5-15-2019

REDUCING THE COGNITIVE LOAD OF DECISION-MAKERS IN EMERGENCY MANAGEMENT THROUGH AUGMENTED REALITY

Milad Mirbabaie
University of Duisburg-Essen, milad.mirbabaie@uni-due.de

Jennifer Fromm
University of Duisburg-Essen, jennifer.fromm@uni-due.de

REDUCING THE COGNITIVE LOAD OF DECISION-MAKERS IN EMERGENCY MANAGEMENT THROUGH AUGMENTED REALITY

Research in Progress

Mirbabaie, Milad, University of Duisburg-Essen, Duisburg, Germany, milad.mirbabaie@uni-due.de

Fromm, Jennifer, University of Duisburg-Essen, Duisburg, Germany, jennifer.fromm@uni-due.de

Abstract

Decision processes in emergency management are particularly complex. Operations managers have to make decisions under time pressure while the situation at hand changes continuously. As wrong decisions in emergencies often have drastic effects, operations managers try to receive information from various sources such as the emergency control centre, their operation forces, databases, electronic location maps and drones. However, previous research has shown that humans have only limited information processing capabilities, and once these are exceeded, task performance decreases. Augmented Reality (AR) offers entire new possibilities to visualise information. Previous research on the relationship between the use of AR for information visualisation and the experienced cognitive load yielded contradictory results. By using the design science approach, we therefore aim to develop an AR decision support system. In a comparative eye-tracking study, we plan to examine how different types of AR information visualisation affect the experienced cognitive load of operations managers and thus decision-making. In this research-in-progress paper, we present the results of expert interviews with six operations managers who described three AR use cases in emergency management and five requirements for an AR decision support system.

Keywords: Augmented Reality, Cognitive Load, Decision-Making Support, Emergency Management.

1 Introduction

An emergency typically occurs suddenly and may result in severe human, environmental and economic damage (Mirbabaie & Zapatka, 2017; Parker, 1992; Stieglitz, Mirbabaie, & Milde, 2018). Preventing further damage requires emergency managers to quickly gain situational awareness and make decisions for immediate action (Seppänen et al., 2013; Stieglitz, Mirbabaie, Fromm, et al., 2018). It would be ideal if emergency managers could take their time to carefully collect enough verified information to make an optimal decision, as every wrong decision could result in further damage. In practice, however, emergency managers have to make decisions under time pressure and based on incomplete or uncertain information while the situation at hand often changes unexpectedly (Bunker et al., 2017). Besides, emergency managers typically have to process a large amount of information simultaneously as they frequently receive situational updates from emergency control centre personnel and their operation forces (Carver & Turoff, 2007). Prior studies on cognitive load have revealed that decision-making performance decreases with an increasing amount of information which needs to be processed in particular under time pressure (Workman, 2016). To improve decision-making in emergency situations, it is thus highly relevant to examine how information visualisation could be optimised to increase the information processing capabilities of emergency managers.

In recent years, Augmented Reality (AR) has moved into the focus of information systems research as a technology enabling to visualise a large amount of information in an entirely different way (Olshannikova et al., 2015). AR systems allow to enhance the user's field of vision by superimposing the real world with virtual objects (Azuma, 1997). The results of previous studies suggest that AR could enhance analytical reasoning and decision-making by allowing to present information in direct association with relevant objects in the real world (Chandler et al., 2015; ElSayed et al., 2016). In the context of emergency management, however, it is still uncertain how AR could be utilised to reduce the cognitive load of emergency managers and improve decision-making. Over the course of a two-year design science project, we therefore aim to develop and evaluate an AR decision support system for emergency managers in close cooperation with practitioners. Thereby, the project focuses on evaluating the impact of an AR decision support system on the experienced cognitive load of emergency managers and their decision-making performance in rescue and evacuation operations. In this research-in-progress paper, we describe how we plan to achieve our research goal by following the Design Science Research Process Model (Peffers et al., 2007) and present the results of the first and second phase of this research process. Hence, we address the following research questions within the scope of this paper:

RQ1: How can AR be utilised to support decision-making in emergency management?

RQ2: What requirements do emergency managers have for AR decision support systems?

This paper is structured as follows: The next section provides an overview about the theoretical foundations of decision making with a focus on how decision support systems influence the trade-off between maximising decision quality and reducing cognitive effort. Afterwards, previous studies on the relationship between AR and cognitive load are presented. Subsequently, the implementation and results of expert interviews with six emergency managers are described. The aim of these interviews is to identify use cases and requirements for AR decision support in emergency management to be able to develop a prototype for one of these use cases in the further course of the design science study. In the last section, it is described how the prototype development and evaluation will be carried out based on the results.

