Examining the Impact of Increasing Location-Based Information Fidelity on Command Center Decision-Making

by

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AUTHOR'S DECLARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Abstract

The deployment of high-fidelity information systems in command and control environments is common, however it is not yet well understood what impacts these systems have on decision-making processes, or whether the implementation of these systems is always a positive change. Research in military domains has suggested that these types of systems can create substantial increases in micromanagement, but these changes have not been empirically investigated. In this thesis, the effect of high-fidelity information on command environments is experimentally evaluated.

A baseline set of data is collected within a real-world command center that uses only low-fidelity information. Then, a laboratory-based controlled technology experiment is used to gather information about how the command processes change as information fidelity is increased. Finally, the same system is implemented within the functioning command center and a preliminary comparison is carried out against the original baseline data. The experimental study suggests that an increase in micromanagement may occur with an increase in information fidelity, while increases in situation awareness and performance improvements during times of both extremely low and high workload are seen. The preliminary ecological validation study shows support for these effects.

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List of Acronyms

ANOVA – Analysis of Variance

GIS – Geospatial Information System

NCW – Network Centric Warfare

Chapter 1

Introduction

The design and deployment of technology to better display information in command environments has long been the focus of both industry and researchers. Environments such as military command and control (Kaempf et al., 1996), emergency response (Kyng et al., 2006), and disaster management (Bharosa, et al., 2003) share the common goal of supporting decision makers in understanding an unfolding situation, and making the best decisions they can with the information that is available to them. Much of the focus of design to support these types of operations has been on providing access to more accurate and higher fidelity information (eg: Rauschert et al., 2002; Turoff, et al,. 2004; Willems & Vuurpijl, 2007). Despite this research, it is not always well understood exactly how these technologies affect the way decisions are made in these contexts, or if the increase of information fidelity is always an appropriate and useful change.

As the cost of implementing technology to display higher fidelity (i.e. higher quality and more detailed) information continues to decline, organizations outside of the military and high-budget emergency response teams may begin to investigate how information displays can be incorporated into their operations. Specifically, smaller emergency service organizations and volunteer coordination organizations may find this technology more accessible. These environments, with less highly trained operators and decision makers, and smaller teams, are different from previously studied command environments (Derekenaris et al., 2001; Jedrysik, et al. , 2003; Jiang et al., 2004). The deployment of high-fidelity information displays within these command environments may have a significant impact on the way decisions are made, but the effect has not yet been studied.

Indicative of the unforeseen consequences of increasing information fidelity are recent findings about Network Centric Warfare (NCW) in the United States military, which show that increasing information fidelity may be causing micromanagement among commanding officers (Boila et al., 2006; Hakimzadeh, 2003). NCW, defined as "an information superiority-enabled concept of operations that generates increased combat power by networking sensors, decision makers, and shooters to achieve shared awareness" (Hakimzadeh, 2003), highlights the movement of military operations towards electronic information linking and electronic information access. Before NCW, military commanders were responsible for strategic decisions, and made those decisions using information from sources that varied in both accuracy and fidelity (Hakimzadeh, 2003). There was also often a time delay in when this information was received. With the rise of NCW, military commanders can now make strategic decisions based on detailed information, which they can pull from a multitude of accurate and high-fidelity sources, often in real time (Hakimzadeh, 2003). On the surface, this transition would seem to be a positive change, but recent research has started to reveal that access to higher fidelity information may result in micromanagement on the part of command officers, who find it hard to ignore the temptation to react to all of the available information (Boila et al., 2006; Hakimzadeh, 2003; Thomson & Adams, 2005). This research in the military domain provides a basis for challenging the assumption that increasing information fidelity in a command center environment necessarily provides a positive impact on command decision-making.

As higher-fidelity information displays become more common in civilian contexts, such as emergency response and disaster preparedness, the impact of the technology may extend to many communities. Although this research examines only one aspect of the overall command system, its potential contribution is an important first step in understanding the impact of high-fidelity data access in civilian command contexts. The command center operations within the studied organization may be most directly impacted by this work, however their work in turn affects the well being of members of the general public.

This thesis examines how command center processes may be affected by increasing information fidelity. Specifically, this thesis examines the case of a volunteer emergency service organization, Waterloo Regional REACT (REACT), and the installation of a new software system to display higher fidelity location-based information within their mobile command center. By investigating the impact of providing high-fidelity information on command processes within the mobile command center, this thesis provides insights into the possible impacts in similar situations when increasing information fidelity.

1.1 Motivation

Two important factors motivated the work within this thesis: the need for a better understanding of the impact of high-fidelity information on command processes, and the need for design verification and justification of high-fidelity displays for use in emergency response contexts.

1.1.1 Lack of Understanding of the Impact of High-Fidelity Information on Decision Makers

Work within the military context raises questions about whether high-fidelity information displays and NCW are causing an increase in micromanagement (Boila et al., 2006; Hakimzadeh, 2003; Thomson & Adams, 2005). Such research is based primarily on observational accounts of incidents occurring after NCW deployment, and has not been rigorously tested. In parallel, research in other domains suggests that information fidelity, in terms of complexity of information for problem solving, can have a significant impact on the decision-making process and problem solving approaches (Coskun & Grabowski, 2005; France et al., 2005; Wilson et al., 2006). It would therefore appear that these changes in information fidelity in command contexts could have a significant and measureable impact on command team processes.

However, little empirical research has been done on the micromanagement effect, and the continued focus on designing systems to provide high-fidelity information as a method of improving command centers makes it appear that the assumption is that the impact must be positive. By critically examining what might be expected when information fidelity is increased in a command operation context, the assumption of positive impact can be evaluated and addressed. For instance, in a volunteer-based organization, where high levels of autonomy of field agents is highly valued, increased micromanagement from command may diminish the volunteer field agents' sense of pride, accomplishment, and purpose, and ultimately impact their desire to continue to volunteer.

1.1.2 Need for Guidance for Display Designers

Designers of systems for the emergency response context develop requirements based on the needs they see in the context, the requirements set out by their customers, and the research conducted within the emergency response space. However, little research exists to show them how well their designs will address the issues they intend to address, and if there will be any other consequences associated with the deployment of their system.

With little-to-no understanding of how information fidelity directly impacts use of command center technologies, designers cannot adequately design information displays for emergency response. Better awareness of potential impacts, revealed through investigations of how increasing information fidelity can affect command center operations, can help designers create applications that will create the desired effect within the context of use.

1.2 Research Context: Waterloo Regional REACT

REACT provides three main services: safety and support at community events in the area, volunteer support to emergency services in times of need, and equipment for use by emergency services in times of need. As a registered charity, they provide all of these services through donated funds and specially trained volunteers who are passionate about making a difference in their community. REACT uses a mobile command center as their base of operations during the larger events they support, from which command personnel direct the actions of other REACT personnel, referred to in this thesis as field agents.

Primarily, REACT's function at community events is to be a "safety umbrella" for the general public. REACT field agents patrol at events to provide a first level of support to members of the public in case of medical issues or other similar emergencies. They also assist the community event organizers with crowd control and event coordination. A single REACT volunteer acts as "Command" during these events and directs all of these operations at events from the mobile command center. The field agents maintain contact with Command through radios. From this radio contact, Command is able to maintain awareness about the location of field members and their actions and any incidents that occur.

As issues arise, field agents report their issues to Command who triages the issue and decides on an appropriate course of action. Command is responsible for determining if the field agent requires extra support, and for tasking nearby field agents when required. In addition to this role, Command acts as a connection to other emergency service providers, and will call 911 or other services as necessary.

The opportunity provided by REACT was ideal for this research because of the smaller and less formal nature of the organization, providing a unique opportunity to have significant access to their operations. Operating in a relatively independent manner, with a small number of members, creates a simplified space where effects will hopefully be easily observed.

To assist Command within the mobile command center, a new software system is being designed and implemented to provide higher-fidelity information about the location of field agents. The focus of this thesis is this technological deployment and its impact on REACT operations.

1.3 Research Objectives

The research in this thesis addresses the following research question:

How does increasing information fidelity in mobile command centers impact the command and teamwork processes exhibited by users of that information?

Based on this research question, the following three research objectives were identified. These research objectives also highlight the intended contribution of this thesis to the research community as a whole. These objectives are:

1.3.1 Objective #1 – Develop a means to capture and analyze relevant data in the REACT context.

The REACT context provides some unique requirements and constraints on how data can be collected. To properly evaluate the research question it is important to develop a battery of data collection tools that can be used to understand as much as possible about how the increasing information fidelity changes different aspects of command process, while still being practically useful within the environment. The development of a measurement methodology for collecting the data provides a basis for completing the other two objectives, and will assist future researchers studying similar situations or looking to capture a similarly broad understanding of a decision-making context.

