Assessing the Impact of a GIS for Improving Novice Crisis Decision-Making

Completed Research

Adam R. Albina
Saint Anselm College
aalbina@anselm.edu

Abstract

An increase in organizational emergencies warrants investigation into emergency management information systems that serve a novice crisis decision-maker. Small campus-based enterprises such as higher education, and corporate campuses, with no dedicated emergency management offices generally press novice decision-makers into emergency management roles. An investigation was conducted to assess the impact of an emergency management geographic information system (EMGIS) on the decision performance of novice crisis decision-makers through the use of a scenario-based simulation. A mixed method design was used to collect quasi-experimental data on decision time, decision accuracy and situational awareness. Qualitative analysis was also conducted. Statistical results indicated that decision accuracy is positively affected by the use of an EMGIS. Data Envelopment Analysis indicated that efficiency ratios of the EMGIS group outperform the traditional group. Geographic information systems hold much promise in providing systems that are easy to use, promote heightened levels of situational awareness and decision support.

Keywords

Emergency Management, geographic information systems, novice decision support

Introduction

Organizations are often faced with crisis in the form of natural and man-made hazards. A crisis is generally referred to as a point in time event, perhaps within the context of a disaster, as events unfold and lead to potential increases in a dangerous situation (Haddow, Bullock, & Coppola 2014). Natural disasters impact organizations and surrounding communities concurrently, often limiting the intervention of civil emergency response personnel. These types of events tax the organizational structure and the decision-making of the institution. Generally, smaller organizations lack dedicated emergency management departments and formally trained staff. In smaller organizations such as small institutions of higher education (IHEs), staff supporting the emergency management function are often doing so as an additional duty and have very little or no experience in emergency management (Sullivan, 2012).

A Geographic Information System (GIS) is a combination of hardware, software, and communication medium, employed to generate, collect and disseminate useful contextualized information (Jung, Schneider, & Valacich, 2010). A natural extension of mapping and cartography in the digital age, the GIS represents the earth and multi-layers of related objects in a familiar map-based paradigm. GISs are increasingly used in professional emergency management and are gaining wider acceptance. Free web-based tools allow greater familiarity with basic GIS operations and have become ubiquitous in their use in personal navigation.

There is a potentially important gap of research focused on novice decision-maker support during crisis events especially in a smaller organizational context. Local emergency response organizations such as police, fire and emergency medical services may be fully engaged in the most serious centers of the incident or be spread quite thin over a geographically large response area. Under such conditions, it is likely that novices who are on the scene by virtue of their positions in affected organizations will be temporarily forced into roles for which they are ill equipped, untrained, and unprepared. The use of GISs may provide support for novice crisis decision-makers and facilitate more timely and accurate decision-making in smaller organizations faced with large to medium-scale crisis situations.

This study investigates the impact of an emergency management GIS on the decision performance of novice crisis decision-makers through the use of a scenario-based simulation.

Review of Literature

A general understanding of the context for this research begins with emergency management in the United States shifting from a central governmental preparedness and response to one that includes community-based preparedness and response. A brief review of research in the area of decision-making in emergency management will underscore the issues in novice decision-making. The research into GIS in emergency management provides a picture of the current technology. Each of these areas is explored against the backdrop of Situational Awareness theory.

Emergency Management

Managing, responding and reacting to emergencies, disasters, crises and catastrophes are all considered part of the emergency management domain. Emergency management can be defined as a "discipline that deals with risk and risk avoidance" (Haddow et al., 2014, p2). The 1993 World Trade Center bombing in New York City and the Oklahoma City Federal Building bombing ushered in a new era of emergency management as terrorism became a national priority. The Federal Emergency Management Agency (FEMA) published a new community-based approach called Project Impact: Building Disaster-Resistant Communities. The project called for communities to establish partnerships across the community to include all stakeholders. In 2003, FEMA, now under the Department of Homeland Security, extended the whole community approach and published a guidebook on building the disaster-resistant university. Several phases rely on detailed campus wide and local community mapping technologies to inform related activities. GIS systems were recommended as an appropriate tool for creating detailed hazard profiles, predicting scope and extent of potential damage associated with a hazardous incident, as well as identifying potential vulnerabilities. The FEMA Guide Book specifically detailed the type of information needed in a GIS. FEMA Publication 386-2: Understanding your risks - Identifying Hazards and Estimating Losses states, "maps produced with GIS can help to explain hazard events, predict outcomes, visualize scenarios, and plan strategies" (p. 6).