2 Background

2.1 Cognitive Effort Model of Decision-Making

Due to their limited capacity to absorb and process information, humans cannot always make optimal decisions (Sweller, 1988). To process information, humans first absorb cues via sensory memory, filtering out only the most relevant information and passing it on to working memory (Huang et al., 2009). There, information is processed and linked, while the newly acquired knowledge is then stored in long-term memory (Dosher, 2003). In contrast to long-term memory, however, working memory has a very low capacity. On average, humans are able to store seven unknown isolated information units in their working memory (Miller, 1956). If these information units have to be linked and processed with each other, the capacity is further reduced to four information units (Cowan, 2000). The cognitive effort associated with these mental operations can be reduced through the use of decision support systems which provide functionalities to decrease processing effort, memory effort and information tracking effort (Taylor, 1975). However, there remains the question of how the decision behaviour changes when using a decision support system. Traditional decision support systems literature assumes that decision makers would use the additional support to maximise the quality of their decisions (Keen & Scott Morton, 1978). In contrast, other scholars suggest that reducing cognitive effort also plays an important role and decision makers therefore make a trade-off between maximising decision quality and reducing cognitive effort (Payne, 1982). In a series of experiments, Todd and Benbasat (1991) examined this trade-off more closely and found that decision makers tend to use strategies to reduce cognitive effort as long as decision quality is not massively compromised.

In this context, it has also been shown that decision quality increases with the amount of available information up to the point where the information processing capacities of decision makers are exceeded (Schroder et al., 1967). A number of other studies have confirmed that cognitive load increases with a larger amount of information available and is associated with decreased decision quality (Deck & Jahedi, 2015; Hwang & Lin, 1999). A further study has revealed that higher cognitive load increases the time needed to make a decision as well as decision uncertainty (Davcheva & Benlian, 2018). When making decisions in emergency situations, cognitive load is particularly relevant since time pressure (Hahn et al., 1992; Workman, 2016), task complexity (Lyell et al., 2018) and personal involvement (Schaefer et al., 2015) have been shown to increase cognitive load. In order to make the best possible decisions during emergency situations, emergency managers must continuously process a large amount of information from various sources in order to maintain situational awareness (Seppänen, 2013). Thus, a high cognitive load is an inherent characteristic of decision-making in emergency situations. However, emerging technologies could influence the perceived cognitive load which is caused by a complicated representation of information. Since AR offers new possibilities to visualise information, it is relevant to investigate how this technology could contribute to reducing cognitive load of decision-makers in emergency management.

2.2 Augmented Reality and Cognitive Load

The basic characteristics of AR systems are that they 1) combine real and virtual content, 2) are interactive in real time and 3) registered in three dimensions (Azuma, 1997). Virtual content, however, does not only comprise the visual augmentation of the real world, but also the augmentation with artificially generated sounds, haptic experiences, smells and tastes (Geroimenko, 2012). AR can be experienced through a wide range of different devices including head-up displays, head-mounted displays, virtual retina displays, smart glasses and hand-held devices (van Krevelen & Poelman, 2010). An essential difference between AR and the similar concept of virtual reality is that users of an AR application always perceive their real environment, while a virtual reality application completely replaces their real environment with a virtual one (Milgram & Kishino, 1994). For this reason, AR is considered most useful when "the success [of a task] is increased or made more likely (...) through additional visual information being presented alongside the physical world" (Steffen et al., 2017). In the context of emergency management, there are already examples of AR applications that improve information access and situational awareness of first responders and operations managers (Lukosch et al., 2015; Tsai & Yau, 2013), cross-organisational and intra-organisational collaboration (Brunetti et al., 2015; Nilsson et al., 2011), and emergency response training (Sebillo et al., 2016).

Although researchers have developed AR applications for emergency management, the influence of information visualisation by means of AR on cognitive load has rather been investigated in other application domains. For example, earlier research revealed that AR assembly instructions in the user's field of vision required fewer cognitive resources to mentally transfer instructions from a computer screen to the assembly object (Tang et al., 2003). The potential of AR instructions to reduce cognitive load, assembly time and error rates has also been demonstrated in more recent studies (Hou et al., 2013; Re et al., 2016). Using a navigation system while driving is another task requiring mental transformation, since drivers must constantly switch their attention between the traffic situation and the navigation system. A study by Kim and Dey (2009) has revealed that displaying navigation arrows in the car windshield could reduce cognitive load by eliminating the need to divide attention between windshield and navigation system. In the context of student learning, AR could reduce cognitive load by allowing to present related information spatially close to each other (Bujak et al., 2013). The information presentation mode plays an important role for the reduction of cognitive load as well. Related to this, it has been demonstrated that the performance of warehouse pickers could be increased more drastically by a graphic-based AR user interface than by a text-based AR user interface (Kim et al., 2019). However, previous studies also revealed perceptual problems related to AR applications that could result in an increased cognitive load. The positioning of virtual content in the user's central field of vision, for example, could obscure real world objects and negatively affect information processing (Kishishita et al., 2014). The incorrect depth interpretation of virtual objects also represents a perceptual problem, which makes information processing more difficult (Kruijff et al., 2010). To avoid negative effects on cognitive load, researchers have emphasised the necessity to choose visualisations matching the mental models of users and to avoid overly cluttered user interfaces when designing AR applications (T. C. Endsley et al., 2017).