1.3.2 Objective #2 – Investigate existing command processes in the REACT organization.

Once a measurement suite is created, the specific context of REACT can be examined to develop a set of baseline data. It is not possible to understand the impact of the new technology without first understanding the state of operations in the command trailer prior to technology deployment. Applying the measurement suite within the REACT context will capture this initial state in a way that can easily be compared to data collected at a later date. In achieving this objective, this research should provide a baseline for future research to take place within the REACT mobile command center once the technology is implemented.

1.3.3 Objective #3 – Determine potential command process changes resulting from the introduction of a high-fidelity information display.

The final objective of this thesis is to understand potential changes that might be seen in the REACT mobile command center, based on process changes that are seen in a lab-based environment. These changes are measured in an experiment that examines how participants' processes change as they act as Command in environments with both low- and high- fidelity information. The objective is to understand the types of changes that occur as a result of increasing information fidelity, in order to assist in the future design and deployment of similar systems.

1.4 Thesis Organization

The remainder of the thesis is organized as follows:

- **Chapter 2: Background** contains a review of research related to geographical information system (GIS) technologies in command environments, the impact of such technologies on their respective users, and findings in other fields that show changes due to increasing information fidelity. It also overviews measurement techniques to capture decision-making processes
- **Chapter 3: Research Methodology** describes the processes used to develop a measurement suite, understand the REACT context, and experimentally measure the changes incurred by increasing information fidelity in a lab-based command center environment. It also described some cross-study measures in further detail.

- **Chapter 4: Baseline Study** describes the results of the study conducted within the REACT mobile command center prior to the deployment of the high-fidelity information display.
- **Chapter 5: Controlled Technology Study** details the results of a lab-based study that examined the changes that occurred when information fidelity was changed in a simulated mobile command center environment.
- **Chapter 6: Ecological Validation** describes preliminary results from an initiative to look for changes due to increased information fidelity within an accurate REACT context.
- **Chapter 7: Discussion** describes how the research objectives were met and explores the implications of the findings.
- **Chapter 8: Conclusions and Future Work** summarizes the main findings of this thesis and makes recommendations for future research to build upon those findings.

Chapter 2

Literature Review

Significant research has been dedicated to creating and deploying information systems to increase information fidelity. The following sections present a review of literature examining deployment of GIS technologies in command environments.

The first section provides background on how information fidelity is normally increased, and how little the effects of that information fidelity have been examined. The second reviews research changes in micromanagement due to Network Centric Warfare (NCW). This research provides insight into how increased information fidelity may impact command processes, but also shows the lack of controlled empirical examination of this process. This research also discusses the potential for other outside factors to influence the observed changes. A third section compares the findings on the relationship between fidelity and increased micromanagement in NCW with research in other fields that shows how increasing or changing information fidelity can cause changes in decision-making behavior. The final section, discusses measures previously used to measure micromanagement and changes in decision-making strategies across a range of different research contexts; this provides a basis for the measures used in this thesis.

2.1 Designing GIS for use in Command Environments

GIS are technological systems that provide assistance with geospatial visualization, decision support, and access to different sources of data, usually through the form of annotated map data (Laurini & Thompson 1992; Johansson et al. 2007). Although often very complex in nature, GIS are intended to increase performance and operators' ability to respond in command situations through better communication of information. Historically, GIS is rooted in the use of plot tables and map tables by military commanders to coordinate teams, an important method of offloading complex memory tasks and communicating situation circumstances to command teams.

There has been considerable research into the design and deployment of displays to increase the fidelity of geographical information provided in command environments. Previous research has documented the motivation for implementing these displays, and proposed designs that address the needs identified in each situation. However, there is an unverified assumption that these specific displays will have a positive impact on the command environments, and that as long as users are able to easily use the application, they will be able to effectively perform their command roles.

The motivation for implementing GIS in command environments is usually to increase performance by supporting assessment of events, access to better data and resources, and information exchange (Johansson et al. 2007). Measurement of the success of these types of systems, not surprisingly, tends to focus on whether or not these goals have been met by the system itself. For example, Derekenaris et al. (2001)

created a technology for use in managing ambulance deployment by better designing the algorithm used to determine the path that should be taken by an ambulance. Their focus was on creating the best possible algorithm, and determining how to integrate it into a GIS in a command center (Derekenaris et al., 2001). The measure of success for this system was in a better performing algorithm and did not include any examination of how the algorithm might be used or interpreted by those coordinating the ambulances. This same approach was also used by Tomaszewski et al. (2007) as they developed a system to visualize geographic information to better support situation awareness, decision-making, and problem solving. Although their system, on paper, met their identified requirements, they did not empirically validate its effectiveness during real-world use (Tomaszewski et al., 2007).

Even those studies rooted in designing for the user do not tend to evaluate their designs in a way that acknowledges the potential for impact on command processes. In creating their ubiquitous computing system for firefighters, Jiang et al. (2004) put much effort into using field studies, interviews, and observational studies to determine that firefighters needed a large GIS display to provide accountability, assessment of the situation, resource allocation, and communication support. However, after such a thoroughly user centered design, the team never observed how the system was actually used, and whether their design was able to provide those features without impacting other aspects of command (Jiang et al., 2004). Other examples of similar research methodologies and shortcomings were seen in the creation of the Digital Map Table for use in an emergency operation center (Bader et al., 2008), and a multimodal GIS interface for emergency management (Rauschert et al., 2002). These findings all make a base assumption that the deployment of higher-fidelity information systems such as GIS will be able to improve command processes if information is displayed properly.

Despite this lack of retrospection in GIS research focused on design, other research has examined the effects of GIS use in laboratory settings. One of the strongest finding from this research is that GIS can greatly improve the performance of command teams, as measured by time to respond and other objective and subjective performance measures. In laboratory studies, Johansson et al. (2010) examined the differences between command and control teams battling simulated forest fires with a GIS, and with simple paper maps. They found that the teams with GIS were able to significantly increase their performance by using real-time sensor data to make better decisions (Johansson et al. 2010). Interestingly, they also found some significant changes in the types of communications being sent; participants with GIS sent significantly fewer communications, and the content of their communications changed to include less information about locations and actions (Johansson et al. 2010). Grabowski et al. (2003) also found that GIS technology could significantly improve performance, although only in lower-stress situations.

Aside from performance studies, some examinations of GIS have focused on user adoption once deployed. One of the most salient themes in these studies is that abandonment of these systems is commonplace. Systems were examined by Mendonca et al. (2001, 2007) that provided rich information and exciting features, yet their downfall was that, in high stress situations, they were not able to support improvisation on the part of command, an integral aspect of managing emergency situations (Mendonca et al. 2001; Mendonca & Wallace 2007). Indeed, one of the key failures of GIS is a lack of simplicity and usability (Oonk et al. 2001; Bharosa et al. 2003; Mendonca & Wallace 2007; Mendonca et al. 2001). In these cases, the reaction of operators was to abandon the systems and return to command without the GIS. The observed systems in these studies were certainly designed to provide optimal access to information and data, yet they suffered failures because little attention was paid to the true impact of the systems in real environments.

In summary:

- GIS research has traditionally been focused on most effectively conveying high-fidelity information to users
- Only a subset of that research has been based on user-centered principles; changes to decision-making processes were not the focus of design efforts
- The impact of the deployment of GIS can be quite extreme; a number of studies have highlighted abandonment during high workload situations

This review of GIS literature clearly shows that there is a need for more in-depth investigation of the changes that are caused by the deployment of higher-fidelity information systems within command contexts.

2.2 Changes Due to Increased Information Fidelity in GIS Environments

Despite assumptions about the potential impacts of GIS technology in command, military-related research is starting to examine how the high-fidelity information inherent in NCW affects command behavior. This research, although examining a wide variety of systems and environments, challenges a core assumption about how the displays may affect operators. Through both experimental and observational techniques, this research indicates potentially important effects of NCW, and that there are many complex factors that must be explored to fully understand the root cause of those effects.

NCW is the movement of military operations towards completely networked technology, providing unprecedented access to high-fidelity information about situations in the field (Hakimzadeh, 2003). The traditional role of command in military contexts has always been to make strategic decisions at a high level, leaving fine-grain tactical decisions to subordinates with a better understanding of the specific context and situation. However, as the military moves towards NCW, research has shown that Command is encroaching on the tactical decisions, engaging in micromanagement.

