an incident were not able to communicate intra-departmentally because of the different radio channels used by each department, this became an obstacle in the response process.

A further example is provided by knowledge management systems (KMSs). Dorasamy, Raman and Kaliannan (2013) found that a well-designed KMS may promote a timely response in disaster situations by bringing together experts with prior knowledge and experience. In addition, a KMS may be used to capture crisis specific knowledge and assist in the making of certain decisions with regard to the response to the crisis (Dorasamy, Raman & Kaliannan, 2013). If technology enables the sharing of information and knowledge (in real-time) between all the actors involved in an incident this may in turn minimise both the risk and fatalities by mobilising and facilitating a fast and effective response (Balfour, 2014). The next aspect to be discussed is the concept of incident management systems – a key component of this research study.

2.2.4 Incident Management Systems

The importance of the role of a central system for incident management must not be taken lightly as was seen in the terrorist attacks on the World Trade Centre in New York and the Pentagon in Washington DC (Anderson, Compton & Mason, 2004). These events called for the creation of a National Incident Management System in the United States (Hambridge, Howitt & Giles, 2017). There are various definitions of what an incident management system is. For example, according to Kim, Sharman, Rao & Upadhyaya (2007:236), “a critical incident management system (CIMS) is a system that utilises people, processes, and technologies for managing critical incidents”, while Anderson, Compton and Mason (2004:4) define an incident command system as “a management system designed to enable effective and efficient domestic incident management by integrating a combination of facilities, equipment, personnel, procedures and communications operating within a common organisational structure”. On the other hand, Rose et al. (2017: S130) define an incident management system as “a scalable, flexible system for organising emergency response functions and resources characterised by principles such as standardised roles, modular organisation, and unity of command”.

Figure 2.4 presents an outline of the structure of such a system (Anderson, Compton & Mason, 2004; Hambridge, Howitt & Giles, 2017):

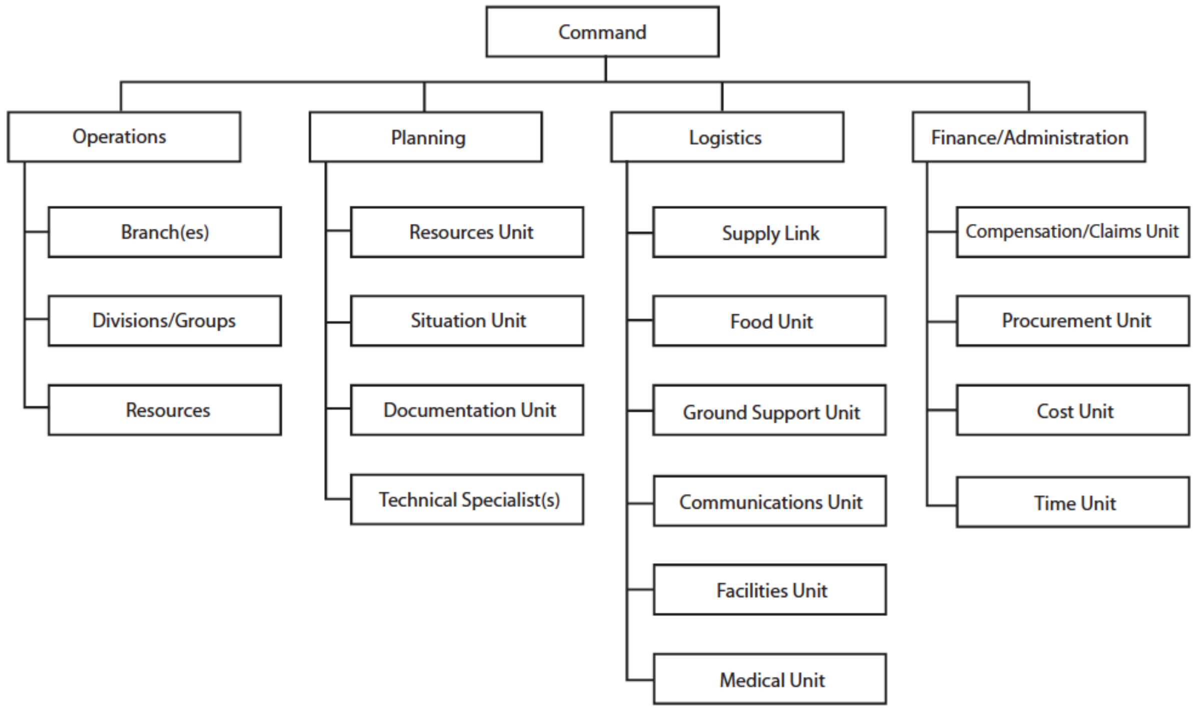


Figure 2.4 – Incident Command System (Anderson, Compton & Mason, 2004; Hambridge, Howitt & Giles, 2017)

The various definitions are all similar in their mention of the entities used to manage and respond to a incident. The resources, personnel and technological infrastructure used in the efficient and effective management of an incident constitute the components that make up an incident management system (IMS). This is in line with the following definition of an IMS as proposed by the NFPA 1600 (National Fire Protection Association, 2013:6), namely, "[t]he combination of facilities, equipment, personnel, procedures and communications operating within a common organisational structure and designed to aid in the management of resources during incidents". Rose et al. (2017: S130) are in agreement with this definition when they state that "An effective IMS hinges on the integration and co-ordination of staff, systems and infrastructure under a standardised organisational structure".

These definitions all indicate that an IMS consists of more than just technology and that, in fact, it comprises a conglomeration of the various entities that make up the system. This was important to note as this study focused on KV in IMS and knowledge is a human cognitive constituent. The interaction of personnel with the technology in allocating multiple and distinctive resources render the IMS a live entity in the management of an incident.

Kim et al. (2007) suggested the following figure (Figure 2.5) to indicate a typical process involved in the flow of information between different organisations involved during an incident in the United States:

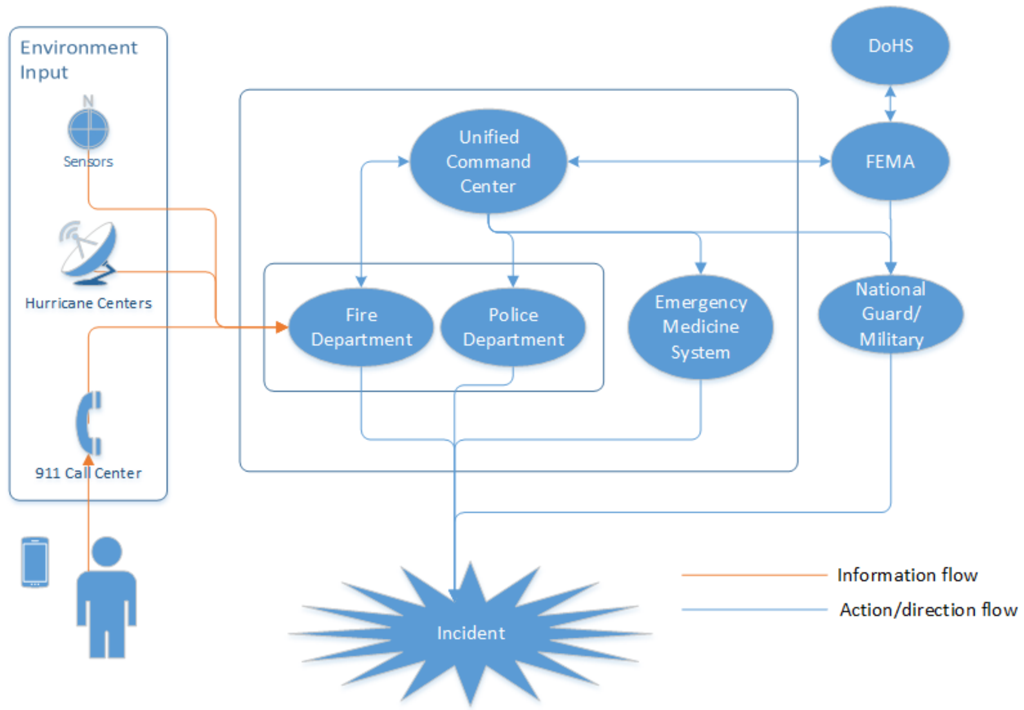


Figure 2.5 – Incident Management Flow of Information (Adaptation from Kim et al., 2007)

Figure 2.5 provides an example of the way in which the information pertaining to the incident alert activation flows. Firstly, the activator dispatches a notice of the incident (making use of any available method) to a call centre. A dispatch office (in this example, the fire department) is then notified of the incident. This office then forwards the incident information to the command centre should additional support be required from other first responder entities. This command centre carries out calculations and allocates an adequate number of first-responders to the incident. The command centre is responsible for determining the response output with relation to the capacity of each department. In this example the nature of the incident determines the department in charge of the command centre (Kim et al., 2007). The DoHS and FEMA in the diagram represents institutions in the United States Government (Department of Homeland Security and Federal Emergency Management Agency, respectively). However, while the example provided above is detailed example it does not necessarily define the information flow of all IMSs.

First-responders include actors from different professions. It is crucial to the success of the success of an IMS that this is taken into account and that a distinction is made in relation to other responders (Hambridge, Howitt & Giles, 2017). While first-responders are considered to be the fire, police and medical disciplines other public and non-public agencies may also form part of this group of responders (Hambridge, Howitt & Giles, 2017). According to Hambridge, Howitt and Giles (2017), agencies whose principal purpose it is to respond to emergencies should be considered as the first-responders. The circular diagram in Figure 2.6, adapted from Howitt & Makler (2005), illustrates the relation between first-responders and other types of responders. In the diagram the first circle represents the first-responders while the second and third circles represent the rest of the responders.

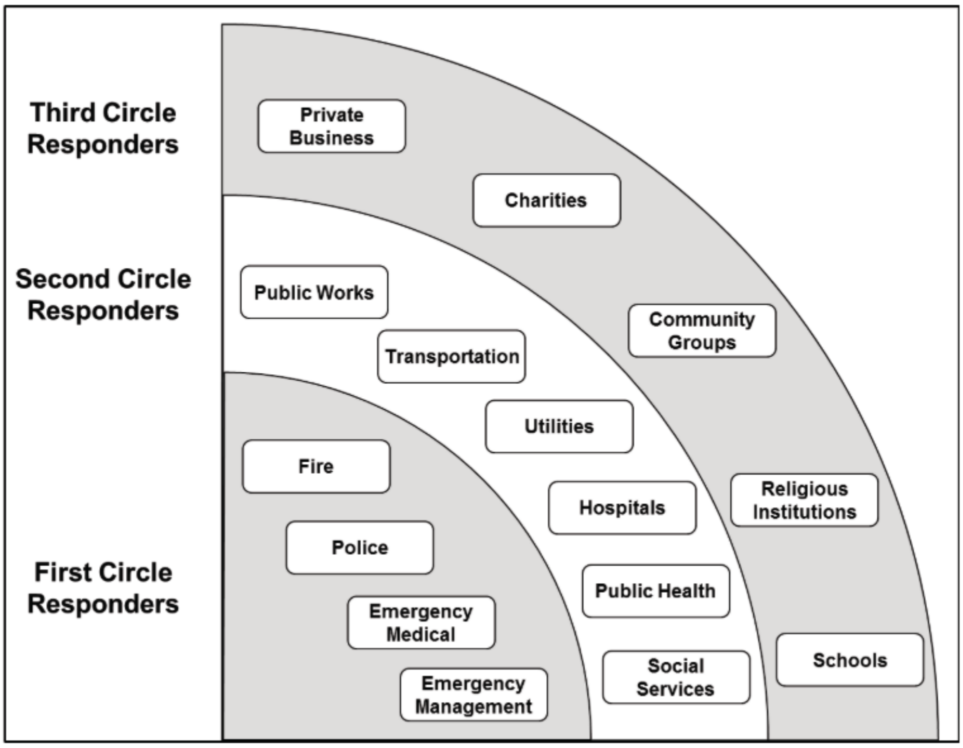


Figure 2.6 – Centrality of Emergency Response to Organisational Mission (Hambridge, Howitt & Giles, 2017)

This study focused on the first responders and their interaction with the IMS under investigation. While an activator is involved in activating the incident response and providing additional information this study focused only on the interaction between the operators and the responders and the system under discussion in this study; especially the visual elements of the system and the impact of the system on transferring knowledge between the actors involved.

In an incident management system one of the visual elements that appears the most frequently is maps, often accompanied by a marker indicating the location or area of the incident and/or the route a responder should follow to the incident (Khattak, Wang & Zhang, 2012; Wilson et al., 2013; Ingal et al., 2016; Vassell et al., 2016). Maps as a visual artifact in IMSs is further supported by the fact that emergency information is virtually always related to the location of the incident (Ley, Ludwig, Pipek, Randall, Reuter & Wiedenhoefer, 2014). Geographical Information Systems (GIS) are therefore relevant to the presentation of emergency information (Ley et al., 2014).

Utilizing a map (electronically) allows for the additional manipulation of visual elements. Information influencing the response to the incident, such as weather, traffic, and location-based resources, may augment the map that is indicating the location of the incident. Having access to geospatial information, such as the dangers surrounding the incident as well as the available resources plays an important role in situational assessment (Reuter, Ludwig & Pipek, 2014). Providing such information may ensure that the responders (or emergency actors) and decision makers are more informed about the condition of the incident and the level of severity.

Wu et al. (2013) found that emergency management teams find it useful to have an information system that is capable of the following: firstly, it must depict the plan(s) of the response (and allow the participants to annotate the plan) and the role of each participant in the plan and, secondly, it must be accessible to the geographically distributed participants (remote access).

2.2.5 Awareness

Awareness is a component of the sense-making perspective discussed above – more commonly known as situational awareness. Situational awareness is defined as “the perception of the elements in the environment within a volume of time and space, comprehension of their meaning, and the projection of their status in the near future” (Seppänen, Mäkelä, Luokkala & Virrantaus, 2013:3; Seppänen & Virrantaus, 2015:113). It has to do with the way in which an actor (or a team) understands the situation in which he is operating with this in turn affecting the decisions the actor makes and what he communicates (Luokkala & Virrantaus, 2014). Awareness has been cited as being of prime importance in the management of crisis situations and is, thus, considered as a vital component of sense-making (Dixon et al., 2017).

Awareness of all the activities of all the participants is important because this is part of the information which is being incorporated into the IMS in the effort to achieve synchronised collaboration. Figure 2.7 was based on Wu et al.'s (2013) discussion on awareness and presents the factors that make up the activity awareness that acts as a component of collaboration from a geo-visualisation standpoint.

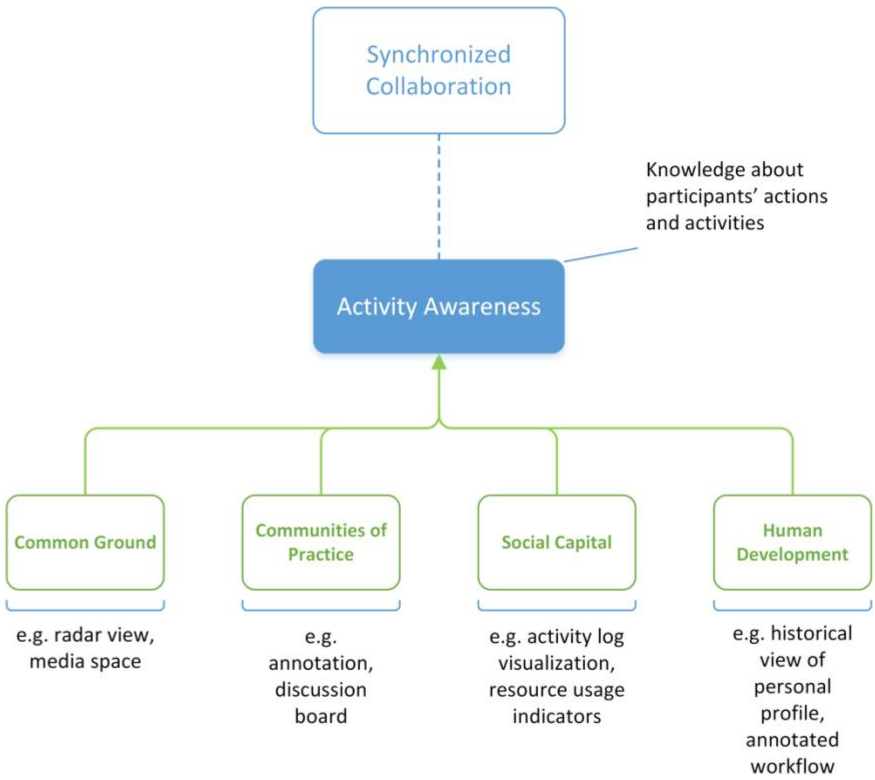


Figure 2.7 – Activity Awareness (Researcher's Original Work)

Geo-collaboration assists group activities (and decision-making) by making use of maps (Wu et al., 2013). Collaboration technologies such as geo-collaboration may reduce (positively) the management efforts of response teams which are spatially distributed (Ley et al., 2014). Wu et al. (2013) developed this concept further by investigating geo-visualisation which takes into account issues such as knowledge construction with geo-spatial information, which play a critical role in the collaborative decision-making which is part of emergency management planning. Reuter et al.

(2014) further support this notion by indicating that spaces for sharing visual information increase both the knowledge of the task structure as well as the situational awareness. Renaud and van Biljon (2017) take this further by stating that contextualisation is important to enable users to make sense of the knowledge being depicted.

In short, this identification of a geo-visualisation artifact provides an answer to research sub-question 1, namely, ‘What are the visualisation components of an IMS?’ We have determined that a geo-visualisation of an incident and its context may assist in establishing a geo-spatial awareness of the incident. Thus, a geographical map and the supporting information on the map regarding the incident and its context were deemed to be the visualisation artifacts of an incident for the purposes of this study. This map may be an interactive map with real-time updates of the incident’s status and surroundings or a more simplistic interface whose goal is to provide users with information in order to elicit a response to the incident.

2.3 Visualization

The use of textual representations of knowledge without visualisations does not address the requirements of the knowledge society of today (Meyer, 2010). Visualisation has the ability to synthesise data into effective graphics, thus making it easier for the human brain to comprehend the data (Kelleher & Wagener, 2011; Yaacob, Liang & Mohamad, 2017). Thus, visualisation may be said to exist as a means of supporting sensemaking in human beings (Yaacob, Liang & Mohamad, 2017). It must be remembered that visualisation is not applicable to data only but also to information and knowledge with each of these demonstrating different levels of abstraction (Chen, Ebert, Hagen, Laramee, Van Liere, Ma, Ribarsky, Scheuermann & Silver, 2009).

2.3.1 Goals of Visualization

In relation to the goals of visualisation Burkhard (2005) proposes the following 10 aims for visual representation:

1. To address emotions (Bresciani & Eppler, 2015; Valkanova, Jorda & Vande Moere, 2015)

2. To illustrate relations (Gómez Aguilar, García-Peñalvo & Therón, 2013; Wu & Hsu, 2013; Valkanova, Jorda & Vande Moere, 2015)
3. To discover trends, patterns and outliers (Manovich, 2011; Borkin, Vo, Bylinskii, Isoa, Sunkavalli, Oliva & Phister, 2013; Renaud & van Biljon, 2017)
4. To attain and maintain the attention of recipients (Patterson et al., 2014; Bresciani & Eppler, 2015)
5. To support remembering and recall (Borkin et al., 2013; Patterson et al., 2014; Ryan, 2016)
6. To present an overview and details (Hornbæk & Hertzum, 2011; Munzner, 2014; Roberts et al., 2014)
7. To facilitate learning (Brucker, Scheiter & Gerjets, 2014; Caligaris, Rodríguez & Laugero, 2015; Patwardhan & Murthy, 2015)
8. To co-ordinate individuals (Yaacob et al., 2018)
9. To motivate and establish a mutual story (Azzam, Evergreen, Germuth, Kistler, 2012; Borkin et al., 2013)
10. To energise individuals and initiate actions by illustrating the various options available in relation to action (Valkanova, Jorda & Vande Moere, 2015; Xiangyi, 2018)

When considering these points, it becomes apparent that the end result of visualisation is concentrated on the human user forming a perception of the content, whether it be data, information, or knowledge. Burkhard (2005) suggests four points which indicates why visualisation is effective in relation to the aims listed above:

1. The human input channel capacity is greater when visual abilities are used.
2. Human brains have a strong ability to identify patterns.
3. Visual recall appears to be more efficient than verbal recall for human beings.
4. Visual representations are superior to verbal-sequential representations in different tasks.

2.3.2 Defining Visualization

Shneiderman (1996), the father of the 'Visual Information Seeking Mantra', stated that information becomes more difficult to explore as the volume of the information increases. This assertion is further supported by Ahn and Brusilovsky (2013), Wu and Hsu (2013), Renaud and van Biljon (2017) and Yaacob, Liang and Mohamad (2017). Visualisation has the power to reveal patterns, gaps, and outliers in data, while visual technologies have advanced to a stage where they allow for visually appealing and interactive displays (Shneiderman, 1996).

Visualisation entails the representation of data, information or knowledge which may act as a communication mechanism for information (Grainger, Mao & Buytaert, 2016; Yaacob et al., 2018) or knowledge transfer (Masud et al., 2010; Marchese & Banissi, 2013; van Biljon & Renaud, 2015a). It is important to know and understand the difference between these concepts (data, information and knowledge) as the way in which they are incorporated into visualisation artifacts, and their purpose as visualisation artifacts differ. The main difference between data, information and knowledge in the computational space are as follows:

- **Data**: Computerised representations of models and attributes of real or simulated entities (Chen et al., 2009). Data may be seen as symbolic representation of the properties of objects and events and the world in which these objects and events exist (Aven, 2013) and which may be considered to represent either the entities or the relationships (Ware, 2012) in their environment.

- **Information**: The results of a computational process, such as statistical analysis, for assigning meanings to the data, or the transcripts of meanings assigned by human beings (Chen et al., 2009; Aven, 2013). Information is data that has been given meaning and which has been made sense of (Ursyn, 2014).

- **Knowledge**: The results of a computer-simulated cognitive process, such as perception, learning, association, and reasoning, or the transcripts of knowledge acquired by human beings (Chen et al., 2009). Knowledge is information which has been introduced into a particular context which influences our understanding of the information (Marchese & Banissi, 2013).

Each of these components are unique in what they present but, as may be seen from the definitions above, the existence of each one is not completely independent of the others. Robert Meyer (2010) suggested an example of the relation between these components which provides a comprehensible outline of both their differences and similarities. He explained that the statement ‘It is raining’ is considered to be data because it is merely a fact. If we were to change the statement to ‘It is raining because the temperature dropped 15 degrees’ the statement becomes information due to the comprehension of cause and effect. Knowledge would then be the understanding of the cause and effect as well as the relation between humidity and temperature in the atmosphere.

The hierarchy presented in Figure 2.8 illustrates that processed data becomes information, processed information becomes knowledge, and processed knowledge becomes wisdom (Müller, van Biljon & Renaud, 2012):

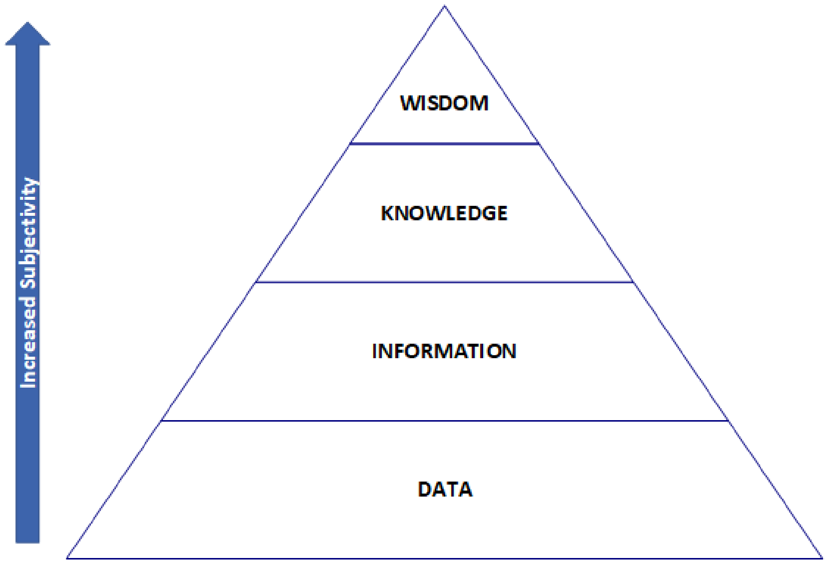


Figure 2.8 – Data-Information-Knowledge-Wisdom Hierarchy (Müller, Biljon & Renaud, 2012)

This figure is important, not only because it demonstrates the dependence of the next level on the former level but also because it brings to light the subjectivity of the concepts at each level. In the figure each level of processing is characterised by a certain degree of subjectivity due to the subjective selection of processing procedures (Müller, van Biljon & Renaud, 2012). Information is subjective due to the selected method of processing of data from which it originated. This also applies to the knowledge processed from information and the wisdom processed from knowledge. Each iteration or advancement to the next level adds more subjectivity to the following level. One way in which to ensure that the subjectivity is managed is to state the assumptions beforehand and to constantly be aware of and open to constraints.

The intertwining of these concepts may be better understood by investigating a further extension of the diagram. A web of interweaving bi-directional threads between data, information, knowledge and wisdom indicates that these concepts are entangled and are dependent on each other. Spiekermann et al. (2015) provided such a diagram which indicated that learning, insight and intelligence are further connecting elements between the data, information, knowledge and wisdom with context, meaning and understanding existing as the linkage between data, information, knowledge and wisdom, respectively.

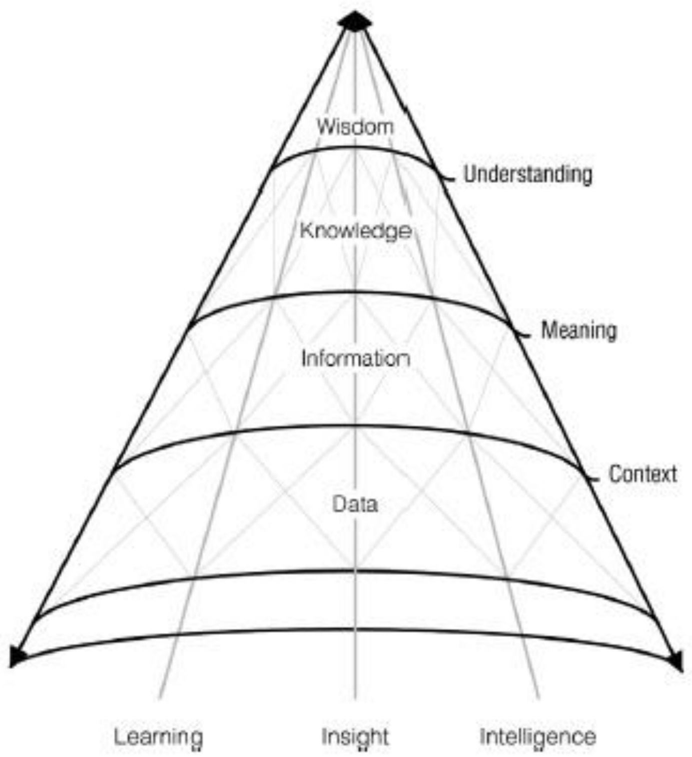


Figure 2.9 – DIKW Web (Spiekermann et al., 2015)

Based on the definitions of data, information and knowledge above we now consider the difference between these concepts when they exist as visualised entities:

- **Data visualization** entails any visual artifact which explains any data in any discipline (Kelleher & Wagener, 2011; Azzam et al., 2012; Gatto, 2015), and is a commanding method for reasoning about data in order to explore data (Azzam et al., 2012), and bring to light any details that may have being obscured in the computed statistics (Gatto, 2015; Nielsen, 2016).

- **Information visualization** provides a condensed illustration of the information, thereby assisting the viewers to reason about the content (Hornbæk & Hertzum, 2011) and also, in some cases, providing an interactive method for navigating the content (Eppler & Burkhard, 2004; Burkhard, 2005; Hornbæk & Hertzum, 2011; Patwardhan & Murthy, 2015).
- **Knowledge visualization** refers to the use of visualisation representations to improve the transfer and creation of knowledge (together with experiences and insights as well as changing insights) between at least two persons (Burkhard, 2005; Renaud & van Biljon, 2017).

Eppler and Burkhard (2004:4) compare information visualisation with knowledge visualisation as follows:

> "Information visualisation aims to explore large amounts of abstract (often numeric) data to derive new insights or simply make the stored data more accessible. Knowledge visualisation, in contrast, aims to improve the transfer and creation of knowledge among people by giving them richer means of expressing what they know."

Some writers believe that visualisations are not merely the final outcomes of representations of data, information or knowledge but, instead, that they are transformation processes that exist on a DIK (data, information and knowledge) continuum as indicated in Figure 2.9 (Masud et al., 2010):

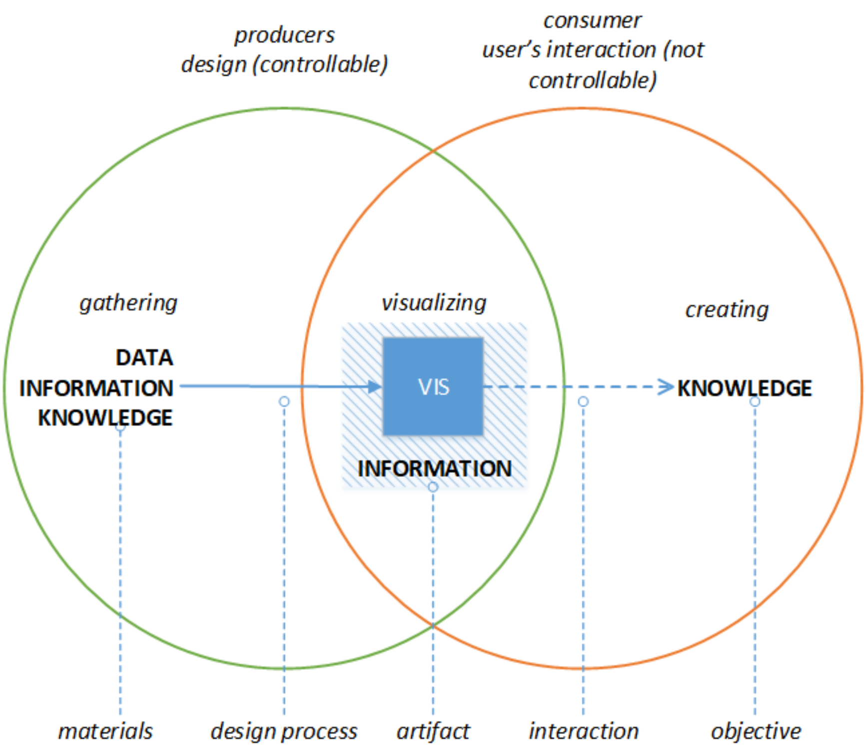


Figure 2.10 – Visualisations as processes on the DIK continuum (Masud et al., 2010)

The figure above shows that data, information and knowledge are the 'material' that is used to create a visualisation by means of a design process. The resulting visualisation supports interaction between the user and the content which leads to the creation of new knowledge for the user. Although the design process is labelled as a controllable process, the interaction and final usage of the visualisation are not controllable by the producer of the visualisation.

Gatto (2015:5) defined data visualisation (DV) as "the visual representation of statistical and other types of numeric and non-numeric data through the use of static or interactive pictures and graphics". He goes on to state that DV reveals patterns, gaps, and connections in the raw data that are not easily identified.

Two of the figures presented (Figures 2.10 and 2.11) in this literature review were derived from Chen et al. (2009) and depict their understanding of the way in which data, information and knowledge all combine together to provide a visualisation artifact. These figures provide a clear indication of the relations between the concepts of data, information and knowledge and how they are processed from their various origins and linked together.

Figure 2.10 presents a typical visualisation process according to Chen et al. (2009):

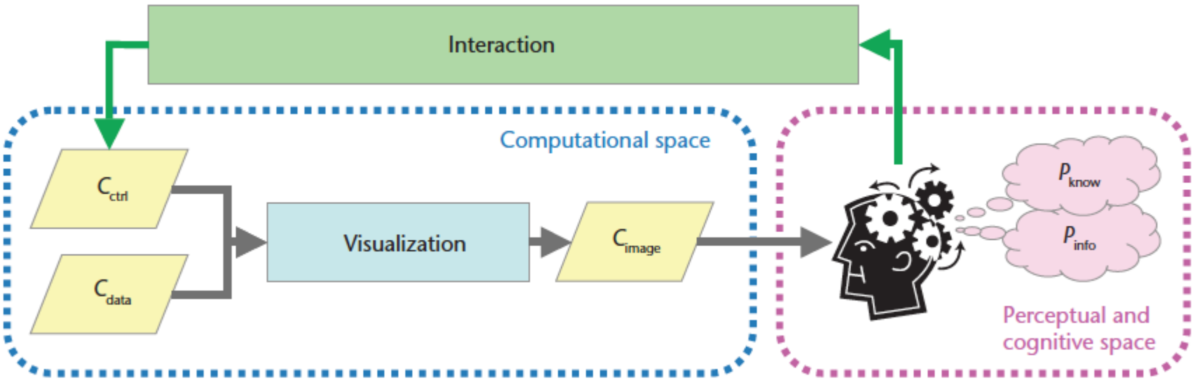


Figure 2.11 – Typical Visualisation Process (Chen et al., 2009)

The computational space in the figure above is the space where the control parameters and input data (C_{ctrl} and C_{data}) are combined through a visualisation process to produce a visualisation artifact (C_{image}). The P_{know} and the P_{info} represent the information and knowledge acquired by the user.

It is clear from the figure that the components (data, information or knowledge) of the visualisation process are not entirely separate or independent of each other. Thus, DV may assist a user to acquire information or knowledge from the visualisation.