3 Design Science Research

The key objective of the described design science study is to investigate how an AR application should be designed in order to reduce the cognitive load of decision-makers in emergency management. In doing so, we followed the Design Science Research Methodology Process Model depicted in Figure 1 (Peffers, 2007) and the seven design science guidelines by Hevner (2004). In this research-in-progress paper, we present the results of the first two phases of the design science research process: 1) problem identification 2) objective definition of the solution.

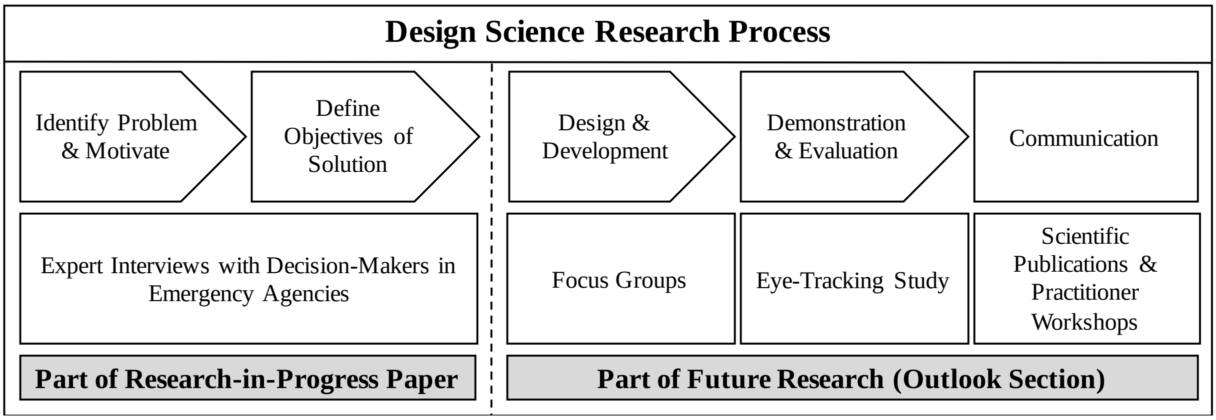

Figure 1. Design Science Research Methodology Process Modell based on Peffers (2007)

In order to gain an understanding of the problems faced by decision-makers in emergency management and to obtain ideas and requirements for an AR solution, we conducted semi-structured interviews with decision-makers from six different emergency agencies in Germany. In emergency management, a distinction can be made between strategic decision-making processes in the crisis unit and operational decision-making processes of operations managers on site. In this study, we focus on the use of AR to support the decision-making processes of operations managers, who accompany their task forces to the scene of the crisis, obtain an overview of the current situation there and coordinate their task forces on this basis. All respondents have already been active as operations managers for more than 10 years and made decisions about the activities of their assigned operations forces during emergency situations. Three of the interviewed operations managers belong to fire departments and take the lead in firefighting and rescue operations while the other interviewees work for different emergency organisations usually providing assistance for the fire department in charge. An overview of the persons interviewed can be found in Table 1.

No.	Name of Emergency Agency	Type of Emergency Agency	Job Title	Years of Service
1	Voluntary Fire Department No. 1	Fire Department	Formation Leader	26
2	Voluntary Fire Department No. 2	Fire Department	Fire Extinguishing Train Guide	18
3	Federal Agency for Technical Relief	Civil Protection and Disaster Management Organisation	Head of Department	27
4	Voluntary Fire Department No. 3	Fire Department	Head of Operations	16
5	German Red Cross	Welfare Organisation	Head of Operations	10
6	Johanniter-Unfall-Hilfe e.V.	Evangelical Aid Organisation	Specialist Supervisor	33

Table 1. Description of Respondents

Before the interviews were conducted, an interview guide with main questions on three topics was prepared. At the beginning of the interviews, the participants were informed about the aim of the study and their rights as participants. The interviewees then gave their consent to the recording of the interviews. In the first part of the interview, the interviewees were asked to describe which activities they carry out in their organisations, in which crises they become active and which decisions they make in their daily work. In the second part, the interviewees described the decision-making processes in their organisations in detail, including challenges and existing technical aids. Subsequently, AR was explained to the respondents with the help of an informative YouTube video (Intelligente Welt, 2014). In the third part of the interview, respondents were asked about ideas for using AR to support decision-making in crisis management. The interviewees were also asked to describe how they envision the implementation of such an application and what requirements they would have for an AR decision support system.