Novice Decision-making in Emergency Management

Laakso and Palomäki define three simplified questions all emergency management decision-makers face: "1. What has happened and what is happening? 2. What should be done now (and next)? and 3. How can we gather the necessary resources available to do that?" (p. 1712). In the early stages of a crisis or disaster, the first people on the scene are generally from the affected organization. Assuming the role of an incident commander, making appropriate decisions, acting as effectively as possible and communicating with those affected and emergency services is vital (2013).

Emergency Management decision support research has largely been conducted using emergency management teams that have a fairly high level of experience. Perry et al. (2012) found that although inexperienced decision-makers can be guided to attend to the same information to which experienced decision-makers attend, the decision accuracy of less-experienced decision-makers does not necessarily improve. Lack of decision maker experience is an important limitation in decision performance (Klein 1997). To exacerbate the lack of experience, environmentally imposed time pressure, as in a crisis situation, contributes negatively to decision performance. Mishra et al. confirm prior research that suggests that novices make decisions in entirely different ways than do experienced decision-makers (Mishra, Allen, & Pearman 2013). They conclude that it is imperative to study the information practices of novice and experts separately when working under environments that are time constrained, complex and uncertain. Novices tend toward normative decision-making strategies and experienced decision-makers tend toward more intuitive recognition primed models.

Geographic Information Systems in Emergency Management

Command and control have been of interest to the Human Computer Interaction (HCI) community for many years (Scott, Wan, Rico, Furusho, & Cummings 2007). In practice, a map or GIS-based display is an effective tool for fostering situational awareness (SA), confirming earlier research into decentralized command and control environments. In a crisis, the novice will be more easily overwhelmed with information and this could hinder their ability to process relevant information and result in a decrease in decision performance (Perry, Wiggins, Childs, & Fogarty 2012). Using a geospatial reference and augmenting familiar mapping constructs with annotations externalizing situational artifacts such as road blockages, flooded areas, weather related phenomena etc. provides a reduced burden on cognitive overhead needed to process such contextual information (Wu, Convertino, Ganoe, Carroll, & Zhang, 2013). SA is a critical and ongoing activity informing decision-making and subsequent action in emergency response (Ley et al. 2014). A geospatial paradigm is an effective technology for SA in a distributed environment (Gorman, Cooke, & Winner 2006).

Situational Awareness Theory

SA has long been a staple construct of the HCI community and codified in 1995 with a long standing theory by Endsley who recently defended it (Endsley 2015). SA for an individual in an emergency management context is composed of three levels: perception, comprehension and projection. Perception, or Level 1 SA, involves attending to the important attributes and information in the affected emergency environment. Comprehension, or Level 2 SA, of the situation is achieved through synthesis of the relevant elements recognized in Level 1 SA and an understanding of their significance in light of the goals of the crisis manager. A novice crisis decision-maker may not be able to extract the broader meaning of the Level 1 elements as well as a more experienced one. Finally, a crisis manager is able to project the future actions or states of the relevant elements recognized in Level 1 and operationalized in Level 2 in order to be actionable in the projection, or Level 3 SA (Kaber et al. 2013). The crisis manager seeks necessary information and balances information seeking against the goal driven requirements of the crisis, protecting life, protecting property, adhering to time constraints, etc. Crisis situations are most often very time sensitive and characterized by significant uncertainty compounding the achievement of Level 3 SA for a novice.

Methodology

A mixed methods sequential explanatory design was selected in order test the research hypotheses and answer the posited research questions. The research relied on a quantitative method for initial experimental data collection while concurrently acknowledging that the addition of qualitative post experimental data collection and analysis could yield a greater depth of understanding. The quantitative strand of research was concerned with the measurable impact of an EMGIS on decision time, decision accuracy and SA. The qualitative strand was concerned with the interaction between the variables and the perceived impact of the treatment. The specific design for the quantitative research strand was quasi-experimental. The specific design for the qualitative research strand was a combination of non-parametric statistical method in the form of Data Envelopment Analysis (DEA) and phenomenological method using structured interviews. Data analysis was the point of mixture of the methods.

Participants were pre-screened for qualification as novice crisis decision-makers and randomly assigned to two groups. A computer based virtual table top exercise was conducted with participants acting as the incident commander during the scenario-based simulation. One group used an Emergency Management GIS (EMGIS) and the other group used more traditional paper-based resources. For both groups, the nonEMGIS group and the EMGIS group, the same information relevant to the decision scenarios was provided. Each group had a period of training designed by the researcher, and conducted by previously trained undergraduate research assistants to familiarize them with the resources they had available to them in the conduct of the simulation. The EMGIS group received training on the EMGIS. The non-EMGIS group received training on the use of traditional paper-based tools, and an orientation of the informational assets available to them. Decisions were required at specific times throughout the scenario and decision accuracy, and decision time were recorded. SA was evaluated post experiment using standard SA instrument.