The first extensive description of micromanagement due to NCW is by Hakimzadeh (2003) in a paper that highlighted reports of temptation being placed on command to make tactical decisions. Hakimzadeh (2003) discussed how commanding officers experience temptation to overstep their traditional decision-making power, and micromanage their subordinates. As an analysis of previous events, the research implicated other factors, such as media scrutiny, in the effect. However, this discussion of micromanagement also provided a launching point for other analyses of the phenomenon.

Further support for the trend towards micromanagement in NCW by military command teams is presented by both Boila et al. (2006) and Thompson and Adams (2005). This research describes how the increased information access provided by NCW significantly changes the way command teams make decisions. Aside from creating greater temptation towards micromanagement NCW appears to obfuscate the division of command roles, reduce accountability, and increase trust in sensor data rather than reports by subordinates (Boila et al., 2006; Thomson & Adams, 2005).

Although supported through case studies and reports, none of the NCW research related to micromanagement empirically linked the changes seen in command directly to NCW. As mentioned by Hakimzadeh (2003), it is very possible that some of the changes are due to outside factors that are impacting how modern military commanders must conduct themselves.

In summary:

- NCW has been implicated by a number of researchers in the rise of micromanagement within the military domain
- The unprecedented accesses to high-fidelity information is hypothesized to cause irresistible temptation to micromanage, as well as to obfuscate the role

of command, reduce accountability, and increase trust in sensor data rather than personnel

- Other factors, such as media scrutiny and journalists in the field, may have also played a role in the increase in micromanagement
- These findings have not yet been empirically investigated

These issues, although described in the context of NCW, have greater implications when considering the deployment of information systems in other decision-making and command contexts. If the use of such systems in the military context has had such effects, the same effects may occur in emergency response contexts. The lack of discussion in the GIS and emergency response technology design community about the potential for micromanagement indicates how little attention it had been given, and that some important considerations may be neglected at this time.

2.3 Changes Due to Increased Information Fidelity Outside of Command Centers

Research from other domains also helps to support the claim that the impact of high-fidelity displays should be investigated. Primarily, this research shows that the way in which information and imagery is presented to users can completely change the way in which those users make decisions. Additionally, it highlights specific experiments that showed that increased information fidelity could sometimes be a hindrance rather than help. These findings provide support for challenging the assumption that implementing higher-fidelity information displays in command centers will necessarily improve command performance.

There is strong evidence that there is a point at which more information will hinder the user's ability to use that information. For example, irrelevant information can distract a decision-maker and divert attention from key information (Lucas & Nielsen 1980), while information overload is a real problem resulting in reduced performance levels and anxiety (Schroder et al., 1967). Decision performance is also influenced directly by information presentation format (Austin, 2003; Desanctis & Gallupe, 1987; Littlepage et al., 1997; Speier et al., 2003). Additionally, the experience and knowledge of the user dramatically changes whether or not they can use that information effectively (Biehal & Chakravarti, 1982; Littlepage et al., 1997; Lucas, 1975), meaning the right level of information fidelity for one situation is not the same across different contexts. The effectiveness of information presentation format is also highly dependent on the task it is being used for (Benbasat & Dexter 2011; Speier et al. 2003; Vessey & Galletta 1991).

Similar effects have also been noted in a number of different real world research contexts, often as an unexpected consequence of increased information fidelity. Interestingly, deployments within medical centers have shown a number of cases where information presentation has affected behaviors and decision-making. One notable case was discussed by Wilson et al. (Wilson et al., 2006) after implementing a large display showing information that was previously available verbally. They found that this change in the fidelity and display of information caused more experienced physicians to micromanage the younger physicians, which, in turn, resulted in the omission of data to avoid embarrassment or dissatisfaction (Wilson et al., 2006). Similar results were seen in other examinations of display deployments – changing the presentation format of the data alone had an impact on the way users treated that data, and the associated perception of how data would be viewed (Biehal & Chakravarti, 1982; Kakkar & Bettman, 1977; Painton & Gentry, 1985).

Researchers focused on consumers of products and consumer acquisitions have also noticed that the presentation of information has an important impact on the way consumers react and make decisions. For example, Painton and Gentry (1985) found that information presentation format changed the amount of cognitive search and information processing – one format changed the type of attributes considered, while another format changed the number of brands considered. Researchers in similar fields have shown that the presentation of the task and the information changes the way consumers utilized information (Biehal & Chakravarti, 1982; Kakkar & Bettman, 1977).

In summary:

- Information presentation format can greatly affect performance and decision-making
- Both the task and the experience of the user affect how effectively the displayed information can be used

- Real world examples show how change in information fidelity can result in significant changes in information perception and use

These findings show how there are many different consequences that can result from changes in information presentation and fidelity. Although the same information may be displayed, a change of format and fidelity may have repercussions in terms of decision-making, performance, anxiety, and micromanagement.

2.4 Previously Established Measures to Capture Decision-Making Processes

Teams and their ability to make decisions have been studied in many different research contexts, and with many different methodologies. Due to the wide variety of contexts in which research is conducted, there are many different measurement tools available to capture different aspects of decision-making. Some of these tools were appropriate for the research contexts presented in this thesis, while others were not. Previous tools were reviewed in order to identify appropriate measures for meeting Objective 1, as outlined in Chapter 1. Measures for decision-making fall loosely into four main categories: measures of performance, qualitative observations, measures of communication, and subjective ratings of perception.

2.4.1 Performance Measures

As discussed by Brannick et al. (1993), there are consistent findings that tie effective team process measures to effective team outcome measures. For example, Johansson et al. (2010) examined the use of a GIS tool to position simulated firefighting units to control a simulated fire outbreak. They were able to evaluate the performance of participants during different conditions by counting the number of simulated acres saved from simulated fire, and were able to compare those measures of performance by ensuring that each participant performed the same task under the same task conditions (Johansson et al. 2010). Other examples of performance metrics include the time taken to complete a task (Brannick et al., 1993; Coskun & Grabowski, 2005; Kenyon, 1999; Molleman & Slomp, 1999), and the number of correct or incorrect decisions (Brannick et al., 1993; Coskun & Grabowski, 2005; DeVita et al., 2004). Performance measures are best used when there is a known measure of performance, and when the task itself can be controlled. When examining real-world changes, or when performance cannot easily be quantified, performance measures are difficult to evaluate.

2.4.2 Qualitative Observations

Rather than understand just the outcome of decision-making, other research methods look to learn about the processes that take place. Qualitative observations are rooted in sociological tradition of ethnographic observations, used to gather information about how people interact, and are often analyzed using open-ended coding methodologies (Lareau & Schultz, 1996). Researchers in the decision-making domain often use methods drawn from the social sciences used to answer open-ended questions about wide themes. For example, Tang and Carpendale (2008) used qualitative observations, informal interviews, and examination of documents to learn about the use of a technology system implemented in a medical environment. The technique allowed them to draw conclusions about how the system was used and how that use affected other related activities in the hospital. These types of qualitative observations are best suited for use in real-world contexts where intrusive research methods are not viable (Lareau & Schultz, 1996). However, direct comparison of observations between cases is not always systematic and is difficult to support (Lareau & Schultz, 1996).

2.4.3 Measures of Communications

The most commonly used method for capturing information about decision-making processes is through monitoring and coding communications between team members. The communications used during decision-making processes are an easily observable indication of the decision-making process. Although researchers appear to agree that communications can be used to understand decision-making, there are many different methods and theories for analyzing the communications data to gather meaningful findings (Thorstensson 2001; Hollingshead 1998; Hutchins et al. 1999; Schraagen & Rasker 1998; Johansson et al. 2010; Kruger et al. 2004; Camp et al. 2000). These analysis methods fall into two main categories: coding schemes that evaluate the flow of information, and coding schemes that evaluate team dynamics. For example, Entin and Serfaty (1999) code communications by examining the content in an attempt to learn about how information is flowing between team members. In turn, that coding data are used to calculate measures of anticipation that show how well team members understand each others' needs. On the other hand, Hutchins et al. (1999) used a coding scheme to examine the intent of the communication to try to capture team functioning.

For example, their coding scheme might identify a communication as intended to develop a shared understanding, while another communication might be for providing backup to other teammates. These measures are useful when communications can be observed and coded, although the coding scheme used must be selected carefully to collect the data that are most useful for evaluating the behavior being studied.

2.4.4 Subjective Ratings of Perception

The measurement techniques described previously all attempt to measure external indications of internal cognitive processes. To gather information from the participant's own perspective, other techniques ask for their feedback and perception of events. For example, situation awareness – one's level of understanding of the world around them (Endsley, 1995) – is often measured through self-reporting techniques such as Situation Awareness Rating Technique (Taylor, 1990) – a tool that records situation awareness perception through a series of survey questions. These tools capture participants' perceived experiences during the decision-making tasks. Cognitive workload is often measured through self-ratings both during and after technology use. For example, NASA-TLX (Hart & Staveland, 1988) is a commonly used self-reporting technique to learn about cognitive workload. These self-reports are difficult to implement in many real-world contexts as they are highly intrusive. However, they may be better suited to lab-based research.