The method of inductive category formation according to Mayring (2014) was used to analyse the interviews. Based on the research questions formulated at the beginning, two different category systems were formed: 1) AR use cases and 2) requirements. We defined selection criteria for both category systems, and then checked the transcripts line by line for relevant text passages. A relevant text passage was either assigned to an existing category or a new category was created. Finally, similar categories of use cases or requirements were combined into one category to reduce the number of categories. For the first category system, all text passages describing use cases for AR decision support in emergency management were considered relevant. Mentioned use cases that did not fall under the definition of AR or did not refer to decision-making processes were not considered in the category system. The category system included three main use cases summarising six subcategories (U1: drone images and electronic location maps, drone images and setup of evacuation rooms or parking spaces, drone images and intelligent clothing; U2: car rescue instructions; U3: additional building information, simulation of hazardous substance reactions). For the second category system, all text passages were considered relevant in which the respondents described the requirements an AR application would have to fulfil in order to be accepted by them in everyday working life. The category system included five main requirements summarising nine subcategories (R1: tablet vs. safety visor, adaptable for different roles and emergency types; R2: intuitive usage, familiar devices and interaction; R3: robustness of hardware and software; R4: only visual stimuli, only limited selection of AR elements; R5: access to additional information, faster information access). The coding process was performed by two researchers independently of each other (Krippendorff's alpha = .83) and discrepancies were resolved by discussions.

4 Results

4.1 AR Use Cases

Use case 1: Augmenting live drone images with information gained from other sources

Almost every interviewee has explained that drones are already being used occasionally to increase the situational awareness of operations managers (*I1, I2, I4, I5, I6*). In particular, drones are used when large areas are affected by a crisis or when exploration by task forces would be too dangerous due to harmful substances. An operations manager can view the recordings of the drone in real time on a tablet and make decisions on this basis. All respondents also reported that electronic location maps showing the locations of sewers, water pipes, hydrants and pollutant storage sites have been in use for quite some time. Two respondents could well imagine displaying the information from electronic location maps as a visual overlay on live drone images (*I1, I4*). This would bear an immense advantage for decision making, as operations managers would no longer have to mentally link the information from the live drone image on a tablet with the information from the electronic location maps. Two respondents further thought it would be useful if they could add virtual objects to the live drone image to plan where evacuation rooms, treatment rooms, parking spaces for operations forces or helipads could be set up spontaneously (*I5, I6*). Another respondent had the idea to equip firefighters with intelligent protective clothing which allows to measure heart frequency and body temperature (*I2*). The interviewee considered it useful to augment live drone images with such information, so that an operations manager could make a timely decision to withdraw endangered forces.

Use case 2: Displaying instructions to free a person from an accident car

Many respondents have described that the release of a person from an accident car is associated with great uncertainty (*I2, I3, I4*). It is very important for emergency personnel to know where airbags, car batteries and gas cylinders are located as making a cut in the wrong place could result in an explosion further endangering the injured person and the emergency personnel. All those questioned have explained that the operations manager currently communicates the number plate of an accident car to the control centre, the control centre then retrieves the required data from the crash recovery system and sends it back to the operations manager by fax. The rescue of injured persons from accident cars is delayed by the cumbersome communication channels and the mental processing of the information from the fax. Three interviewees wished to have the position of explosive objects in the car displayed in their field of vision (*I2, I3, I4*). In addition, places should be marked where cuts can be made without risk of explosion (*I2, I3*).

Use case 3: Displaying additional information about buildings

Two respondents have explained that decisions in rescue operations are strongly influenced by the characteristics of a building (*I1, I3*). A lot of information is needed to decide which measures need to be taken to safely rescue people from a building. For example, it is relevant to know the type of building, the number of people inside, whether there are children, elderly or disabled people in the building and whether hazardous substances are stored in the building. One respondent therefore would like to have an AR application which automatically recognises a building when it is viewed and then displays such information in their field of vision (*I3*). As a result, improved decisions would be made in rescue operations and operations managers would experience less uncertainty when giving instructions. A few respondents further thought it would be useful if buildings with hazardous substances were automatically detected and warnings about hazardous substance reactions were then displayed in the field of vision of emergency personnel (*I1, I3*). An additional function could be the simulation of hazardous substance reactions, so that operations managers can better assess the consequences for the environment when making decisions (*I1*).

4.2 Requirements

Requirement 1: It should be possible to adapt AR hardware and software to the role of the user in the emergency operation and the type of emergency.