Hypotheses and Research Questions

A scenario-based simulation was conducted to test the following hypotheses:

H1: Use of an Emergency Management GIS-based system by a novice decision-maker reduces critical decision-making time during a simulated crisis response.

H2: Use of an Emergency Management GIS-based system by a novice decision-maker increases accuracy in critical decisions during a simulated crisis response.

H3: Use of an Emergency Management GIS-based system by a novice decision-maker increases SA during a simulated crisis response.

Additionally, the following research questions (RQs) were addressed qualitatively through DEA and a phenomenological qualitative approach:

RQ1: How does the use of an Emergency Management GIS-based system by a novice decision-maker affect decision-making performance, as a function of time, accuracy and SA during a simulated crisis response?

RQ2: What are the perceived benefits and drawbacks of an Emergency Management GIS for the novice decision-maker in a small organizational context?

Approach

A computer based virtual table top exercise similar to those used for training at the FEMA Emergency Management Institute, was conducted with one participant at a time acting as the incident commander during the scenario-based simulation. The crisis scenario was as realistic as possible for the participant as well as sufficiently specialized to require information seeking and good SA. Throughout the course of the simulation, a set number of decisions were required of the participant at specific and consistent times. Although participants were told that weather conditions were automatically updated through the EMGIS connection to the National Oceanographic and Atmospheric Administration, the connection was simulated. Additionally, participants were told that the EMGIS was connected to the state GIS system and that the state would be updating incident locations and road closures, the connection was also simulated. For both groups, the nonEMGIS group and the EMGIS group, the same information relevant to the decision scenarios was provided. The manner in which the information was provided was different for each group. The EMGIS group was able to select layers in the EMGIS using custom coded intuitive buttons to overlay information on the GIS system and select informational attributes from the GIS artifacts. The non-EMGIS group had the 2016 Emergency Response Guidebook and relevant informational binders. The EMGIS group received training on the EMGIS. The non-EMGIS group received training on the use of the Guidebook, and an orientation to the other informational assets available to them. Training took approximately 15 minutes. The training provided was specific to the operation of the EMGIS or use of the materials provided. Training did not include emergency management nor crisis response training. The scenario from start to finish took between 23 and 30 minutes and five decision choices were required of the participant.

In order to test H1, the time to make a decision was measured during the experiment. Decision time is a fairly straightforward construct and is defined as the time required to reach a decision outcome (McGrath 1990, 1991). Time was started when each of the five decisions was required in the simulation and stopped when the decision was rendered. In order to test H2, the accuracy of each required decision during the scenario was measured. The decision accuracy construct is defined as the difference between the decision-maker's choice and the prior choice ranking determined from the answers of experts. In order to test H3, SA was measured using a standard rating scale. SA was measured using the Situational Awareness Rating Technique (SART) (Taylor 1990) administered post scenario The SART responses were calculated and score for each SA component (understanding, attentional demand, and attentional supply) as well as the single composite SART score were recorded for each participant. In order to answer RQ1, a DEA was performed with the input of decision time and the outputs of decision accuracy and SA. A relative efficiency frontier was constructed from the efficiency scores for each participant. A DEA model based on a constant return to scale was used as a non-parametric measure in recognition that decision time, decision accuracy and SA are likely related in non-trivial ways. In order to answer RQ2, a qualitative assessment of the use of an EMGIS was measured through structured interviews with EMGIS group participants immediately following the conclusion of the simulation. Questions were structured in terms of evaluation of the overall impact, issues or concerns with EMGIS use in a small organizational context, and positives and negatives with EMGIS. Thematic analysis was conducted through an open coding method followed by an axial coding method of the interviews.

Instrumentation

Instrumentation for the experiment included a qualification questionnaire, the simulation scenario, an EMGIS system, simulation software and SART instrument. Instrumentation was tested during pilot experimental trials and modified as necessary. Where such modifications were required, threats to validity were evaluated. In order to determine if a potential participant was actually a novice crisis decision-maker, a simple questionnaire was developed to assess the experience level of the potential participant in the area of emergency management.