2.3.2.1 Knowledge Visualization

In considering knowledge visualisation and its relation to information and data it is worth noting Figure 2.11 which indicates a knowledge-assisted visualisation according to Chen et al. (2009):

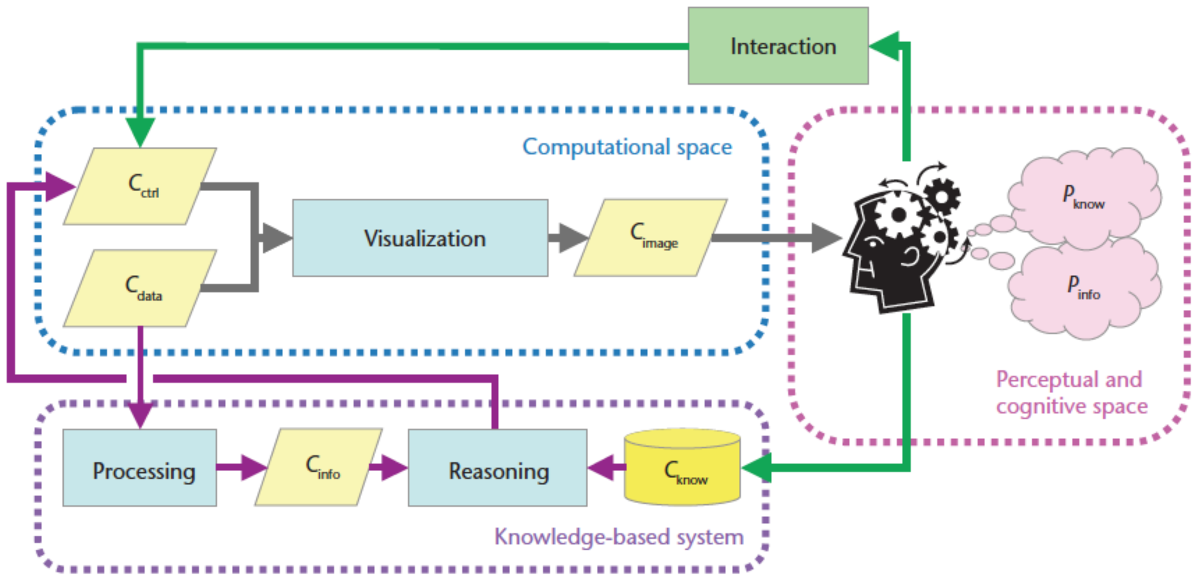


Figure 2.12 – Knowledge-assisted Visualisation with Acquired Knowledge Representations (Chen et al., 2009)

The knowledge-based system is where the input data C_{data} is processed to display information about the data. This information is then combined together with a knowledge base (C_{know}), which consists of stored knowledge representations captured from expert users, to produce an appropriate set (or sets) of control parameters (C_{ctrl}) for the computational space. The perceptual and cognitive space is where information (the meaning assigned to data by human beings or computers) P_{info} and knowledge P_{know} are acquired by the user. The visualisation supports this interaction between P_{info} and P_{know}.

As may be seen from Figure 2.11 the knowledge component of the visualisation process is not disjoint from the data or information but is, instead, a rule-based reasoning process which makes use of the data and information, together with knowledge from experts, to determine the control parameters that reduce the search space for users.

In addressing the inconvenience of collecting knowledge from experts and the difficulties in specifying the actual knowledge which must be captured, Chen et al. (2009) suggest an alternative approach, namely, a visualisation infrastructure that collects, processes, and analyses data about the visualisation processes. This system may infer knowledge by using case-based reasoning in relation to successes and failures as well as making use of common associations between the data sets and control parameters, and other patterns presented by the visualisation tools, tasks, users, and interactions. In other words, this approach is a simulation of possible cognitive processes.

Computer supported visualisation provides several benefits in relation to the process of delivering insight but, as Chen, Floridi and Borgo (2014) indicate, insight is a crucial concept and is usually based on the personal understanding of the crafters of the visualisation artifact.

Van Biljon and Renaud (2015b) identify two methods for crafting a visualisation artifact, namely, to create it new from inception or to alter an already existing visualisation model. The first procedure requires the crafter to broaden his/her understanding of the subject matter and to find ways in which to convert it into visualisation while the second method allows the crafter of the new visualisation to expand his/her understanding of the subject matter.

According to Eppler and Burkhard (2004), for knowledge visualisation and transfer to be effective, the following three aspects must be considered:

1. knowledge type,
2. visualization motive, and
3. visualization format

Knowledge type must be considered because it defines the knowledge being visualised, the visualisation motive distinguishes the reason(s) for the existence of the visualisation and, finally, the visualisation format defines the format utilised in order to represent the visualisation. In Table 2.1 presents an overview of what each aspect consists of and also a sample of mapping between the concepts (Eppler & Burkhard, 2004).

Table 2.1 – Three Different Perspectives of the Knowledge Visualisation Framework with Mapping (Eppler & Burkhard, 2004)

Knowledge Type *(what?)*	**Visualization Goal** *(why?)*	**Visualization Format** *(how?)*
Know-what	Sharing or Transferring (clarification, elicitation, socialization)	Heuristic Sketches (e.g. ad-hoc drawings)
Know-how	Creating (discovery, combination)	Conceptual Diagrams (e.g., Toulmin or process diagrams)
Know-why	Learning (acquisition, internalization)	Visual Metaphors (e.g., a tree, bridge, juggling, etc.)
Know-where	Codifying (documentation, externalization)	Knowledge Animations (e.g., ruler, mixer, etc.)
Know-who	Finding (e.g., experts, documents, groups)	Knowledge Maps (e.g., knowledge structure maps)
	Assessing / Evaluating (knowledge rating)	Scientific Charts (e.g., co-citation webs)

Renaud and van Biljon (2017) agree with Eppler and Burkhard's (2004) identification of knowledge types as indicated in the Table 2.1 but also added 'when' as a knowledge type.

The following five perspectives on knowledge were proposed by Burkhard (2005), namely:

- Viewed as an object
- Viewed as a process
- Viewed as a capability
- Viewed as access to information
- Viewed as a state

These perspectives are all possible end results of knowledge transfer between individuals or groups in the context of knowledge visualisation.

Knowledge visualisation designs use information visualisation techniques and systems as their point of departure (Zeiller & Edlinger, 2008; Bai, White & Sundaram, 2012). The difference between KV and IV can be identified by taking into account the aim and targets of the visualisation (Masud et al., 2010), where information visualisation aims to support pattern identification by humans while knowledge visualisation aims to support knowledge transfer between humans.

2.3.3 Knowledge Visualization Criteria

For the purposes of this study the researcher conducted a systematic literature review on KVC for IMSs. The following queries were used to in the search for articles (on the 16th of September 2017):

1. (Knowledge visualisation) AND (Criteria) AND ((Incident Management System) OR (Emergency Management System)
2. (Knowledge Visualisation) AND (Criteria)
3. (Visualisation) AND (Criteria)

The results are presented in Table 2.2.

Table 2.2 – Systematic Literature Review

Query No.	Results	Search Type	Year	Area	Document Type
Scopus					
1	1	Article Title, Abstract, Keywords	Any	Any	Any
2	212	Article Title, Abstract, Keywords	2010–Present	Any	Any
3	-	-	-	-	-
Web of Science					
1	1	Topic	Any	Any	Any
2	52	Topic	2010–Present	Computer Science	Any
3	451	Topic	2010–Present	Computer Science	Any
ACM					
1	27	Any Field	Any	Any	Any
2	52	Any Field	Any	Any	Any

3	84	Any Field	Any	Any	Any
Springer					
1	1	Any	Any	Computer Science	Any
2	142	Any	Any	Computer Science	Any
3	21 741	Any	Any	Computer Science	Any
IEEE Xplore					
1	79	Any	2010–2017	Any	Any
2	68	Any	2010–2017	Any	Any
3	843	Any	2010–2017	Any	Any
Science Direct					
1	0	Any	2010–2017	Computer Science	Any
2	28	Any	2010–2017	Computer Science	Any
3	8015	Any	2010–2017	Computer Science	Journal article

While executing these queries the title, abstract and keywords of the results were evaluated to identify whether the paper addressed the query's requirement of KVC for IMS. If the resulting paper addressed either KVC or IMS individually it was included as a valid result but, if not, it was not included in the search for the KVC for IMS. While the results of Table 2.2 indicate that the search queries indicated a number of papers available on KVC for IMS, none of the papers specifically discussed KVC in IMS. As a matter of fact, two articles only discussed KVC specifically (Eppler & Burkhard, 2004; Marchese & Banissi, 2013) but none discussed KVC for IMS. The papers discussing IMS would automatically refer to KM.

In order to identify specific criteria the researcher approached the literature in as comprehensive a way as possible, taking seminal papers on knowledge visualisation, such as those of Eppler & Burkhard (2004, 2007), Marchese & Banissi (2013), Bresciani & Eppler (2015) and van Biljon & Renaud (2015) as a point of departure, and identifying key concepts when developing the KVC.

Robert Meyer (2010) suggests that it is essential not only to use visualisations for their power in transferring knowledge but also to provide advice on how to construct them. This would require providing guidelines or criteria which offers guidance as well as regulation in respect of addressing the concepts of how, what, why and where a visualisation exists. This process, if applied correctly, would provide for a comprehensive visualisation with regard to the goals and objectives of the visualisation. These concepts of how, what, why and where are further supported by Figure 2.12, which was proposed by Renaud and van Biljon (2017), although with a slight difference as the diagram adds a focus on the audience.

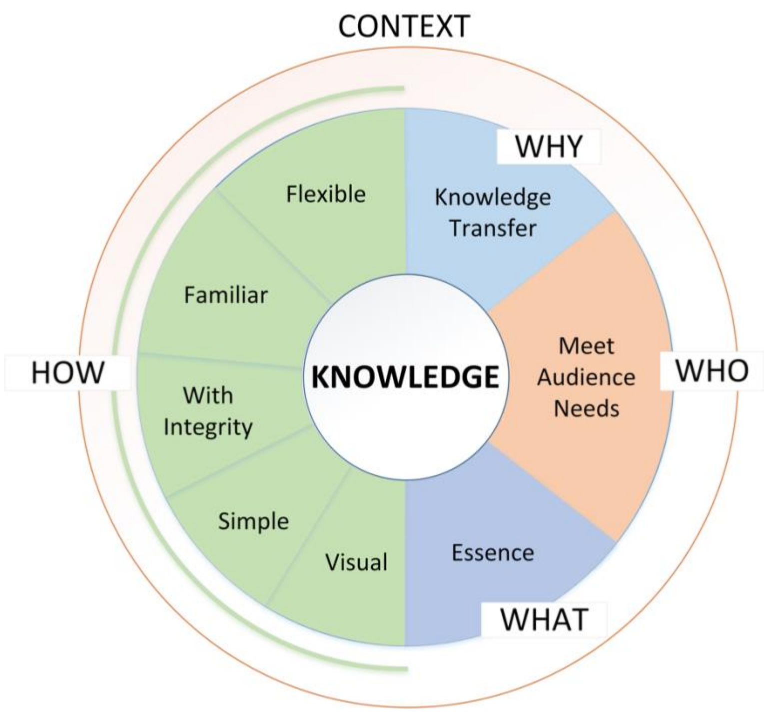


Figure 2.13 – KV Criteria (Renaud & van Biljon, 2017)

The OED defines a criterion as “a test, principle, rule, canon, or standard, by which anything is judged or estimated” while the Oxford Thesaurus refers to a guideline as a recommendation or suggestion, whereas a criterion is a standard or norm – something that can be used to measure against.

On studying the existing literature on knowledge visualisation, the researcher found that multiple concepts contribute to an artifact that supports KV. The following 11 points were identified (from studying the existing literature on IV and KV) in respect of the criteria (Why, What, Whom, How) proposed by Renaud and van Biljon (2017):

1. Clarity
2. Consistency
3. Discrimination
4. Semantic Transparency
5. Complexity Management
6. Dual Coding
7. Legend
8. Context
9. User
10. Intention
11. Layout (Shape)

These 11 points are discussed below so as to provide support for the differentiation between the criteria for KV. The 'What' is, however, not discussed below in view of the fact that an IMS relays information regarding an incident and its constituents to the users of the system.

2.3.3.1 Why

Intention

Different visualisation methods may be utilised in order to achieve a particular goal (Marchese & Banissi, 2013). One common goal of visualisation is to represent a compact version of what is being visualised (Hornbæk & Hertzum, 2011). As seen in the definition of KV the main intention behind designing a visualisation is to transfer knowledge from one individual to another individual or group. Thus, a visualisation must be utilised in order to achieve a particular goal.

2.3.3.2 Whom

Context

Visualizations may include the capability to make sense of context (Masud et al., 2010). Context is seen as playing a significant bigger role with Marchese and Banissi (2013) stating that knowledge visualisation is DV in context, thus implying that context is the differentiating factor between data and knowledge. This transformation is true not only for data but for information as well. Transforming information into knowledge requires adding meaning or context to the information (Figueiras, 2014).

User

When creating effective knowledge visualisation artifacts it is important to take into account, inter alia, whom the artifacts is used by (Marchese & Banissi, 2013). Every user of a visualisation artifact has different needs and every user may experience an artifact differently (Seppänen & Virrantaus, 2015). Thus, when designing a visualisation artifact, one bear the users in mind as it is essential that the artifact's functionality and usability meet the users' needs (Clarke et al., 2014).

2.3.3.3 How

Clarity

Ambiguity results in individuals finding meaning and making sense of things (Mills, Thurlow & Mills, 2010) with the genesis of sense-making lying in ambiguity (Sandberg & Tsoukas, 2015). Ambiguity or, rather, its positive antonym, clarity, plays an important role in making sense of complex environments and situations. People have searched for approaches with which to give visual identity to thoughts and ideas, to store knowledge in an illustrative form, and to incorporate order and clarity into information (Ryan, 2016). Uncertainty compels the search for information, ambiguity the search for meaning (Stralen, 2015). Visual vagueness, for example, may prompt the imaginative reinterpretation of a visual portrayal and, in this manner, prompt new insights (Bresciani & Eppler, 2015). However, this benefit may also have a negative effect in that ambiguity might may difficult to interpret (Bresciani & Eppler, 2015). While some audiences will be able to deal with complexity and ambiguity, others may respond with confusion (Grainger, Mao & Buytaert, 2016). Accordingly, clarity is an important point when considering knowledge visualisation. In addition, it is a dynamic criterion in view of the fact that the presence of ambiguity should be incorporated in varying degrees and controlled by the context in which the visualisation exists.

Consistency

Consistency in visualisation facilitates of process of understand other users' perspectives (Mahyar & Tory, 2014). According to Seppänen and Virrantaus (2015), logical consistency is also a quantitative quality element in the ISO 19113 standard, thus indicating that information should be free of contradictions. Consistency in both the representation and interaction style of visualisations is vital, especially in large organisations which require visualisation standards (Ware, 2013). Renaud and van Biljon (2017) also indicate that every symbol used in a visualisation should have a single meaning or represent a single concept.

Discrimination

The EOD defines discrimination as the action of perceiving, noting or making a distinction between things. In terms of visualisation this would entail distinguishing the difference between the various elements that exist in the visualisation artifact by using different shapes or colours.

A study by Valkanova et al. (2015) used shape and colours to assist in visually differentiating between the different data sets pertaining to neighbourhoods in their study while a study by (Parry & Cowley, 2015) used different colours to represent zones of areas on a map as readability is influenced by colour as is emotional stimuli. However, too many colours and shapes may make the comprehension of visualizations difficult as they may become too complex (Olshannikova et al., 2015).

Semantic Transparency

It has always been stipulated that the encoding of data must be free of uncertainty (Grainger, Mao & Buytaert, 2016). This is important because symbols are relied on to communicate data in meaningful ways (Ryan, 2016). Visualisations that contain unlabelled symbols may cause ambiguity (Bresciani & Eppler, 2015) and, if the symbols used to represent data, the visualisations may have different meanings as compared to the data they represent, thus leading the viewer away from the intended meaning and even resulting in the viewer developing an inaccurate sense of certainty (Grainger, Mao & Buytaert, 2016).

Complexity Management

When designing a visualisation the complexity of the artifact is determined by both the data being visualised and the user of the visualisation (Yaacob, Liang & Mohamad, 2017). Too many components in a visualisation may result in the visualization becoming too complex to understand (Olshannikova et al., 2015). According to Renaud and van Biljon (2017:7), "[e]verything should be made as simple as possible, but not simpler". This would require that a process is put in place that manages both the complexity of the visualisation and what it represents in the context within which it exists.

Dual Coding

Human beings process information both through the textual channel as well as the visual channel (Marchese & Banissi, 2013). If both these channels are used in combination this leads to enhanced understanding (Marchese & Banissi, 2013). Ahn and Brusilovsky (2013) found that users do not want to visual elements as the sole means for navigation but that they prefer to have visualisation artifacts with textual support.

Legend

Legends have been found to be included with certain visualisations (Heer, Shneiderman & Park, 2012; Shamim, Balakrishnan & Tahir, 2015; Renaud & van Biljon, 2017). Low perceptual speed users have been found to use a visualisation's legend more often than individuals who are faster at perceiving visualisations (Candello et al., 2014). However, when using legends it is important to minimise their use and instead to design the visual artifacts to communicate meaning (Ryan, 2016).

Layout (Shape)

The use of spatial variables such as shapes, position and size to represent differences (as well as patterns) in the data being visualised is considered to be a key principle in visualisation (Manovich, 2011). It is essential that a layout enhances the attention, understanding, perception and interpretation in a visualisation (Marchese & Banissi, 2013).

While these criteria were developed from literature it is not an exhaustive set of criteria and may be expanded. Rhetoric was a criterion that was identified but not included in this study. Rhetoric in visualisation (also known as narrative visualisation) entails the interplay between the aspects of explorative visualisation and communicative visualisation (Hullman & Diakopoulos, 2011). The reason for not including rhetoric in the proposed set of KCV was because rhetoric visualisation has a degree of intentionality (Hullman & Diakopoulos, 2011), and is covered in the criterion of *intention* in the proposed KVC.

Table 2.3 presents a summary of the KVC which were investigated in a structured format with each criterion being accompanied by a short description. This description was intended to assist practitioners utilising the criteria to evaluate the criteria's application to visual artifacts. Thus, the table may be said to represent the answer to research sub-question 2 in Table 1.1 (page 15), namely, 'What KVC exist?'

Table 2.3 – Criteria for Knowledge Visualization

No.	Criteria	Explanation	References
1.	Clarity	The meaning of the symbols is exact and unambiguous.	(Mills, Thurlow & Mills, 2010; Bresciani & Eppler, 2015; Sandberg & Tsoukas, 2015; Stralen, 2015; Grainger, Mao & Buytaert, 2016; Ryan, 2016)
2.	Consistency	The same symbol is used to represent the same concept throughout.	(Ware, 2013; Mahyar & Tory, 2014; Seppänen & Virrantaus, 2015; Renaud & van Biljon, 2017)
3.	Discrimination	Shape, colour and texture are used to distinguish between the elements.	(Olshannikova et al., 2015; Parry & Cowley, 2015; Valkanova, Jorda & Vande Moere, 2015)
4.	Semantic Transparency	The mapping between the symbols and their meaning (i.e. what they represent) are clear.	(Bresciani & Eppler, 2015; Grainger, Mao & Buytaert, 2016; Ryan, 2016)
5.	Complexity Management	All concepts are represented but elements are not repeated or multiplied unnecessarily.	(Olshannikova et al., 2015; Renaud & van Biljon, 2017; Yaacob, Liang & Mohamad, 2017)
6.	Dual Coding	Both text and graphics are employed to explain the same construct.	(Ahn & Brusilovsky, 2013; Marchese & Banissi, 2013)
7.	Legend	The legend is provided.	(Heer, Shneiderman & Park, 2012; Candello et al., 2014; Shamim, Balakrishnan & Tahir, 2015; Ryan, 2016; Renaud & van Biljon, 2017)
8.	Context	The visual artifact is adequate for the circumstance, conditions, situation and environment in which the artifact exists.	(Masud et al., 2010; Marchese & Banissi, 2013; Figueiras, 2014)
9.	User	The symbols and notation match the end user's mental model.	(Marchese & Banissi, 2013; Clarke et al., 2014; Seppänen & Virrantaus, 2015)

10.	Intention	The visual artifact is aimed at realising a specific goal.	(Hornbæk & Hertzum, 2011; Marchese & Banissi, 2013)
11.	Layout (Shape)	Related symbols and information are properly positioned and structured as symmetrically as possible.	(Manovich, 2011; Marchese & Banissi, 2013)

2.4 Factors Contributing to Knowledge Visualization

When designing a visualisation for the purpose of transferring or creating knowledge (a knowledge visualisation) the concepts of knowledge visualisation, together with the criteria identified and discussed above, play an equal role in influencing the design process, thus leading to a visual artifact in order to realise a specific goal. Figure 2.13 presents all the factors which contribute to the design of a visualisation when the visualisation is being constructed in accordance with the knowledge visualisation theory. The visualisation is constructed based on the definition and exposition of KV by both Eppler and Burkard (2004) and Renaud and van Biljon (2017) and in line with the criteria identified in Table 2.3.

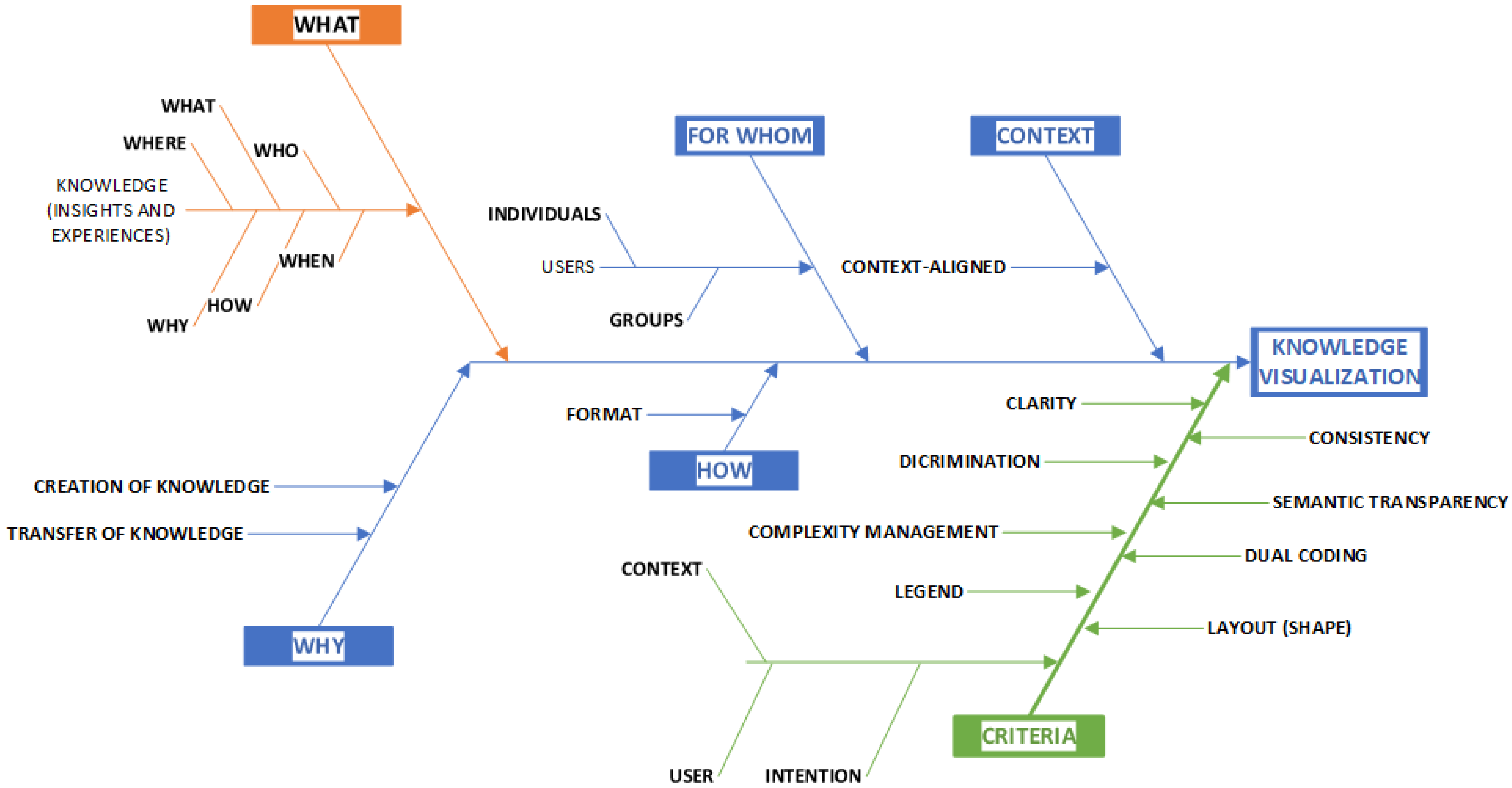


Figure 2.14 – Factors contributing to the KV Design Process (Author's Original Work)

These concepts and factors should all be taken into account, in varying degrees, according to the context, when a visualisation artifact is designed with the core purpose of knowledge transfer.

This leads onto to the updating of Figure 1.1 – Research Objectives as presented in Figure 2.14. The additions in Figure 2.14 includes the identification of the KVC of the knowledge visualisation process, the sense-making by individuals involved in an incident, the influences on sense-making during an incident, the IMS visual artifacts and how it is perceived as a technological influence on sense-making.

This diagram (Table 2.14) indicates that the IMS obtains detail from the incident and its surrounding environment and then displays this detail visually by means of a geo-visual artifact. This geo-visual artifact is informed by the KVC identified to enable knowledge transfer to take place. This knowledge transfer is achieved by influencing the sense-making by the individuals (responders) involved in the incident.

In view of the fact that technology is perceived as an element that may influence sense-making during an incident (section 2.2.3), the geo-visual artifact of the IMS is seen as a technological influence in sense-making. With the KVC informing the geo-visual artifact, the transfer of knowledge assists by influencing the sense-making of the individual through this visual artifact.

Accordingly, Figure 2.14 represents an extended version of Figure 1.1 in view of the addition of the concept of the KCV that were developed in section 2.3.3, the geo-visualisation artifact of an IMS discussed in section 2.2.5, the sense-making process explored in section 2.2.2 and the influences on the sense-making process, as identified in 2.2.3.

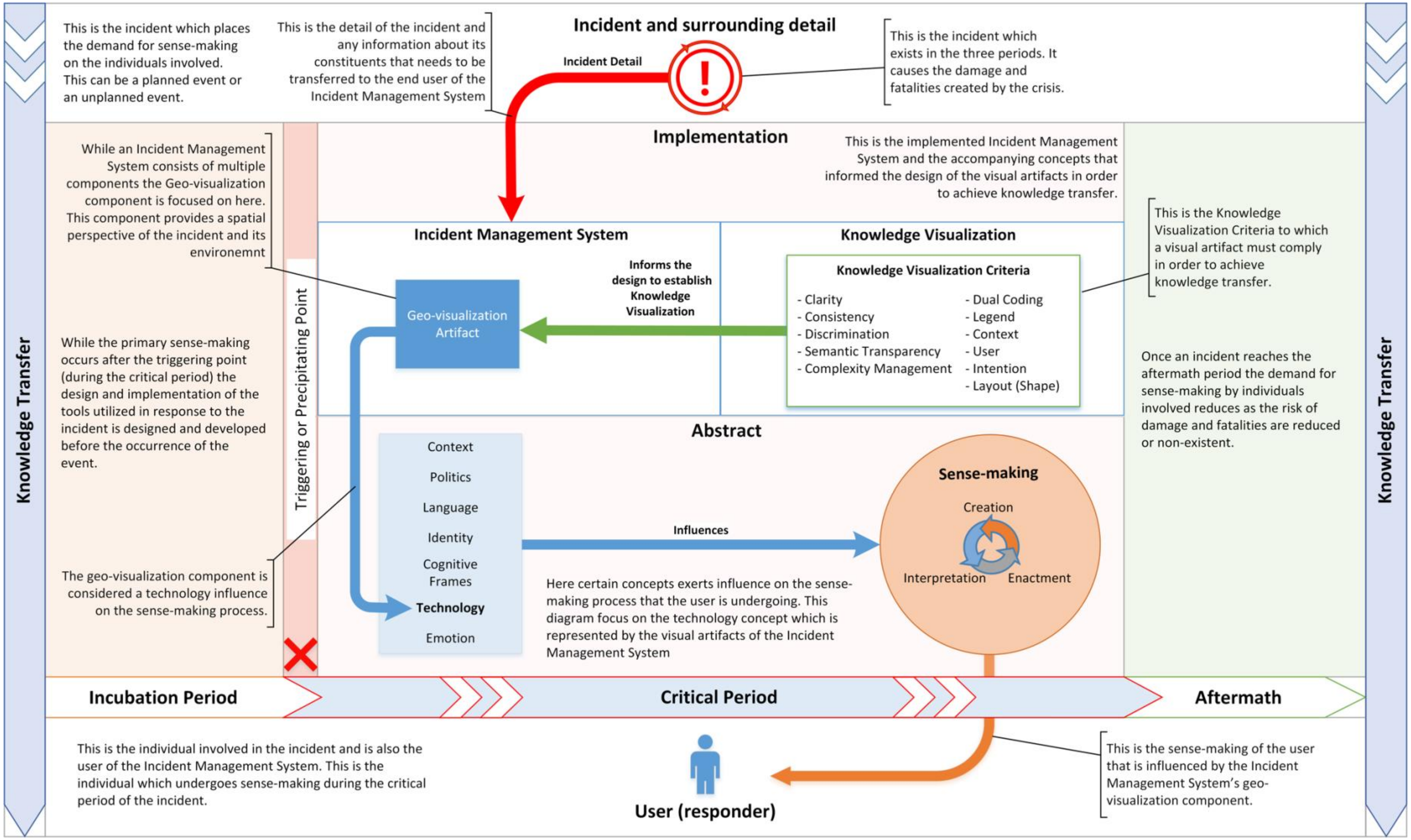


Figure 2.15 – Research Objectives

2.5 Summary

The literature review revealed that emergency incidents comprise periods and that these periods are characterised by various factors that impact on the context of the incident. This study focused on the critical period and the response to an incident during this period. Sense-making was identified as preferred cognitive function required by responders instead of decision-making. It was shown that the context, politics, technology, emotion, cognitive frames, identity and language may all exert an influence on the sense-making process of the individuals involved in an incident. IMSs were discussed as such an influence by virtue of their existing as a technological implementation.

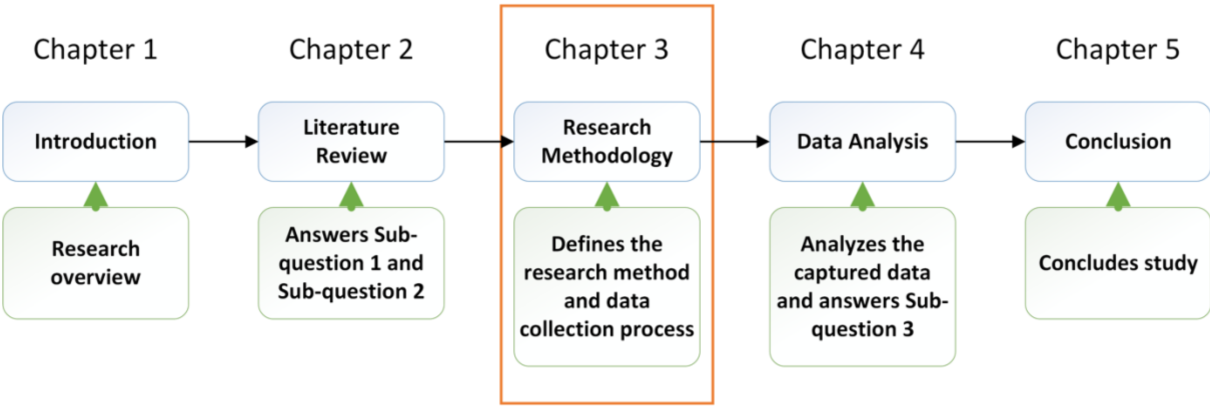
The chapter also introduced the concepts of data, information and knowledge and revealed that they are inter-related and also that each concept builds on the structure established by the previous concept. While DV refers to the visual, or symbolic, representation of data, information visualisation refers to the interactive representation of the information in a more condensed format. The visualisation of knowledge exists for the sole purpose of the creation and transfer of knowledge between individuals and groups. Based on existing literature 11 criteria were selected and expanded upon, thus generating a list of criteria to be utilised for the application of KV in this study (Section 2.3.3). These 11 points include clarity, consistency, discrimination, semantic transparency, complexity management, dual coding, legend, context, user, intention and layout (shape). This set of KVC provided the answer to research sub-question 2 of the main research question.

The visual artifacts of an IMS were also identified from the literature (Section 2.2.5). A geo-visualization is essential in the awareness element of the participants involved in an incident. The use of a geographical map structured with information pertaining to the incident and its context is considered indispensable for the responders to an incident. This role of a map in IMSs provided the answer to research sub-question 1 of the main research question.

The following chapter (Chapter 3) describes the procedures which were employed to evaluate the way in which the KVC established in this chapter (Chapter 1) applied to the visual artifacts of an IMS as well as how the evaluation of IMS compliance with the KVC was set-up and performed.

CHAPTER 3
Research Methodology

Chapter Content:



3.1 Introduction

This research study focused on identifying and evaluating criteria for the visualisation of knowledge and how the KVC apply to an incident management system. The criteria were identified from the literature review discussed in Chapter 2 and were then utilised to evaluate the visual artifacts (established in Chapter 2) in the incident management system. The visualisation artifacts were evaluated by means of a questionnaire which was completed by content experts during questionnaire-driven interviews. A second questionnaire was completed by usability experts who also completed a SUS questionnaire during questionnaire-driven interviews. The questionnaires and their composition are now discussed, how they were completed, and by whom they were completed. These usability experts were also eye-tracked to capture additional data on the usability of the IMS responder mobile interfaces.

Section 3.2 below discusses the research methodology, namely, design science research (DSR) used in the study. In addition, the research questions from Chapter 1 are restated. The choice of DSR is also motivated and DSR is defined in terms of (and application for) the research conducted by the researcher. This is followed with a discussion of the research environment in which the research was conducted, the application of the research methodology (DSR) is indicated, the data capturing is discussed and the details of the participants as well as the methods and processes used to capture the requisite data presented. Section 3.2 then concludes with a discussion of the ethical considerations which were taken into account during the study. Section 3.3 provides an overview of the ethical clearance obtained for the study and also a summary of the chapter.

3.2 Research Design

The study was conducted in an incident management environment. An incident management environment refers to the space in which an incident (usually critical of nature) is managed until the point is reached at which the consequences of the incident encompass a low degree or non-existing factor of fatality (known as the aftermath period). The users involved include activators, operators and responders. The communication of knowledge between these actors was the main focus of the study.

The primary data were collected by means of questionnaires that were completed by both the content experts with experience in responding to an incident, and usability experts with a background in usability theory. The data from the content experts was used to ascertain the extent to which the criteria which had been identified were applicable to the incident management system in question. On the other hand, the usability expert group was selected to evaluate the visual artifacts against the proposed criteria. The data collected from the usability experts was used to analyse and determine the extent to which the visual artifacts complied with the criteria against which they had been compared.