According to the respondents, operations managers are currently already working with a tablet and often view the information displayed together with other managers (*I1, I2, I3, I5, I6*). An AR application for operations managers should therefore run on a handheld device that is large enough to be viewed by several people at the same time (*I1, I5, I6*). In some operations, on the other hand, operations managers are required to wear protective clothing and do not have their hands free to operate a handheld device. The interviewees therefore considered the integration of AR elements into the visor of safety helmets or breathing masks as more useful in these cases (*I2, I3, I4*). Furthermore, emergency agencies are very hierarchically structured, and the information considered relevant for decision-making is different for each management level. An AR application should therefore be designed specifically for a certain management level or the type of information should be adaptable with as little effort as possible (*I2, I4*). The type of information required also depends on the type of emergency, so an AR application should either be designed for a particular type of emergency or be easily adaptable to different emergency situations (*I2, I4*).

Requirement 2: An AR application should preferably work on familiar end devices and be controlled in a way that is familiar from everyday smartphone use.

For many respondents, it was of great importance that an AR application could be operated intuitively even under stress and time pressure (*I1, I3, I6*). Instead of purchasing AR glasses as new, unfamiliar and expensive devices, the respondents preferred end devices such as tablets, which are already in use (*I1, I2, I3, I5, I6*). The display of visual elements in safety helmets was also evaluated as intuitive (*I2, I4, I4*), but one respondent doubted that investments would be made in protective clothing with AR functionalities, as these would have to be replaced more often due to damages (I2). The respondents further suggested that an AR application should preferably be operated with wiping gestures familiar from everyday smartphone use (*I1, I3, I6*). Voice input was also mentioned by one respondent as a possibility (*I2*), but the other respondents considered this to be less useful, as operations managers are often exposed to heavy noise (*I1, I4, I6*).

Requirement 3: AR hardware should withstand shock, moisture and extreme temperatures.

Since operations managers often work in extreme situations, all respondents considered a high degree of robustness of AR hardware necessary. Especially when used in burning buildings, AR hardware would have to withstand extremely high temperatures, while AR hardware would have to be water-resistant in the event of flooding or heavy rainfall. It was important for all respondents to be able to rely on AR hardware in emergency operations. However, many respondents doubted the robustness of current AR hardware and would fall back on tried and tested tools if necessary (*I1, I3, I6*).

Requirement 4: An AR application should only include a limited selection of visual AR elements to avoid a flood of stimuli and information overload.

In principle, AR offers not only the possibility to extend reality by visual elements, but also by auditory or haptic virtual elements. Respondents were asked explicitly whether they also have ideas for using these other forms of AR. Some respondents described ideas that were either not related to supporting decision-making or did not correspond to the definition of AR (*I1, I2, I4*). These use cases were therefore not included in the results. However, some respondents also explicitly objected to including further sensory experiences in AR applications, as they already perceive the flood of stimuli in emergency operations as stressful (*I3, I4, I5*). Furthermore, it was emphasised that although there is a lot of information that could be displayed as visual AR overlays, an AR application could only have an added value if the displayed information is limited to a meaningful selection. Otherwise, this would lead to information overload and thus worsen the decision-making performance (*I3, I4*).

Requirement 5: An AR application must provide information faster than other information systems or provide information that is not otherwise available.

Operations managers already have access to a large number of databases and information systems. According to the respondents, a major disadvantage of these existing technical aids is that often several communication steps are necessary to retrieve information (*I2, I3, I4*). Furthermore, a query often provides not only the information that is relevant in the current situation, but also a wealth of other information. All respondents were therefore interested in the possibilities of AR and would be willing to try out an AR application for the use cases described above. However, the respondents also emphasised that the costs and training effort would only be worthwhile if the AR application provided information faster than the existing information systems (*I2, I3, I6*). For a high acceptance on the part of decision-makers in emergency management, the added value should therefore play an essential role in the development of an AR application.

5 Conclusion and Outlook

In the previous section, we have presented the results of the first and second phase of a design science research study in which we aim to develop and evaluate an AR decision support system for emergency management. In future phases, we plan to investigate how the use of AR for information visualisation influences the experienced cognitive load of operations managers and their decision behaviour. As previous studies have come to contradictory results regarding the relationship between the use of AR for information visualisation and cognitive load, the results of our research will be an important theoretical contribution. Some studies have already shown that AR can reduce the cognitive effort for mental transformation tasks, since information can be visualised in direct connection with the relevant real world objects (Bujak, 2013; Kim, 2009; Tang, 2003). Other studies, however, pointed out that the perception and mental processing of several virtual overlays on top of the real world might increase cognitive load (T. C. Endsley, 2017; Kishishita, 2014; Kruijff, 2010). We therefore plan to develop a prototypical AR decision support system and evaluate in a comparative eye-tracking study how different types of AR information visualisation affect cognitive load and decision-making performance of operations managers.

