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Visualization Criteria: supporting knowledge transfer in Incident Management Systems

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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.

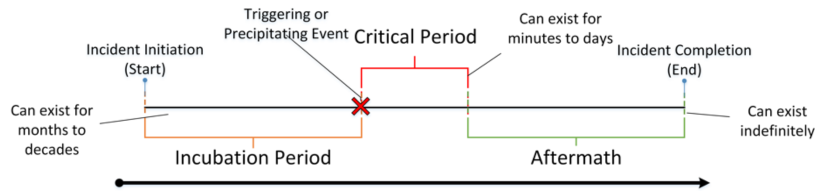

Figure 1: Disaster Sequence

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 has 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 are 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.

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

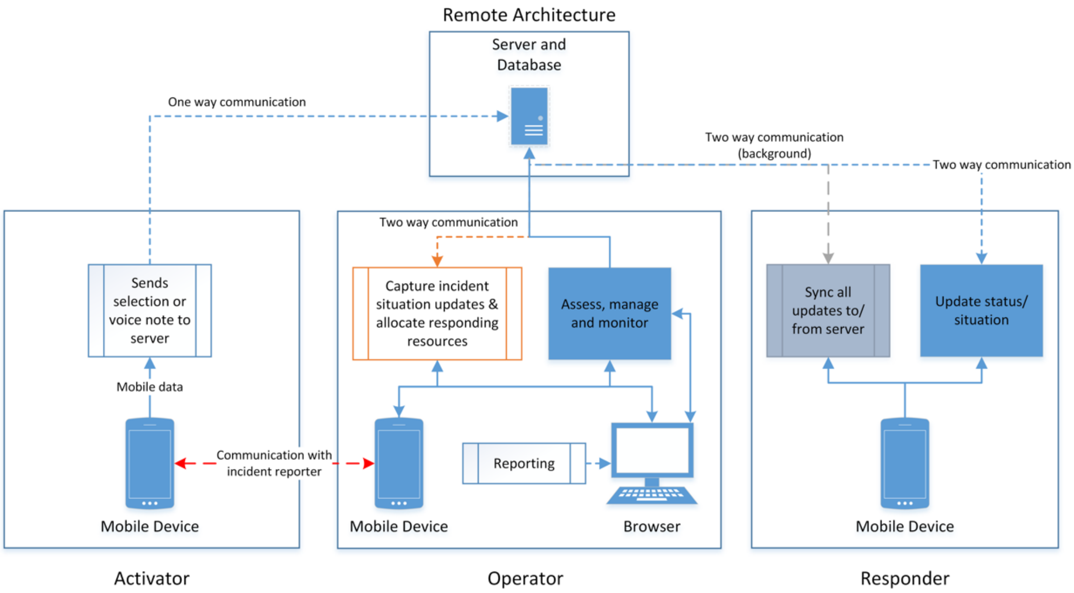

Figure 2: Incident Management System Tiers

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.

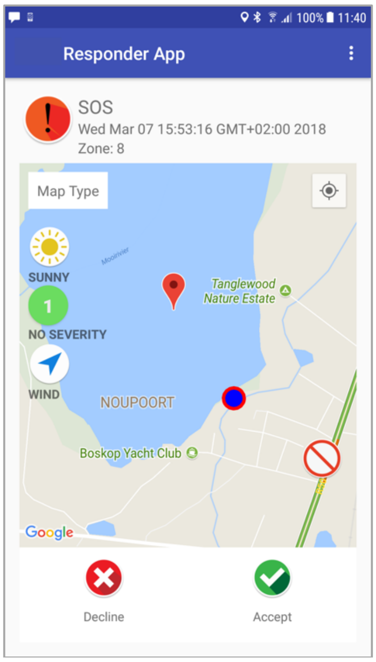

Fig. 3 - SOS Screenshot

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].

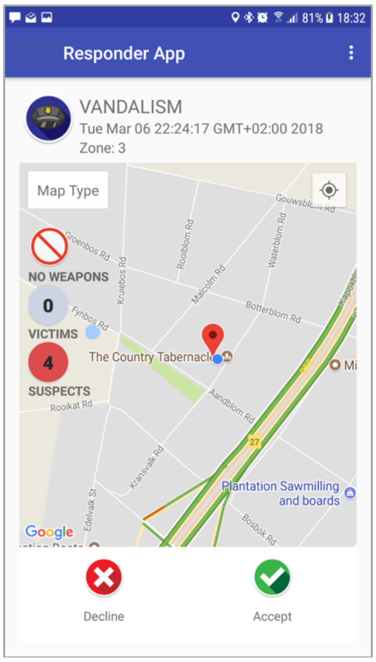

Fig. 4 - ENFORCEMENT Screenshot

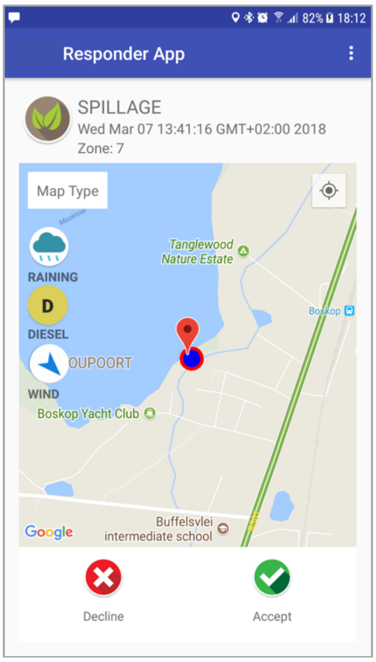

Fig. 5 - HAZMAT Screenshot

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 others 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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