3.2.1 Research Questions

The research question (defined in Chapter 1) is cited again at this point but with the results of sub-questions 1 and 2 in the output column.

Table 3.1 – Research Questions and Objectives (Updated)

Main Research Question			
What are the knowledge visualisation criteria to optimise knowledge transfer by visual artifacts in incident management systems?			
Sub-questions		**Action**	**Output**
1.	What are the visualisation components of an incident management system?	Literature review	Visualisation components of an IMS identified (*Geo-visualisation artifacts* and *supporting information*). See Section 2.2.5 (page 39)
2.	What knowledge visualisation criteria exist?	Literature review	A set of knowledge visualisation criteria. See Table 2.3 (page 59)
3.	How do knowledge visualisation criteria apply to incident management systems?	Literature review, questionnaire driven interviews, eye-tracking, System Usability Scale questionnaire	List of incident management system-specific knowledge visualisation criteria.
Main Objective			
The purpose of this research study is to establish a set of criteria to optimise an incident management system's visual artifacts to be used as knowledge visualisation artifacts to support knowledge transfer. The anticipated end result of this study is to have established			

the criteria for the evaluation of the visualisation artifacts in incident management systems and also how these criteria relate to knowledge visualisation.	
Sub-objectives	
1.	To use existing academic literature to establish the visual artifacts that exist in incident management systems.
2.	To establish what knowledge visualisation criteria exist based on the existing academic literature.
3.	To determine the how the knowledge visualisation criteria established in answering sub-question 2 apply to the visual artifacts in an incident management system, as determined in the answer to sub-question 1, to achieve knowledge transfer.

3.2.2 Design Science Research – Literature Review on Methodology

Design science research (DSR) is a research paradigm that has been practised in the fields of Computer Science and Information Systems for decades (Iivari, 2007). According to Iivari (2007), DSR has been used in the new development of systems since the inception of CS and IS. Drechsler and Hevner (2016) point out that DSR has become an established research paradigm in the field of IS in the past few years and that, in his experience alone, the majority of the CS and IS research proposals use DSR (Hevner, 2007).

De Villiers, based on Simon (1997), proposed the following definition of design science (de Villiers, 2005:32): "Design sciences, by contrast, are the 'sciences of the artificial' and relate to man-made objects and artificial phenomena, generated in applied sciences such as medical technology, engineering, architecture, product design, and instruction". DSR outputs are generated by following two main complementary activities (Hevner et al., 2004):

- Building: the design and construction of the artifacts to meet identified needs.
- Evaluation: determining the extent to which the generated artifact addresses the identified need and used as feedback into the building process to replace existing technologies with more effective ones.

DSR knowledge may be produced through the following outputs (Table **3.2**) in the form of artifacts (Vaishnavi & Kuechler, 2004):

Table 3.2 – Outputs of Design Science Research (Vaishnavi & Kuechler, 2004)

	Output	Description
1	Constructs	The conceptual vocabulary of a domain.
2	Models	Sets of propositions or statements expressing relationships between constructs.
3	Frameworks	Real or conceptual guides to serve as support or guide.
4	Architectures	High level structures of systems.
5	Design Principles	Core principles and concepts to guide design.
6	Methods	Sets of steps used to perform tasks – how-to knowledge.
7	Instantiations	Situated implementations in certain environments that do or do not operationalise constructs, models, methods, and other abstract artifacts; in the latter case such knowledge remains tacit.
8	Design Theories	A prescriptive set of statements on how to do something to achieve a certain objective. A theory usually includes other abstract artifacts such as constructs, models, frameworks, architectures, design principles, and methods.

A model assists in the effective execution of a DSR study by providing a structured plan to adhere to. Drechsler and Hevner (2016) proposed a three-cycle view of DSR which has since become a widely cited model for DSR.

Drechsler and Hevner (2016) extended the three-cycle view of DSR to a four-cycle view (Figure 1.1). The sole difference between the three cycle and the four cycle is the addition of another cycle termed the change and impact cycle which covers the social and organisational contexts of the second order impacts of the design artifacts.

The relevance cycle acts as a bridge between the contextual environment of the research project and the design science activities while the design cycle is an iterative process that cycles between the actual activity of the building of the design artifacts and processes and the evaluation of these artifacts. The rigour cycle represents a connection between the design science activities and the knowledge base informing the research project.

According to De Villiers (2005), if DSR is applied to information systems, its outputs are made up not only of a complete system but also consist of the building blocks of the system. Thus, the result from a DSR study provides the researcher with a complete system together with all the working elements that allow the system to function. This provides greater insight into the actual components and the relations between them which may provide the researcher with an opportunity to conduct an integrated analysis of the system.

Nevertheless, other research methodologies do exist. Vaishnavi & Kuechler (2004) compared the research perspectives of positivism, interpretivism and design, as presented in the table below (Table 2):

Table 3.3 – Philosophical Assumption of the Three Research Perspectives (Vaishnavi & Kuechler, 2004)

	Research Perspective		
Basic Belief	**Positivist**	**Interpretive**	**Design**
Ontology	A single reality. Knowable, probabilistic.	Multiple realities, socially constructed	Multiple, contextually situated alternative world-states. Socio-technologically enabled.
Epistemology	Objective; dispassionate. Detached observer of truth.	Subjective, i.e. values and knowledge emerge from the researcher-participant interaction.	*Knowing through making*: objectively constrained construction within a context. Iterative circumscription reveals meaning.
Methodology	Observation; quantitative, statistical	Participation; qualitative. Hermeneutical, dialectical.	Developmental. Measure artifactual impacts on the composite system.
Axiology: what is of value?	Truth: universal and beautiful; prediction.	Understanding: situated and description.	Control; creation; progress (i.e. improvement); understanding

3.2.3 Research Environment

The study's research context was that of an incident management setting. This particular environment involves individuals from a comprehensive spectrum of backgrounds, ranging from emergency management personnel to ordinary farmers. The technology used to implement the system makes use of hosted servers as the principal system with which ordinary browser-based interfaces and native mobile device interfaces communicate. This allows a more virtual (remotely-accessible) environment for the incident management system to function in.

The incident management system used in the study provided the basic infrastructure required – See in Figure 3.1. The activator section is where the incident is reported from and acts as the initiation point of the incident reporting. The client application consists of a single interface through which the incident reporter (activator) may report an incident.

Once the incident has been received on the server, the operator has an option of two interfaces from which to analyse the incident detail, namely, a web interface and a mobile interface. Both these interfaces have the same functionality although the web interface may also provide reporting. This section is known as the operator section.

Once the operator has determined the incident type and severity (by calling the incident reporter), he or she notifies the response group which has been assigned to respond to the specific incident type in the area in which the incident occurred. The detail sent to the responder is accessible through a responder application (see the responder section).

The main visual component of the system is a geographical map and appears in the activator mobile application, the browser interface as well as the responder mobile application (these entities are depicted in Figure 3.1). The additional information (knowledge) which is captured for the knowledge visualisation is captured by the operator via the browser interface. This, in turn, is displayed either on the geographical map or together with the map in the responder's mobile application.

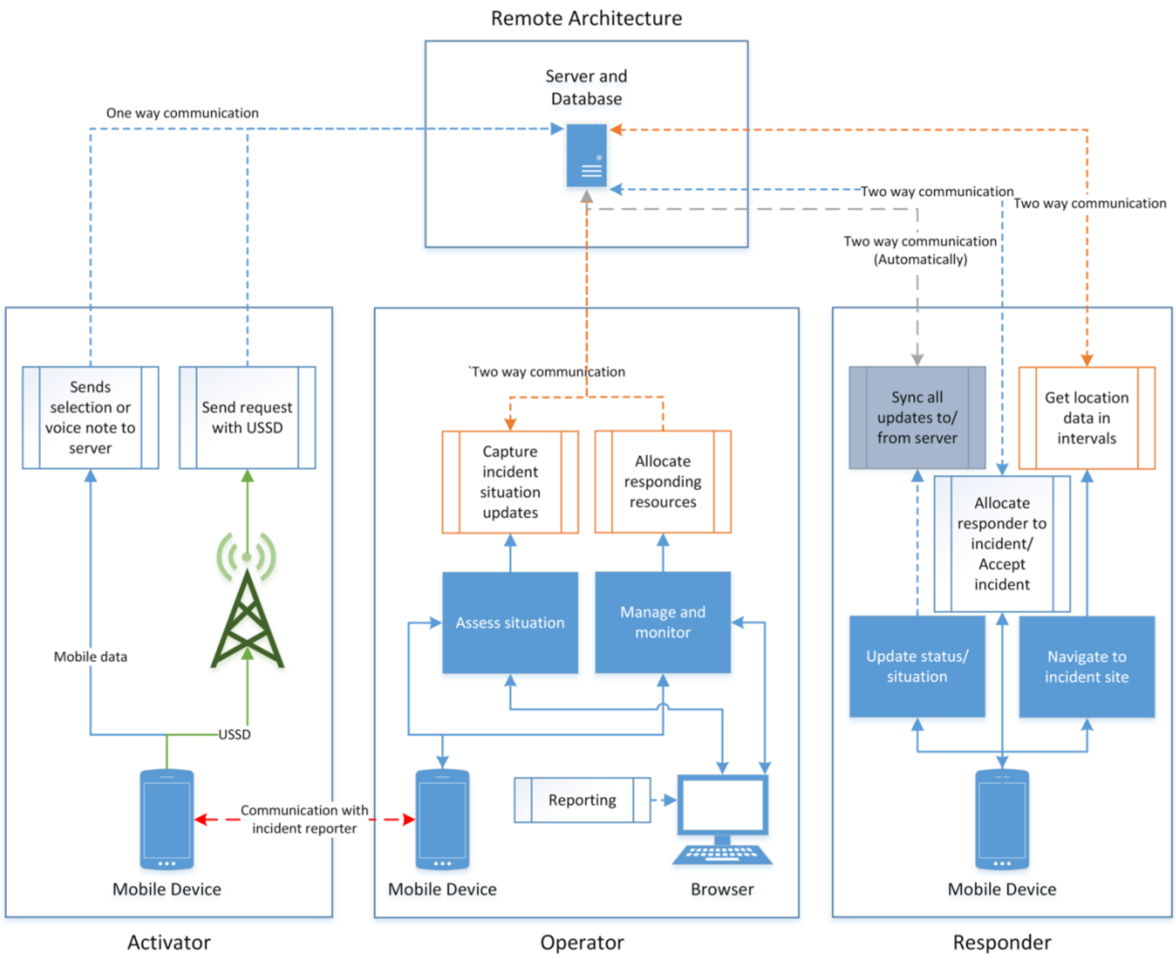


Figure 3.1 – IMS Infrastructure Layout

No matter how important an information technology (IT) artifact is it only plays a part in (or comprises a fragment of) an information system (IS) artifact (Lee, Thomas & Baskerville, 2015). A system is, therefore, greater than the sum of its parts. An information system consists of an information artifact, a technology artifact, and a social artifact. This triumvirate is indicated in Figure 3.2 below:

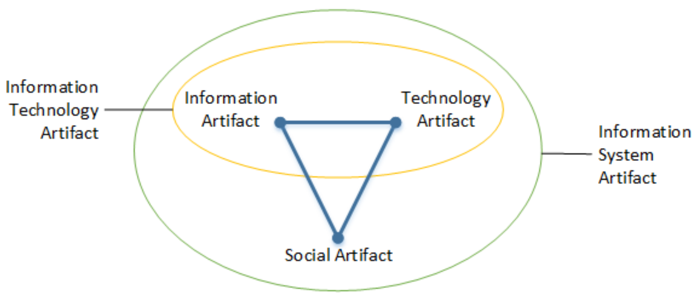


Figure 3.2 – The Triumvirate of an IS Artifact (Researcher's Original Work)

Lee et al. (2015) define the information artifact as the instantiation of information by either the direct or indirect action of a human being. A technology artifact is a human-created tool with the primary goal of solving a problem while a social artifact comprises relations and interactions between human beings in the process of solving a problem.

With this as a guide the system on which the researcher focused and the description of its artifacts were outlined in the following way. The technical artifact used in the study comprised an incident management system (IMS) or, to be more precise, a virtual incident management system (VIMS). A VIMS consists of a software architecture that is remotely accessible via a web interface (browser) and mobile devices.

The social artifact of the research environment comprised individuals characterised as activators, operators or responders. Activators refer to those individuals who have experience or who have become aware of an incident and who send a notice of the incident to the system via a mobile application which activates the incident in the IMS; thus, the identification as activator. Operators are those individuals who receive the incoming notification and, upon receiving the notice, manage the incident by confirming its validity (identifying whether the activation was false or valid), collect additional details on the incident and allocate the resources required to address the incident.

The third group of individuals who are part of the social artifact is known as the responders. These are those individuals who form part of the resources managed by the operators of the IMS. Thus, these individuals will be at the actual scene of the incident and they are responsible for executing specific duties to resolve the incident (or prevent further damage and fatalities) to which they were allocated. The spectrum of backgrounds from which these individuals originate may vary significantly and may include professionally trained and experienced firefighters to conventional farmers.

In the specific system used in the study more than just information passed through the system (data and knowledge as the other entities) and the researcher accepted that these entities existed in the information artifact. Accordingly, the information artifact comprised the data, information and knowledge passed between the actors of the social artifact.

The IMS under investigation in the study had multiple corporate clients utilising the system while interest in the system had also been shown by the Department of Water and Sanitation (DWS) of the South African government. The DWS had undergone multiple tests and a full demonstration of the system at remote water reservoirs had been carried out. Some of the corporate clients utilised the system to protect assets such as factories and occupied office buildings. The IMS had also been tested to report municipal infrastructure issues such as problems in relation to potholes, broken storm drains, etc while a private sector fire service, known as FIRE OPS SA (FOSA), was utilising sections of the system for reporting fire incidents. Private sector entities also utilise the system to protect their assets.

The company responsible for the development and management of the system's technical aspects is known as Jovansoft. The researcher's role at the company is at an executive level but he is also involved in the architecture as well as the development of the systems which the company produces. The researcher had planned, designed and developed the IMS utilised in this study single-handedly, only receiving advice from industry experts in respect of the implementation of the system.

The system was built using hosting technology for remote processing and the storage of incident data. The hosting is performed on a Linux-based system. The choice of this system was based on Jovansoft's approach in utilising open-source software and tools. The core of the system is built on the Laravel framework and, thus, PHP is the main language implemented on the system. MySQL is used to integrate the data on the system as Laravel is designed to incorporate MySQL as one of its data storage systems. The browser interface was built using web technologies such as HTML5, CSS3, and Javascript (jQuery).

For the mobile interfaces, native languages and tools (Android and Swift) are implemented instead of hybrid technologies in order to provide access to all the hardware features offered by mobile devices. For the communication of data between the remote system, the browser and the mobile devices three technologies are used, namely, RESTful technology, a propriety web-based push technology known as Pusher and Google's Firebase Cloud Messaging (FCM).

When the activator activates an incident on his/her device the device sends an encrypted data pack containing the incident detail to the server by means of the RESTful technology. The operator, using the browser interface, is notified of the new incident in real-time by the Pusher technology. This happens as follows: the system receives the data from the activator's device, creates the incident in the database and then sends a push notification to all the browsers on the push-channels registered to receive notifications of new incidents. The operator receives the incident notification and may then view the incident detail by opening a new page on the browser. The system also sends an SMS (Short Message Service) message (containing a notification about the incident) to the operator's mobile device as an extra precautionary measure.

In order to send the incident detail to the responders' devices the FCM technology is used. Once an operator has compiled the information pertaining to an incident he then pushes the data to the selected responders. The process flows in the following way: first, the system pushes the system generated identifier (the system-assigned id of the incident) to the responders' devices by making use of FCM. Once the responders' devices receive the push message the device takes the identifier and makes a RESTful request back to the remote system requesting to synchronise its own database with the detail of the incident on the remote database. Once the synchronisation is complete the device informs the remote system that the incident has been synchronised and then displays a notification (accompanied with a notification sound) on the device that a new incident has been pushed to the device. Any further interaction on the responder device by the responder is communicated to the remote system by means of RESTful technology.

3.2.4 Application of the Research Methodology

At the time he embarked on this study the researcher had been involved in the development of a virtual incident (emergency) management system to assist operators (who are not present at the scene of the incident) with the management and allocation of resources. The structure of this system is presented in Figure 3.1. The researcher played a major role in the architectural design and the actual development of all the components and tiers of the system.

The researcher used DSR as the research methodology in the study as the iterative nature of DSR (Hevner et al., 2004) was deemed to be appropriate to adapting the artifact after evaluation. The study was based on the Four Cycle DSR Model (Figure 1.2), through which scientific theories were identified and applied to the study. An adaptation of the model is presented in Figure **3.3** below, configured to indicate the research that was conducted.

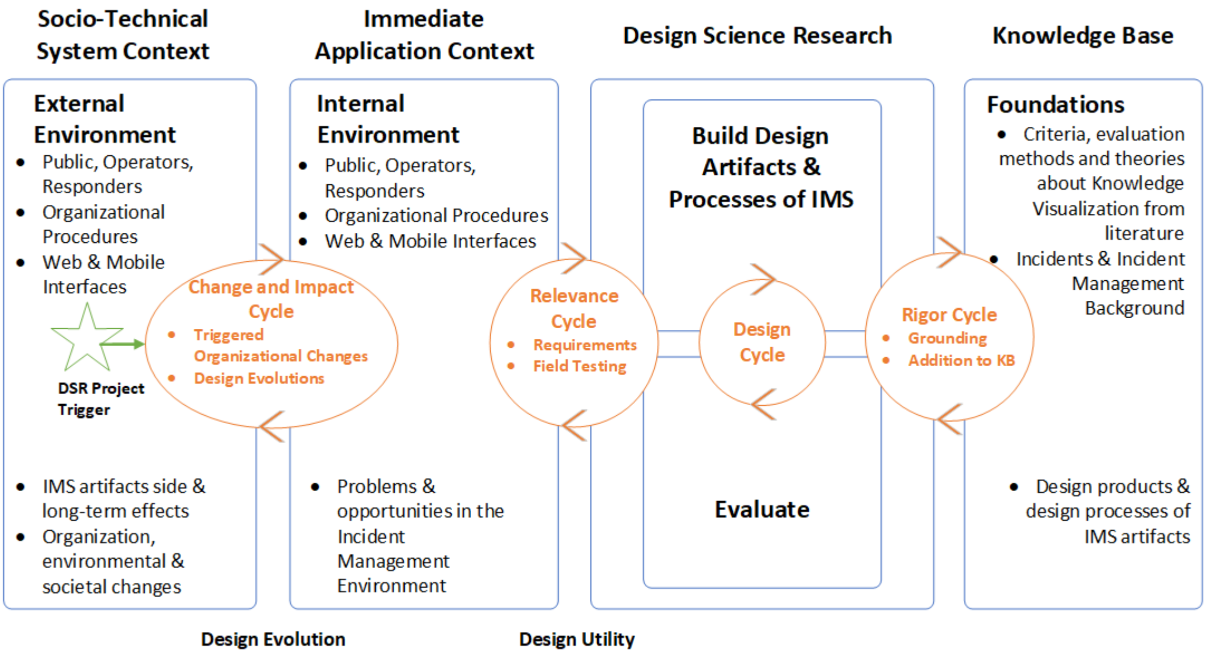


Figure 3.3 – DSR Applied to the Research Project

The immediate application context of the research is that of an incident management environment. This environment includes the individuals involved in any incident such as responders, incident activators (persons reporting an incident), and operators (receive the incident report and allocate response resources to the incident). This context also includes the remote system as well as the browser and mobile interfaces that link into the incident management system.

The knowledge base in Figure **3.3** consists of the literature review of the research that was conducted and forms the academic foundation and background of the research. This part of the research included the literature review on KVC, incidents and their processes and influences, and incident management systems as well as the artifacts making up an IMS. The literature review generated the KVC used in the study and enabled the identification of the visual artifacts of the IMS for the study.

The design science research in Figure **3.3** constituted the core of the research. This cycle of the DSR was also the cycle where the steps of the research were executed. The artifacts of the IMS on which the research was conducted were designed and build during this cycle. The relevance cycle provided assurance that the artifacts were applicable to the incident management field by means of requirements of an IMS (to comply with the KVC) while the results from the evaluation provided suggested improvements for the artifacts. These cycles combined represented the primary implementation of the design science research approach used in the study.

The rigour cycle in Figure **3.3** provided assurance that the foundation of the research was academically sound by means of the literature review and the evaluation of the artifacts against the academic material. This cycle also incorporated the incident and usability experts' evaluation. In addition, it provided a retrospective view on the literature to ensure that the research artifacts were innovative (Hevner, 2007). The execution of the rigor cycle was also the process which provided additions to the knowledge base on which the research rested.

The socio-technical system context of the model (the component that differentiates the previous DSR cycles) in Figure **3.3** represented the social entities of the incident management process that integrated with the technical implementations that constitute the IMS. It was this stage that the criteria's applicability in guiding the visual artifacts to achieve their goals to represent the knowledge of incidents were evaluated by the participants and provided the option to investigate this applicability using a more long-term approach. This section of the model played an important role in the application of the particular system on which the research was conducted.

One of the clients who had requested an IMS (DWS) was structuring the practical application of the system to suit wider contexts as compared to its primary function (at the time of the study). The client had included other departments within the government as official users of the system. Even if incidents are homologous at their nucleus, the context in which incidents occur differs between departments and this has an influence on the process used for the incident. The socio-technical system context of the DSR model was, therefore, of cardinal importance in collecting, evaluating and understanding the information provided during the application of the system in its various contexts. The concept discussed above was also applicable for the corporate clients of the system.

The steps taken during the research process are illustrated in Figure **3.4**:

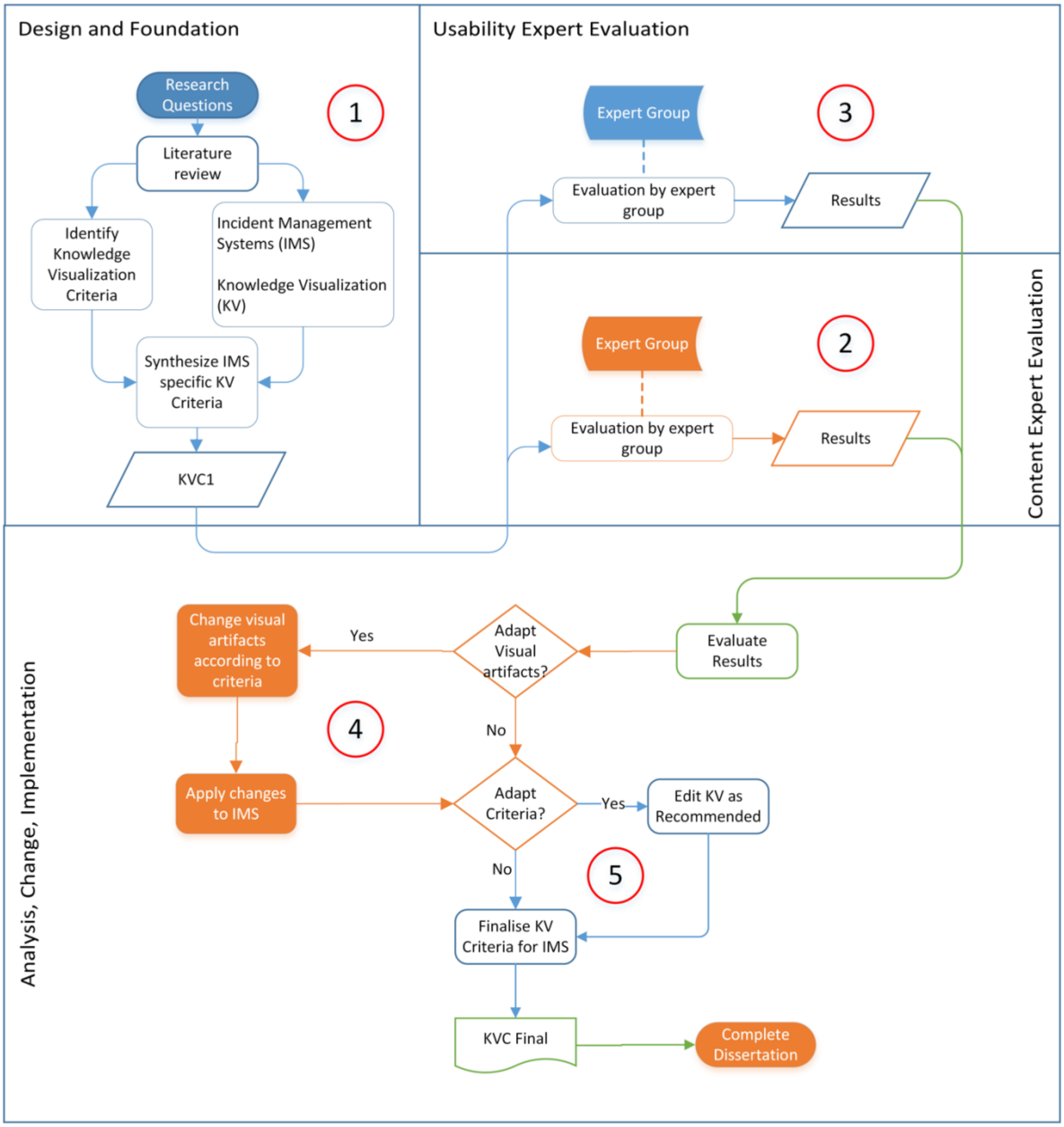


Figure 3.4 – Research Process Diagram

The numbered steps in the diagram are explained as follows:

1. Identify criteria from literature: a literature review was conducted in order to identify the criteria currently existing in the field of visualisation with regard to knowledge representation and transfer. Research into the background of

incidents and their dynamics was also conducted to establish the importance of IMS.

2. Content expert evaluation: the experience of content experts was sourced and utilised in order to evaluate how important the identified criteria were in the context of the IMS being investigated. Highly experienced and qualified individuals were provided with details of the system and the role of the criteria in the IMS and they were then interviewed to establish how important each criterion was. This evaluation was conducted only on the responder interface. Any additional feedback provided by the was utilised to establish the applicability of the criteria to the IMS.
3. Usability expert evaluation: at this point the visual artifacts of the responder mobile interface were evaluated against the criteria which had been identified. These experts were asked to navigate the interface of the responder application (without prior training) to evaluate the extent to which the interface supported knowledge transfer. The experts then evaluated the same interface against the criteria with some of them then also making additional suggestions. Finally, the experts completed a System Usability Scale questionnaire with regard to their experience of using the system.
4. The findings from the feedback of the users were analysed and incorporated into the design of the criteria and IMS (where applicable) accordingly. The feedback from the content experts established the importance of each criterion in the context of IMSs while the feedback from the usability experts not only indicated the extent to which the IMS met the criteria but also how the criteria could be improved. In addition, the results from the SUS questionnaire completed by the usability experts indicated the extent to the interface provided a usable experience.
5. The visualization criteria which had been identified in step 1 were evaluated and adapted accordingly. They were also evaluated to determine their importance when utilised in IMSs. This is illustrated in Table 4.5 (page 109).

The initial evaluation process in step 1 related to the rigour and relevance cycles of the four-cycle design science research model, while the evaluation process in steps 2 to 5 formed part of the change and impact cycle of the model. Iterations were carried out during the building (or adaptation) and design process of the artifacts after evaluation. The design cycle was addressed by means of the active development of the criteria and the visual artifacts of the IMS investigated during the study.

Step 1 provided academically supported answers to sub-questions 1 and 2 of the main research question while steps 2 to 4 provided practical answers to research sub-questions 1, 2 and 3 through the evaluation and analysis of the criteria in the context of an IMS.

3.2.5 Data Capturing

Qualitative data refers to data that is not numeric, for example, words, images, sounds, etc. (Oates, 2006). According to Oates (2006), even if qualitative data is non-numeric, it is possible to carry out quantitative analyses on qualitative data by, for example, counting the number of times a particular word occurs in a text.

The focus of this research study was on visual artifacts built on the concepts of data, information and knowledge. In line with the criteria identified in the literature these visual artifacts have goals which they must achieve with respect to the users of the system in which the artifacts are located, namely, they must to be able to transfer knowledge regarding the incident to the responders to the incident. Content experts with experience in responding to incidents evaluated whether these artifacts would be able to play a role in realising the goals of the criteria applied. These experts played a crucial role in determining whether the criteria were applicable to the artifacts and how important the KVC were in the context of an IMS. In light of this importance of the participants' contributions a qualitative paradigm was adopted for the purposes of this study.

3.2.5.1 Participants

Seeing that the research is done on an IMS the input of *content experts* is essential to the contribution of the research. Individuals who have a background in incident response and management were included in this group as they provided information based on having practical experience in the utilization of IMSs.

The opinions of *usability experts* are related to how the visualization align to the criteria as well as how the artifacts contribute to a positive user experience. They approached the questionnaire from a different perspective than the content experts. Therefore, two groups of participants were used in this study: a content expert group and a usability expert group.

The focus of the usability group was two-fold: they were to evaluate the visual artifacts against the criteria and, to a lesser extent, evaluate the criteria itself. Both groups were provided with the details to understand the application of the criteria. Both groups evaluated the same mobile application interfaces.

Content Expert Participants' Profile (Group 1)

The study involved seven participants from a background in incident response and management. Their level of expertise in this respect varied. All of the participants had a minimum of ten years of experience as firefighters in the South African Fire Service with some having over 30 years of experience. Three of the seven participants were still employed as municipal firefighters at the time of the study. Of these three two were senior officers (chief and deputy chief) and the other an officer heading the training department of his municipal station. The other four participants had become fire safety consultants on their retirement from active service and had each consulted for a minimum of thirteen years, with one participant having twenty-six years of consulting experience. All four of these participants had been officers in the fire department.

Usability Participants' Profile (Group 2)

Eight usability experts were involved in the study, all of whom had a minimum of honours degree as well as experience in teaching human computer interaction. Their ages ranged from 35 to 61. Four were Caucasian and 4 were African.

Table 3.4 – Usability Experts' Positions

Participant	Position
1	Senior Lecturer
2	Junior Lecturer
3	Senior Lecture
4	Administrator
5	Senior Lecturer
6	Senior Lecturer
7	Associate Professor
8	Lecturer

3.2.5.2 Research Instruments

The data capturing strategies used to collect the requisite data included questionnaire-driven interviews, heuristic evaluation and usability testing with eye-tracking. The first questionnaire, aimed at establishing the link between the criteria and visualisation relation, was divided into two individual questionnaires (both with a similar structure) – one for the content experts and one for the usability experts. The only difference between these two questionnaires was *what* was being evaluated. The content experts were asked how important the criteria which had been identified were in IMSs while the usability experts were asked how well the visual artifacts complied with the criteria. Table 3.5 presents the details of the way in which the questionnaire was structured for the two participant groups. The questionnaires were administered to the participants on printed paper. The questions in the questionnaires were as indicated in Table 3.5. Since all the questions were in the format of a Likert scale the users were given the possible options for each question. This made it easier for the users to complete the questionnaire as well as improving their efficiency in completing the questionnaire. The questionnaires are contained in Appendices B to G, as administered to the relevant participants. Each participant was also provided with a table of descriptions of the criteria (see Appendix H).

Table 3.5 – Questionnaire Detail

<table>
<tr><th>Criteria</th><th>Evaluation</th><th>Instruction:</th><th>Answers:</th></tr>
<tr><td>Simplicity</td><td></td><td rowspan="9">Content Expert: Provide a number from 1 to 5 in the “Importance” column where 1 = no importance and 5 = high importance.

Usability Expert: Provide a number from 1 to 5 in the “Compliance” column where 1 = no compliance and 5 = full compliance.</td><td rowspan="9">Likert scale of 1 – 5</td></tr>
<tr><td>Consistency</td><td></td></tr>
<tr><td>Discrimination</td><td></td></tr>
<tr><td>Semantic Transparency</td><td></td></tr>
<tr><td>Complexity Management</td><td></td></tr>
<tr><td>Dual Coding</td><td></td></tr>
<tr><td>Legend</td><td></td></tr>
<tr><td>Context</td><td></td></tr>
<tr><td>User</td><td></td></tr>
</table>

Intention			
Layout (Shape)			

The usability experts also participated in a survey by completing a SUS (System Usability Scale) questionnaire. However, this questionnaire had been set up using Google Forms and completed on the researcher's laptop. This questionnaire was completed during the same session during the usability experts had undergone the eye-tracking and completed the criteria-visualisation questionnaire.

Every incident consists of a different type of event with this event forming part of a certain category of incident types. The incident management system utilised at the time of this research study had been set up to manage 62 different incident types. While each incident type has its own context and elements involved during its existence the researcher decided to conduct investigate the three main categories only. This decision was made in view of the limitations imposed by both the time constraints and the resources available to the researcher. Every category consists of certain elements which are generic to the types found in the category. This generic factor allowed for research to be conducted on these elements and obtain information relevant to the other incident types in the same category. Figure 3.5 depicts the icons used to represent the three incident type categories in the IMS.

SOS
Any emergency issue

HAZMAT
Any ecological or hazardous issue

ENFORCEMENT
Any issue requiring some form of enforcement

Figure 3.5 – Incident Category Types

In view of the fact that the study focused on visualisation criteria the aim in collecting the data was to analyse the extent to which the criteria applied informed the visual artifacts and to establish the effectiveness in respect of the goal of the artifacts (to transfer knowledge). The participants indicated the applicability, or conformance, level that closely related to their experience of evaluating the various artifacts in the responder interfaces.

The three interfaces that were utilised for the purposes of this research study are presented in Figures 3.7, 3.8 and 3.9 below. The figures contain sample data of incidents with additional information on the context of the incident. Figure 3.6 depicted the interface of the responder application presenting the list of incidents to be evaluated.