2.4.5 Summary

Found different categories of measures of decision-making were presented. These are the measures from which the suite of measurement tools to be used in this thesis was selected.

In summary:

- Measures are either measures of performance, qualitative observations, measures of communications, or subjective ratings of perception
- Each of these methods can be used to measure different aspects of the decision-making process
- Different researchers have developed and used these techniques in different contexts with different levels of realism and sensitivity to interruption

The measures described were evaluated to properly select the correct measures for use within the context of this thesis. The measures selected, and the reasons why they were selected, are described in further detail in Chapter 3.

2.5 Chapter Summary

A literature review was conducted to provide a basis for the research presented in this thesis. The review highlights the research that has been done before in related domains, upon which this thesis builds, and presents evidence of the need for this research through a lack of understanding about how increasing information fidelity affects command operations in a mobile command center.

Previous work in the GIS domain was reviewed, and it was found that primarily this research is focused on designing ways to provide high-fidelity information to decision makers, yet little research has been dedicated to the impact of those designs. Some research takes a user-centered focus, but does not seek to understand the real-world implications after deployment. However, some research suggests that deployment of GIS in certain environments can cause significant changes in usage, suggesting the need to better examine the impact.

Work in the military domain further motivated the need for this thesis. NCW is becoming increasingly common in the modern military, yet concern has been raised that the unprecedented high-fidelity information may be causing micromanagement. Specifically highlighted is an increase in temptation to use the new high-fidelity information in ways not previously possible. However, alternate theories exist, and the effect has not been empirically verified.

Indeed, other research in different domains has shown how information fidelity can change the decision-making of users. Both the task and the information presentation format can change how well information is used. This research showed that information fidelity can change decision-making tasks, but it is not known how those findings might translate to a real world command center context.

Finally, research methods from other domains were examined to provide a basis for the analysis and data collection methodology presented in this thesis. Research methods fell into four main categories: measures of performance, qualitative observations, measures of communication, or subjective ratings of perception. Each of these categories requires a different level of intrusion, and allows for collection of different types of information. To create a data collection tool for use in the REACT context, care will be taken to gather the right set of measurements that are practical for the context and provide coverage to best understand the effect of deployment.

Chapter 3

Methodology

As stated in Chapter 1, the inspiration and driving force behind this research is the research question: How does increasing information fidelity in mobile command centers impact the command and teamwork processes exhibited by users of that information? To address this research question three research objectives were developed and presented in Chapter 1.

The objectives have been met through the development of a measurement suite, and conducting two formal studies: a study to establish a baseline data set within the REACT mobile command center, and a controlled laboratory-based study to understand changes caused by an increase in the fidelity of available information in a command task. These two studies together form a picture of how increasing the information fidelity within the REACT mobile command center affects the operations that utilize that information, and are supported by the measures that are developed. Following the completion of these two studies, ecological validation studies were conducted to learn more about how well the data collected within the lab context reflected the actual changes that occurring in the REACT context.

The design of these studies and the accompanying measurement suite is described within this chapter, giving an overview of the research conducted within this thesis. More detailed accounts of the procedures undertaken and the results collected can be found within later chapters.

3.1 Development of a Data Collection Suite

To address Objective 1, a suite of measures was established. The measures used play a critical role in ensuring the capture of an accurate and useful picture of communications and command processes within the REACT mobile command center. Without a carefully planned measurement suite, the significant changes that occur within the command environment may be completely missed. As such, the creation of such a measurement suite is guided by both the themes discussed in the literature review, and by restrictions that exist in the context of the data collection.

There are a number of specific themes that should be addressed with the measurement suite: the impact of increased fidelity on micromanagement, situation awareness, cognitive workload, and decision confidence. These themes have been expressed as questions, summarized in Table 1. Table 1 also shows specific sub-questions that, when answered, will create a comprehensive overview of the changes in command processes that are reasonably expected as a result of changes in information fidelity.

To answer these questions, a suite of measurement tools was created. The tools were selected to provide coverage such that each focus question could be answered through at least three data sources. In making sure there was coverage for each question from at least three sources, findings could be triangulated from multiple sources, and findings could be confirmed through different data sources examining the same process.

Table 1: Data Collection Questions

#	Question	Sub Questions
1	How does the increase in information fidelity impact the level of micromanagement on the part of Command?	How does the increase in information fidelity impact Command's perception of their level of micromanagement?
		How does the increase in information fidelity impact the level of micromanagement exhibited by Command?
2	How does the increase in information fidelity impact the level of situation awareness maintained by Command?	How does the increase in information fidelity impact Command's perception of their situation awareness?
		How does the increase in information fidelity impact Command's ability to anticipate the needs of field agents?
		How does the increase in information fidelity impact the breakdowns in Command decision-making?
3	How does the increase in information fidelity impact the cognitive workload placed on Command?	How does the increase in information fidelity impact Command's perception of their cognitive workload?
		How does the increase in information fidelity impact the cognitive resources available to Command?
		How does the increase in information fidelity impact the level of attention required by Command?
4	How does the increase in information fidelity impact the confidence Command has in their decisions?	

The data sources are shown in Table 2, and their applicability to each focus question is indicated with an "X". Each of the data sources are used to address multiple focus questions, and to create the ability to better support conclusions by demonstrating that similar trends are seen in different sources. Due to restrictions in the REACT context some of the measures could not be used in the baseline study. To indicate this, measures are categorized by the studies in which they were collected.

Table 2: Data Collection Tools and their Relation to the Data Collection Questions

	Baseline Study and Lab-Based Study			Lab-Based Study Only			
	Audio Coding	**Qualitative Observations**	**Artifact Analysis**	**Questionnaire Responses**	**Interview Responses**	**Workload Rating**	**Secondary Task Performance**
1 - Micromanagement	X	X		X	X		
1a - Perception of Micromanagement		X		X	X		
1b - Level of Micromanagement	X	X					
2 - Situation Awareness	X	X		X	X		
2a - Perception of Situation Awareness		X		X	X		
2b - Anticipation Ratios	X	X			X		
2c - Decision-making Breakdowns	X	X		X	X		
3 - Cognitive Workload		X	X	X	X	X	X
3a - Perception of Cognitive Workload		X		X	X	X	
3b - Available Cognitive Resources		X	X				X
3c - Attention		X	X		X		
4 - Decision-making Confidence		X		X	X		

The choice of data sources is explained below, along with a discussion of how the data is intended to provide adequate data triangulation to answer each of the questions.

3.1.1 Audio Coding

The communications that take place within the mobile command center provide a window into the way that the team is working and the way in which Command is interacting with the field agents.

The audio coding measure was chosen to provide a quantitative method to compare real-world behaviors across different events by comparing communication patterns and proportions of communication types, while being practical for the research context. It was chosen specifically because it provided the kind of information that could be compared across different events, while being compatible with being captured in real time. Audio coding provided initial data that pointed towards specific trends and significant findings, which could then be confirmed and explained through the other measures. It was the basis for the understanding of happenings in the real-world REACT context, as it could easily be used within the restrictions of the command center.

3.1.2 Qualitative Observations

Qualitative data collection methods, as described in Chapter 2, are very useful for collecting information in real-world contexts, and to gather a wide variety of information; it can be particularly valuable in identifying surprising or unexpected findings. The qualitative observations collected in this thesis were chosen to capture a timeline of events that describes when and how important events unfold. In those settings where audio and video recording were captured, these observations were completed after-the-fact. In some situations recording was not possible and it was necessary to collect these observations in real time. In either case, general observations were noted about events that were occurring, reactions on the part of Command or field agents, decisions being made, or other notable incidents.

As was also discussed in Chapter 2, qualitative information collected within this thesis was best suited to support findings found from other data sources, and provide information to answer "why" certain changes were occurring. As summarized below, qualitative observations were focused in four areas to provide information about specific questions.

3.1.2.1 Micromanagement

To provide support to other quantitative findings about changes in micromanagement on the part of Command, observations of decision granularity, the level of independence experienced by field agents, and the attachment of Command to control over those field agents were recorded. For example, comments by Command about whether field agents should act without authorization, or demands of constant updates, were taken as indications of an increase in micromanagement.