Potential scenarios and situation manuals were provided by a Program Manager at FEMA Emergency Management Institute. The Program Manager is the Virtual Table Top Exercise Program (VTTX) Manager and an expert in the development and execution of scenario-based exercises for training and evaluation in emergency management. From the scenarios and materials provided by FEMA, the Hazardous Material (HAZMAT) spill of chlorine liquid requiring evacuation and mitigation was selected.

ESRI ArcMap™ was used largely due to the Python API library (arcpy) that allows add-ins to be developed for specific geospatial applications. In order for the interface to support a novice user, only the simplest elements were allowed on the screen. Four custom add-ins buttons were developed in Python, installed into ArcMap™ and aggregated into an EMGIS toolbar that was positioned alongside the basic navigation toolbars in the ribbon menu. Almost all of the screen real-estate was dedicated to the mapping function. The EMGIS toolbar contained four buttons. There was a custom add-in button that launched the Cameo Chemical Database as a sub-process of ArcMap™ and allowed the participant to search for a hazard by name or United Nations/North American Hazardous Materials (UN/NA) Code typically found on a vehicle placard. Once found, the participant was able to read the Material Safety Data Sheet (MSDS) for the hazard which included isolation guidance as well as downwind protection guidance. A second button was developed that launched a chemical danger zone predictor tool and provided a dialog box that accepted the name of the chemical, the type of spill and the amount of the spill. Since the EMGIS was automatically updated in terms of weather conditions, no weather information was required. The third button was a toggle for the danger zone overlay. Clicking this button effectively turned on a previously created layer of the downwind chemical dispersion cloud with the accident site automatically selected as the point of origin for the spill.

An agreement with Applied Training Solutions, LLC (ATS) provided free use of the Consequences Management Staff Trainer™ (CMST) for the experiment. CMST is a simple-to-use, interactive, web-based exercise platform used by commercial, government and military organizations to prepare for a wide range of natural and man-made emergency situations (Applied Training Systems, 2017). The final simulation contained twenty scenario events, five decision points and a compressed timeline of twenty-three minutes.

SA was measured using the Situational Awareness Rating Technique (SART) (Taylor 1990) administered post scenario. The SART instrument provides a high – low rating scheme on a scale of 1-7 and rating are combined in order to arrive at a single composite measure of participant SA. SART is focused on ten dimensions grouped into three domains to measure SA. Familiarity with the situation, information quantity and information quality make up the domain called understanding (U). Division of attention, concentration of attention, arousal and spare mental capacity make up the domain called attentional supply (S). Instability of the situation, complexity of the situation and variability of the situation make up the domain called attentional demand (D). A composite SART score was calculated using the following formula: $SA = U - (D - S)$. Where: U = summed understanding, D = summed demand, S = summed supply. The post scenario SART score was calculated and each domain score as well as a single composite SART score recorded for each participant.

Results

Data was collected on participant decision time, decision accuracy and SA. Decision times for each of five decision points was summed for a total decision time variable in seconds for each participant. Decision accuracy for each of the five decision points was summed for a total decision accuracy variable for each participant. SA was measured immediately after the simulation concluded using the SART instrument. The SART score was recorded for each participant.

Responses to the qualification questionnaire for qualified participants indicated that none of the selected participants had any formal emergency management training. No selected participant had ever been an incident commander. No selected participant had ever served in the armed forces or was currently serving, nor had ever been in law enforcement or emergency medical services. About a quarter of the participants were between the ages of 20 and 29. The majority of the participants were 40 or older (56%). There were slightly more female participants than male (57%) and overwhelmingly participants held an academic degree of bachelor's or higher (93%) with slightly more than half holding at least a master's degree (60%).

Preliminary Data Analysis

The data for all variables were pre-screened for quality, missing data, outliers and normality. Analysis showed there were no bad or missing data elements. Mahalanobis distance and an associated chi-square statistic was calculated for each respondent and evaluated against an alpha level of 0.05. There were two cases classified as outliers in the data set ($p < 0.05$) and both cases were excluded from parametric analysis. All variable distributions were sufficiently normal for the purposed of conducting the t-test (i.e., skew < |2.0| and kurtosis < |9.0|). Total decision time exhibited skewness and kurtosis of -0.876 and 0.392 respectively, total decision accuracy exhibited skewness and kurtosis of -0.605 and .925 respectively, and SART exhibited skewness and kurtosis of -0.876 and .392 respectively.

A two-tailed bi-variate Pearson Correlation (using an alpha level of 0.05) for the dependent variables for all hypotheses indicate there is a strong negative correlation between decision time and decision accuracy ($r = -0.502$, $n = 28$, $p = 0.007$). This indicates that as decision time increased, decision accuracy decreased. It is not unexpected that decision time and decision accuracy are related. More difficult decisions potentially require more time and analysis then less complex decisions.