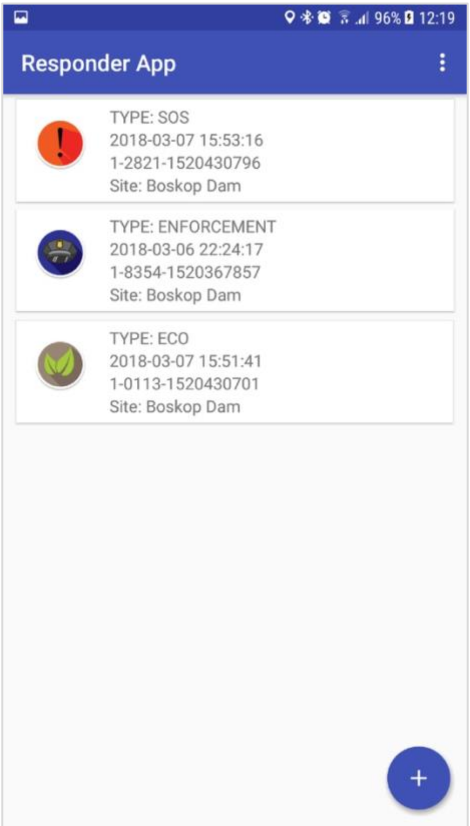


Figure 3.6 – Responder App Incident List

Figure 3.6 depicts the interface which lists the three incident categories as indicated in Figure 3.5 above. This interface was utilised only in the usability tasks. It was displayed when the user was assigned a task to complete together with the eye-tracking process. The user selected the specific incident according to the task. These interfaces are displayed in either Figures 3.7, 3.8 or 3.9, depending on the incident selected from the list.

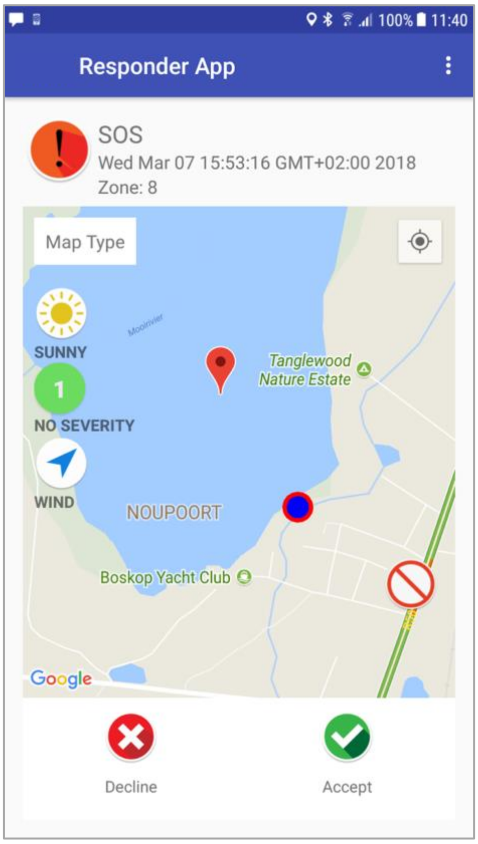


Figure 3.7 – SOS Responder Mobile Interface

Figure 3.7 displays a typical SOS incident with additional information regarding the incident and its immediate surroundings. It provides a geographical map with a pin indicating the location of the incident and displays the type of incident with the date, time and predefined zone of the incident. This predefined zone is client specific. Additional information on the screen is displayed on the map and on the left-hand side of the screen. The red and blue circles (on the map) indicates a point of service for all responders. This detail is set up beforehand according to the client and area of any potential incident. The 'no entry' sign on the map indicates a restriction of access, indicating (in this particular incident) that the road is closed.

The information on the left of the interface is as follows. The first icon from the top is a sun and is accompanied by a label beneath it indicating that the weather is sunny. The second icon indicates the level of severity of the incident which, in this case, is 1, indicating no severity (as may be seen by the icon's label). The green was also used to assist in indicating the level of severity. The third and final icon indicates the wind direction at the site of the incident. The 'Map Type' button is a feature provided by the mobile plugin of Google Maps and provides the options for the map to display the ‘terrain’ or to display as a ‘satellite’ image.

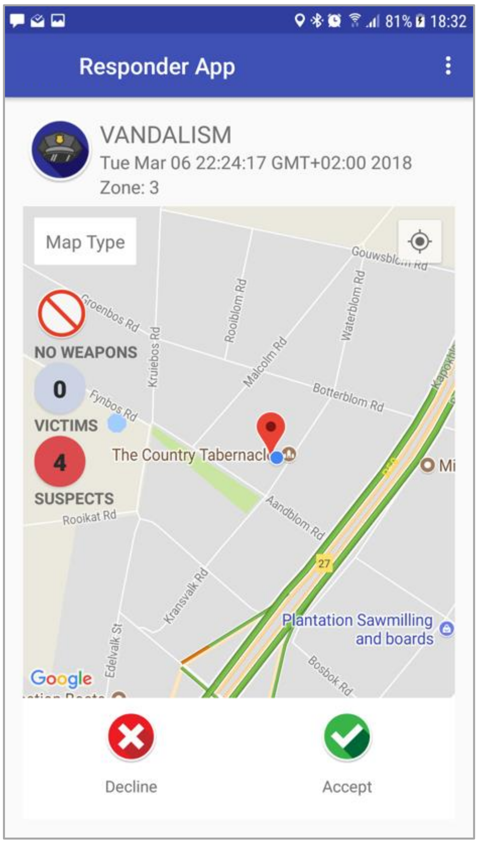


Figure 3.8 – ENFORCEMENT Responder Mobile Interface

Figure 3.8 depicts a typical ENFORCEMENT incident with additional detail. The first icon at the top on the left of the interface indicates that there are no weapons involved in this incident, the second icon indicates that no victims are involved and the third icon indicates that there are four suspects involved.

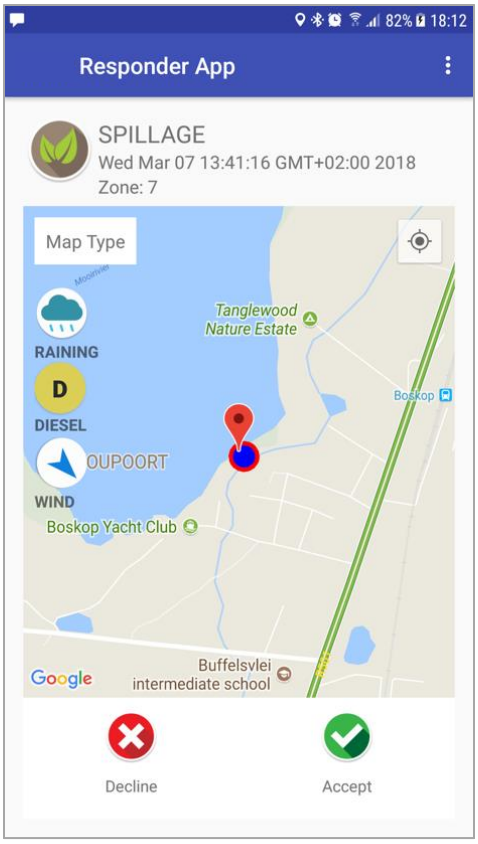


Figure 3.9 – HAZMAT Responder Mobile Interface

Figure 3.9 represents a typical HAZMAT incident. The geographical location is in the same area as that of the SOS incident depicted in Figure 3.7. The first icon of the additional information uses a cloud with rain to indicate that it is raining at the site of the incident, the second icon indicates that the incident involves a spillage of diesel fuel while the third icon indicates the direction of the wind, similar to the SOS incident.

3.2.5.3 Data

The purpose of designing the questionnaire using a Likert scale format was to ensure that completing the questionnaire was as simple as possible. The data received was specific as that the participants were given with possible answers and selected the value (integers 1 to 5) which they deemed to be the most appropriate in evaluating the criteria or artifacts. If the participant wished to add additional comments a comment box was provided on the paper questionnaire to enable the participant to add anything they felt was worth commenting on.

The eye-tracking data provided two different types of information – firstly, it provided an indication of the way in which the users perceived the interface and the visual artifacts as a whole by tracking how they perceived the artifacts and, secondly, it gave an accurate time-tracing of how long it took the participants to evaluate each interface according to the tasks assigned. The participants were required to indicate whether there was sufficient information presented by the visual artifacts to enable them to make an informed decision in respect of responding to the incident. This information was also tracked.

3.2.5.4 Analysis

The researcher analysed the results of the questionnaires administered to the content experts and the usability experts together with any suggestions and comments provided by these two groups. The analysed results led to the conclusion being that minor changes only may be required on the IMS so that the IMS would portray more information regarding an incident although these were too minimal to justify changes for the purposes of this study. However, the captured data did influence the synthesis of KVC specifically for IMSs from the KVC identified from the literature.

3.2.5.5 Data Collecting Process

The *content experts* completed the questionnaires within an interview context. These participants were required only to complete the questionnaires and, thus, any informal setting or location was deemed to be suitable. The participants were given a basic overview of the study as well as guidance (as and when they needed it) as they completed the questionnaire. The participants were interviewed either together and individually based on their availability.

The *usability experts* were interviewed individually. Figure 3.10 presents an overview of the process that were followed during the data collected from these experts. Firstly, an introduction to the research was provided giving the background of the research. The participants then completed the usability tasks using a computer onto which the eye-tracking technology had been loaded. Once all three usability tasks (for the SOS, ENFORCEMENT and HAZMAT interfaces) had been completed the participants completed the questionnaires for each of the three incident category type interfaces. Finally, the participants completed the SUS questionnaire on the researcher’s laptop.

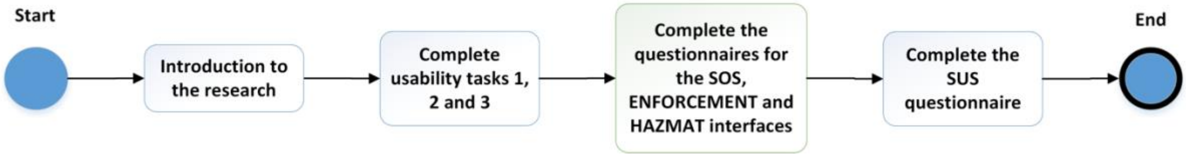


Figure 3.10 – Usability Expert Data Capturing Process

Although an introduction was provided with regards to the study the researcher did not disclose any details that the participants may have expected in relation to the interfaces and their visual artifacts (additional information). This data collection process of the usability experts took place at the Eye-tracking Laboratory of the School of Computing of the University of Unisa. The eye-tracking was conducted using a Tobii 1750 eye-tracker. This is a desktop computer setup and, thus, the mobile interfaces were displayed as a simulation on the computer's screen. A 5-point eye tracking calibration was used at all times. The usability participants were interviewed individually at different times due to the availability and limitation of the tools utilised.

For the eye-tracking collection process it was required that the participants complete certain tasks on the interface for which the eye-tracking was conducted. This was done so that the results of the eye-tracking could be analysed against a tangible objective. For the capturing of the eye-tracking data in the study each interface of the mobile application (SOS, ENFORCEMENT and HAZMAT) was set up with the following usability tasks (completed by the usability experts):

- Task 1 (SOS) – By looking under the SOS tab, is there sufficient information to enable you to respond to the incident?
- Task 2 (ENFORCEMENT) – By looking under the ENFORCEMENT tab, is there sufficient information to enable you to respond to the incident?
- Task 2 (HAZMAT) – By looking under the HAZMAT tab, is there sufficient information to enable you to respond to the incident?

Each of these tasks were accompanied with the instruction of 'Please click on ACCEPT for Yes or DECLINE for No'. Two screens per task only were displayed, namely, the list of incidents (Figure 3.6) and the incident detail screen (Figure 3.7, Figure 3.8 or Figure 3.9) according to the task to be completed.

3.2.5.6 Eye-tracking

Eye tracking assists in determining the visual attention distribution during a visual stimulus (Djamasbi, Siegel & Tullis, 2010; Rakoczi & Pohl, 2012; Borgo, Maciejewski, Viola, Blascheck, Kurzhals, Raschke, Burch, Weiskopf and Ertl, 2014) as well as measuring completion times of visual tasks (Pretorius, van Biljon & de Kock, 2010; Borgo et al., 2014). This is done to study the usability of webpages and their components (Djamasbi, Siegel & Tullis, 2010; Pretorius, van Biljon & de Kock, 2010) and any screen projecting visuals (Ehmke & Wilson, 2007).

Eye tracking is the process of recording gaze points (eye movements) of participants while their view an interface (Djamasbi, Siegel & Tullis, 2010; Rakoczi & Pohl, 2012; Borgo et al., 2014). This process of capturing eye movement and gaze of participants while doing specific, predefined tasks provides information about the sequence, timing and nature of the cognitive procedures that took place (Pretorius, van Biljon & de Kock, 2010).

The process of doing eye tracking during the execution of tasks on an interface is usually done in a laboratory or controlled environment as can be seen from (Djamasbi et al., 2010), (Djamasbi, Siegel & Tullis, 2010) and (Duchowski, 2017). Some laboratories even consists of a participant room and an observer room which is separated by a one-way mirror (Pretorius, van Biljon & de Kock, 2010). While a laboratory environment is the conventional setup for eye tracking there is a trend to move the eye tracking process to the natural environment of participants and to observe their cognitive processes in their everyday existence (Majaranta & Bulling, 2014).

Data captured during eye tracking provides us with various metrics of the participants' viewing process such as fixation, saccade, and Areas of Interest (AOIs) (Borgo et al., 2014). Fixation is the accretion of all the gaze points captured from viewing an interface (Borgo et al., 2014). Fixation also be used to generate a heatmap of the interface (Borgo et al., 2014). This heatmap indicates where the participants' viewed the interface and how intensely they viewed it. A saccade is the quick movement between fixations (Ehmke & Wilson, 2007). AOIs are highly important stimulus on an interface (Borgo et al., 2014) and that are more noticeable than other stimuli (Ehmke

& Wilson, 2007). In this study gaze plots and heat maps will be used to capture data on participants interaction with the system.

3.2.6 Ethical Considerations

The type of information that the system handles consists of user details (names provided by the activators and responders themselves, their location), information about the incident (type of incident, severity, time of occurrence) and any communication between the responders via the system. While, for the purposes of this study, the focus was on the visual display of some or all of this information test data was utilised in order to ensure that no confidential information integrated with the IMS was compromised. No unauthorised person had permission to access this detail and the utmost care were taken to ensure that the information was protected.

The participants' anonymity was guaranteed by the researcher not making use of personal information or anything that may have revealed their personal details. If, in the event that information being displayed that may have compromised this arrangement, the researcher replaced the personal detail with that of a pseudonym where applicable. Any participant completing the questionnaire was constantly provided with the option to opt out of completing the questionnaire with no consequences in the event of such a decision.

In view of the possibility that the confidentiality of the users may have been compromised (as indicated above) the researcher attempted to address, and prevent, this in all feasible and confidential ways.

3.3 Ethical clearance

The researcher completed the relevant forms for ethical clearance with descriptions of the data to be collected as well as the procedures that would followed. Ethical clearance was granted to conduct the research on 27 March of 2017 and was valid for three years.

Ethical Clearance Number: 018/QVW/2017/CSET_SOC

The ethical clearance certificate is contained in Appendix K.

3.4 Summary

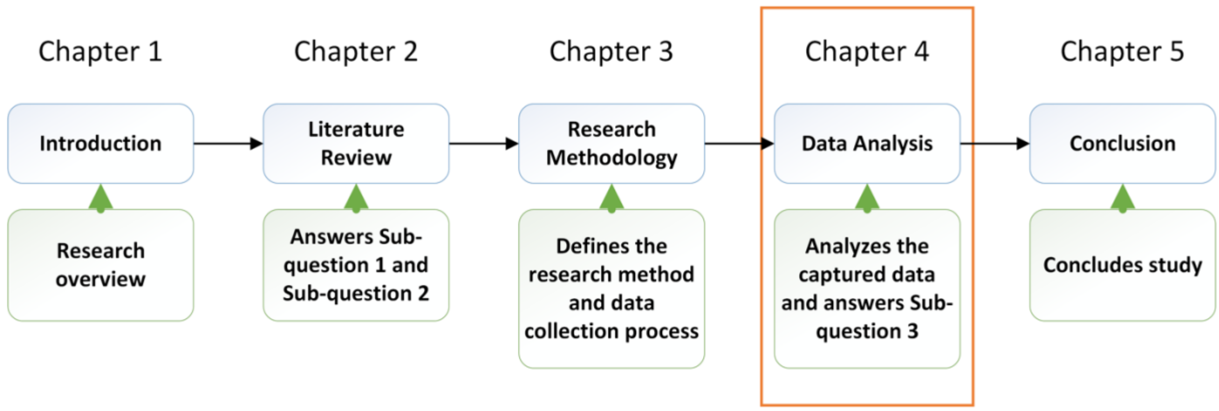
The focus of this research study was on determining, defining and evaluating criteria for the visualisation of knowledge in an IMS and, thus, evaluations based on both content expertise as well as usability expertise were utilised in the research. Content experts and usability experts were required to complete questionnaires within an interview setting while eye-tracking was conducted on the responder mobile application. Three incident category types were established for the interfaces that were being evaluated (SOS, ENFORCEMENT and HAZMAT) and were integrated as the representations of the visual artifacts for the questionnaires as well as the usability tasks.

The aim of structuring the collection of the data, as discussed in this chapter, was to analyse the criteria's applicability to IMS interfaces, to identify the extent to which these criteria should influence the design of these interfaces and to evaluate the degree to which the IMS interfaces of the responder application complied with these criteria. An additional aim was to evaluate how knowledge was transferred in the IMS (under the eye-tracking process conducted during the execution of the usability tasks). This data assisted in answering the main research question and the sub-questions. These research processes were all conducted using the design science research methodology.

The following chapter describes the data capturing process and discusses the results of the data collected, as discussed in this chapter. The study findings are discussed and detailed, thus enabling the third sub-question to be answered.

CHAPTER 4
Data analysis and results

Chapter Content:



4.1 Introduction

The questionnaires used in the study to collect the requisite were structured in a format that would ensure that it would possible to find answers to the research question and sub-questions. Using the research design as described in Chapter 3, the data was provided by both usability experts and content experts. It was anticipated that this data would provide insight into the overlapping of the fields of usability (especially on mobile interfaces) and emergency response with the IMS as the focus of the study in this intersection of these fields.

Section 4.2 of this chapter explain the conducting process of the interviews which were conducted with the content experts and usability experts, and also explains the format of the questionnaires utilized during these interviews. The results of the interviews are then discussed in section 4.3. This is followed by an analysis of the interview results of the two groups in section 4.4. The usability tasks and their results are discussed in sections 4.5, 4.6 and 4.7 while the final results are discussed in section 4.8.

4.2 Data Collection Through Interviews

The data which was collected and the questionnaires that were used to capture the data during the interviews are discussed in the following sections. This is accompanied by a detailed discussion of the results arising from the data.

4.2.1 Conducting the Content Expert Interviews

The content experts were given three forms which contained a list of the criteria which had been identified, a screenshot of the mobile application interface and a description of the required action. The experts were required to indicate how *important* they perceived each criterion point on the screen provided to be. The importance indicator comprised a Likert scale where 1 denoted 'No importance' and 5 'High importance'. All the participants were first requested to complete the consent form before participating in the study. The participants were briefed on the purpose of the study and informed of the reason for their participation before the commencement of the data collection process.

4.2.2 Conducting the Usability Expert Interviews

As already mentioned, all the participants were required to complete the consent form before the data capturing commenced. The participants were then requested to complete an evaluation of the criteria against the three sample screens of the mobile interface (by means of an interview).

The criteria for the evaluation of the mobile screen were the same as the those used for the content experts although the usability experts were required to indicate to extent to which the screen *complied* with the criteria, using a Likert scale with 1 denoting ‘No compliance’ and 5 ‘Full compliance’.

4.2.3 Questionnaires used

The two questionnaires used during the interviews were of the same format, but with different goals. Both questionnaires consisted of the list of criteria and an accompanying screenshot of the interface being evaluated, as well as space for additional comments. The difference between the two questionnaires was that, where the content expert group were required to indicate the importance of the criteria in relation to the interface, the usability experts were required to evaluate the extent to which the interface complied with the criteria. Any additional comments which the participants felt were of importance could be included as a comment.

4.3 Results from Interviews

The results presented below involve the criteria identified from the literature review, the results of the interviews which were conducted with both the content expert group and the usability expert group and the usability evaluation results. The eye-tracking data is also discussed, and certain points of interest highlighted.

4.3.1 Results from Content Expert Interviews on Criteria Questionnaire

The interviews with the content experts provided the data presented in Table 4.1. The table represents the experts’ answers to the question ‘How important is the criterion for the incident category type?’ for each criterion as discussed in Table 3.5. Each cell represents the average value allocated to the importance of the criterion by the incident management experts. The green cells in the table indicate the highest scores and the red indicate the lowest scores. The content experts demonstrated significant interest in the mobile approach of the IMS with some even questioning how they had managed to operate effectively without such a system (the systems they utilised did not implement mobile application technology). They were all in agreement about the importance of the system and how it could improve the performance of responders. The active firefighters even requested permission to test the system.

During the interviews the active firefighters indicated that they would like to have had access to the global positioning system co-ordinates of the incident cited. They reasoned that this could be necessary should they be required to provide location detail for other systems such as navigational systems integrated into the response vehicles.

Three of the retired members of the content expert group (now fire consultants) indicated that they felt strongly that the need for a legend in a visual display of the details of an incident was not required. They reasoned that it would distract the user from focusing on the incident and would suggest that the visual detail being displayed was inadequate. Some of them also mentioned that designing the system specifically for the user would require too much variance as each user would have different requirements which would complicate the design and development of the interface. They suggested that the user should be trained on the system and also develop an incident response mindset to see the incident from the visual artifact provided.

In relation to the majority of the other criteria all the content experts felt that they were important in the context of the system provided. This is clear in the results of the interviews presented in Table 4.1. The results of each criterion are discussed in section 4.4.

Table 4.1 – Content Experts - Averages

	Average value for each incident type			Average over all incident types
CRITERIA	**SOS**	**ENFORCEMENT**	**HAZMAT**	
Clarity	4.7	4.3	4.3	4.4
Consistency	4.6	4.6	4.4	4.5
Discrimination	4.1	3.6	4.1	3.9
Semantic Transparency	4.3	4.0	4.4	4.2

Complexity Management	4.4	4.3	4.6	4.4
Dual Coding	3.3	3.4	4.0	3.6
Legend	3.3	3.3	3.7	3.4
Context	4.7	4.7	4.7	4.7
User	3.4	3.7	3.4	3.5
Intention	4.6	4.4	4.6	4.5
Layout (Shape)	2.9	3.0	2.9	2.9

4.3.2 Results from Usability Expert Interviews on Criteria Questionnaire

Table 4.2 depicts the averages of the evaluation results for the criteria on the mobile application screens (green cells indicating highest scores and red the lowest scores).

Table 4.2 – Usability Experts - Averages

	Average value for each incident type			**Average over all incident types**
CRITERIA	**SOS**	**ENFORCEMENT**	**HAZMAT**	
Clarity	3.4	3.8	4.1	3.8
Consistency	4.0	3.9	4.4	4.1
Discrimination	3.5	3.4	3.8	3.6
Semantic Transparency	3.6	4.0	4.1	3.9
Complexity Management	3.5	3.5	3.5	3.5
Dual Coding	3.4	3.6	3.9	3.6
Legend	3.1	3.3	3.3	3.2
Context	4.3	4.1	4.0	4.1
User	3.6	4.0	3.6	3.7
Intention	4.3	4.1	4.1	4.2
Layout (Shape)	3.9	3.8	3.9	3.9

The SOS screen included an additional icon which indicated a restricted access route on the map. This symbol (Figure 4.1) caused confusion for some of the participants as to the exact location of the incident as they confused the symbol with the default location pin on the map. However, this was done on purpose to investigate whether the symbol would be perceived as representing what it was intended to represent. This same symbol was used in a different capacity on the ENFORCEMENT screen. However, some of the participants indicated immediately that this was not correct, and that the symbol must be differentiated.

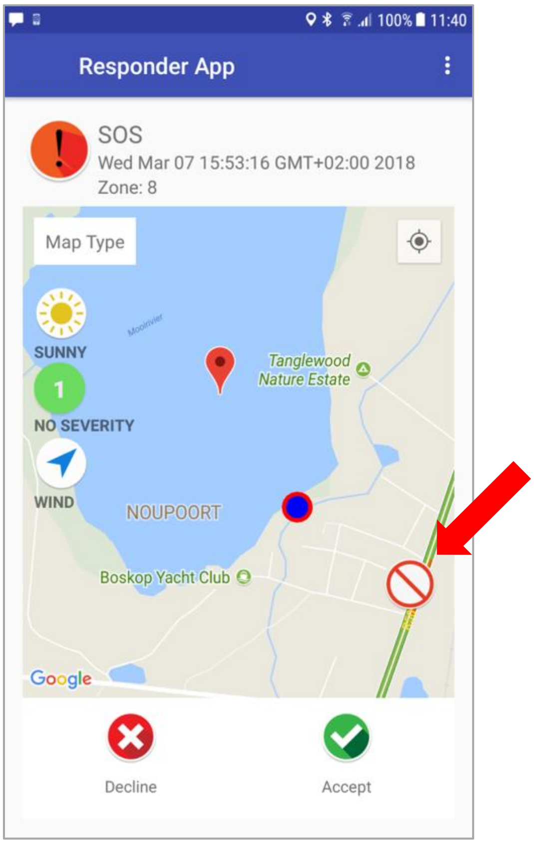


Figure 4.1 – SOS Responder Mobile Interface

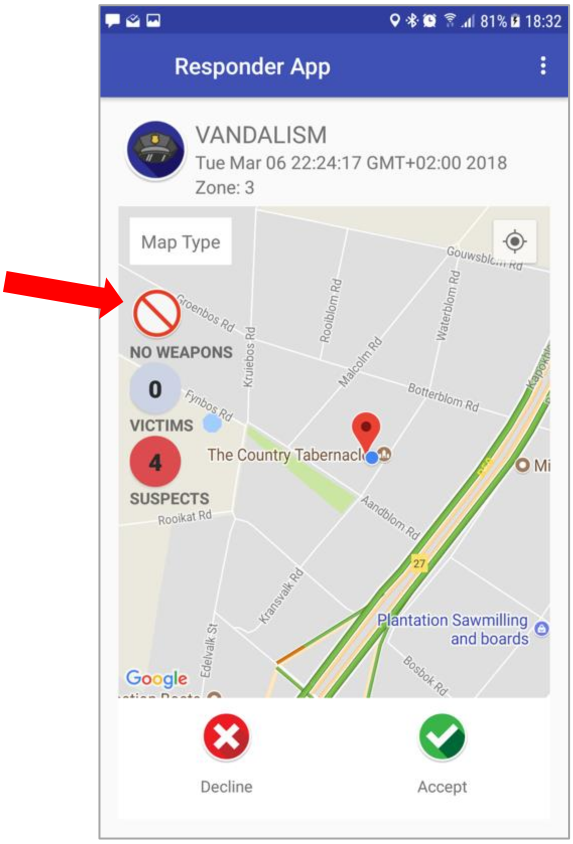


Figure 4.2 – ENFORCEMENT Responder Mobile Interface

The criterion of ‘discrimination’ caused a degree of confusion for some of the participants. They indicated that they did not understand what ‘discrimination’ meant until it was explained that it was used to differentiate between objects on the visual artifact (e.g. white text on a yellow background would have low discrimination).

Some of the participants asked whether the ‘consistency’ criterion was applicable to all the elements on a single screen or considered between the three screens being evaluated. They were given the option to evaluate it as an overall criterion but were guided by the researcher that it should be applicable to all the elements on the – screen.

One of the participants commented that the ‘legend’ criterion is not required when the criteria points of ‘clarity’ and ‘transparency’ were involved in designing the visual artifact. This is in line with the statement made by the content experts that a legend is of little importance in such a system. Also, the question was continually asked as to whether the end users of the system would be trained in using the system – the answer being yes.

4.4 Analysis of Interviews on Criteria Questionnaire Results

The results of the criteria questionnaires for both the content and the usability experts are discussed in this section. The results from the interviews conducted with the content experts showed that, according to the content experts, the criterion ‘Layout/shape’ is of the least importance, obtaining a score between 2.9 and 3.0 out of 5 for all three interfaces. While this score was relatively low in comparison with the other criteria it was, nevertheless, still above 2.5 (50%) and, thus, remains significant as a criterion. The usability experts evaluated ‘layout/shape’ at between 3.8 and 3.9 out of 5, indicating that they felt that the degree of compliance of the screens of the IMS with this criterion was above average.

The content experts all indicated ‘clarity’, ‘consistency’ and ‘intention’ as being particularly important for such a system with all of them assigning it scores of above 4.2. On the other hand, the usability experts assigned scores which indicated that, whereas ‘intention’ has been well applied (a minimum of 4.1), the IMS interface (visual artifacts) compliance with ‘clarity’ and ‘consistency’ should be improved (minimum of 3.4 and 3.9 respectively).

The content experts labelled ‘context’ as the most important criterion in any IMS with this criterion receiving an average of 4.7 for each interface. This was accompanied by a minimum of 4.0 from the usability experts, thus indicating that context is deemed to be an exceedingly important criterion in IMSs.

‘Dual coding’, ‘legend’ and ‘user’ received lower scores (compared to the other criteria) from the content experts, with the majority of the averages being between 3.3 and 4.0 (only ‘dual coding’ received a single 4.0). This was, however, in line with the content experts’ opinion of the legend and user criteria (see interview results above). ‘Legend’ also received the lowest score for all three interfaces from the usability experts, thus indicating that the IMS interface in this study corresponded with the content experts’ assertion that legends are of less importance as compared to the other criteria. Nevertheless, as was indicated in relation to the ‘layout (shape)’ criterion, while still relatively low, ‘legend’ remained important in relation to the set of criteria as it had a score of above 2.5.

'Discrimination', 'complexity management' and 'semantic transparency' were all rated moderately strongly as important by the content experts as they generally received above 4.0 with a single minimum of 3.7 for 'discrimination'. As mentioned above, some of the usability experts appeared to be confused with regard to the criterion being labelled 'discrimination'. This may, however, have been due to South Africa's history of segregation.

As indicated by the comments made by the participants there was clearly an interrelatedness between the criteria. For example, three of the content experts indicated that the legend was of little value to the responder interface. This was supported by one of the usability expert's comments which indicated that, if the interface complies with clarity and transparency, the legend would not be necessary This highlighted that certain of the criteria are interrelated and support each other's functions (to a limited degree).

The content experts indicated that designing for the user (under the user criteria) should not be necessary as the user should be trained to use the system. However, this comment needs to be considered in relation to the content experts' domain of operation. From a design perspective (HCI) the user is the reason for the existence of the interface and, thus, plays a pivotal role in the design process. Accordingly, the user criterion is still considered to be a fundamental element of the KVC.

4.5 Data Collection via Usability Tasks (Eye-tracking)

The usability tasks with the eye-tracking procedure implemented, as well as the technology used for the eye-tracking (a Tobii 1750 eye-tracker) in this research study, closely resembled that of other researchers (van Biljon & Pretorius, 2009; Pretorius, van Biljon & de Kock, 2010; Lehong, van Biljon & De Kock, 2018). The participants were interviewed individually (as indicated in section 3.2.5.5), and were, first, before commencing with the usability task, introduced to the research and the purpose behind the collection of the data. The participant was also required to sign a consent form at this point.

The participant was then briefed on how the usability tasks would be presented and the actions that would be required on his/her part. The eye-tracking system was then calibrated according to the participant's eye movement. Once the calibration had been completed the participants were presented with the first task. The participant completed the task as required and was then presented with the following task. This procedure was followed until all three tasks had been completed.

The usability tasks (together with the eye-tracking) constituted one of two components of the data collection process which was carried out on a computer with the other being the SUS questionnaire (Appendix I). As explained in Chapter 3 the reason the usability tasks process was carried out on a computer was because the researcher only had access to computer-based eye-tracking technology and had to set up a simulation of the mobile interface of the IMS. The tasks to be completed, while eye-tracking was being done, were constructed in such a way that the user had to indicate whether there was sufficient information on the interface to enable the user to make an informed decision regarding the incident represented. All interaction was done using the mouse of the computer.

4.6 Results of Usability Tasks (and Eye-tracking)

Table 4.3 presents the usability evaluation results from the usability experts. The table consists of three columns which contain the following details: the participants' indexing, the time it took to complete the usability tasks and the System Usability Scale (SUS) questionnaire results. The time column is divided into a further 3 columns in order to indicate the time it took to complete the 3 individual tasks. Participant 3 took an excessively long time to complete the tasks, especially the SOS task. However, this was due to the participant asking questions regarding the interface being evaluated. The fourth column of the table presents the users' satisfaction according to the SUS questionnaire's results. The last row of the table represents the average of the time (in seconds) to complete the tasks of all the participants. The average of the SUS questionnaire ratings resulted in an overall degree of observed usability. There was also a notable decrease in the time required to complete a task from the first task to the third task, thus indicating that the participants were learning how to use the system.

Table 4.3 – Usability Tasks Timing & Usability Evaluation Results

Participant number	Time (seconds)			User Satisfaction (SUS results)
	SOS	ENFORCEMENT	HAZMAT	
1	26	31	24	77,5

2	51	41	28	60
3	230	180	107	62,5
4	247	32	14	82,5
5	21	32		85
6	12	22	10	67,5
7	35	23	11	100
8	99	131	124	52,5
Average	**90**	**62**	**45**	**73,44**

4.7 Analysis of the Usability Tasks (Eye-tracking)

Figure 4.3 presents the usability tasks timing data of Table 4.3 in graph format. This provides the linear average line indicating that the tasks took progressively less time to complete.