3.1.2.2 Situation Awareness

Situation awareness was difficult to measure in the REACT context, so special attention was taken to use qualitative observations to provide additional findings to confirm or refute other data sources. One important indication about Command's situation awareness was the method by which Command gathered and stored that information. For example, in constantly asking field agents for updates about location and events, Command was revealing that their situation awareness was not sufficient and needed to be updated. Further understanding of situation awareness was collected through an analysis method looking at decision-making breakdowns. These are described in further detail in Sub-Section 3.5.2.

3.1.2.3 Cognitive Workload

Qualitative observations of performance on secondary tasks were used as indications of Command's cognitive workload (Ogden et al., 1979). Although no artificial secondary task could be inserted into the REACT context, performance on non-primary tasks could be monitored for indications of a lack of spare cognitive resources. Those tasks not directly related to Command's primary task of coordinating field agents were observed, and any instances where they were not performed well on those tasks indicated that Command was under higher cognitive workload. Similarly, paying proper attention to the primary task while still completing some secondary tasks indicated a lower cognitive workload.

3.1.2.4 Decision-Making Confidence

Although hard to identify, it was important to capture information about the decision-making confidence of Command within the REACT context. This was particularly important, as a lack of decision-making confidence could directly impact the use of technology, and the performance gains associated with that use (Johansson et al. 2010). Observations were made of study participants' willingness to give commands, and speed of response to learn if deployment of the information display negatively or positively affected the perception Command had of their decision-making abilities.

3.1.3 Artifact Analysis

Artifact analysis was also used to examine cognitive workload. In the field and in the experiment, Command had various materials available for their reference – paper maps, paper event plans, and a pen. Their use of these materials provided insight into the way they were thinking about the task, and how they were coping with the available information sources. This was another observable source of data to triangulate findings using multiple sources.

In particular, the use of a pen to annotate maps provided an indication of whether participants needed to offload information onto such physical artifacts, potentially because of unmanageable cognitive workload. To analyze this data, the papers were collected after each task, and were examined. Consistent use of maps for offloading of memory tasks was taken as evidence of higher levels of cognitive workload. Conversely, intermittent or rare use of maps for memory task offloading was seen as evidence of lower levels of cognitive workload.

3.1.4 Questionnaire Responses

During the lab-based study, questionnaires were used to collect information from study participants about their agreement with various statements. This information was easy to collect and provided a quantifiable way of understanding participant perception of different effects. The specific procedure in which the questionnaires were used is described in Chapter 5, and the questionnaire itself is included in Appendix B.

3.1.5 Interview Responses

Along with the questionnaire, participants in Study 2 also answered a number of interview questions about their experiences with the technology. Similarly, this information was easy to collect and provided a wealth of information about participant perception and understanding of events. It provided additional support for findings from other sources, and to explain what was causing certain changes. The specific procedure in which the interview was used is described in Chapter 5, and the guiding questions are included in Appendix B.

3.1.6 Cognitive Workload Measures

During the lab-based study, where more intrusive measures could be used, workload was captured in greater detail through both subjective workload ratings and the use of a secondary task. Both of these techniques were chosen as they provided complimentary data points showing both perception and external measures of cognitive workload.

The specific method of capturing cognitive workload is outlined in Chapter 5, including the tools used to capture the data. These quantitative measures, combined with qualitative and other subjective measures of cognitive workload, together created a comprehensive measure of cognitive workload in the lab setting.

3.2 Study 1: Initial Baseline Testing

The first study was designed to establish baseline data that capture the operations within the REACT mobile command center prior to any technology deployment. Although video and audio recording was not permissible due to confidentiality and privacy concerns, the ability to physically be present within the REACT mobile command center provided sufficient access to operations to enable the capture of the required data set.

To collect this baseline data, multiple REACT events were observed, and data was collected using the developed measurement suites as described previously. The data described how REACT Command operated without the use of a high-fidelity information display, and provided a basis for designing appropriate methods and tasks for Study 2.

Data collected about the REACT context was used to design the experimental tasks for Study 2, a controlled lab-based experiment. In using the baseline data to design authentic and realistic scenarios for study participants to perform, the data collected within the second study provided more ecological validity and enabled more grounded generalization of the results to the actual REACT context. The procedure used and the results collected from this first study can be found in Chapter 4.

3.3 Study 2: Controlled Technology Study

Following the capturing of baseline data in the REACT context, a laboratory-based study was designed to gather as much information as possible about the potential changes that might occur within the mobile command center due to increasing information fidelity. This study served to answer the specific focus questions presented above, providing detailed data about command center behavior both with and without the high-fidelity information display. In a controlled setting, participants acted as Command as they encountered situations and tasks that were closely related to the types of situations and tasks that would be encountered in the REACT context.

A mock-up of the communications hub in the mobile command center was constructed that closely resembled the REACT command center. Within this environment, participants coordinated field agents over mock-radio in two different situations: with and without the assistance of the technology that increased information fidelity of field agent positions. In using the measures to capture the processes used during these activities, a picture was developed of the types of differences that can be seen between the two different scenarios, and specifically answered the data collection focus questions.

Designed to be as close as possible to the real REACT context, the lab-based experiment provided an opportunity to repeatedly measure the effects that can be seen in response to increasing information fidelity. The experimental design also allowed for the creation of scenarios and events that were interesting but unpredictable during a real REACT operation. For example, medical emergencies of varying urgency may or may not occur during any given real-world event, but they could be artificially created and controlled through scripts used during the experiment. The procedure used and the results collected from this second study can be found in Chapter 5.

3.4 Ecological Validation

Following the completion of the two data collection studies, two activities were completed to determine the ecological validity of the results of the previous studies. The first activity was a experimental simulation, conducted by having a REACT Command personnel participate in the laboratory-based study, experiencing the same conditions. Contrasting the data collected from someone with actual REACT Command experience to other study participants (who had little Command experience), it was possible to understand where the conclusions were more or less applicable to the real REACT situation. To further support this a field study was conducted. Once the technology was deployed within the REACT mobile command center, data was collected for comparison to the baseline data. Preliminary analysis of this real-world data provided context and future direction for research surrounding this project. This ecological validation is presented in Chapter 7.

3.5 Cross-Study Data Collection and Analysis Tools

Some of the data collection tools used in this thesis were employed across all three studies, as they were applicable to both the real-world and lab-based contexts. They are described below.

3.5.1 Audio Coding Scheme

To distill hours of communication data into simpler information that could be interpreted, each communication was categorized, or coded, based on the contents of the message and the people for whom the message was intended. This coding method provided a way to easily analyze and characterize the communications through analysis tools, providing clues about the situation awareness being maintained, and the level of micromanagement.

The coding scheme used to characterize each communication is one described by Entin and Entin (2001), used as part of the A2C2 Research Programs. The scheme captures both the type and content of each communication, and in turn provides insight into a number of different verbal communication measures. Each communication transmitted was categorized using the simple scheme shown in Table 3.

Table 3: Coding Scheme for Audio Communications

Type	Content	Description of Transmission
Request	Information	Asking for information of any type
	Action or Task	Asking for direction or instruction
	Resource Utilization	Asking for a specific piece of equipment or personnel
	Coordination	Asking for assistance organizing personnel
Transfer	Information	Sending information of any type
	Action or Task	Sending a direction or instruction
	Resource Utilization	Allocating a specific piece of equipment or personnel
	Coordination	Assisting in organization of personnel
Acknowledgement		Response indicating communication receipt

The coding of communications in this manner showed where the focus of communication efforts was aimed and provided clues about the level of micromanagement. The makeup of the communications can be described by the ratio that fall into each code, which can give an interesting picture of how communications were used through the event. Changes in these ratios indicate if and how the technology changes the focus of Command and how the interactions between Command and field agents change. For example, a shift in the attitude of Command towards increased micromanagement would be indicated by a higher percentage of action transfers from Command to field agents. Alternatively, an increase in information requests being posed by Command might indicate that Command was struggling to maintain an appropriate level of situation awareness.

Some other pieces of useful information that were calculated using the data collected with this coding scheme are shown in Table 4 (taken from Entin and Entin (2001)). Primarily useful were the measures of overall communication rate, which provided another indication of micromanagement within the communications hub, and the anticipation ratios that have proved very useful in understanding team communication and function in other studies (Entin & Serfaty 1999). Specifically, anticipation ratios that are greater than 1.0 can be assumed to show that field agents and Command are functioning well as a group, as such ratios show that they are anticipating each others' requirements, and transmitting that information before it is requested (Entin & Serfaty 1999). Each of these metrics was calculated for each coded session, the results of which were compared to look for interesting effects.