Data Analysis

The EMGIS group (N = 14) was associated with shorter overall decision time M = 392.79 (SD = 100.09). By comparison, the non-EMGIS group (N = 14) was associated with numerically longer overall decision time M = 472.07 (SD = 154.85). To test H1, an independent sample t-test was performed. The assumption of homogeneity of variance was tested and satisfied via Levene's F test, $F(26) = 3.353$, $p = 0.079$. The independent sample t-test was not associated with a statistically significant effect, $t(26) = 1.609$, $p = 0.120$. There is little statistical support for H1 and therefore requires a failure to reject the NULL hypothesis. The EMGIS group was not associated with a statistically significant improvement in decision time over the non-EMGIS group.

The EMGIS group (N = 14) was associated with higher overall decision accuracy M = 16.64 (SD = 1.59). By comparison, the non-EMGIS group (N = 14) was associated with numerically lower overall decision accuracy M = 15.29 (SD = 1.77). To test H2, an independent sample t-test was performed. The assumption of homogeneity of variance was tested and satisfied via Levene's F test, $F(26) = 0.003$, $p = 0.959$. The independent sample t-test was associated with a statistically significant effect, $t(26) = -2.127$, $p = 0.043$, significant at the $p<0.05$ level. There is statistical support for H2 and the NULL hypothesis is rejected. The EMGIS group was associated with a statistically significant improvement in decision accuracy over the non-EMGIS group.

The EMGIS group (N = 14) was associated with higher overall SA scores M = 20.57 (SD = 4.831). By comparison, the non-EMGIS group (N = 14) was associated with numerically lower overall SA scores M = 19.86 (SD = 3.634). To test H3, an independent sample t-test was performed. The assumption of

	EMGIS			Non-EMGIS				
Measure	*M*	*SD*		*M*	*SD*	*t*(26)	*p*	Cohen's *d*
Time	392.79	100.09		472.07	154.85	1.60	0.120	0.60
Accuracy	16.64	1.59		15.29	1.77	-2.12	0.043*	0.79
SA	20.57	4.83		19.86	3.63	-0.44	0.662	0.16

Note: * Significant at the p<.05 level.

Table 1. Group differences for decision time, accuracy and SA.

homogeneity of variance was tested and satisfied via Levene's F test, F(26) = 0.065, p = 0.800. The independent sample t-test was not associated with a statistically significant effect, t(26) = -.442, p = 0.662. There is little statistical support for H3 and therefore requires a failure to reject the NULL hypothesis. The EMGIS group was not associated with a statistically significant improvement in SA over the non-EMGIS group. All results are summarized in Table 1.

Intuitively, the three variables under analysis appear to be related. The time required to make a decision may be influenced by the complexity/difficulty of the decision. The accuracy of the decision may be influenced by one's understanding of the situation and perhaps the time one has to make a decision. The