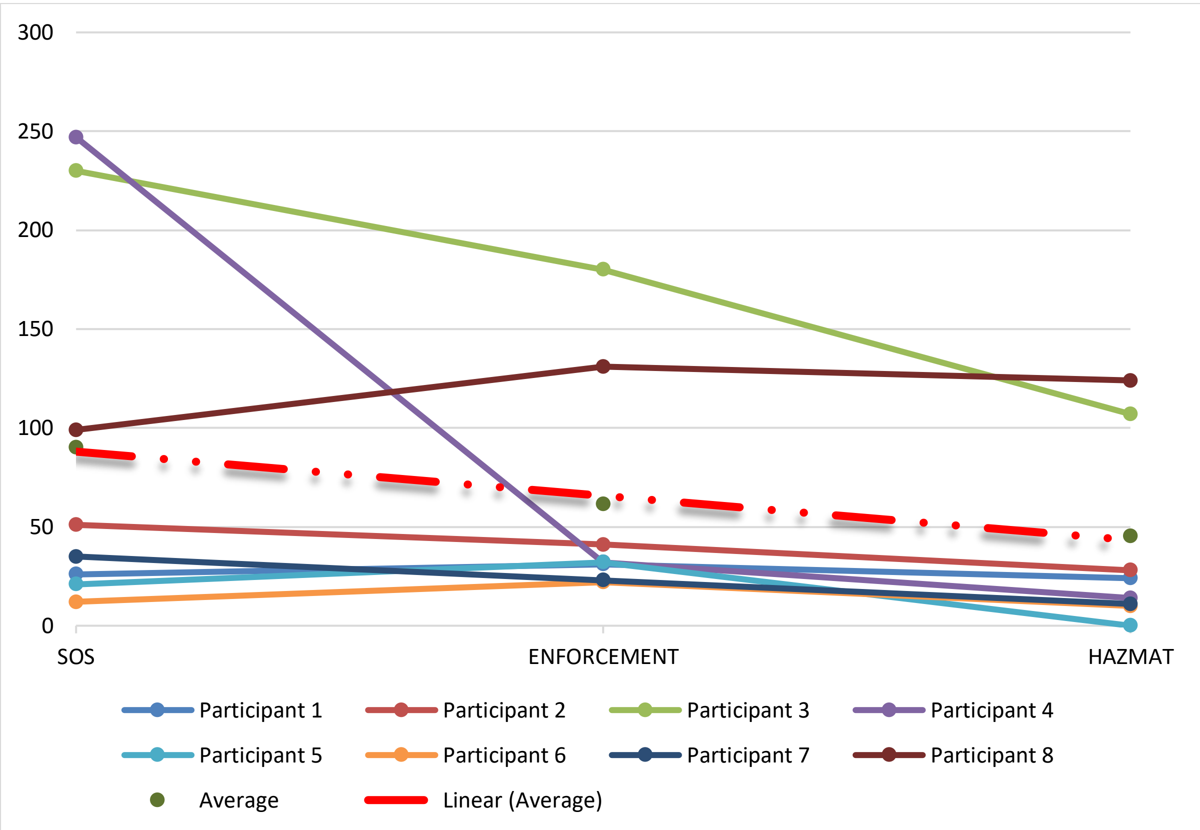


Figure 4.3 – Usability Tasks Timing Chart

When considering the average length of time it took to complete each of the three individual tasks it may be seen that the first task took longer to process than the following two tasks. As indicated earlier, one of the participants took extraordinary long to complete the tasks while some of the others also spent more time than the average to complete the tasks, especially on the first task. Participant 5's data for the third screen (HAZMAT) was corrupted and, thus, the resulting average is calculated using the remaining 7 participants' data only. The processing (completing) of the tasks is discussed below.

Task 1: The participants were not introduced to the IMS but were told only what the research entailed. The aim of this was to test whether the participants would be able to understand what to do by merely reading the task and using the interface for the first time. As the time result in Table 4.3 indicates the first task took the most time. This was the result of the participants taking more time to figure out how to navigate and interact with the system. If they did not know what to do, they were guided by the researcher. Most of the participants required such assistance on the first task. An example of this was to assist the participant by indicating that the participant should use the desktop computer's mouse to select the incident from the list as described by the task.

Task 2: Once the users had familiarised themselves with this task they were quicker in selecting the associated incident and were then able to analyse the interface of the incident detail far more quickly before indicating whether there was sufficient information. Very little assistance was required.

Task 3: At this point the participants' confidence in relation to the system was at its highest and it took them a few seconds only to read the task and select the associated incident. Inspection of the incident detail and selecting the result took the least time of all the tasks. Figure 4.4 presents an example of how task three had a lower fixation on the interface than task 1. The SOS figure in the table indicates that the SOS screen had a maximum fixation (61 according to the gaze-plot in Figure 4.4), but that the HAZMAT figure indicated a minimum fixation (35 according to the gaze-plot, almost half the amount of fixations of the SOS interface). This indicates that the participants had learned how to use the system and, thus, the use of the system became more effortless the more the users interacted with it.

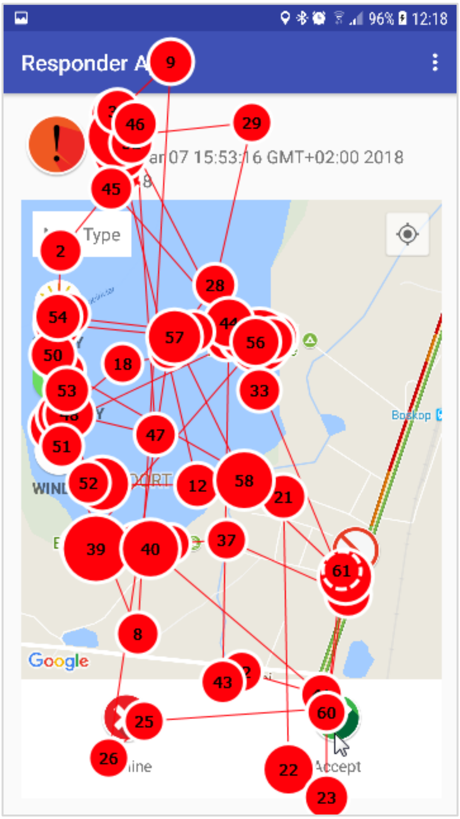
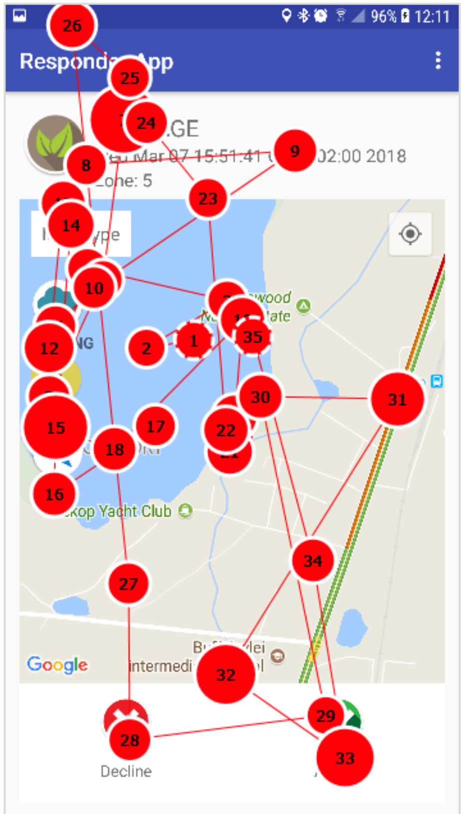
SOS Gazeplot	HAZMAT Gazeplot
	

Figure 4.4 – Participant 7 Comparison

In their completion of the three tasks, the majority of the participants felt that the interfaces displayed sufficient information to make an informed decision with regards to the incident type. Table 4.4 presents all the participants' (usability experts) answers to each of the tasks involved in the eye-tracking tests.

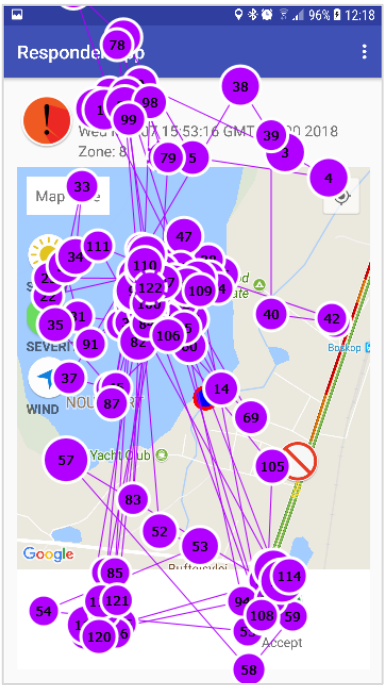
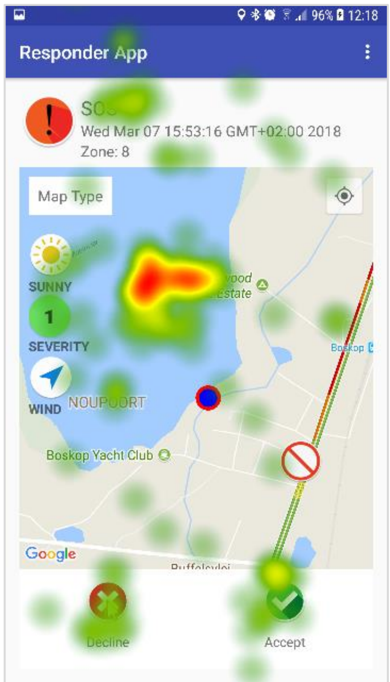
Table 4.4 – Task Results

<table>
<tr><th rowspan="2">Participant number</th><th colspan="6">Answers to Tasks</th></tr>
<tr><th colspan="2">Task 1 (SOS)</th><th colspan="2">Task 2 (ENFORCEMENT)</th><th colspan="2">Task 3 (HAZMAT)</th></tr>
<tr><td>1</td><td colspan="2">YES</td><td colspan="2">YES</td><td colspan="2">YES</td></tr>
<tr><td>2</td><td colspan="2">YES</td><td colspan="2">NO</td><td colspan="2">YES</td></tr>
<tr><td>3</td><td colspan="2">YES</td><td colspan="2">YES</td><td colspan="2">YES</td></tr>
<tr><td>4</td><td colspan="2">YES</td><td colspan="2">YES</td><td colspan="2">YES</td></tr>
<tr><td>5</td><td colspan="2">YES</td><td colspan="2">YES</td><td colspan="2"></td></tr>
<tr><td>6</td><td colspan="2">YES</td><td colspan="2">YES</td><td colspan="2">YES</td></tr>
<tr><td>7</td><td colspan="2">YES</td><td colspan="2">YES</td><td colspan="2">YES</td></tr>
<tr><td>8</td><td colspan="2">NO</td><td colspan="2">NO</td><td colspan="2">NO</td></tr>
<tr><td>YES/NO</td><td colspan="2">7/1</td><td colspan="2">6/2</td><td colspan="2">6/1</td></tr>
<tr><td rowspan="2">%</td><td>YES</td><td>NO</td><td>YES</td><td>NO</td><td>YES</td><td>NO</td></tr>
<tr><td>87.5%</td><td>12.5%</td><td>75%</td><td>25%</td><td>85.7%</td><td>14.3%</td></tr>
</table>

The data analysis indicates that the responder mobile application interfaces assisted in learning how to use the interface and that the users generally found the usability of the system to be acceptable. Suggestions included that more detail be provided with regard to the visual elements utilised for additional content and that the additional detail should be displayed for integration with other systems (e.g. global positioning coordinates).

An interesting case was that of Participant 8. After the participant had completed the first task the participant asked the following question: 'What are the icons on the left-hand side of the screen?' The researcher then indicated that the icons represented additional information related to the incident. The researcher explained that each icon with its associated text provided supporting information with regards to the incident to assist the responder in deciding how (if at all) to respond to the incident. The participant then expressed the opinion that, had this been known before starting, it would have assisted in evaluating the interface.

On continuing with the tasks on the second (Figure 3.8) and third (Figure 3.9) interfaces Participant 8 spent more time on the additional information, focusing on the icons on the left of the screen as well as any other details that may be on the interface. This is indicated by the eye-tracking gaze-plot and heatmap figures in Figure 4.5 for this participant.

<table>
<tr><th colspan="2">SOS Gazeplot & Heatmap</th></tr>
<tr><td></td><td>
</td></tr>
<tr><th colspan="2">ENFORCEMENT Gazeplot & Heatmap</th></tr>
</table>

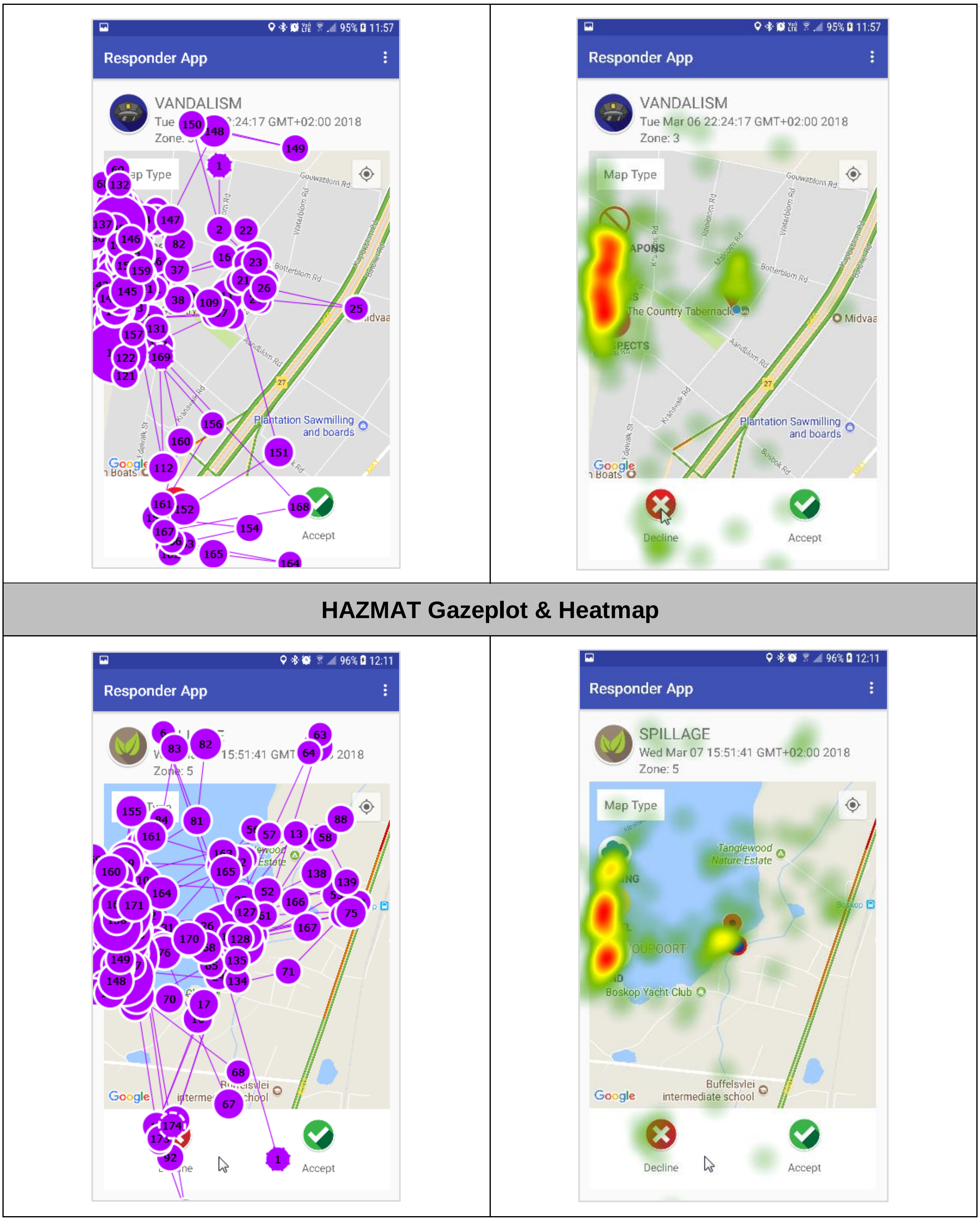


Figure 4.5 – Participant 8 Comparison

The figures above indicate that the participant was more fixated on the additional information regarding the incident after having been informed of its existence. The SOS images in Figure 4.5 indicate that the incident location was the primary focus. While the incident location was still receiving the participant's attention the

ENFORCEMENT and HAZMAT images indicate that the focus was centred primarily on the additional information on the interface.

4.8 Discussion on the Combined Results

The results presented in Table 4.4 show that the majority of participants agreed that they would have been able to make an informed decision with regard to the incident by just considering the interface (the visual artifacts in the IMS). This brought to light an extremely important point, namely, the IMS interface was sufficiently aligned to the KVC to achieve *knowledge transfer* of the incident. While some of the participants may have suggested that additional information be provided the study had shown that the IMS being utilised complied with the 11 KVC points synthesised in this study.

Based on the results of the interviews, especially the interviews conducted with the content experts, the researcher was able to identify two different levels with regard to the criteria, namely, high-level managerial concern and low-level implementation (designer/developer) concern. These two levels expressed different concerns regarding the 11 KVC criteria points in the context of an IMS. Table 4.5 presents the concerns of these two levels with regard to the KVC.

Table 4.5 – High- & Low-Level Concern of Criteria

CRITERIA	High-level (Managerial)	Low-level (Implementation)
Clarity	✓	✓
Consistency		✓
Discrimination		✓
Semantic Transparency	✓	✓
Complexity Management		✓
Dual Coding		✓
Legend		✓
Context	✓	✓
User	✓	
Intention	✓	

Layout (Shape)		✓

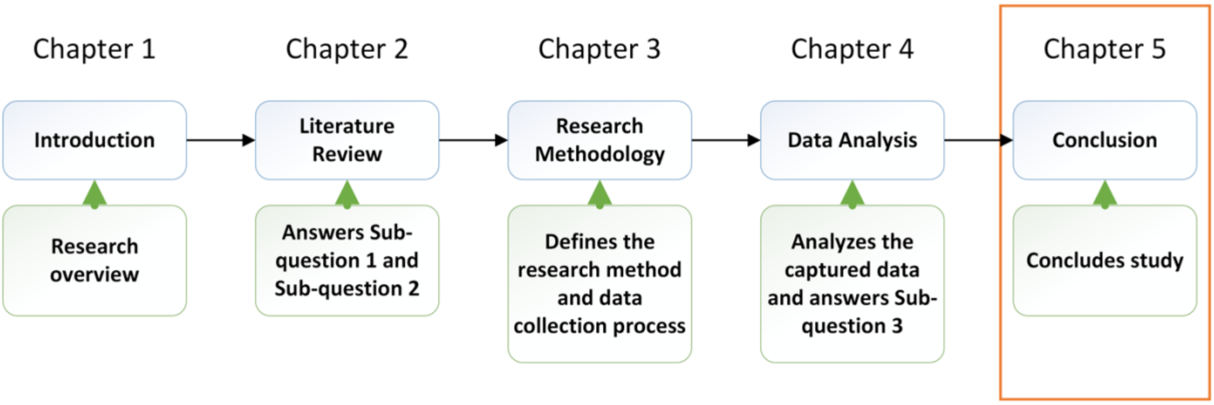
4.9 Conclusions

The criteria identified from the literature were all found to be applicable, in varying degrees of importance, to the IMS interface design. The study provided evidence that, in respect of its application to IMSs, both a legend as well as 'designing for the user' are of little concern to incident personnel but that context plays an extremely important role for the users of an IMS. This would appear to indicate that the IMS should be designed more around the context in which it operates and less around the user of the interface. However, as the user is part of the context this would be ill-advised. The participants' argument that each user has unique requirements is true but UCD is based on the premise of providing a minimum standard of usability.

The following chapter concludes the study. The research is reviewed, and the research questions revisited in order to confirm that the main research question and sub-questions were, indeed, answered and to summarise how these answers were reached.

CHAPTER 5
Conclusions and contributions

Chapter Content:



5.1 Introduction

The father of KV, Remo Burkhard, states that visualization is superior in communicating knowledge compared to verbal and textual representations (Burkhard, 2004). According to him KV provides a solution to overcoming problems such as information overload, misinterpretation and misuse of information when utilizing visualizations in sharing information (Burkhard, 2004). A system, be it a general information system or a specialized system, wishing to achieve knowledge transfer, must be designed according to certain principles underlining the transfer of knowledge. The general question is "What are the criteria that a system must comply with to achieve this transfer of knowledge?" Until now mostly abstract research was conducted towards finding these criteria; this study contributes to providing a solution in the context of emergency medical and fire response incident management systems.

A literature review was conducted to establish the background for incidents and the context in which they exist and then to identify the KVC. The data collection methods and tools utilised was considered, constructed and selected in such a way so as to best provide answers to the main research question and sub-questions. In order to do this the study utilised the data provided by the content experts and usability experts who participated in the data capturing process. The KVC which were identified were used to evaluate an IMS utilised for the purposes of the study while the KVC themselves were evaluated in the context of an IMS. This chapter concludes the study.

An overview of the dissertation is provided in section 5.2. Having collected the data, analysed it and discussed it, the findings that it provided are discussed in section 5.3 in the light of how the collected data answers the main research question and its constituent sub-questions. The contributions of the study are discussed in section 5.4 and the chapter is then concluded by providing suggestions for future research in section 5.5.

5.2 Summary of the Dissertation and How the Research Questions were Answered

What KVC exist to optimise knowledge transfer in IMS? The aim of this study was to investigate this question as well as the sub-questions the main research question generated. This focus determined the first step in the process, namely, an investigation of existing literature on incidents and their constituents (section 2.2). It was established that an incident comprises three different periods, namely, the incubation period, the critical period and the aftermath period with these periods affecting the context in which an incident unfolds in various ways. The type of response to the incident is influenced by these periods. Sense-making is a vital element for the responders to an incident, especially if the nature of the incident may lead to damage or fatalities. There are multiple factors which may impact on sense-making and influence the response (by the responder) to the incident. One such factor is technology. This serves as the introduction to IMSs – the geo-visualisation component of an IMS to be exact. This identification of geo-visualization as the visual element of an IMS is the answer to sub-question 1 of the main research question.

An IMS (especially in the context of critical emergency incidents) is acknowledged as a system which exists for the sole purpose of managing the resources utilised during a response to an incident. These resources include equipment, communication and groups or individuals responding to the incident. The IMS (by means of the technology it utilizes) is viewed as a positive influence on the sense-making process of the responders. Once the importance of sense-making had been established as a preferred alternative to decision-making and its importance in relation to incidents and the individuals involved in such incidents, then, in section 2.3 the study moves on to examining KV.

KV is essential in order to achieve knowledge transfer when utilising visualisation artifacts. KV exists as a method for the creation of knowledge and the transfer of the said knowledge between individuals or groups. This study focused on establishing KVC and investigated existing literature with the aim of identifying KVC. The researcher selected 11 points found in the literature and used these to compile the list of criteria. These 11 points included clarity, consistency, discrimination, semantic transparency, complexity management, dual coding, legend, context, user, intention and layout (shape). This set of criteria constituted the answer to sub-question 2 of the main research question.

In an effort to answer sub-question 3 of the main research question design science research (DSR) was used to collect the requisite data by means of questionnaire-driven interviews which were conducted with content and usability experts, usability tasks which also involved eye-tracking as well as the completion of an SUS questionnaire (usability experts only).

The results (in Chapter 4) indicated that, despite the 11 KVC synthesised in this study having varying degrees of importance, all were deemed important for KV in an IMS. The usability tasks indicated that the users were generally of the opinion that the interface of the IMS utilised was acceptable although improvements were suggested. Table 5.1 highlights the research question and sub-questions, the research objectives, the findings, observations and the contributions made by the study.

Table 5.1 – Research Questions and Objectives Final

Main Research Question				
What are the knowledge visualisation criteria required to optimise knowledge transfer by visual artifacts in incident management systems?				
Sub-questions		**Action**	**Output**	**Contribution**
1.	What are the visualisation components of an incident management system?	Literature review	See section 2.2.5 (page 39)	Visualisation components of an IMS identified (Geo-visualisation artifacts and supporting information).
2.	What knowledge visualisation criteria exist?	Literature review	See Table 2.3 (page 59)	A set of knowledge visualisation criteria.
3.	How do knowledge visualisation criteria apply to IMS?	Literature review, questionnaire driven interviews, eye-tracking, SUS questionnaire	See Table 4.5 (page 109)	Set of incident management system-specific knowledge visualisation criteria. High- and low-level concern in respect of knowledge visualisation criteria for incident management systems.
Main Objective				
The purpose of this research study is to establish a set of criteria to optimise an incident management system's visual artifacts to be used as knowledge visualisation artifacts to support knowledge transfer. The anticipated end result of this study is to have established the criteria for the evaluation of the visualisation artifacts in incident management systems and also how these criteria relate to knowledge visualisation.				
Sub-objectives				

1.	To use existing academic literature to establish the visual artifacts that exist in incident management systems.
2.	To establish what knowledge visualisation criteria exist based on the existing academic literature.
3.	To determine the how the knowledge visualisation criteria established in answering sub-question 2 apply to the visual artifacts in an incident management system, as determined in the answer to sub-question 1, to achieve knowledge transfer.

In particular, this study contributes a validated set of KVC (Table 2.3) as well as insights into prioritising those KVC for IMSs (Table 4.5). A second contribution of the study was the demonstration of the implementation of evidence-based KVC in an IMS. This study further investigated the verification of the criteria for the specific system and were provided with general feedback on improving the usability of the IMS. It is, however, recommended that further studies be conducted on field testing, how users perceive the knowledge transferred from the site of an actual incident to their devices and how effective the system is in achieving its goals.

The literature indicated (section 2.2.5) that an IMS is concerned with the location of an incident and, thus, the concept of a geographical map is regarded as the vital visual artifact in an IMS. Any additional visual components may be incorporated into the artifact to support the basic location display of the incident on a geographical map. This provides the answer to sub-question 1.

Sub-question 2 was answered by the identification and development of KVC in section 2.3.3 on the literature review. These criteria points were recognised and expounded upon with the support of existing literature.

Sub-question 3 was answered based on the analysis of the data which had been collected (section 4.3). Table 4.5 depicted the priority assigned to the criteria in respect of high-level concerns (managerial) and a low-level (design and development) concerns.

As was established in the review of existing academic literature, information regarding explicit criteria for KV are limited. This is even more marked in the case of KV criteria for IMSs while the study found that no literature exists on the application of KV criteria to IMSs. The identification of KVC for IMS during the study provided the answer to sub question 3.

In answering the sub-questions, the main research question was answered in the following way: while no IMS-specific KV evaluation criteria exist the criteria for KV identified in this study are applicable, in varying degrees, to IMSs.

5.3 Key contributions

The study is novel in researching knowledge visualisation in the field of Computer Science, where most research has focused on information visualisation. The research made both theoretical and practical contributions. The *theoretical* contributions include the study's contribution of the abstraction and synthesis of KVC from the existing literature (Table 2.3) with knowledge visualisation criteria being identified, discussed and defined with the support of literature on knowledge visualisation.

A further *theoretical contribution* of this study is the empirical evidence of the importance or applicability of the existing KVC in respect of IMSs. The importance of the criteria that were identified in the application to IMSs was evaluated by content experts in the incident response environment. This, together with the interviews conducted with the content experts, provided insight into the importance of the KVC in IMS. A refined and prioritised list of KVC (Table 4.5), in the perspective of both high-level (managerial) and low-level (implementation) users, was presented.

Another *theoretical contribution* of the study is the explanation of the influences on sense-making during a critical incident which were identified from the academic literature. Context, politics, language, identity, cognitive frames, technology and emotion were found to be possible entities that may exert an influence on the sense-making of individuals involved in an incident. This was indicated in Figure 2.1 and Figure 2.2.

A final *theoretical contribution* was the diagram indicating the factors which contribute to the design of a knowledge visualisation (Figure 2.14).

The *practical contribution* of the study lies in the validation of the knowledge transfer in the IMS utilised which resulted in a set of verified KV criteria for the specific IMS.

This is to say that the KV in the IMS structures the system so that knowledge transfer is achieved through its visual artifacts.

With regard to the IMS investigated, comments, suggestions and the data collected from the usability experts indicated that, while the IMS is effective, it could, nevertheless, be improved in terms of providing more detail with regard to the visual elements being displayed on the geographical map of the responder application. This improvement to the IMS would ensure a further *practical contribution* of the study.

Figure 5.1 below provides an overview of the study's research objectives and the contributions made by the study. Figure 5.1 It is based on Figure 2.14 with the added contributions as indicated.

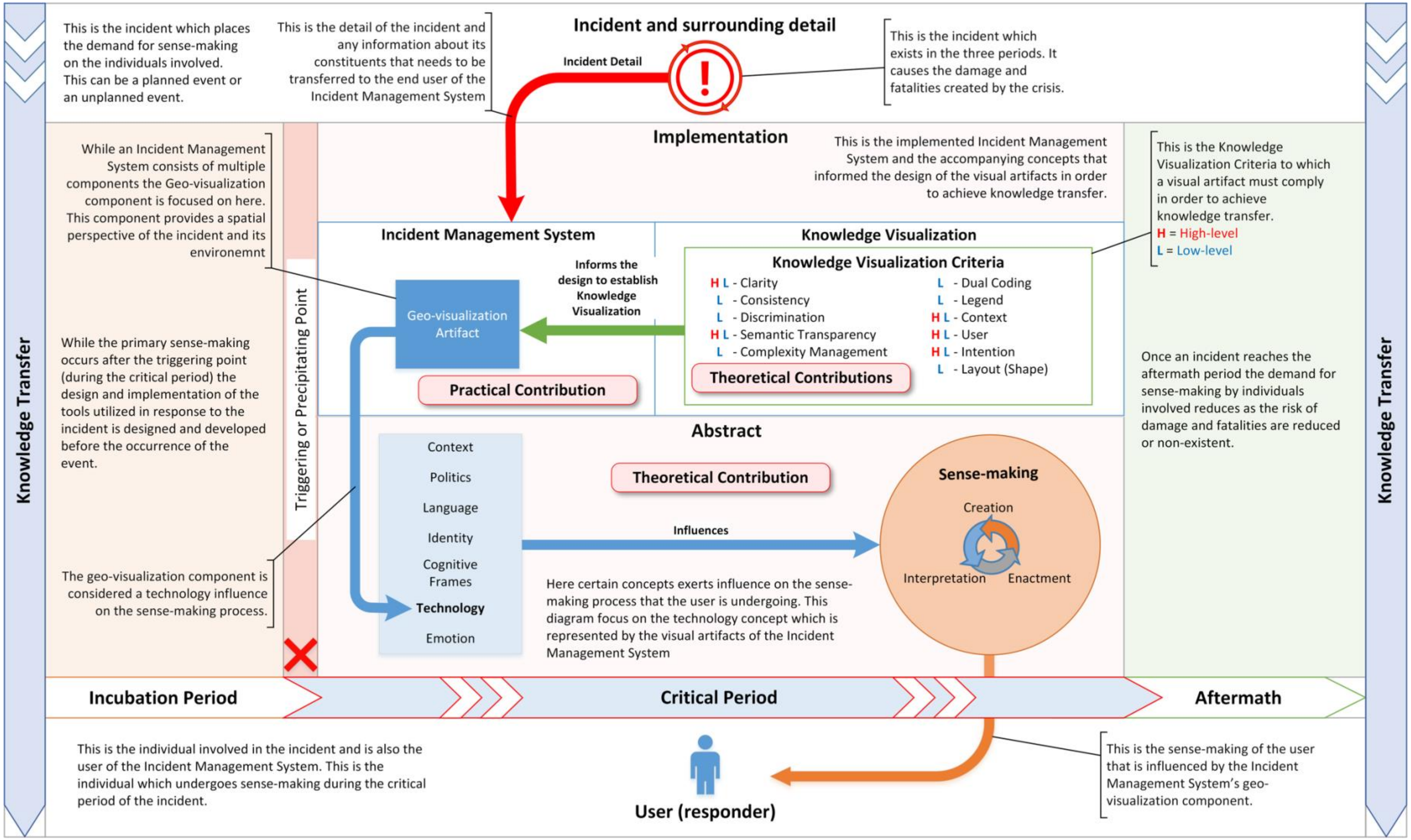


Figure 5.1 – Research Objectives & Contributions

5.4 Limitations

The researcher had planned to conduct a field evaluation of knowledge transfer in the IMS (evaluation on the mobile application). However, this had to be abandoned as the client intending to use the IMS was experiencing financial difficulties in relation to acquiring funds during the research process. At the time of writing the dissertation the client was still in the process of finalising procurement of the system.

5.5 Recommendations

While the study evaluated the application of KVC criteria to an IMS the researcher did not conduct field testing to evaluate how effectively the IMS transferred knowledge in the environment of application. Given the critical nature of an IMS it was necessary to evaluate the system with usability experts and content experts before actual use. A further study could focus on the effectiveness of the knowledge transfer process – the actual goal to be achieved by the responder application.

This study identified a link between knowledge visualisation and the sense-making process of individuals involved in an incident through the influence of technology. Considering the broader concept of sense-making instead of focusing only on decision making is a novel insight in the context of IMS which deserves more research attention. While this study investigated critical incidents which may result in fatalities other types of incidents also exist. As discussed in section 2.2.2 organisations may impose sense-making within a context of ill-defined demands. This would create an opportunity to investigate how sense-making, influenced by knowledge visualisation, can be realised in the context of commercial organisations experiencing a business process incident such as a hosting server going offline due to technical failure or a security breach, a service delivery organisation experiencing a service incident, or a production line experiencing a process failure.

5.6 Reflection

This study has challenged me intellectually and exposed me to various learning experiences since its inception in 2016. The approach to systematically and critically evaluate academic literature to identify certain concepts improved my ability to recognise ideas and notions in literature while drafting my dissertation. Reviewing the document iteratively improved my writing and presentation abilities. In general, conducting this study improved my research capabilities and enabled me to be able to investigate concepts in my professional career as a software developer and present them professionally.

Having developed a solid understanding of research has enabled me to assist academics in defining research projects in the software and technology industry and also placed me in a position where I am able to assist undergraduates in their research processes as a result of the academic-quality research mind-set I have developed.

The opportunity to research novel concepts and applying the research in a practical context has been a great privilege. I feel humbled to have embarked on this journey, and to now have completed this dissertation confirms this humbleness. Guidance by some of the greatest minds I have ever had the privilege of working with has greatly influenced my way of thinking regarding the utilisation of research methods.

I feel I am more enlightened than I was before I embarked on the study while my cognitive functionally has been stimulated. My horizons have been extended to attain new and higher dimensions and I hope to retain this information seeking, evidence-based, critical mind-set throughout my life.