To develop a prototypical AR decision support system, we conducted expert interviews with six operations managers in a first step. From these interviews, we identified three use cases for AR in decision processes and five requirements for an AR decision support system. All respondents would be willing to use an AR decision support system and expected less cognitive load related to the mental merging of real world objects (e.g. buildings, vehicles) with information from different sources (e.g. live drone images, electronic location maps, toxin databases, crash recovery system). In the context of the first use case, a few respondents also explained that it requires a high degree of imagination to make decisions about the setup of ad hoc treatment rooms, evacuation rooms, emergency response parking areas, and helipads. According to these respondents, cognitive load could be reduced if an AR decision support system would allow operations managers to create such areas as virtual objects, since a lower level of imagination would be required. However, for the successful implementation of an AR decision support system, respondents also described some requirements – in the context of cognitive load, the fourth requirement is particularly noteworthy. Some respondents have pointed out that they are already experiencing a flood of stimuli and information overload in operations, which is why an AR decision support system should only contain a limited number of virtual objects and should also be limited to a visual augmentation of the real world.

In the further course of the design science study, we will conduct explanatory focus groups with operations managers. Thereby, we will follow the procedural model of Tremblay et al. (2010) which outlines how focus groups can be used in a design science context to refine and evaluate prototypes. In these focus groups, the participants will discuss which use case has the greatest potential to reduce cognitive load of operations managers in emergency situations and then select this use case for implementation. For this specific use case, we will conduct a goal directed task analysis specifically developed to derive requirements for systems enhancing situational awareness and decision-making (M. R. Endsley et al., 2003). The knowledge obtained through this analysis will help us to refine the requirements we already presented in this research-in-progress paper. During the evaluation phase, the AR decision support system will be used by operations managers during emergency exercises. The perceived cognitive load and the decision-making performance of operations managers will be compared during an exercise without AR and during an exercise with AR. As a subjective measurement instrument, we will use the NASA-Task Load Index which is a commonly used scale to measure cognitive load (Galy et al., 2012). Decision-making performance will be measured with this instrument as well, since the NASA-Task Load Index also includes a performance subscale. In addition, the decision-making performance will be rated by the instructor and we will measure the time needed to make decisions. In the AR exercises, we further plan to vary the number, placement and presentation form of the visual AR elements to determine differences in cognitive load. The Dikablis eye tracking glasses will be used to record the fixation count, dwell time and blink rate of the operations managers (Ergoneers, 2018) as it has already been shown in previous studies that these metrics vary depending on the cognitive load (Martin, 2014). Based on these results, we aim to derive design principles for the development of future AR decision support systems.

References

Azuma, R. T. (1997). A Survey of Augmented Reality. *Teleoperators Virtual Environment*, *6*(4), 355–385.

Brunetti, P., Croatti, A., Ricci, A., & Viroli, M. (2015). Smart Augmented Fields for Emergency Operations. *Procedia Computer Science*, *63*, 392–399.

Bujak, K. R., Radu, I., Catrambone, R., Macintyre, B., Zheng, R., & Golubski, G. (2013). A Psychological Perspective on Augmented Reality in the Mathematics Classroom. *Computers & Education*, *68*, 536–544.

Bunker, D., Mirbabaie, M., & Stieglitz, S. (2017). Convergence Behaviour of Bystanders: An Analysis of 2016 Munich Shooting Twitter Crisis Communication. In *Proceedings of the 28th Australasian Conference on Information Systems*.

Carver, L., & Turoff, M. (2007). Human-Computer-Interaction: The Human and Computer as a Team in Emergency Management Information Systems. *Communications of the Association for Computing Machinery, 50*(3), 33–38.

Chandler, T., Cordeil, M., Czauderna, T., Dwyer, T., Glowacki, J., Goncu, C., Klapperstueck, M., Klein, K., Marriot, K., Schreiber, F., & Wilson, E. (2015). Immersive Analytics. In *Proceedings of the International Symposium on Big Data Visual Analytics*.

Cowan, N. (2000). Processing Limits of Selective Attention and Working Memory: Potential Implications for Interpreting. *Interpreting*, *5*(2), 117–146.

Davcheva, E., & Benlian, A. (2018). Visual Decision-Making in Real-Time Business Intelligence: A Social Media Marketing Example. In *Proceedings of the 51st Hawaii International Conference on System Sciences* (pp. 1319–1328).

Deck, C., & Jahedi, S. (2015). The Effect of Cognitive Load on Economic Decision Making: A Survey and New Experiments. *European Economic Review*, *78*, 97–119.