Additionally, indications of micromanagement can be found in examining the results of this coding. Micromanagement would most be seen through an increase in Action Transfers (issuing of commands), as this would indicate more direction being given. Additionally, a greater number of Information Requests may also indicate greater micromanagement, as that may be an indication of Command trying to keep closer tabs on field agent activities. However, qualitative investigation of the way these increased communications were used was needed to verify that micromanagement was indeed the cause.

Table 4: Metrics Derived from Audio Coding Scheme (Entin & Entin, 2001)

Measure		**Description**
Overall Rate	Total Communications	Total number of communications per minute
Communication Types	Information Requests	Number of requests for information per minute
	Information Transfers	Number of transmission of information per minute
	Action Requests	Number of requests for an action per minute
	Action Transfers	Number of statements of actions (to be) taken per minute
	Coordination Requests	Number of requests to coordinate an action per minute
	Coordination Transfers	Number of agreements to coordinate an action per minute
	Acknowledgements	Number of non-substantive acknowledgements of receipt of communication (e.g., 'ok' to acknowledge receipt of information) per minute
Communication Ratios	Overall anticipation	All communication transfers divided by all communication requests
	Information anticipation	Information transfers divided by information requests
	Action anticipation	Action transfers divided by action requests

Coding each communication and simultaneously recording information about the message sender and contents is not feasible for a single researcher. This was especially true during high-stress incidents such as medical emergencies or other incidents where communications become more rapid and difficult to follow. Because of this difficulty, a tool was created that would assist the researcher in easily coding the communications.

Figure 1, this tool allowed easy coding of communications within the command center, in real time. Keyboard based input made the use of this application simple. *Alt* keys were used to navigate to the specific line required, and tabbing through the categories made for quick input of communication type and medium. The most common type and medium were set as defaults, further reducing the number of keystrokes required to input a single code. The text field also allowed for free-form input about who was speaking (in this case, three-digit radio call numbers are easily inputted) along with the contents of the communication. Below the input area, a view of the log file was available to provide feedback to the researcher that their codes are being recorded properly. The “Invalid Previous” button allowed for correction of mistakes. All of this information was used to calculate the communication measures previously described.

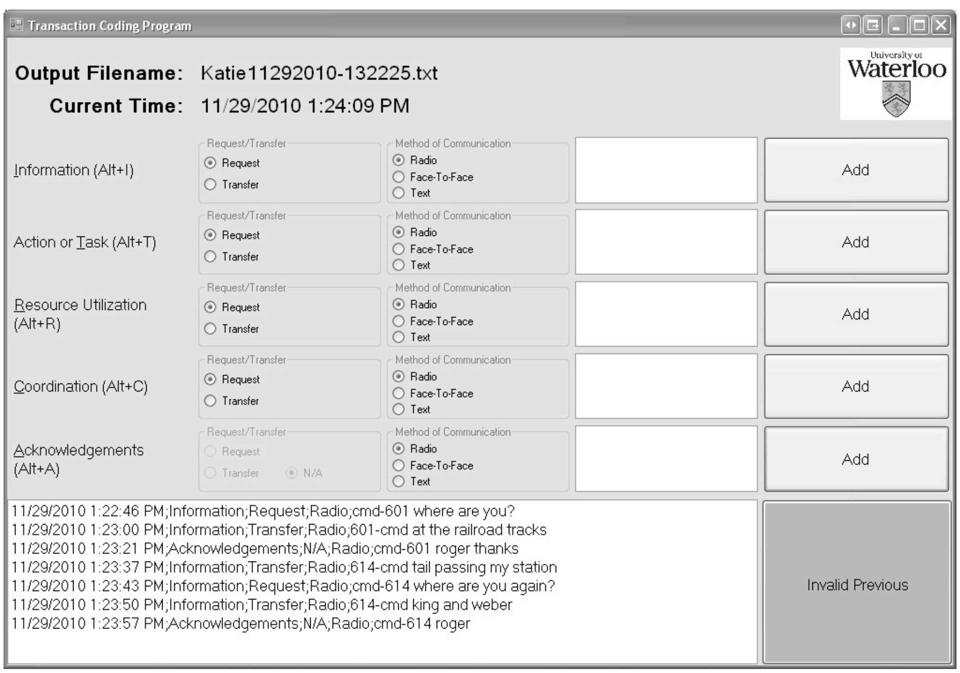

Figure 1: Coding Assistance Tool Interface

3.5.2 Decision-Making Breakdowns

As described by Bearman and Thomas (2010), coordinated decision-making can be explored through analysis of the nature and resolution of breakdowns. Events can be considered to be breakdowns when there is a "failure of coordinated decision-making that leads to a temporary loss of ability to function effectively" (Bearman & Thomas, 2010). As technology was implemented, changes in the types of breakdowns that are occurring provided information about how the technology was affecting the way decisions were being made.

Each decision or action made by Command had the potential to create a breakdown. In making qualitative observations of communications and decision-making, breakdowns were observed. These breakdowns were then categorized as being caused by one of three different types of disconnects: operational disconnects, informational disconnects, and evaluative disconnects (Bearman & Thomas, 2010).

Operational disconnects occur when the person giving a command and the person carrying out the command have a conflicting understanding of the action to be carried out (Bearman & Thomas, 2010). If this type of disconnect was occurring, it was important to look for suggestions of why actions were being understood differently by different parties. The ability to properly describe the desired action may be one cause, potentially as a result of a lack of ability to reference locations or settings. It's also possible that terminology or requirements were not clear.

In contrast, *informational disconnects* occur when different parties possess different information (Bearman & Thomas, 2010). One party has one set of information with which they are making decisions, while the other party has a different set and is therefore making different evaluations of the situation. The cause of these disconnects might have been be a blockage in the flow of information, or different and conflicting information sources.

Finally, *evaluative disconnects* occur when different parties with the same information come to a different evaluation or conclusion (Bearman & Thomas, 2010). Different team members possessing different mental models of the environment, or different interpretations of the correct course of action might cause this.

These breakdowns, as mentioned previously in this chapter, were used to evaluate Command's situation awareness through looking at changes in numbers and types of breakdowns.

3.6 Chapter Summary

This chapter outlined how the thesis objectives presented in Chapter 1 were addressed. Objective 1 was addressed through the definition of questions, which were answered through the selection of a suite of measures. The measures selected were those that were usable in the research context, and approached each question from different perspectives to triangulate findings. Each of the measures was motivated, and cross-study measures were defined in further detail. Additional measures are defined in the chapters of the studies in which they are used.

Study 1, the baseline study, was created to address objective 2. This study was planned to collect information about the operations in the REACT context to learn about how they operate without the use of high-fidelity information. The measures defined previously for use in the REACT context were used to create this data set, for comparison to data collected after deployment.

Study 2, the controlled-technology study, was designed to address objective 3, and learn about how the change in information fidelity changes the command processes. A mock-up of the command center was created in a lab setting, and participants completed coordination tasks with and without high-fidelity information. The previously defined measures were collected and compared between conditions to learn about the changes caused by the increase in information fidelity.

To further support the findings in study 2, a pair of ecological validation studies were planned to gather information about how applicable the results of study 2 are to the real world context of REACT.

Chapter 4

Baseline Study

As discussed in Chapter 3, the baseline study is intended to capture the operations within the REACT communications hub prior to the deployment of the location-based information display. This provides an understanding of how current operations are conducted, used for later comparison and direction of the lab-based studies.

It was found that REACT operations are well established and the team functioned well during both routine and emergency situations. There was also a strong culture of independence and low levels of micromanagement; something that the literature review has shown may be in jeopardy when the high-fidelity information system is implemented. However, there were also strong indications that, during emergency situations, Command sometimes had difficulty maintaining proper situation awareness, and experienced unmanageable workload due to a need to gather information. This chapter describes the data collection and the study results.

4.1 Methodology

The baseline study was conducted in 2010 at seven different REACT events. These events represented a cross-section of the different types of activities that are performed by REACT, creating an opportunity to capture an accurate picture of how REACT command center operations take place, and an opportunity to observe different types of incidents handled by REACT.

4.1.1 Events Studied

The characteristics of each observed REACT event is outlined in Table 5. A more thorough description of the events is described in Appendix C.