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Appendices

Appendix A – Participant Interview Data

Table 5.2 – Content Experts - SOS Screen

	Participants							Average
CRITERIA	P1	P2	P3	P4	P5	P6	P7	
Clarity	4	5	5	5	5	4	5	4,7
Consistency	4	5	4	5	5	4	5	4,6
Discrimination	4	5	5	4	5	3	3	4,1
Semantic Transparency	4	4	5	5	4	5	3	4,3
Complexity Management	4	4	4	5	5	5	4	4,4
Dual Coding	4	4	4	5	1	1	4	3,3
Legend	4	5	5	5	1	1	2	3,3
Context	4	5	5	5	5	5	4	4,7
User	4	5	5	5	3	1	1	3,4
Intention	4	5	5	5	5	5	3	4,6
Shape	4	4	4	5	1	1	1	2,9

Table 5.3 – Content Experts - ENFORCEMENT Screen

	Participants							Average
CRITERIA	P1	P2	P3	P4	P5	P6	P7	
Clarity	4	4	5	5	3	4	5	4,3
Consistency	4	5	4	5	5	4	5	4,6
Discrimination	4	5	5	4	2	2	3	3,6
Semantic Transparency	4	5	5	5	1	5	3	4,0
Complexity Management	4	5	4	5	5	3	4	4,3
Dual Coding	4	5	4	5	1	1	4	3,4
Legend	4	5	5	5	1	1	2	3,3
Context	4	5	5	5	5	5	4	4,7
User	4	4	5	5	3	4	1	3,7
Intention	4	4	5	5	5	5	3	4,4
Shape	4	5	4	5	1	1	1	3,0

Table 5.4 – Content Experts - HAZMAT Screen

	Participants							Average
CRITERIA	P1	P2	P3	P4	P5	P6	P7	
Clarity	4	4	5	5	3	4	5	4,3
Consistency	4	5	4	5	3	5	5	4,4
Discrimination	4	5	5	4	4	3	4	4,1
Semantic Transparency	4	5	5	5	4	5	3	4,4
Complexity Management	4	5	4	5	5	5	4	4,6
Dual Coding	4	5	4	5	5	1	4	4,0
Legend	4	5	5	5	4	1	2	3,7
Context	4	5	5	5	5	5	4	4,7
User	4	4	5	5	3	1	2	3,4
Intention	4	5	5	5	5	5	3	4,6
Shape	4	4	4	5	1	1	1	2,9

Table 5.5 – Usability Experts - SOS Screen

	Participants								Average
CRITERIA	P1	P2	P3	P4	P5	P6	P7	P8	
Clarity	3	4	3	2	5	3	5	2	3,4
Consistency	4	4	5	5	4	4	4	2	4,0
Discrimination	4	1	3	5	4	3	5	3	3,5
Semantic Transparency	3	3	4	4	4	3	5	3	3,6
Complexity Management	4	4	1	5	4	4	4	2	3,5
Dual Coding	2	3	3	5	5	3	4	2	3,4
Legend	3	4	1	5	4	4	1	3	3,1
Context	4	4	3	5	5	4	5	4	4,3
User	3	5	1	5	4	3	5	3	3,6
Intention	4	4	4	5	4	4	5	4	4,3
Shape	3	4	3	5	5	5	5	1	3,9

Table 5.6 – Usability Experts -ENFORCEMENT Screen

	Participants								Total	Average
CRITERIA	P1	P2	P3	P4	P5	P6	P7	P8		
Clarity	4	2	3	5	5	4	5	2	30	3,8
Consistency	4	2	5	5	5	4	4	2	31	3,9
Discrimination	3	1	3	5	4	3	5	3	27	3,4
Semantic Transparency	4	3	4	5	4	4	5	3	32	4,0
Complexity Management	4	4	1	5	4	4	4	2	28	3,5
Dual Coding	4	2	3	5	5	4	4	2	29	3,6
Legend	4	4	1	5	4	4	1	3	26	3,3
Context	4	4	3	5	4	4	5	4	33	4,1
User	3	5	1	5	5	5	5	3	32	4,0
Intention	4	3	4	5	4	4	5	4	33	4,1
Shape	4	3	3	5	5	4	5	1	30	3,8

Table 5.7 – Usability Experts - HAZMAT Screen

	Participants								Total	Average
CRITERIA	P1	P2	P3	P4	P5	P6	P7	P8		
Clarity	4	5	3	5	5	4	5	2	33	4,1
Consistency	4	5	5	5	5	5	4	2	35	4,4
Discrimination	4	1	3	5	5	4	5	3	30	3,8
Semantic Transparency	4	4	4	5	4	4	5	3	33	4,1
Complexity Management	4	4	1	5	4	4	4	2	28	3,5
Dual Coding	4	4	3	5	5	4	4	2	31	3,9
Legend	4	3	1	5	5	4	1	3	26	3,3
Context	4	2	3	5	5	4	5	4	32	4,0
User	3	4	1	5	4	4	5	3	29	3,6
Intention	4	2	4	5	5	4	5	4	33	4,1
Shape	4	5	3	5	4	4	5	1	31	3,9

Appendix B – Content Expert SOS Questionnaire

Evaluating IMS against KV Criteria – SOS Screen

Name[1]: ____

Please evaluate the screen on the right of the page using the criteria in the table on the left of the page as indicated in the instructions. You can provide additional comments in the comment box provided at the bottom of the page.

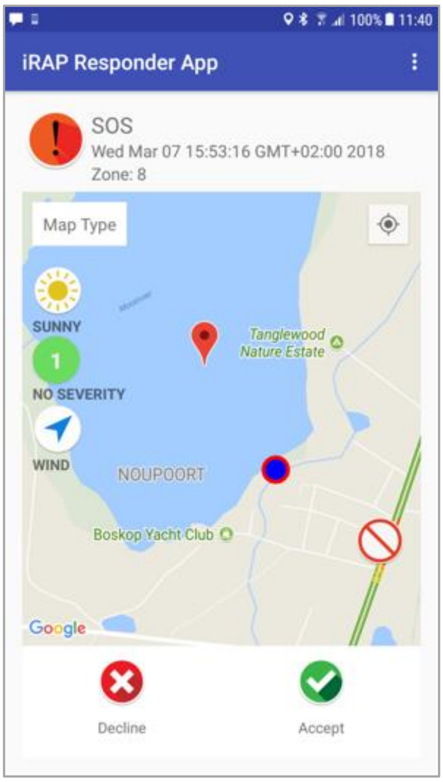
Incident Type – SOS (any incident that falls in the SOS category such as fire, medical, etc.)

Goal – The aim of this particular screen is to provide the user (an IMS Responder) with enough knowledge of the reported incident to make an informed decision on whether he/she should respond according to the knowledge provided.

Criteria
Please provide your answers in the column below

	Importance
Clarity	
Consistency	
Discrimination	
Semantic Transparency	
Complexity Management	
Dual Coding	
Legend	
Context	
User	
Intention	
Layout (Shape)	

Provide a number from 1 to 5 in the "Importance" column where 1 = no importance and 5 = high importance.



Comments

[1] All personal information will be treated as confidential. No personal information will be used in this study.

Appendix C – Content Expert HAZMAT Questionnaire

Evaluating IMS against KV Criteria – HAZMAT Screen

Name[1]: ____

Please evaluate the screen on the right of the page using the criteria in the table on the left of the page as indicated in the instructions. You can provide additional comments in the comment box provided at the bottom of the page.

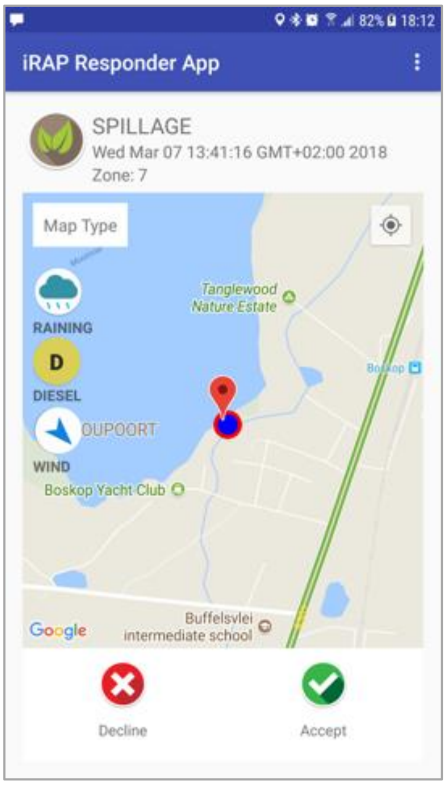
Incident Type – HAZMAT (any incident that falls in the HAZMAT category such as pollution, spillage, etc.)

Goal – The aim of this particular screen is to provide the user (an IMS Responder) with enough knowledge of the reported incident to make an informed decision on whether he/she should respond according to the knowledge provided.

Criteria
Please provide your answers in the column below

	Importance
Clarity	
Consistency	
Discrimination	
Semantic Transparency	
Complexity Management	
Dual Coding	
Legend	
Context	
User	
Intention	
Layout (Shape)	

Provide a number from 1 to 5 in the "Importance" column where 1 = no importance and 5 = high importance.



Comments

[1] All personal information will be treated as confidential. No personal information will be used in this study.

Appendix D – Content Expert ENFORCEMENT Questionnaire

Evaluating IMS against KV Criteria – POLICING Screen

Name[1]: ____

Please evaluate the screen on the right of the page using the criteria in the table on the left of the page as indicated in the instructions. You can provide additional comments in the comment box provided at the bottom of the page.

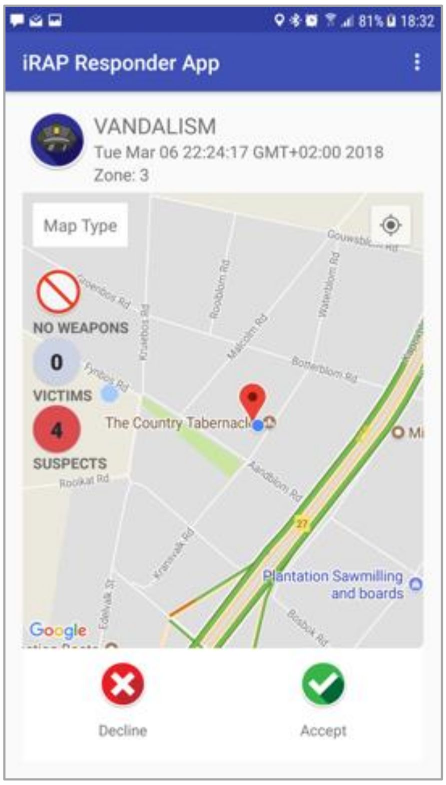
Incident Type – POLICING (any incident that falls in the POLICING category such as robbery, vandalism, etc.)

Goal – The aim of this particular screen is to provide the user (an IMS Responder) with enough knowledge of the reported incident to make an informed decision on whether he/she should respond according to the knowledge provided.

Criteria
Please provide your answers in the column below

	Importance
Clarity	
Consistency	
Discrimination	
Semantic Transparency	
Complexity Management	
Dual Coding	
Legend	
Context	
User	
Intention	
Layout (Shape)	

Provide a number from 1 to 5 in the "Importance" column where 1 = no importance and 5 = high importance.



Comments

[1] All personal information will be treated as confidential. No personal information will be used in this study.

Appendix E – Usability Expert SOS Questionnaire

Evaluating IMS against KV Criteria – SOS Screen

Name[1]: ___________________________________

Please evaluate the screen on the right of the page using the criteria in the table on the left of the page as indicated in the instructions. You can provide additional comments in the comment box provided at the bottom of the page.

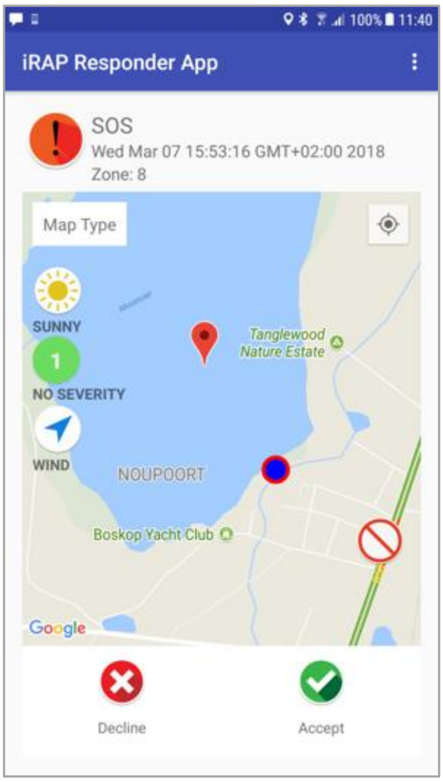
Incident Type – SOS (any incident that falls in the SOS category such as fire, medical, etc.)

Goal – The aim of this particular screen is to provide the user (an IMS Responder) with enough knowledge of the reported incident to make an informed decision on whether he/she should respond according to the knowledge provided.

Criteria
Please provide your answers in the column below

	Compliance
Clarity	
Consistency	
Discrimination	
Semantic Transparency	
Complexity Management	
Dual Coding	
Legend	
Context	
User	
Intention	
Layout (Shape)	

Provide a number from 1 to 5 in the "Compliance" column where 1 = no compliance and 5 = full compliance.



Comments

[1] All personal information will be treated as confidential. No personal information will be used in this study.

Appendix F – Usability Expert HAZMAT Questionnaire

Evaluating IMS against KV Criteria – HAZMAT Screen

Name[1]: ___________________________________

Please evaluate the screen on the right of the page using the criteria in the table on the left of the page as indicated in the instructions. You can provide additional comments in the comment box provided at the bottom of the page.

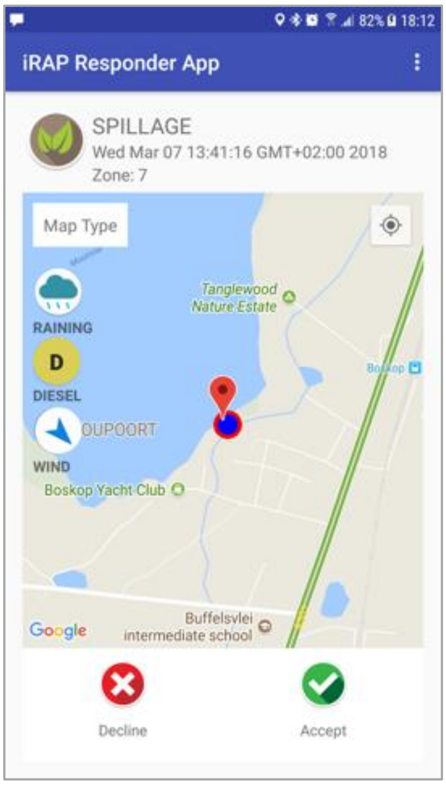
Incident Type – HAZMAT (any incident that falls in the HAZMAT category such as pollution, spillage, etc.)

Goal – The aim of this particular screen is to provide the user (an IMS Responder) with enough knowledge of the reported incident to make an informed decision on whether he/she should respond according to the knowledge provided.

Criteria
Please provide your answers in the column below

	Compliance
Clarity	
Consistency	
Discrimination	
Semantic Transparency	
Complexity Management	
Dual Coding	
Legend	
Context	
User	
Intention	
Layout (Shape)	

Provide a number from 1 to 5 in the "Compliance" column where 1 = no compliance and 5 = full compliance.



Comments

[1] All personal information will be treated as confidential. No personal information will be used in this study.

Appendix G – Usability Expert ENFORCEMENT Questionnaire

Evaluating IMS against KV Criteria – POLICING Screen

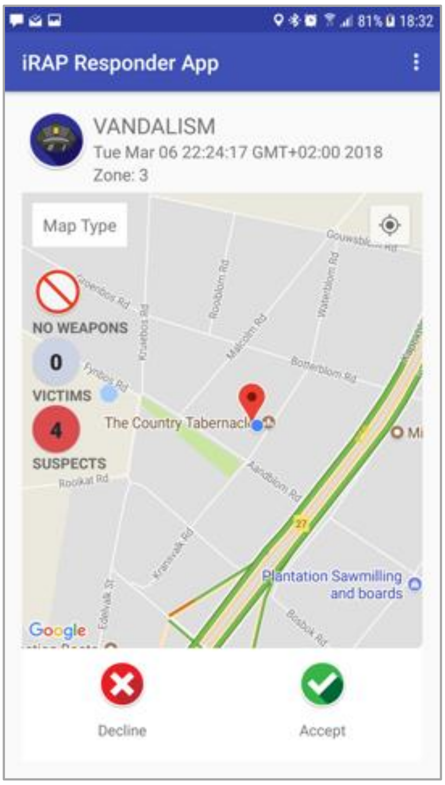
Name[1]: ____

Please evaluate the screen on the right of the page using the criteria in the table on the left of the page as indicated in the instructions. You can provide additional comments in the comment box provided at the bottom of the page.

Incident Type – POLICING (any incident that falls in the POLICING category such as robbery, vandalism, etc.)

Goal – The aim of this particular screen is to provide the user (an IMS Responder) with enough knowledge of the reported incident to make an informed decision on whether he/she should respond according to the knowledge provided.

Criteria *Please provide your answers in the column below*	**Compliance**
Clarity	
Consistency	
Discrimination	
Semantic Transparency	
Complexity Management	
Dual Coding	
Legend	
Context	
User	
Intention	
Layout (Shape)	



Provide a number from 1 to 5 in the "Compliance" column where 1 = no compliance and 5 = full compliance.

Comments

[1] All personal information will be treated as confidential. No personal information will be used in this study.

Appendix H – Questionnaire Criteria definitions

Knowledge Visualization Criteria

	Criteria	Definition
1.	Clarity	The meaning of the symbols is clear and unambiguous.
2.	Consistency	The same symbol is used to represent the same concept throughout.
3.	Discrimination	Shape, colour and texture is used to distinguish between the elements.
4.	Semantic Transparency	The mapping between the symbols and their meaning (i.e. what they represent) is clear.
5.	Complexity Management (parsimony)	All concepts are represented but elements are not repeated or multiplied unnecessarily.
6.	Dual Coding	Both text and graphics are employed to explain the same construct.
7.	Legend	The legend is provided.
8.	Context	The visual artifact is adequate for the circumstance, conditions, situation, environment in which the artifact exists.
9.	User	The symbols and notation match the end user's mental model.
10.	Intention	The visual artifact is aimed at achieving a specific goal.
11.	Layout (Shape)	Related symbols and information are properly positioned and structured as symmetrical as possible.

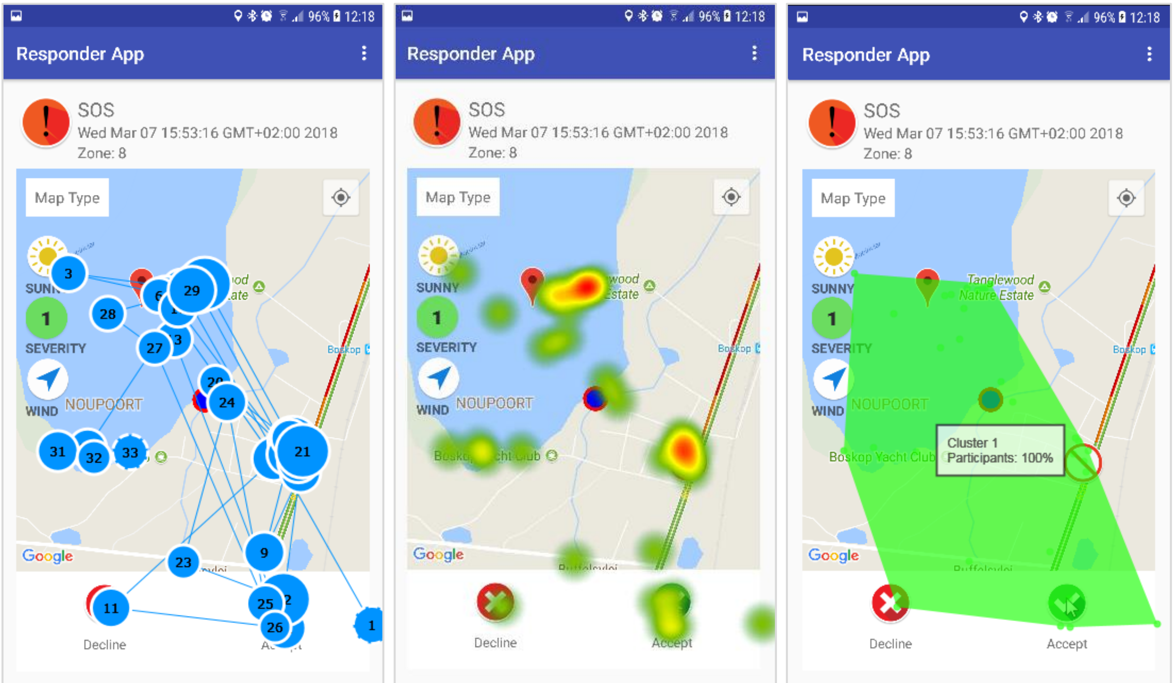
Appendix I – System Usability Scale

SUS Questions

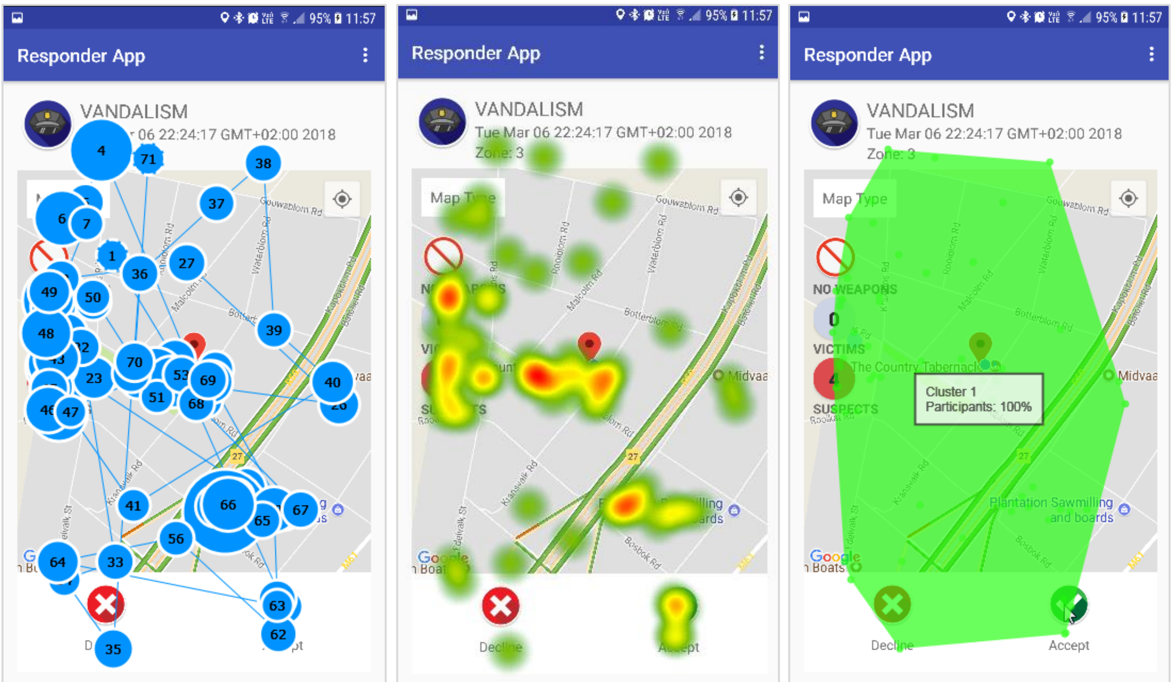
1.	I think that I would like to use this system frequently.
2.	I found the system to be unnecessarily complex.
3.	I thought the system was easy to use.
4.	I think that I would need the support of a technical person to be able to use this system.
5.	I found the various functions in this system were well integrated.
6.	I thought there was too much inconsistency in this system.
7.	I would imagine that most people would learn to use this system very quickly.
8.	I found the system very cumbersome to use.
9.	I felt very confident using the system.
10.	I needed to learn a lot before I could get going with this system.

Appendix J – Eye-tracking Data

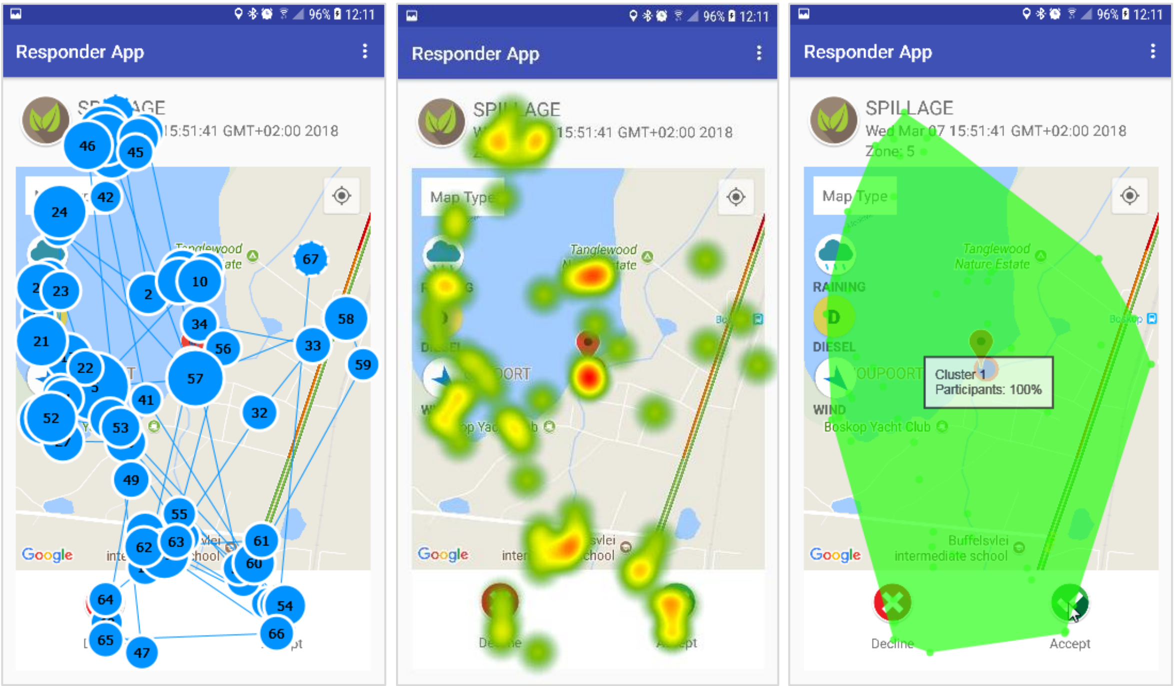
Participant 1 SOS Gazeplot, Heatmap and Cluster



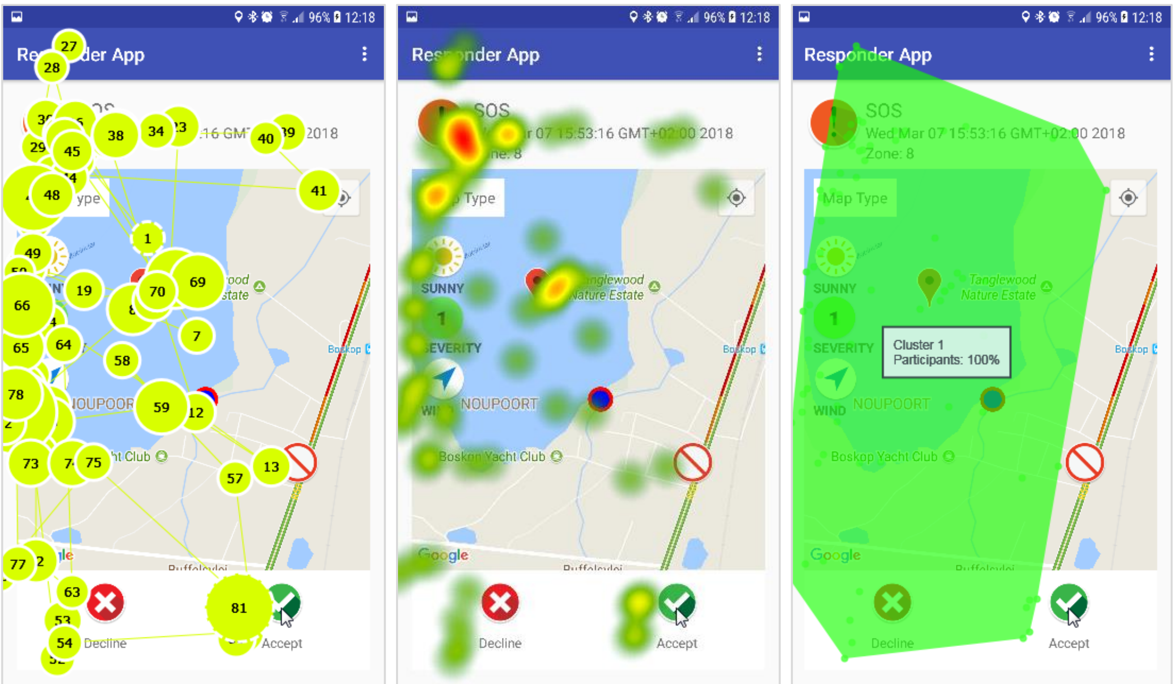
Participant 1 ENFORCEMENT Gazeplot, Heatmap and Cluster



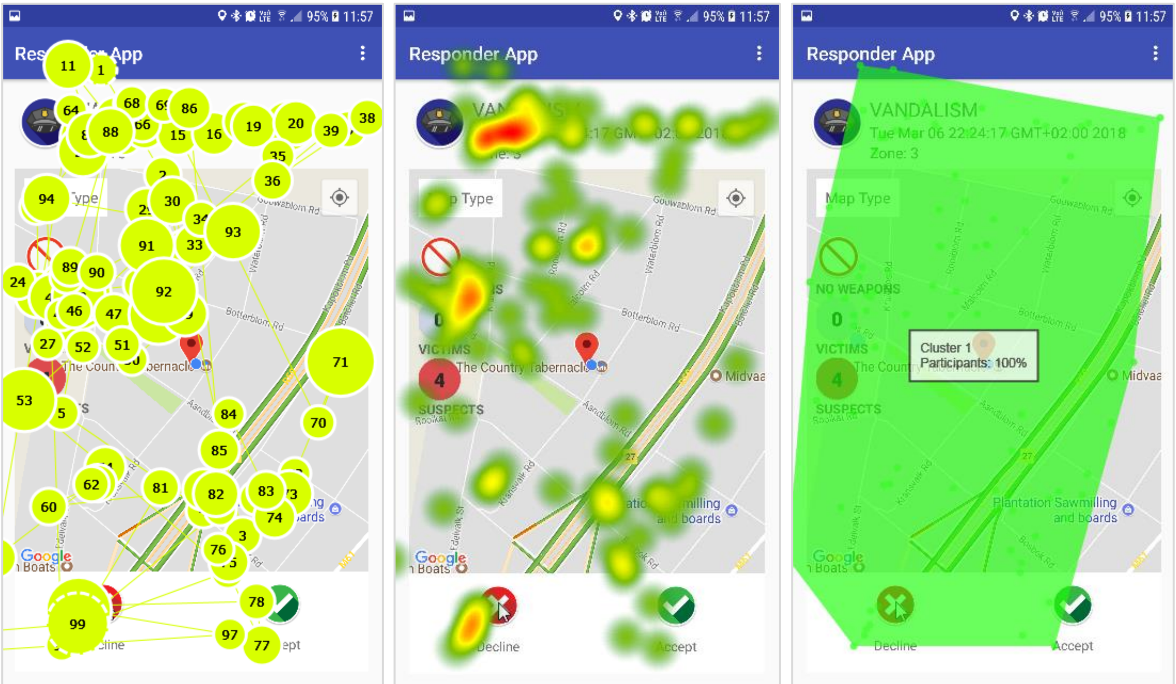
Participant 1 HAZMAT Gazeplot, Heatmap and Cluster



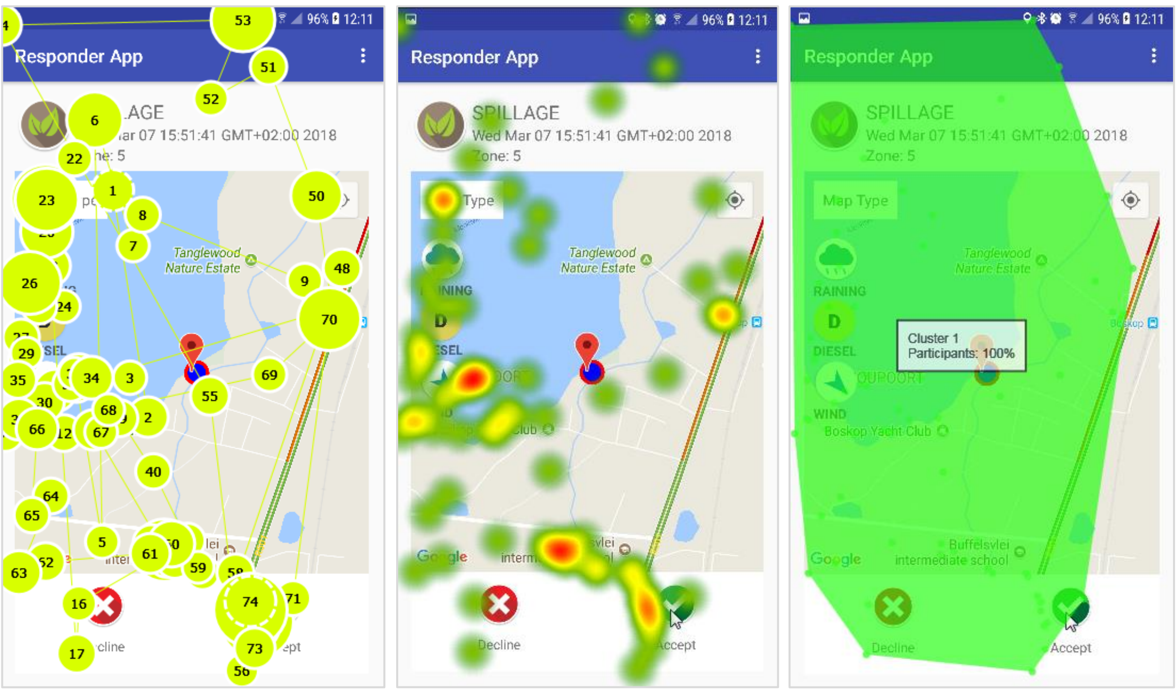
Participant 2 SOS Gazeplot, Heatmap and Cluster