Dosher, B. (2003). Working Memory. *Encyclopedia of Cognitive Science, 4*, 569–577.

ElSayed, N. A., Thomas, B. H., Marriot, K., Piantadosi, J., & Smith, R. T. (2016). Situated Analytics: Demonstrating Immersive Analytical Tools with Augmented Reality. *Journal of Visual Languages & Computing*, *36*, 13–23.

Endsley, M. R., Bolte, B., & Jones, D. G. (2003). *Designing for Situation Awareness: An Approach to Human-Centered Design*. London: Taylor & Francis.

Endsley, T. C., Sprehn, K. . A., Brill, R. M., Ryan, K. J., Vincent, E. C., & Martin, J. M. (2017). Augmented Reality Design Heuristics: Designing for Dynamic Interactions. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* (pp. 2100–2104).

Ergoneers. (2018). *Eye-Tracking Dikablis Glasses*. URL: https://www.ergoneers.com/en/hardware/dikablis-glasses/ (visited on 03/23/2019).

Galy, E., Cariou, M., & Melan, C. (2012). What Is the Relationship between Mental Workload Factors and Cognitive Load Types? *International Journal of Psychophysiology*, *83*(3), 269–275.

Geroimenko, V. (2012). Augmented Reality Technology and Art: The Analysis and Visualization of Evolving Conceptual Models. In *Proceedings of 16th International Conference on Information Visualisation* (pp. 445–453).

Hahn, M., Lawson, R., & Lee, Y. G. (1992). The Effects of Time Pressure and Information Load on Decision Quality. *Psychology & Marketing*, *9*(5), 365–378.

Hevner, A. R., March, S. T., Park, J., & Ram, S. (2004). Design Science Research in Information Systems Research. *Management Information Systems Quarterly*, *28*(1), 75–105.

Hou, L., Wang, X., Bernold, L., & Love, P. E. (2013). Using Animated Augmented Reality to Cognitively Guide Assembly. *Journal of Computing in Civil Engineering, 27*(5), 439–451.

Huang, W., Eades, P., & Hong, S. H. (2009). Measuring Effectiveness of Graph Visualizations: A Cognitive Load Perspective. *Information Visualization, 8*(3), 139–152.

Hwang, M. I., & Lin, J. W. (1999). Information Dimension, Information Overload and Decision Quality. *Journal of Information Science, 25*(3), 213–218.

Intelligente Welt. (2014). *Augmented Reality: Beispiele für den Schritt in eine "neue" Welt*. URL: https://www.youtube.com/watch?v=bejVzZ6vfas (visited on 03/23/2019).