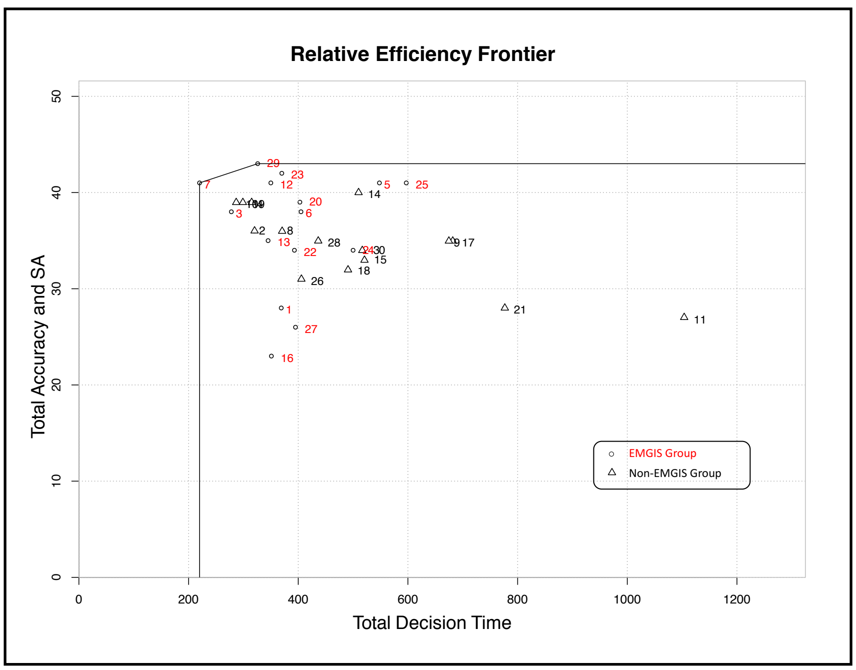

Figure 1. Relative Efficiency Frontier

level of SA likely influences both decision time and accuracy. The previous Pearson Correlation indicated that decision time and decision accuracy where correlated when evaluated (p < 0.05). In order to explore the relationship of these three variables a DEA analysis was conducted using R-Studio and the Benchmarking library. DEA enables a measurement of the level of efficiency of non-frontier units against benchmarks which inefficient units can be compared (Charnes, Cooper, & Rhodes, 1978; Cook & Seiford 2009). Rather than comparing groups across metrics of central tendency that use the mean as the measure of variance, DEA can be used to compare groups by combining multiple inputs and outputs and using the top performers as a means to compare groups. DEA requires values for both input and output and considers the variables together. The decision problem including the three decision variables under investigation fit the DEA model quite well. Decision time is considered optimal if its value is lower or it takes less time to make a decision in a crisis. The other two variables are considered more optimal if they are higher. Higher decision accuracy and higher SA are optimal.

DEA efficiency scores were generated based on a Constant Return to Scale known as the CCR model named so for its authors. The most efficient Decision Making Unit (DMU) receives an efficiency score of 1. All other DMUs are scored between 0 and less than 1. The objective function of the DEA is to find the DMU with lowest decision time as a ratio of the highest decision accuracy and highest SA score considered together. The optimal performing DMU is considered to be on the relative efficiency frontier and all other DMUs are located below the frontier or, as it were, enveloped by the frontier. DEA efficiencies were analyzed in terms of mean relationships in order to answer RQ2. The EMGIS group (N = 15) was associated with higher overall efficiency ratios M = 0.583 (SD = 0.178). By comparison, the non-EMGIS group (N = 15) was associated with numerically lower overall efficiency ratios M = 0.466 (SD = 0.170). Participant efficiency ratios were compared to the overall mean for both groups M = 0.525 (SD = 0.184) with a finding that nine participants in the EMGIS grouped scored above the mean while only five participants in the non-EMGIS group scored above the mean. This represents a 17% improvement in efficiency scores in the EMGIS group when considering decision performance as a ratio of decision time and the combined values of decision accuracy and SA. The DEA relative efficiency frontier graphic visually demonstrates the improvement (see Figure 1). DMU number 7 is the optimal efficiency ratio with low decision time and a high combination of accuracy and SA. Using the DEA frontier provides insight into the interaction between the variables.

This analysis mitigates conclusions from parametric analysis that may reward a quick but sub-optimal decision over a more optimal decision that took a slightly longer time to render. The DMUs clustered at top edge of the frontier also confirm the statistical analysis that showed that the EMGIS group demonstrated a statistically significant difference in decision accuracy.

Immediately following the conclusion of the experiment and administration of the SART instrument, EMGIS participants were interviewed following the interview protocol. Two independent coders compared and consolidated their work after coding separately. Participants generally agreed that the EMGIS eases the burden of decision-making in the simulated crisis event. They found that the geographic and HAZMAT presentation provided by the EMGIS helped them make better, faster, and more informed decisions than they thought otherwise possible. A consistent theme was that of training or familiarization with the EMGIS. Drawbacks included a lack of understanding of geospatial concepts and need for power and network availability in the event of a crisis, which may not be available if the crisis includes a wide spread power outage. Participants listed perceived expense and limited mobility as potential challenges with a computer-based system. In terms of SA, there was general agreement the EMGIS provides good context in a crisis situation. The geospatial nature of the system provides a unique view into population locations and hazard danger zones in the HAZMAT scenario. The was consensus that participant understanding of what was happening and how it would affect the campus was improved by the EMGIS and helped them evaluate the effectiveness of potential protective actions.