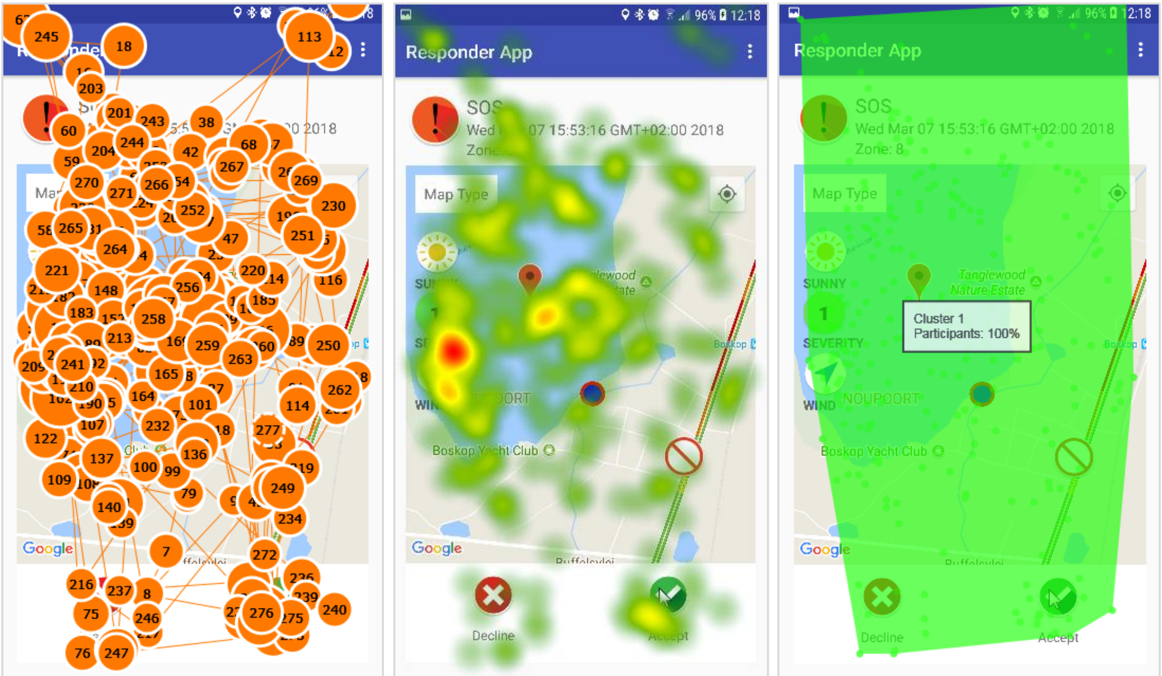
Participant 2 ENFORCEMENT Gazeplot, Heatmap and Cluster



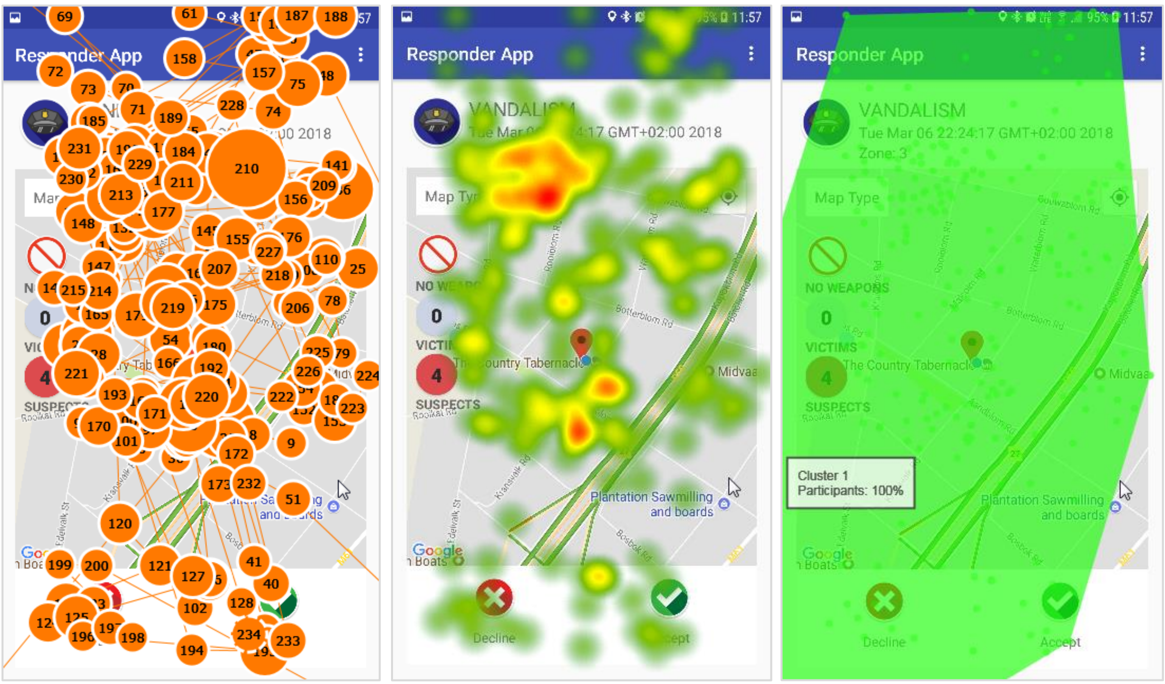
Participant 2 HAZMAT Gazeplot, Heatmap and Cluster



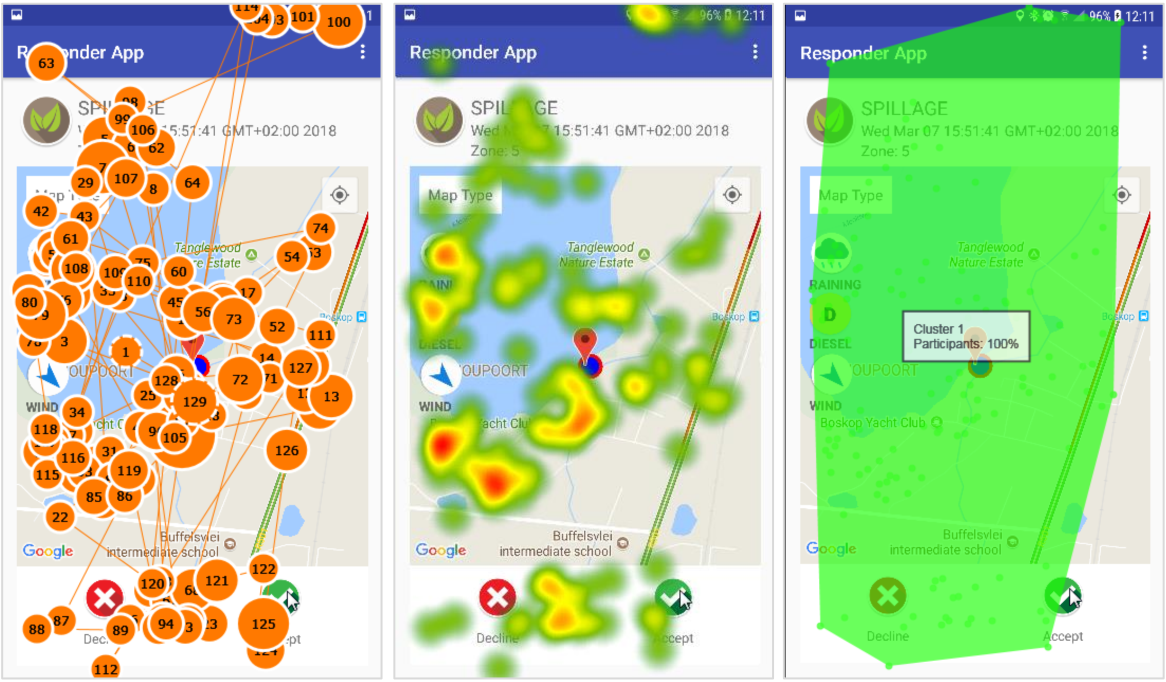
Participant 3 SOS Gazeplot, Heatmap and Cluster



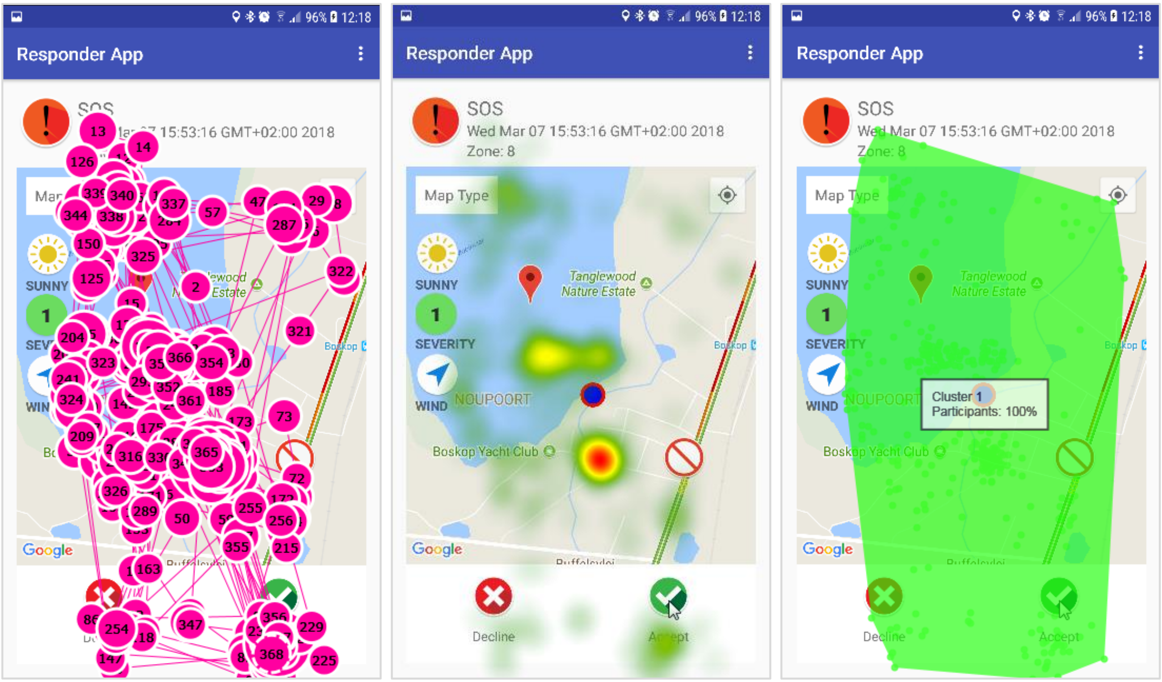
Participant 3 ENFORCEMENT Gazeplot, Heatmap and Cluster



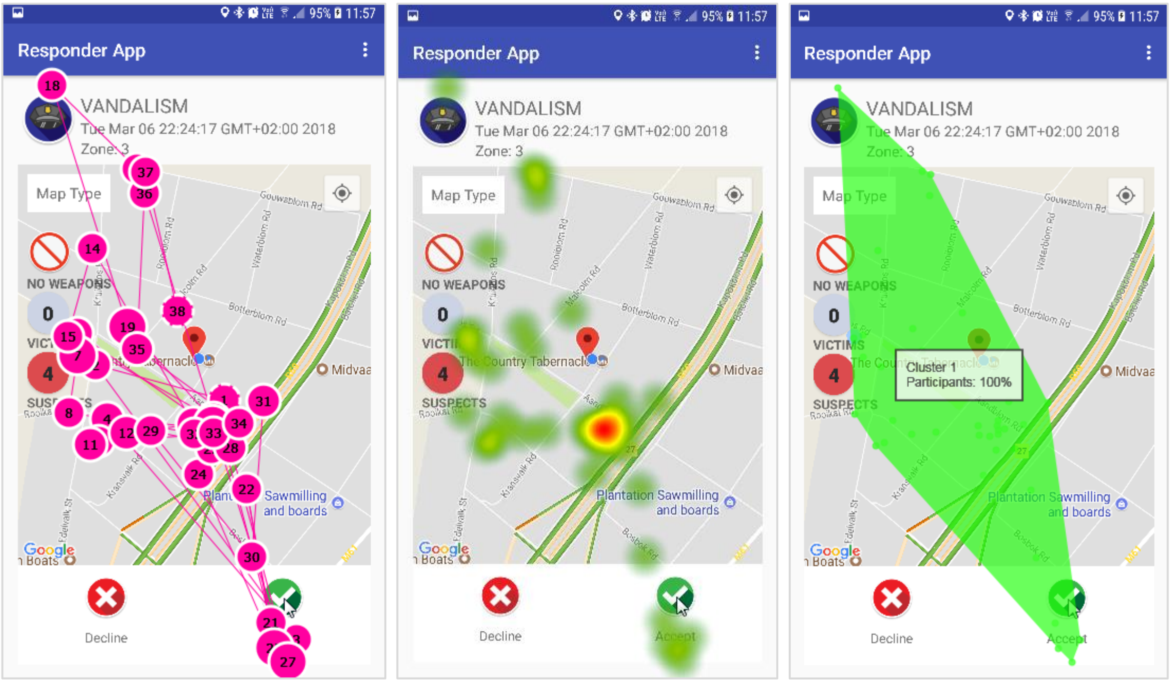
Participant 3 HAZMAT Gazeplot, Heatmap and Cluster



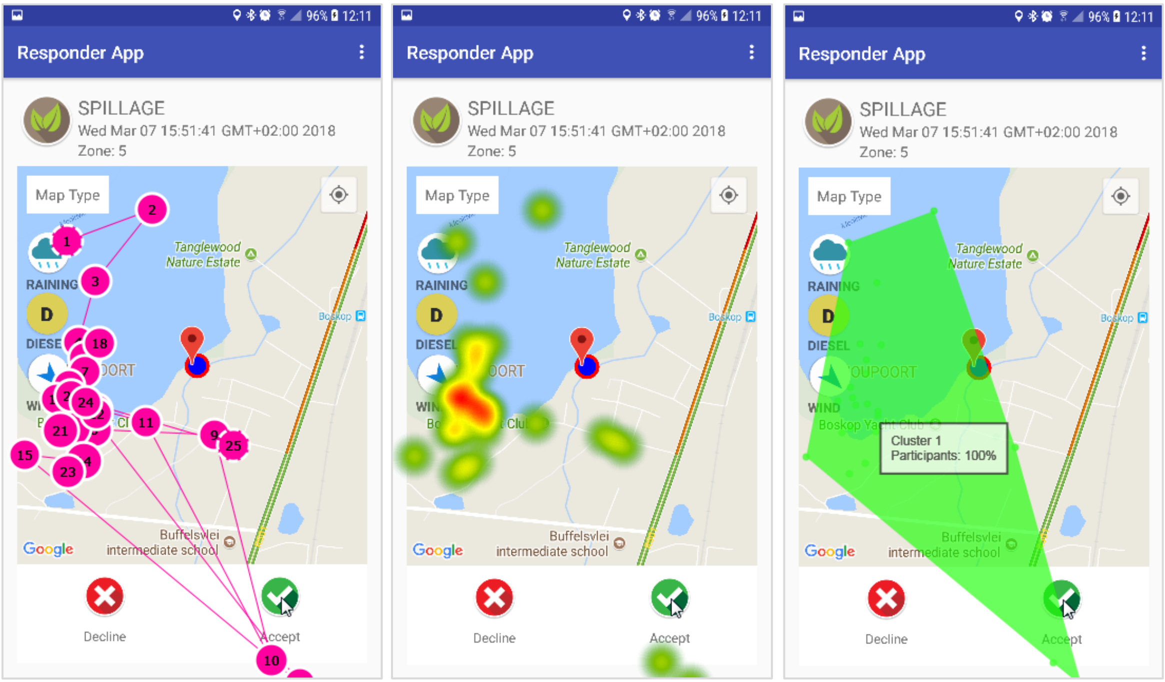
Participant 4 SOS Gazeplot, Heatmap and Cluster



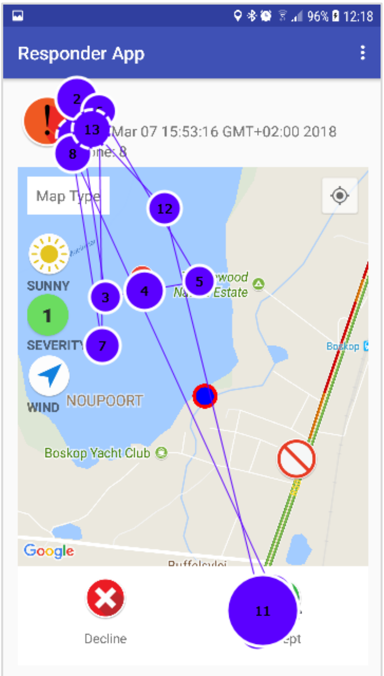
Participant 4 ENFORCEMENT Gazeplot, Heatmap and Cluster

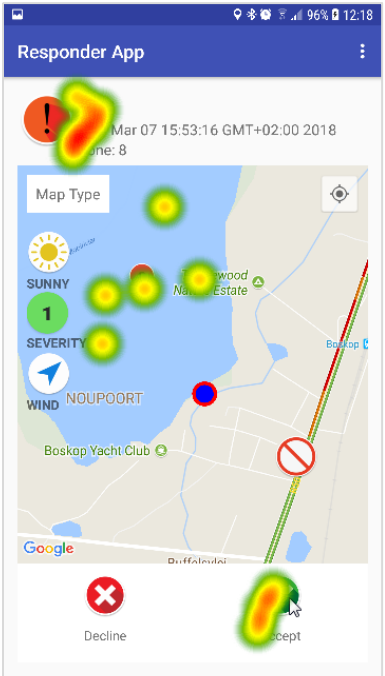


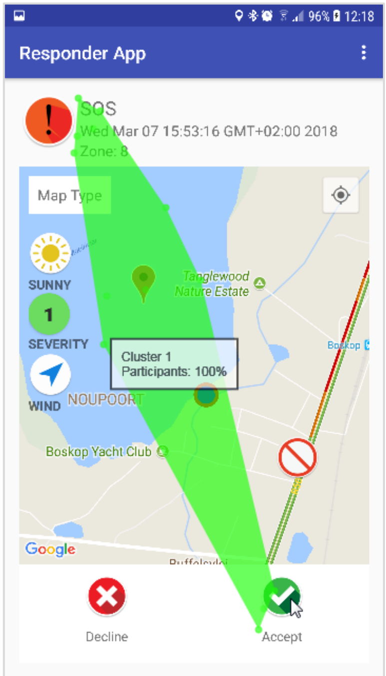
Participant 4 HAZMAT Gazeplot, Heatmap and Cluster



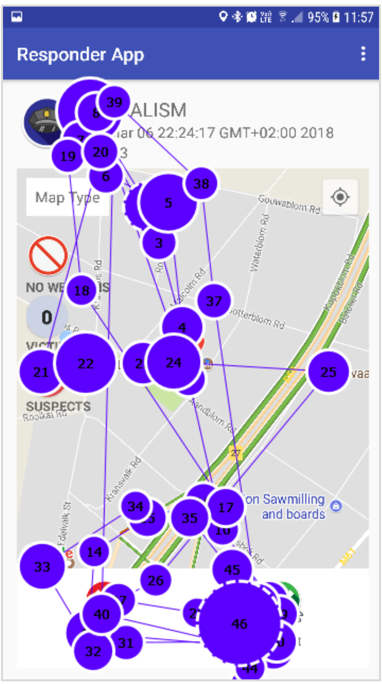
Participant 5 SOS Gazeplot, Heatmap and Cluster

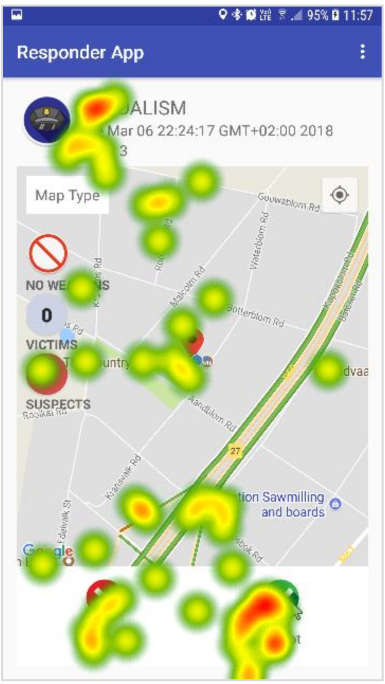


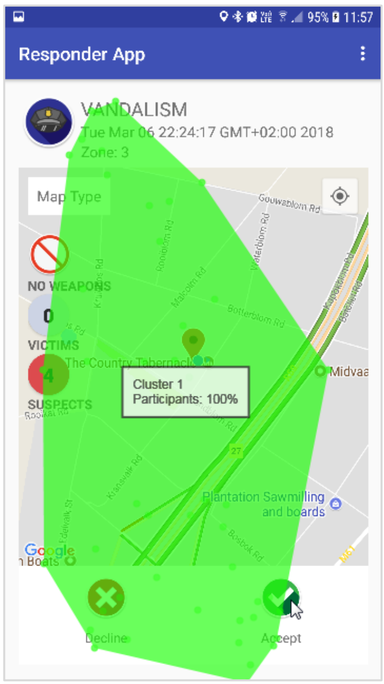




Participant 5 ENFORCEMENT Gazeplot, Heatmap and Cluster



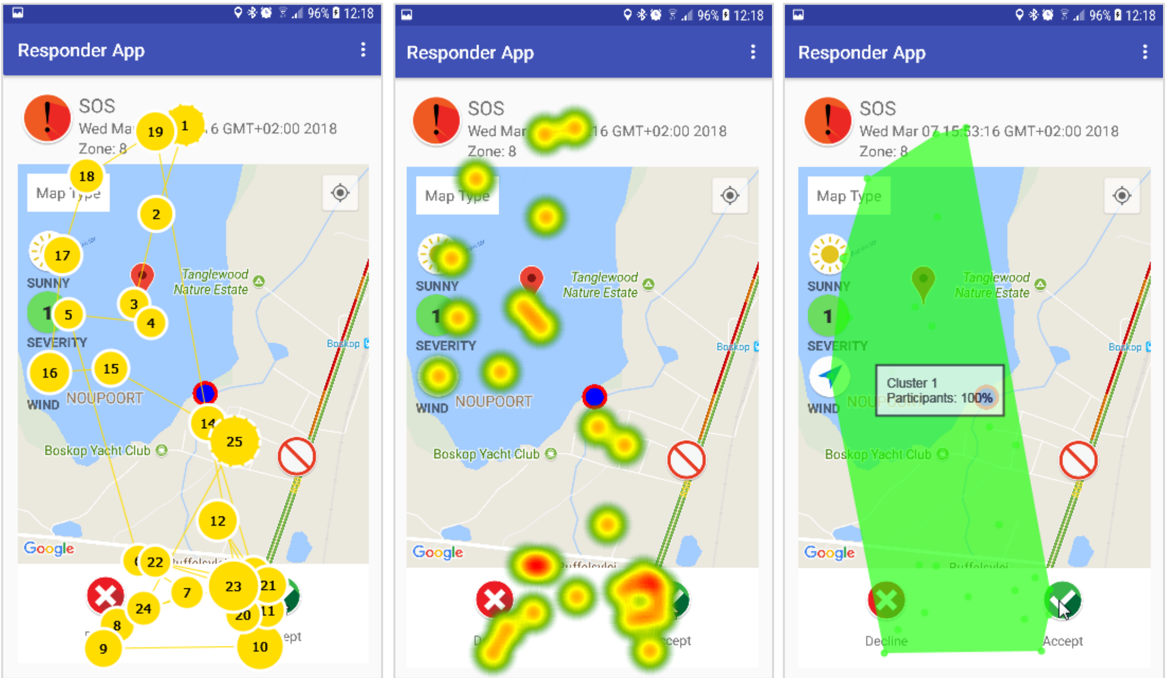




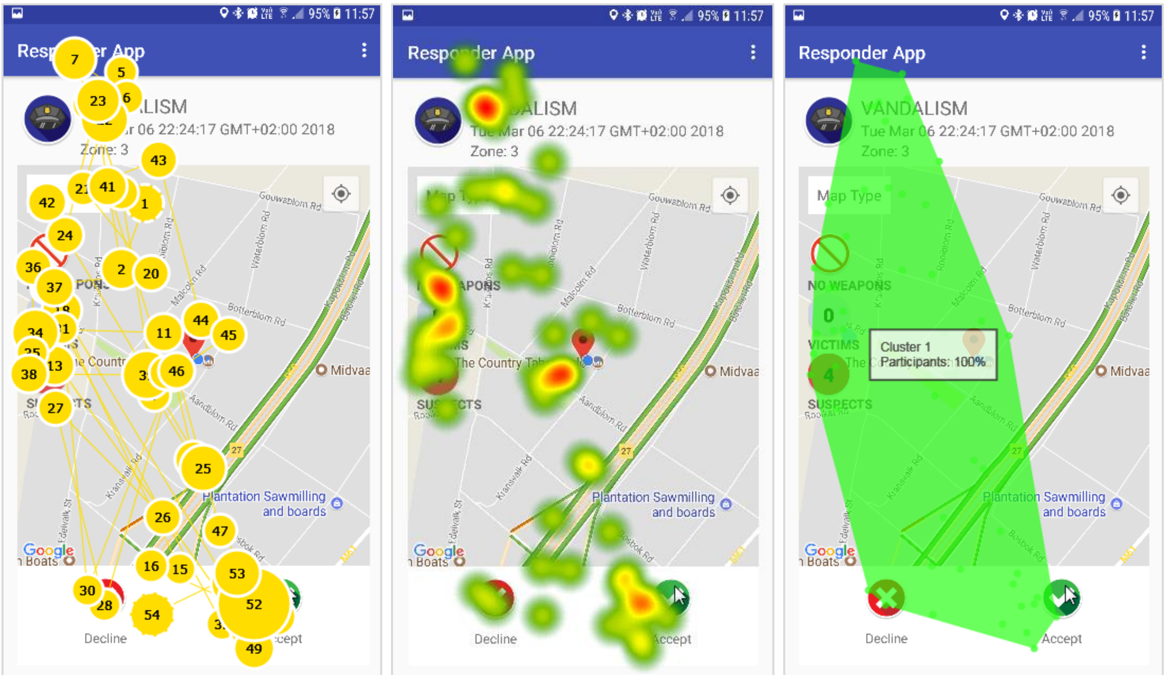
Participant 5 HAZMAT Gazeplot, Heatmap and Cluster

CORRUPT DATA (See section 4.7)

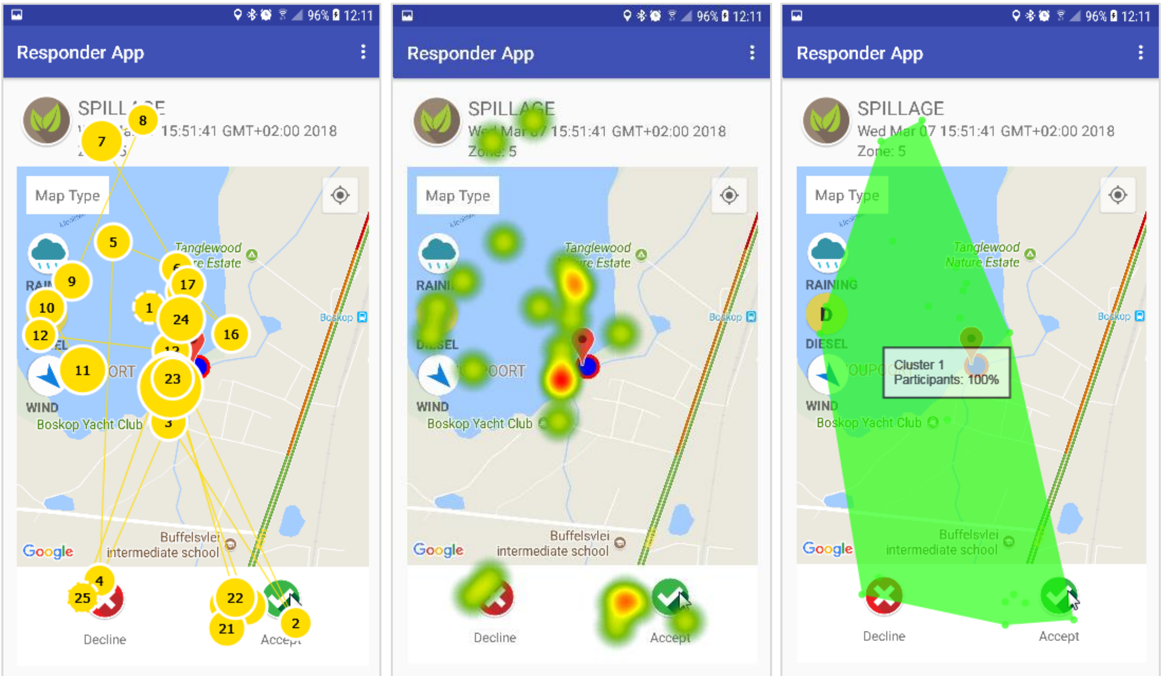
Participant 6 SOS Gazeplot, Heatmap and Cluster



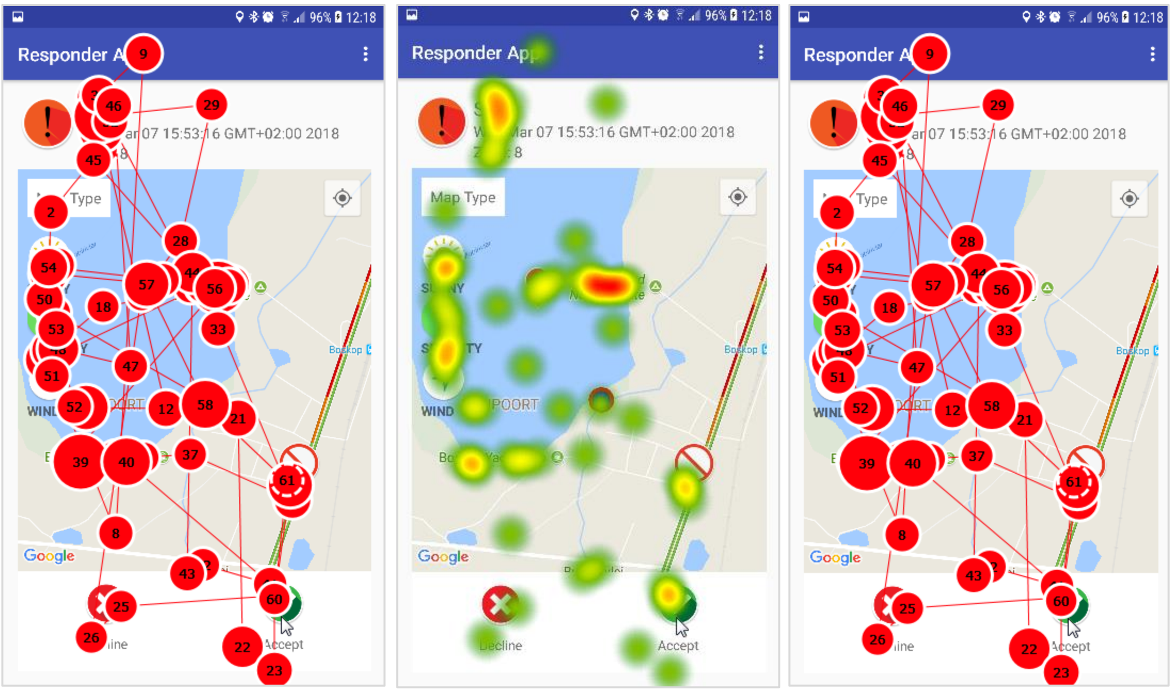
Participant 6 ENFORCEMENT Gazeplot, Heatmap and Cluster



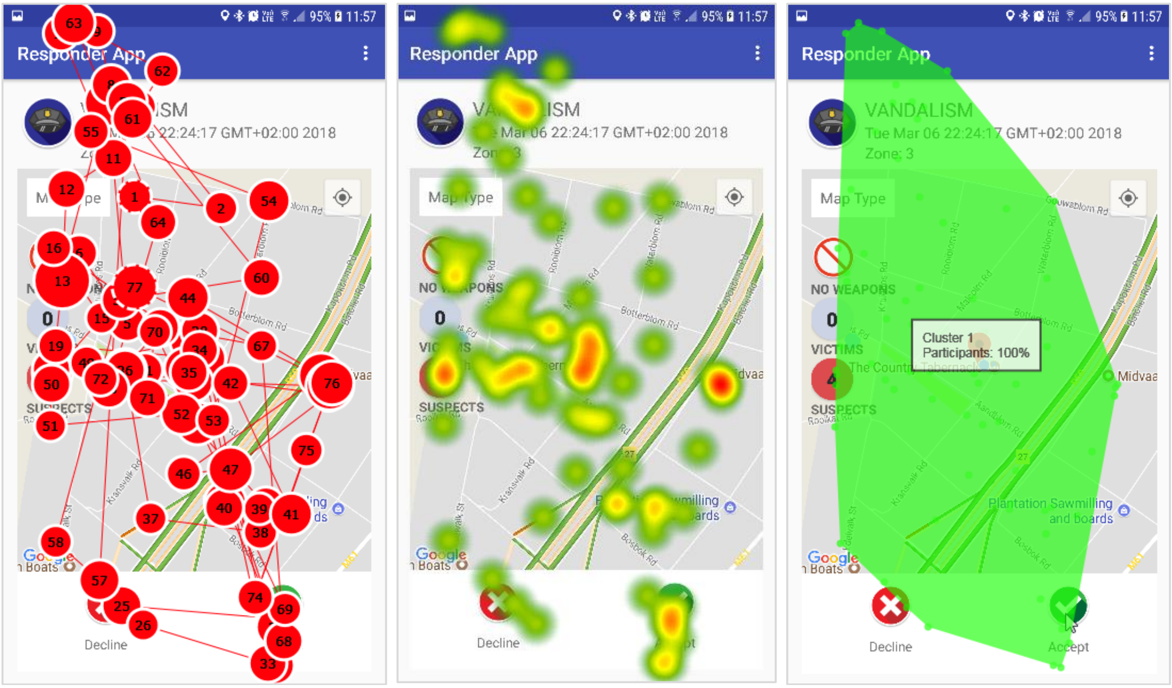
Participant 6 HAZMAT Gazeplot, Heatmap and Cluster



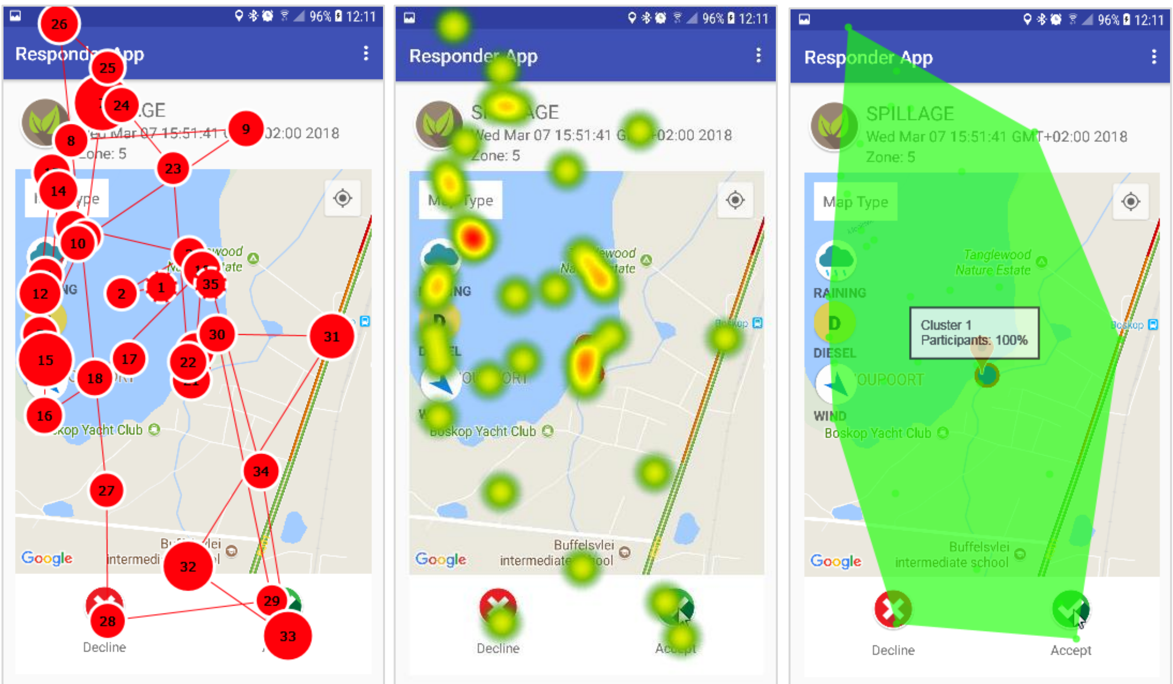
Participant 7 SOS Gazeplot, Heatmap and Cluster