Table 5: Observed Baseline Events

Event	Characteristics	REACT's Role
Manulife Bike and Hike for Heart	Walking and biking routes	Emergency support, patrol roadway routes for participant safety, coordination assistance
Cambridge Tour de Grand	Biking routes ranging from 10km to 160km	Emergency support, patrol race routes for participant safety, monitor progress of all routes
University of Waterloo Canada Day Celebrations	Live concerts, activities, night-time fireworks display	Emergency support, directing traffic, coordination assistance, monitoring restricted areas Included: two medical incidents requiring 911 assistance
Waterloo Aviation Expo and Air Show Practice Event (actual event not observed due to security concerns)	Two day air show, including aerial acrobatics, 25,000 spectators	Monitor restricted areas, emergency support, assist organizers. REACT did not have main coordination role among Emergency Services, but the REACT trailer was used for this role.
Kitchener-Waterloo Oktoberfest Parade	5km long parade, 130 floats	Escorting floats, assisting with parade direction, traffic direction, emergency support Included: one significant medical incident requiring 911 assistance
Kitchener-Waterloo Santa Claus Parade	5km parade, over 100 floats	Escorting floats, assisting with parade direction, traffic direction, emergency support
Cambridge Santa Claus Parade	Smaller route, fewer floats (than above), but at night	Escorting floats, assisting with parade direction, traffic direction, emergency support

4.1.2 Procedure

Throughout the observation of these seven different events, a common procedure was followed. To best observe what was happening during each event, the researchers located themselves within the communications area of the REACT mobile command center. Command monitors the radios and maintains awareness from within the REACT mobile command center. It was important to find a vantage point that did not intrude within the operations, yet provided a view of the happenings within the communications area. Figure 2 shows the configuration of the command center during observations.

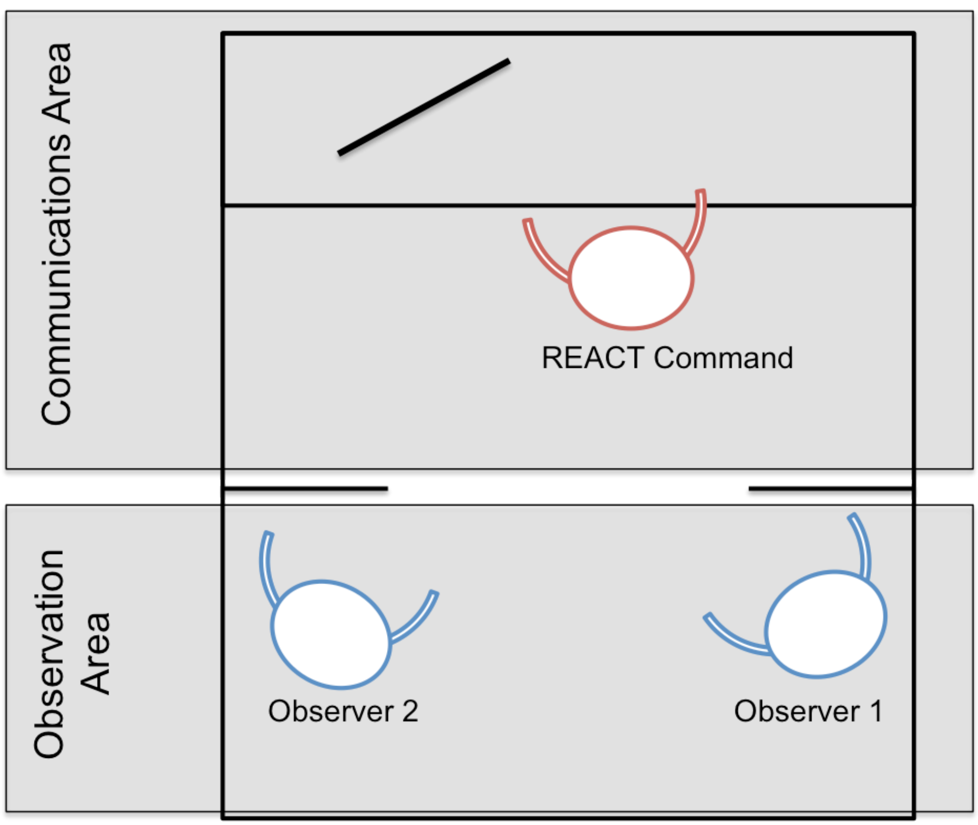

Figure 2: Baseline Study Observation Configuration

Within the communications area is a desk outfitted with a desktop computer and a number of radios. During REACT events, Command monitors these different radio channels concurrently (sometimes up to seven radio channels are being heard and monitored by Command), including channels for REACT, police, event organizers, and emergency services dispatch operators. Command pays most attention to the REACT channel, responding to requests from field agents, and directing their actions. Through the monitoring of the REACT channel, Command attempts to maintain awareness of what is happening outside the mobile command center.

Although the users of the REACT mobile command center are primarily REACT volunteers, the trailer is also provided to emergency services in times of need. For example, the trailer may be used during a search and rescue event, to provide a dry, indoor location from which police can coordinate their efforts and conduct meetings. As such, the technology needs and usage patterns of these extra mobile command center users are generally very similar to those of REACT.

In the first four events, only qualitative observational data in the form of observer field notes and photos were collected. In the last three observed REACT events, both field notes and communications coding were collected. To capture both sets of data, two researchers were present. One collected the field notes, while the other used the coding assistance tool described within Chapter 3 to record the communications as they were transmitted. The REACT personnel working as Command during that time period was accessible to answer unobtrusive questions throughout the event.

4.1.3 Data Analysis

To analysis the collected data, the methods described previously, both quantitative and qualitative methods were used. The affinity diagramming qualitative data analysis technique (Holtzblatt & Jones, 1993) was used to find common themes in observations. Themes seen consistently across different events, or mentioned within discussions with REACT personnel, were used to synthesize patterns of behavior that describe how REACT operated and what their primary decision-making methodology was. Additionally, indications of cognitive workload, situation awareness, and decision-making breakdowns were all analyzed using the same affinity diagramming technique. Patterns of behavior pertaining to these themes are described in the results section below.

The coding data collected using the audio coding tool was aggregated into a graph to provide a visual representation of the distribution of communications between codes and between field agents and Command.

4.2 Results

The results described in this section represent consistent patterns of operation in the REACT command center between events, and allow for comparisons after the technology is implemented within the mobile command center. Three main findings are presented. First, there is a culture of insistence that micromanagement is inappropriate, and that independence of field agents is valuable. This finding specifically highlights how important the impact of increasing fidelity can be; if the deployment causes micromanagement, there may be a very difficult shift in organizational culture. Second, the results revealed issues with low situation awareness. Finally, a wide range of levels of cognitive workload was observed during events. These findings highlight some potential areas where the high-fidelity display may be able to assist REACT in their activities.

4.2.1 Culture of Independence

Although never framed as micromanagement during the field observations, Command expressed specific opinions on who should make decisions in REACT, and how field agents are expected to respond to events. Primarily, Command was very adamant that field agents should maintain their independence. All field agents were said to be trusted as good decision makers and emergency responders, and their ability to react to an emergency was to be unhindered by Command. Updates about what was happening needed to always be relayed to Command, but specific decisions about how to respond to events were often left almost entirely to field agents, with the exception of life-threatening emergencies. During the observations, three different people acted as Command; all presented consistent opinions on these topics.

The qualitative observations showed that Command's role in these situations was often to relay information to other organizations and to other field agents, and to coordinate assistance as necessary based on information from the responding field agent. Command did note that some of the more junior field agents would need more guidance, and so the level of micromanagement was slightly higher during cases when these junior agents were responding. They also made sure to correct any actions taking place that they felt were not the best method of response, but that happened only rarely. Otherwise, there was a conscious effort on the part of Command to maintain the independence of field agents.

Further support for this finding also came from analysis of the audio coding data. The communications that occurred within the last two events were categorized using the coding scheme, described within Chapter 3 in Table 3, to provide information about the level of micromanagement actually exhibited during these events.

Figure 3 shows the distribution of communications within each category of the coding scheme. The majority of the communications were split between Information Requests, Information Transfers, and Acknowledgements within both events. This focus on informational exchange rather than action commands is indicative of how Command allows field agents to act independently. Command was careful to maintain an understanding about what was happening during the event through information requests and transfers. However, they exerted little control over the actions of the field agents.