Discussion

A significant negative correlation was found between decision time and decision accuracy. For the experiment, as decision time increased, decision accuracy decreased. This may seem counterintuitive but is in line with previous studies on decision complexity. As decisions increase in complexity and require greater expertise, decision makers rely on strategies that reduce information processing load and potentially lead to "satisficing" or making decisions that seem good enough when compared to the work necessary to arrive at them (Chu & Spires, 2000; Simon 1997). Between groups, results suggest that the EMGIS did not have a significant effect on decision time. There was, however, a consistent qualitative theme that participants desired more time to become familiar with the EMGIS. Potentially, the EMGIS was simply too complex for a novice to operate effectively given the already increased cognitive load caused by the lack of familiarity with the scenario and the imposed time pressure. This is consistent with previous research on the effects of time pressure and complexity on cognitive load (Jackson & Farzaneh 2012)

Decision accuracy was measurably higher in the EMGIS group. This finding supports the idea that not only do geographic information systems positively affect the decision-making of experts (Wu et al. 2013) but also that of novices in situations with which they are potentially unfamiliar. Qualitative results suggest that there is a perception that a geographic information system was critical in the decision-making of the participants. An improvement in the accuracy of critical decisions by novice crisis decision-makers through the use of an EMGIS is a first step in the research to provide better decision support systems for novices in these unique environments.

SART score is a calculated score subtracting summed understand (U) from the result of subtracting summed attentional demand from summed attentional supply. It is interesting to note that in an independent sample t-test ($a < 0.05$), there was a statistically significant difference in the nonEMGIS group ($N = 14$, $M = 15.93$, $SD = 1.77$) when compared with the EMGIS group ($N = 14$, $M = 14.07$, $SD = 2.20$) on the attentional demand variable (D), $t(26) = 2.458$, $p = 0.021$. The self-reported attentional demand of participants was statistically significant at a lower level than the nonEMGIS group. Although there was not enough variance in the overall SART score to be statistically significant, lower attentional demand for those participants using the EMGIS underscores an important finding. Perhaps the lower attentional demand provided more cognitive resources for decision-making given that there was no significant difference between groups on attentional supply and understanding. It is likely that this lower attentional demand contributed to the higher decision accuracy result of the EMGIS group. Qualitative results indicate the perceptions of understanding of the situation in the EMGIS group were also high.

Perhaps the most striking result was in the investigation of research question two, how does the use of an Emergency Management GIS-based system by a novice crisis decision-maker affect decision-making performance, as a function of time, accuracy and SA during a simulated crisis response. The DEA analysis is sensitive to the relationship between multiple inputs and multiple outputs. A review of the graph of the relative DEA frontier reveals some interesting results from which some conclusions can be made. First it is interesting that the slowest four times between both groups were all in the nonEMGIS group. Although it is likely that the EMGIS was more complicated than the manual materials, the complexity did not seem to slow down the EMGIS group and revealed lower standard deviations in the EMGIS group. The five top performers in the experiment were all from the EMGIS group with two of them essentially creating the efficiency frontier. While parametric measures reveal linearity and mean variance of each of the dependent variables, DEA provides a unique view into the data that suggests that perhaps the relationships of the dependent variables are best viewed with non-parametric techniques. From the DEA results, it is clear that there are measurable gains in decision performance of a novice with the use of an EMGIS in a simulated crisis scenario.

Small campus-based enterprises such as higher education, and corporate campuses, with no dedicated emergency management offices may benefit from the use of a GIS-based EMGIS.

Future Research

Future human computer interaction research into the design and usability of an EMGIS could potentially yield usability results that increase the effective use of the system potentially mitigating the finding that the EMGIS required more training and familiarization. The usability of such a system is critically important due to the nature of the situations for which it will be used. Focusing on usability will decrease the cognitive resources necessary to use the decision support system and potentially free up resources to apply to the crisis situation. Additionally, exploring the effect of option awareness (Pfaff et al. 2013) on the decision performance of novice decision-makers may provide a more complete theoretical picture.

References

Charnes, A., Cooper, W., and Rhodes, E. 1978. "Measuring the Effeciency of Decision Making Units," *European Journal of Operational Research*, *2*, pp. 429–444.

Chu, P. C., and Spires, E. E. 2000. "The Joint Effects of Effort and Quality on Decision Strategy Choice with Computerized Decision Aids," *Decision Sciences*, 31(2), pp. 259–292.

Cook, W. D., and Seiford, L. M. 2009. "Data Envelopment Analysis (DEA) - Thirty Years On," *European Journal of Operational Research*, 192(1), pp. 1–17. (http://doi.org/10.1016/j.ejor.2008.01.032)

Endsley, M. 2015. "Final Reflections: Situation Awareness Models and Measures." *Journal of Cognitive Engineering and Decision Making*, *9*(1), pp. 101–111.