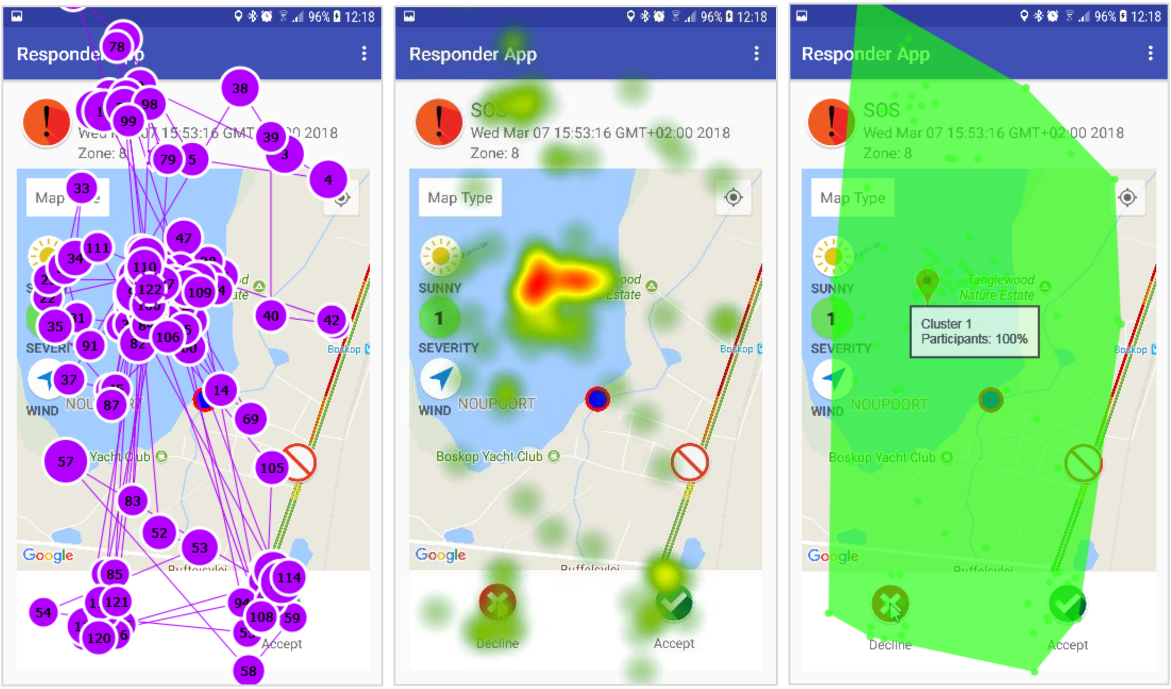
Participant 7 ENFORCEMENT Gazeplot, Heatmap and Cluster



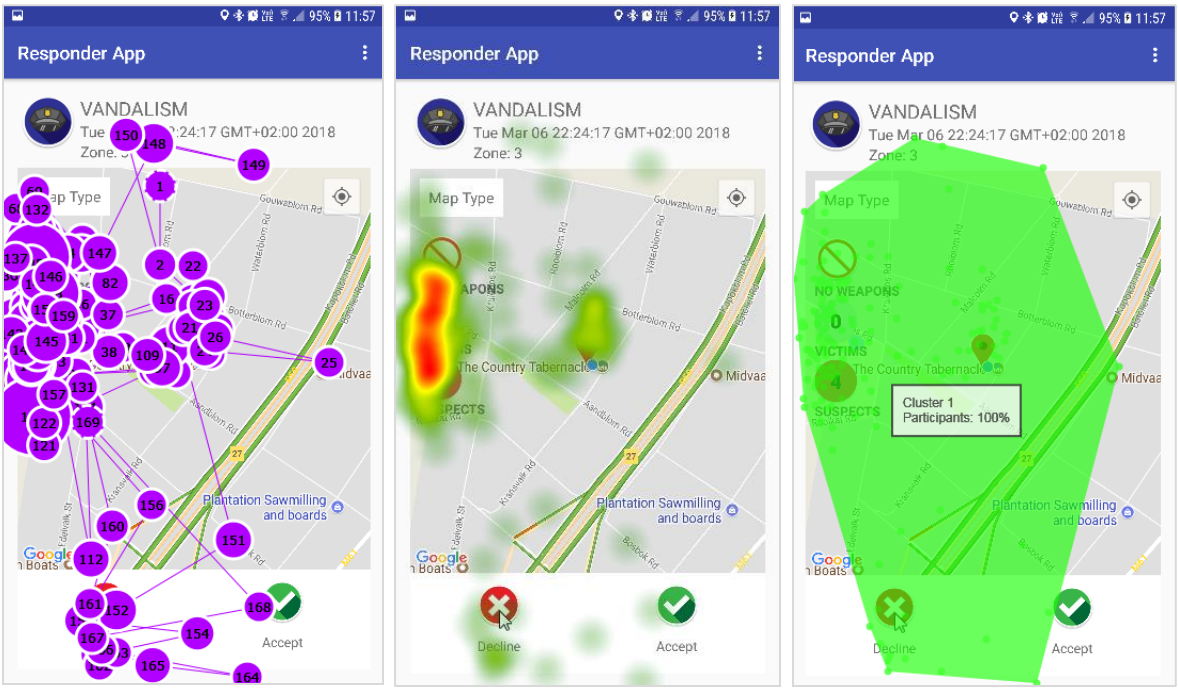
Participant 7 HAZMAT Gazeplot, Heatmap and Cluster



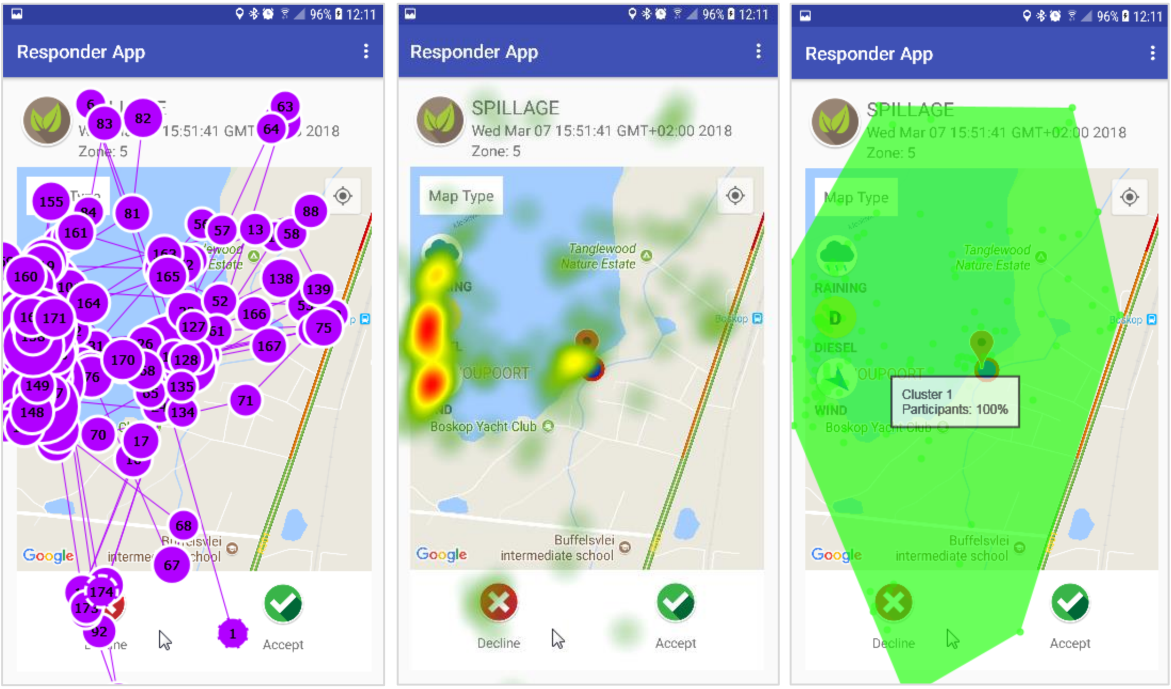
Participant 8 SOS Gazeplot, Heatmap and Cluster



Participant 8 ENFORCEMENT Gazeplot, Heatmap and Cluster



Participant 8 HAZMAT Gazeplot, Heatmap and Cluster



Appendix K – Ethical Clearance Certificate

UNISA university of south africa

UNISA COLLEGE OF SCIENCE, ENGINEERING AND TECHNOLOGY'S (CSET) RESEARCH AND ETHICS COMMITTEE

27 March 2017

Ref #: 018/QVW/2017/CSET_SOC
Name: Quintus van Wyk
Student #: 46089594

Dear Quintus van Wyk

Decision: Ethics Approval for three years (Humans involved)

RECEIVED
2017 -03- 2 7
OFFICE OF THE EXECUTIVE DEAN
College of Science, Engineering and Technology

Researcher: Quintus van Wyk
P.O. Box 934, Henley-on-Klip
quintusvw@gmail.com, +27 11 82 553 4810

Supervisor (s): Prof J Van Biljon
vbiljja@unisa.ac.za, +27 11 670 9182
Dr Marthie Schoeman
schoema@unisa.ac.za, +27 11 670 9178

Proposal: Towards Visualization Evaluation Criteria for Incident Management Systems

Qualification: MsC in Computing

Thank you for the application for research ethics clearance by the Unisa College of Science, Engineering and Technology's (CSET) Research and Ethics Committee for the above mentioned research. Ethics approval is granted for three years from 27 March 2017 to 27 March 2020.

1. The researcher will ensure that the research project adheres to the values and principles expressed in the UNISA Policy on Research Ethics.
2. Any adverse circumstance arising in the undertaking of the research project that is relevant to the ethicality of the study, as well as changes in the methodology, should

University of South Africa
Preller Street, Muckleneuk Ridge, City of Tshwane
PO Box 392 UNISA 0003 South Africa
Telephone: +27 12 429 3111 Facsimile: +27 12 429 4150
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be communicated in writing to the Unisa College of Science, Engineering and Technology's (CSET) Research and Ethics Committee. An amended application could be requested if there are substantial changes from the existing proposal, especially if those changes affect any of the study-related risks for the research participants.

3. The researcher will ensure that the research project adheres to any applicable national legislation, professional codes of conduct, institutional guidelines and scientific standards relevant to the specific field of study.
4. Only de-identified research data may be used for secondary research purposes in future on condition that the research objectives are similar to those of the original research. Secondary use of identifiable human research data require additional ethics clearance.

Note:
The reference number 018/QVW/2017/CSET_SOC should be clearly indicated on all forms of communication with the intended research participants, as well as with the Unisa College of Science, Engineering and Technology's (CSET) Research and Ethics Committee

Yours sincerely

Adele da Veiga

Dr. A Da Veiga

Chair: Ethics Sub-Committee School of Computing, CSET

Prof I. Osunmakinde

Director: School of Computing, CSET

Prof B. Mamba

Executive Dean: College of Science, Engineering and Technology (CSET)

Approved - decision template – updated Aug 2016

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Appendix L – ICTAS Publication

Visualization Criteria: supporting knowledge transfer in Incident Management Systems

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Marthie Schoeman
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Abstract— **Incident Management Systems (IMS) assist in managing resources in order to minimize fatalities and damage. Visual artifacts in an IMS can facilitate knowledge transfer between responders to an incident, however, evidence-based guidance on the design of these visualizations are lacking. The aim of this study is to propose evidence-based knowledge visualization criteria (KVC). Design Science Research (DSR) was the guiding methodology. We abstracted a set of KVC from the academic literature, and then applied said criteria to evaluate a cloud-based prototype IMS. The evaluation included interviews with content experts from the South African Fire Service to establish the relevance of the KVC. The KVC were also used in a heuristic evaluation of the IMS by usability experts. The theoretical contribution of the study is the validated set of KVC based on the triangulation of the findings from the content experts and the usability experts. The study also makes a practical contribution by demonstrating the use of evidence-based visualization criteria in IMS.**

Index Terms— Criteria, Incident, Incident Management System, Knowledge, Knowledge Transfer, Knowledge Visualization, Knowledge Visualization Criteria

I. Introduction

DURING an incident of critical nature, damage to infrastructure or even fatalities can occur, therefore proper allocation of resources to the incident is of unreserved significance. Incident Management Systems (IMS) exist for this purpose: to efficiently and effectively manage resources allocated to an incident. IMS uses digital technology for critical communication during an incident and this provides the opportunity to investigate the transfer of knowledge between individuals and groups involved in the management of incidents. There are various approaches to improving knowledge transfer supported by digital technology. In this paper we specifically consider visualization and investigate the visualization criteria applicable to IMS.

Individuals obtain a larger amount of information through visual means than through all other senses combined [1]. Therefore visual perception plays a key role in how individuals receive and process information displayed on digital interfaces [2]. Despite general agreement on the importance of visualization in knowledge representation and transfer, there is a dearth of guidelines on how to evaluate knowledge visualizations. That provides the rationale for this study which is guided by the following research question: What are the knowledge visualization criteria for improving the usability of an Incident Management System?

The research design focused on identifying KVC from literature and evaluating how the criteria applies to IMSs by interviewing content experts (incident management) and usability experts (academic lecturers and researchers). The content experts were interviewed to determine how important the original KVC were with regards to the IMS and a heuristic evaluation was done with the usability experts to evaluate the IMS in terms of the original set of criteria. The contribution of the paper is the evidence-based set of validated criteria.

II. Knowledge Visualization in Incident Management Systems

A. Incidents

An incident is an event that happens or exists for a period of time [39]. Fig. 1 provides an overview of the lifetime of an incident. This study focuses primarily on the period known as the "Critical Period" [3]. According to Kim [5, p. 236] "A critical incident management system (CIMS) is a system that utilizes people, processes, and technologies for managing critical incidents". Anderson, Compton and Mason [6 p4] define an incident command system as "a management system designed to enable effective and efficient domestic incident management by integrating a combination of facilities, equipment, personnel, procedures, and communications operating within a common organizational structure". From the definitions it becomes evident that the resources, the personnel, and the technological infrastructure to process the management of an incident efficiently and effectively are the components that make up an IMS.

B. Knowledge Visualization

Knowledge visualization (KV), a field at the intersection of the Human-Computer Interaction and Knowledge Management domains, has the potential for supporting

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knowledge transfer [6–8]. Research reveals that this potential has been underused in the field of Incident Management Systems (IMSs) with the available guidelines for example [6]–[9]. Parry & Cowley [2] identified critical aspects in maps as a technique for visualizing load-shedding schedules, but also focused on information visualization. Furthermore, communication in IMSs is time critical therefore the appropriate visualization criteria need to be selected and prioritized for relevance to IMS.

Using textual representations of knowledge without visualizations does not address the requirements of the present knowledge society [10]. Visualization has the ability to synthesize data into effective graphics, making it easier for the human brain to comprehend [11]. Visualization is not only applicable to data, but to information and knowledge as well, and each of these have different levels of abstraction [12].

We now consider the difference between these concepts when existing as visualized entities:

- **Data visualization** entails any visual artifact which explains any data in any discipline [11], [13], [14], and is a commanding method for reasoning about data, for exploring data [13], and bringing to light any details that might have being obscured in computed statistics [14], [15].
- **Information visualization** provides a more condensed illustration of the information, thereby assisting the viewers to reason about the content [16], and in some cases to also provide an interactive method for navigating the content [7], [16]–[18].
- **Knowledge visualization** is "the use of graphical means to communicate experiences, insights and potentially complex knowledge in context, and to do so with integrity" [16, p. 5].

C. Knowledge Visualization Criteria

Based on a literature review the following criteria has been identified or proposed, together with their descriptions. The criteria were developed from the categories of Why, What, Whom and How of KV [8]. The order is not related to importance.

1. **Clarity** [19]–[22]: The meaning of the symbols is clear and unambiguous.
2. **Consistency** [23], [24]: The same symbol is used to represent the same concept throughout.
3. **Discrimination** [25], [26]: Shape, color and texture is used to distinguish between the elements.
4. **Semantic Transparency** [8]: The mapping between the symbols and their meaning (what they represent) is clear.
5. **Complexity Management (parsimony)** [27]: All concepts are represented but elements are not repeated or multiplied unnecessarily.
6. **Dual Coding** [28]: Both text and graphics are employed to explain the same construct.
7. **Legend** [29], [30]: The legend is provided.
8. **Context** [12], [28], [31], [32]: The visual artifact is adequate for the circumstance, conditions, situation, environment in which the artefact exists.
9. **User** [28], [33], [34]: The symbols and notation match the end user's mental model.
10. **Intention** [12], [17], [28]: The visual artifact is aimed at achieving a specific goal.
11. **Layout (Shape)** [7], [25], [35]: Related symbols and information are properly positioned and structured as symmetrical as possible.

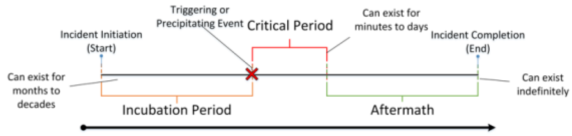

Figure 1: Disaster Sequence

III. Research Design

Design Science Research (DSR) [36], [37], was used as the research methodology with pragmatism as the philosophy. DSR is appropriate in guiding this study since DSR outputs are not only made up of a complete system but also consists of the building blocks of the system [38], i.e. the KVC in this case. The focus of this research was to investigate the application of KVC on IMSs. This research was divided into three phases, namely:

1. Literature review to identify criteria for KVC.
2. Questionnaire-driven interview with content experts regarding the *importance* of the KVC in an IMS.
3. Heuristic evaluation of the IMS user interface according to the KVC.

The IMS on which this study is conducted is a cloud-based system actively being developed by [Anonymized for review]. This system is considered a 3-tier system, having a public interface, an operator interface, and a responder interface.

Fig. 2 provides an overview of these 3 levels of the IMS. The first level is the public component, the initiation point of an incident in the system.

The second level is the operator component, where the operator receives the incident detail, confirms the validity of the incident and compiles additional details regarding the incident.

The third and final level is the responder level, the level which receives the compiled information that the operator captured. The responder level consists of users identified as

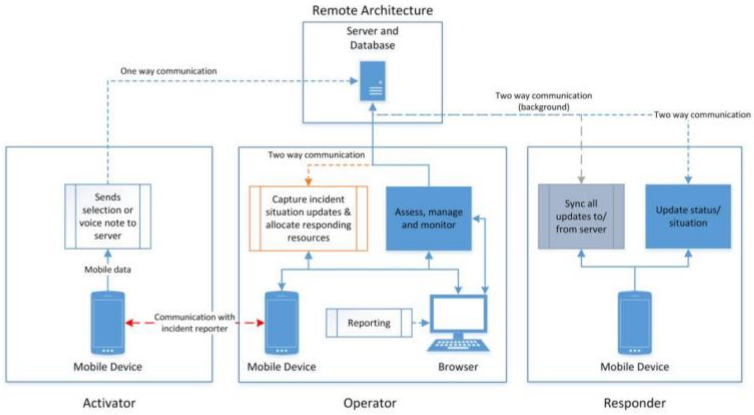

Figure 2: Incident Management System Tiers

responders, and they have the role of responding to an incident in a predefined capacity.

The process flow of an incident in this system is as follows:

1. A member of the public (activator) activates an alert via a public application.
2. The activation appears on the system as a new incident and informs an operator about this by means of a notification on the browser interface of the system.
3. The operator contacts the activator and confirms the validity and type of incident. Additional information regarding the incident is then captured.
4. Once the incident has been verified, the operator pushes the incident detail to a group of predefined responders. The incident detail shows on the responder devices by means of a mobile notification, and once opened displays the information of the incident.
5. The responder then makes an informed decision on whether he or she can respond to the incident.
6. If the responder accepts the incident the mobile interface opens additional functionality to interact with all responders to the incident. Should the responder decline the incident is removed from the responder's device.
7. Once the responder is done responding he or she indicates a standing down status and the incident is then removed from his or her device.

This study is done on the mobile interface of the third level, the responder tier, as depicted in Fig. 2. The IMS used had 62 different incident types at the time of this study. It was not feasible to investigate all 62 and therefore three different screenshots were selected as representative. The incident types were divided into three representative categories: SOS, Enforcement, and Ecological (or Hazmat). Fig. 3 – 5 show screenshots of interfaces for these three categories.

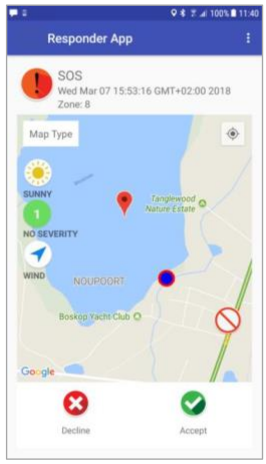

Fig. 3 - SOS Screenshot

A. Questionnaires used

The two questionnaires used during the interviews consisted of the same arrangement, but different goals. Both questionnaires consisted of the list of criteria and an accompanying screenshot of the interface being evaluated, as well as space for additional comments. The difference between the two questionnaires was that where the content expert group were to indicate the *importance* of the criteria to the interface, the usability experts were to evaluate how well the interface *complies* with the criteria. Any additional comments the participants felt were of importance were added on the questionnaire as a comment.

Ethical clearance also guiding the necessary participant consent was obtained from [anonymized for review].

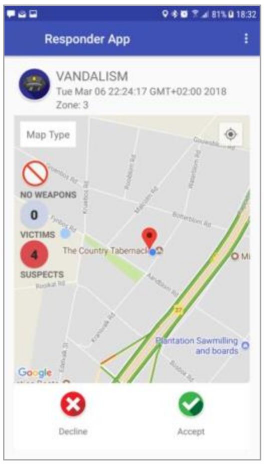

Fig. 4 - ENFORCEMENT Screenshot

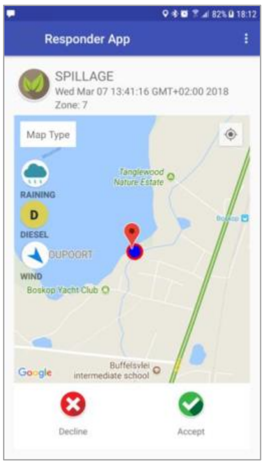

Fig. 5 - HAZMAT Screenshot

B. Content Experts' profile

The study involved seven participants with a background in incident response and management of varying degrees. All of the participants have ten to thirty years of experience as firefighting officers in the South African Fire Service. Three of the seven participants are still employed as municipal firefighters, two senior officers (chief and deputy chief) and the head of the training department of a municipal station. The other four participants have become fire safety consultants upon retiring from active service and have consulted between thirteen to twenty-six years.

C. Usability Experts' profile

Eight usability experts were involved in this study, all of whom has an honours degree at minimum and experience in teaching Human Computer Interaction.

D. Conducting the Content and Usability Expert Interview

The content experts were provided with three forms which contain a list of the identified criteria, three screenshots of the mobile application interface, and a description of the required action. The experts had to indicate how important they perceived each criterion on the provided interfaces (see Fig. 3, 4 and 5). The importance indicator was a Likert scale where 1 is "No importance" and 5 "High importance".

The usability experts received the same forms as the content experts, but their task was to indicate how well the screen *complied* with the criteria, using a Likert scale of 1 being "No compliance" and 5 "Full compliance".

E. Limitations

Since this study focuses on KVC being applied to the mobile interface of an IMS the content and usability experts were provided with sheets of paper containing screenshots of the mobile interface together with the list of criteria. This was done for two reasons: to evaluate the list of criteria to the mobile interface using a single page and because evaluation on a physical mobile interface would complicate the process of providing the complimenting criteria evaluation. This completely removed the benefit of interactivity that the mobile application has.

IV. Results and Discussion

The results presented here involve the criteria identified from literature and the interview results of both the content expert and the usability expert groups, showing the averages of the provided answers to the questionnaires.

A. Interview results on the Content Experts

The interviews with the content experts resulted as displayed in Table I. The table represents the averages of the experts' ratings for the importance of each criterion (rated on a scale of 1 to 5). The content experts showed great interest in the mobile approach of the IMS, and some questioned how they operated effectively without such a system. They all were in unison regarding the importance of the system and how it can improve performance of responders.

During the interviews the active firefighters indicated that they would like to have had access to the global positioning system co-ordinates of the indicated incident. They reasoned that this could be necessary should they be required to provide location detail for other systems such as navigational systems.

Three of the most experienced content experts indicated that they feel strongly that the need for a legend in a visual display of an incident's detail is not required, since it would distract the user from focusing on the incident and would indicate that the visual detail being displayed is inadequate. Some also mentioned that designing the system for the user would require too much variance as each user would have different requirements. The user should rather be trained on the system and also possess a mindset to 'see' the incident from the provided visual artifact.

For most of the other criteria all the content experts felt that they are important in the provided context of the system as can be seen from the results of the interview.

B. Interview results on the Usability Experts

Table I also provides the averages for the usability expert group's evaluation of how well the mobile application screens complied with the criteria (green cells indicating highest scores and red lowest).

The SOS screen had an additional icon which indicated a restricted access route on the map. This symbol caused confusion with some of the participants as to where the exact location of the incident was; they confused it with the default location pin on the map. This was done on purpose to investigate if the symbol would be perceived as representing what it was meant to represent. This same symbol was used in a different capacity on the ENFORCEMENT screen. Some of the participants immediately indicated that this is not correct, and that the symbol must be differentiated.

The criterion "discrimination" caused some confusion. Some participants did not understand what the term discrimination meant until it was explained as differentiating between objects on the visual artifact (e.g. white text on a yellow background would have low discrimination).

One of the participants made a comment that the "legend" criterion is not required when the criteria points of "clarity" and "transparency" were involved in designing the visual artifact. This is in line with the statement by the content experts that a legend is of little importance in such a system.

TABLE I.
CONTENT & USABILITY EXPERTS - AVERAGES

CRITERIA	Average					
	SOS		Enforce-ment		Hazmat	
	Content Experts	Usability Experts	Content Experts	Usability Experts	Content Experts	Usability Experts
Clarity	4,7	3,4	4,3	3,8	4,3	4,1
Consistency	4,6	4,0	4,6	3,9	4,4	4,4
Discrimination	4,1	3,5	3,6	3,4	4,1	3,8
Semantic Transparency	4,3	3,6	4,0	4,0	4,4	4,1
Complexity Management	4,4	3,5	4,3	3,5	4,6	3,5
Dual Coding	3,3	3,4	3,4	3,6	4,0	3,9
Legend	3,3	3,1	3,3	3,3	3,7	3,3
Context	4,7	4,3	4,7	4,1	4,7	4,0
User	3,4	3,6	3,7	4,0	3,4	3,6
Intention	4,6	4,3	4,4	4,1	4,6	4,1
Layout (Shape)	2,9	3,9	3,0	3,8	2,9	3,9

C. Summary of Results

The results from the interviews conducted with the content experts showed that the criterion "shape" is of the least importance, obtaining a score between 2.9 and 3.0 out of 5 for all three interfaces. The usability experts rated "layout (shape)" between 3.8 and 3.9 out of 5, which indicates that they felt the screens of the IMS complied above average with the criterion. "Clarity", "consistency" and "intention" were indicated as being extremely important for such a system by the content experts, all having a score above 4.2. The scores provided by the usability experts indicate that "intention" has been well applied (a minimum of 4.1), but "clarity" and "consistency" could be improved (minimum of 3.4 and 3.9 respectively).

The content experts labeled "context" as the most important criterion in any IMS with an average of 4.7 for each interface. The usability experts rated this at 4.0 thereby supporting the importance of "context" in IMSs.

"Dual coding", "legend" and "user" received lower scores from the content experts, having most of their averages between 3.3 and 4.0 (with only "dual coding" receiving a single 4.0). This is in accordance with the content experts' opinion regarding the legend and user criteria (see interview results above). "Legend" also received the lowest score from the usability experts for all three interfaces indicating that the IMS in this study corresponds with the content experts' assertion that legends are of little importance. "Discrimination", "complexity management" and "semantic transparency" all fared moderately strong as important to the content experts, mostly receiving above 4.0 with a single minimum of 3.7 for "discrimination". Some of the usability experts showed confusing with regard to the criterion being labeled "discrimination". This could be due to the background of South Africa's political segregation history.

D. The Updated Criteria.

The criteria identified from the literature are all applicable, in varying degrees of importance to IMS interface design but it became evident that some are high-level (management considerations) while other are on a lower (implementation) level. Table II displays the criteria in lieu of these two perspectives.

TABLE III.
HIGH- & LOW-LEVEL CONCERN OF CRITERIA

CRITERIA	High-level	Low-level
Clarity	X	X
Consistency		X
Discrimination		X
Semantic Transparency	X	X
Complexity Management		X
Dual Coding		X
Legend		X
Context	X	X
User	X	
Intention	X	
Layout (Shape)		X

V. Conclusion

The paper presents a set of validated KVC in response to the research question, namely "What criteria exists for KV in IMSs?" This theoretical contribution is an evidence-based, validated set of KVC that is applicable to IMSs as well as some insights towards prioritizing those. The practical contribution is the demonstration of implementing evidence-based knowledge visualization in an IMS and feedback on improving the usability of the IMS. More studies need to be done on field testing and how users perceive the knowledge transferred from the site of an actual incident to their devices.

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Appendix M – SAICSIT Symposium

Towards Knowledge Visualization Evaluation Criteria for Incident Management Systems

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ABSTRACT

This study investigates the use of knowledge visualization (KV) in incident management systems (IMS). The usability of incident management systems is critical to ensure the optimal performance of the system under all conditions. Knowledge visualization provides an approach to supporting usability but the existing research literature does not provide guidance on implementing KV in IMS.

The research is being done on is an IMS system requested by the department of Water and Sanitation of the South African government. The main goal of this system is to provide an emergency communication platform for incidents occurring in and around all the dams and rivers in South Africa. The system is known as iRAP (Incident Response Activation Program) and has being in development since early 2016.

The investigation is guided by the following research question: What are the criteria for evaluating knowledge visualization artifacts in incident management systems?

The sub-questions that constitute the main research question are:

1. What KV criteria exist?
2. What are the knowledge artifacts of an IMS?
3. What IMS specific criteria for KV exist?

The research approach used is Design Science Research (DSR) because it supports the iterative development of a complete system. This study will be done on an already developed artifact (the iRAP IMS), with permission to adapt the artifact after evaluation.

The research process flow of this study is depicted in the diagram which can be seen in figure 1 below. The study starts in the *Design and Foundation* section and then the *Expert Evaluation* phase informs the *Analysis, Change and Implementation* section.

The criteria for KV are identified from a systematic literature review. The development of the visual artifacts of the incident management system is informed by these criteria and then the artifacts are then evaluated against the identified criteria by an expert group consisting of professionals in the human computer interaction (HCI) field.

The users involved are activators, operators, and responders. The study concerns the communication of knowledge, by means of visual artifacts, between these users. The effectiveness of the application of the criteria to the visualization artifacts are evaluated by means of a questionnaire completed by the responders making use of the artifacts.

The data collecting process occurs in iterations, where the data collected is evaluated to investigate the effectiveness of the artifacts in achieving knowledge visualization. Any identified changes are implemented on the artifacts, and then a new user group is provided with the questionnaire with regard to the updated artifacts. Once the feedback from the survey indicates saturation the criteria will be formalized.

The theoretical contribution of this study will be the evaluated and refined knowledge visualization criteria for IMS, and the practical contribution will be an IMS that effectively communicates knowledge by means of visual artifacts.

KEYWORDS

Knowledge visualization, incident management system, criteria

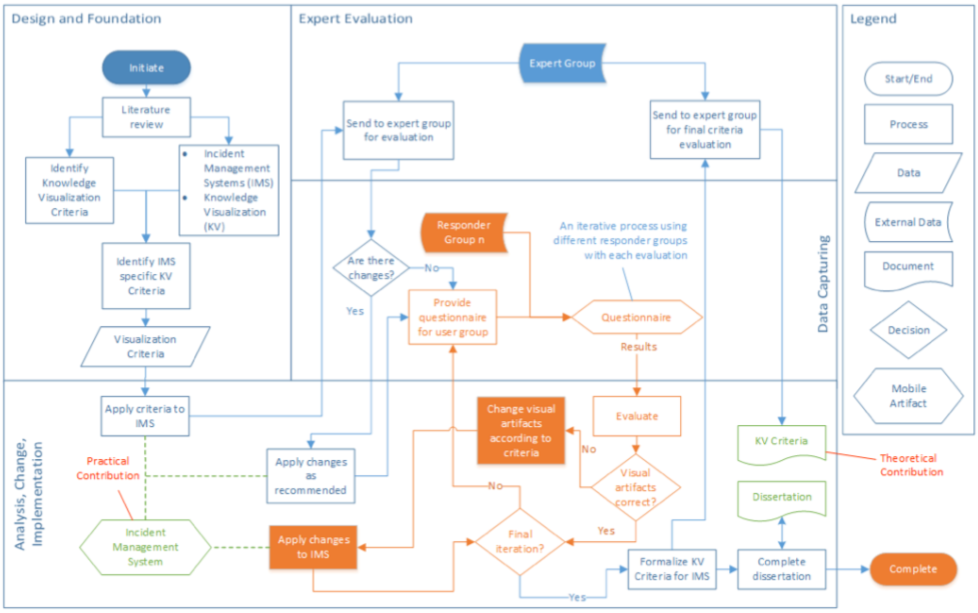

Figure 1 - Research Process Flow