Keen, P., & Scott Morton, M. S. (1978). *Decision Support Systems*. Reading, MA: Addison Wesley.
Kim, S., & Dey, A. K. (2009). Simulated Augmented Reality Windshield Display as a Cognitive Mapping Aid for Elder Driver Navigation. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 133–142).
Kim, S., Nussbaum, M. A., & Gabbard, J. L. (2019). Influences of Augmented Reality Head-Worn Display Type and User Interface Design on Performance and Usability in Simulated Warehouse Order Picking. *Applied Ergonomics*, *74*, 186–193.
Kishishita, N., Kiyokawa, K., Orlosky, J., Mashita, T., Takemura, H., & Kruijff, E. (2014). Analysing the Effects of a Wide Field of View Augmented Reality Display on Search Performance in Divided Attention Tasks. In *IEEE International Symposium on Mixed and Augmented Reality* (pp. 177–186).
Kruijff, E., Swan, J. E., & Feiner, S. (2010). Perceptual Issues in Augmented Reality Revisited. In *9th IEEE International Symposium on Mixed and Augmented Reality* (pp. 3–12).
Lukosch, S., Lukosch, H., Datcu, D., & Cidota, M. (2015). Providing Information on the Spot: Using Augmented Reality for Situational Awareness in the Security Domain. *Computer Supported Cooperative Work*, *24*(6), 613–664.
Lyell, D., Magrabi, F., & Coiera, E. (2018). The Effect of Cognitive Load and Task Complexity on Automation Bias in Electronic Prescribing. *Human Factors*, *60*(7), 1008–1021.
Martin, S. (2014). Measuring Cognitive Load and Cognition: Metrics for Technology-Enhanced Learning. *Educational Research and Evaluation*, *20*(7), 592–621.
Mayring, P. (2014). *Qualitative Content Analysis: Theoretical Foundation, Basic Procedures and Software Solution*. Klagenfurt: Beltz.
Milgram, P., & Kishino, F. (1994). A Taxonomy of Mixed Reality Visual Displays. *Transactions on Information and Systems*, *77*(12), 1321–1329.
Miller, G. A. (1956). The Magical Number Seven, Plus or Minus Two: Some Limits on Our Capacity for Processing Information. *Psychological Review*, *101*(2), 343–352.
Mirbabaie, M., & Zapatka, E. (2017). Sensemaking in Social Media Crisis Communication - A Case Study on the Brussels Bombings in 2016. In *Proceedings of the 25th European Conference on Information Systems* (pp. 2169–2186).
Nilsson, S., Johansson, B. J., & Jonsson, A. (2011). Cross-Organizational Collaboration Supported by Augmented Reality. *IEEE Transactions on Visualization and Computer Graphics*, *17*(10), 1380–1392.
Olshannikova, E., Ometov, A., Koucheryavy, Y., & Olsson, T. (2015). Visualizing Big Data with Augmented and Virtual Reality: Challenges and Research Agenda. *Journal of Big Data*, *2*(1), 22.
Parker, D. J. (1992). Flood Disasters in Britain: Lessons from Flood Hazard Research. *Disaster Prevention and Management: An International Journal*, *1*(1).
Payne, J. W. (1982). Contingent Decision Behavior. *Psychological Bulletin*, *92*(2), 382–402.
Peffers, K., Tuunanen, T., Rothenberger, M. A., & Chatterjee, S. (2007). A Design Science Research Methodology for Information Systems Research. *Journal of Management Information Systems*, *24*(3), 45–77.
Re, G. M., Oliver, J., & Bordegoni, M. (2016). Impact of Monitor-Based Augmented Reality for On-Site Industrial Manual Operations. *Cognition, Technology & Work*, *18*(2), 379–392.
Schaefer, M., Rumpel, F., Sadrieh, A., Reimann, M., & Denke, C. (2015). Personal Involvement is Related to Increased Search Motivation and Associated with Activity in Left BA44 - A Pilot Study. *Frontiers in Human Neuroscience*, *9*, 144.
Schroder, H. M., Driver, M. J., & Streufert, S. (1967). *Human Information Processing: Individuals and Groups Functioning in Complex Social Situations*. New York: Holt, Rinehart and Winston.
Sebillo, M., Vitiello, G., Paolino, L., & Ginige, A. (2016). Training Emergency Responders Through Augmented Reality Mobile Interfaces. *Multimedia Tools and Applications*, *75*(16), 9609–9622.
Seppänen, H., Mäkelä, J., Luokkala, P., & Virrantaus, K. (2013). Developing Shared Situational Awareness for Emergency Management. *Safety Science*, *55*, 1–9.
Steffen, J. H., Gaskin, J., Meservy, T., & Jenkins, J. (2017). The Missing Framework for Virtually Assisted Activities. In *38th International Conference on Information Systems*.

Stieglitz, S., Mirbabaie, M., Fromm, J., & Melzer, S. (2018). The Adoption of Social Media Analytics for Crisis Management - Challenges and Opportunities. In *Proceedings of the 26th European Conference on Information Systems*.

Stieglitz, S., Mirbabaie, M., & Milde, M. (2018). Social Positions and Collective Sense-Making in Crisis Communication. *International Journal of Human-Computer Interaction*, *34*(4), 328–355.

Sweller, J. (1988). Cognitive Load during Problem Solving: Effects on Learning. *Cognitive Science*, *12*(2), 257–285.

Tang, A., Owen, C., Biocca, F., & Mou, W. (2003). Comparative Effectiveness of Augmented Reality in Object Assembly. In *21st Conference on Human Factors in Computing Systems* (pp. 73–80).

Taylor, R. N. (1975). Psychological Determinants of Bounded Rationality: Implications for Decision Making Strategies. *Decision Sciences*, *6*(3), 409–429.

Todd, P., & Benbasat, I. (1991). An Experimental Investigation of the Impact of Computer Based Decision Aids on Decision Making Strategies. *Information Systems Research*, *2*(2), 87–115.

Tremblay, M. C., Hevner, A. R., & Berndt, D. J. (2010). Focus Groups for Artifact Refinement and Evaluation in Design Research. *Communications of the Association for Information Systems*, *26*, 599–618.

Tsai, M. K., & Yau, N. J. (2013). Improving Information Access for Emergency Response in Disasters. *Natural Hazards*, *66*(2), 343–354.

van Krevelen, D. W. F., & Poelman, R. (2010). A Survey of Augmented Reality Technologies, Applications and Limitations. *International Journal of Virtual Reality*, *9*(2), 1–21.

Workman, M. (2016). Cognitive Styles and the Effects of Stress from Cognitive Load and Time Pressures on Judgemental Decision Making with Learning Simulations: Implications for HRD. *International Journal of Human Resources Development and Management*, *16*(1–2), 30–46.