Gorman, J. C., Cooke, N. J., and Winner, J. L. 2006. "Measuring Team Situation Awareness in

Decentralized Command and Control Environments," *Ergonomics*, *49*(12–13), pp. 1312–25.
Haddow, G., Bullock, J., and Coppola, D. 2014. *Introduction to Emergency Management*. Waltham, MA: Elsevier Inc.
Heath, C., and Luff, P. 1992." Collaboration and Control: Crisis Management and Multimedia Technology in London Underground Line Control Rooms," *Computer Supported Cooperative Work*, 1(1992), pp. 69–94.
Jackson, T. W., and Farzaneh, P. 2012. "Theory-based Model of Factors Affecting Information Overload," *International Journal of Information Management*, 32(6), pp. 523–532.
Jung, J. H., Schneider, C., and Valacich, J. 2010. "Enhancing the Motivational Affordance of Information Systems: The Effects of Real-Time Performance Feedback and Goal Setting in Group Collaboration Environments," *Management Science*, 56(4), pp. 724–742. (http://doi.org/10.1287/mnsc.1090.1129)
Kaber, D. B., Riley, J. M., Endsley, M. R., Sheik-Nainar, M., Zhang, T., and Lampton, D. R. 2013. "Measuring Situation Awareness in Virtual Environment-based Training," *Military Psychology*, 25(4)
Klein, G. 1997. "Developing Expertise in Decision Making," *Thinking & Reasoning*, *3*(4), pp. 337–352.
Laakso, K., and Palomäki, J. 2013. "The Importance of a Common Understanding in Emergency Management," *Technological Forecasting and Social Change*, 80(9), pp. 1703–1713.
Ley, B., Ludwig, T., Pipek, V., Randall, D., Reuter, C., and Wiedenhoefer, T. 2014. "Information and Expertise Sharing in Inter-organizational Crisis Management," *Computer Supported Cooperative Work: CSCW: An International Journal*, 23(4–6), pp. 347–387. (http://doi.org/10.1007/s10606-014-9205-2)
McGrath, J. E. 1990. "Time matters in groups," in *Intellectual Teamwork: Social and Technological Foundations of Cooperative Work,* J. Galegher, R. E. Kraut, and C. Egido (eds.), Hillsdale, NJ: Lawrence Erlbaum, pp. 23–61.
McGrath, J. E. 1991. "Time, Interaction and Performance (TIP) a Theory of Groups," *Small Group Research*, 22(2), pp. 147–174.
Mishra, J., Allen, D., and Pearman, A. 2013. Information Use, Support and Decision Making in Complex, Uncertain Environments," *Proceedings of the American Society for Information Science and Technology*, 50(1), pp. 1–10.
Perry, N., Wiggins, M., Childs, M., and Fogarty, G. 2012. Can Reduced Processing Decision Support Interfaces Improve the Decision-making of Less-experienced Incident Commanders?," *Decision Support Systems*, 52(2), pp. 497–504. (http://doi.org/10.1016/j.dss.2011.10.010)
Pfaff, M., Klein, G., Drury, J., Moon, S., Liu, Y., and Entezari, S. 2013. "Supporting Complex Decision Making Through Option Awareness," *Journal of Cognitive Engineering and Decision Making*, 7(2), pp. 155–178. (http://doi.org/10.1177/1555343412455799)
Roth, E. M., Lin, L., Thomas, V. M., Kerch, S., Kenney, S. J., and Sugibayashi, N. 1998. "Supporting Situation Awareness of Individuals and Teams Using Group View Displays," *Proceedings of the Human Factors and Ergonomics Society 42nd Annual Meeting*, 1, pp. 244–248.
Scott, S. D., Wan, J., Rico, A., Furusho, C., and Cummings, M. L. 2007. "Aiding Team Supervision in Command and Control Operations with Large-screen Displays," in *Proceedings of the ASNE Human Systems Integration Symposium (HSIS'07)*. Annapolis, MD.
Simon, H. A. 1997. *Administrative Behavior* (4th ed.). New York, NY: Simon and Schuster.
Taylor, R. M. 1990. "Situational Awareness Rating Technique(SART): The Development of a Tool for Aircrew Systems Design," in *Situational Awareness in Aerospace Operations (AGARD- CP-478)*. Neuilly Sur Seine, France, pp. 50–67 (http://doi.org/10.1007/s13398-014-0173-7.2)
Wu, A., Convertino, G., Ganoe, C., Carroll, J. M., and Zhang, X. L. 2013. Supporting Collaborative Sense-Making in Emergency Management Through Geo-visualization," *International Journal of Human Computer Studies*, 71(1), pp. 4–23. (http://doi.org/10.1016/j.ijhcs.2012.07.007)