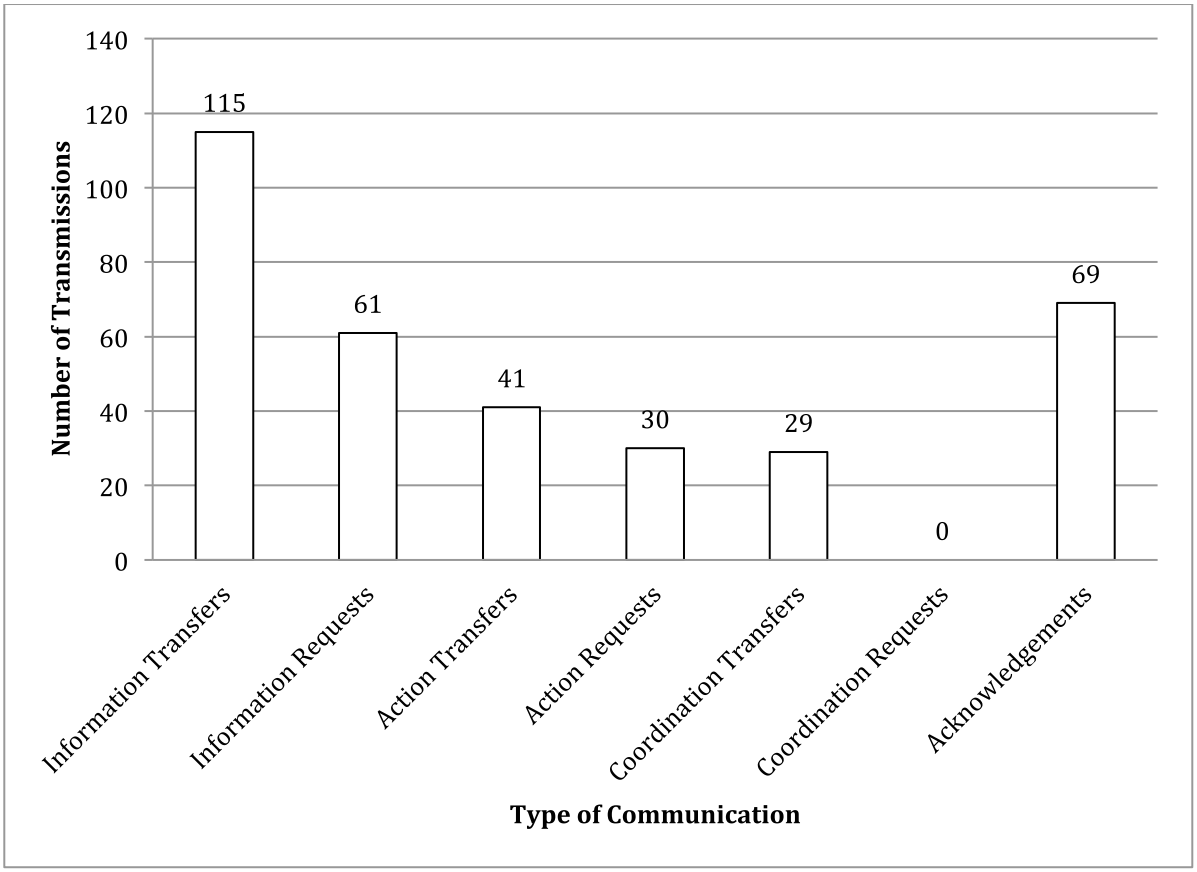

Figure 3: Baseline Communications, By Type

Some of this attempt to keep micromanagement low was also seen in the communications of Command compared to the communications of field agents. In all categories except for coordination, Command had a far fewer communications than the field agents. Even when looking at actions being transferred, the majority of the communications were actually made by field agents. Figure 4 shows the average number of communications by coding scheme for both Command and field agents.

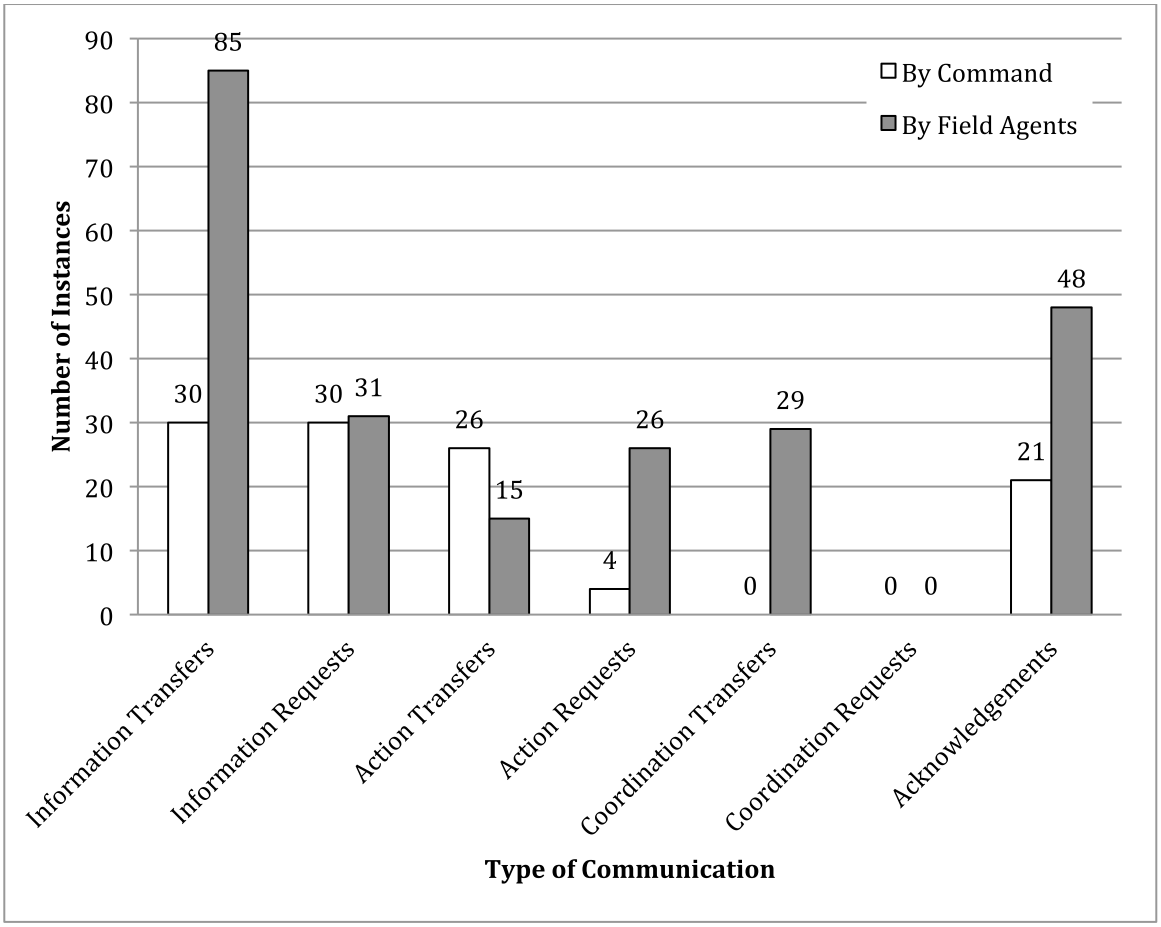

Figure 4: Baseline Communications by Command and Field Agents

The high number of information transfers being sent by field agents, as shown in Figure 4, was a result of efforts by field agents to help Command understand the happenings at the event. Field agents updated Command whenever they felt there was something notable occurring, and did not usually require prompting from Command. Review of the audio coding showed that Command only rarely used that information to relay to other organizations, instead it was only used to maintain situation awareness, or to relay information to other field agents.

4.2.2 Difficulty Maintaining Situation Awareness

The situation awareness of Command, based on the qualitative observations outlined below, was maintained at a basic level throughout each attended REACT event, and was only increased to a high level when there was an emergency to which Command needed to respond. Command appeared comfortable with having somewhat limited levels of SA during the events. However, they sometimes had difficulty increasing their situation awareness when necessary, often resulting in informational breakdowns in decision-making. Although these breakdowns were resolved before errors were introduced, they did slow down decision-making in some cases.

Command spoke very often about their ability to maintain an understanding of the "picture" outside of the command trailer. They noted that they usually assumed that field agents were always in their appropriate stations, unless they were informed of some movement. They were comfortable without knowing every piece of information about the "picture", and felt that they would be able to gather the appropriate information when the need arose.

Specifically, Command would use techniques such as asking field agents to "keep radio silence" during an event, allowing them to more easily collect information from agents involved in an incident without interruption. This quick development of situation awareness was very common in all events observed. It showed that Command maintained only a base level of situation awareness during events, and increased that awareness through questioning only when necessary. This was further confirmed by the frequency of informational breakdowns shown during the events.

Although no decision-making failures were observed, there were several incidents where breakdowns occurred during the course of the decision-making process. The breakdowns observed were primarily informational breakdowns, caused by a lack of situation awareness on the part of Command. Generally, these were addressed effectively through the act of collecting necessary information before making the decision, but these informational breakdowns point to difficulty maintaining situation awareness.

The types of decisions which were most likely to show signs of breakdowns during the decision-making process were those that required knowledge of the whereabouts of field agents and happenings during the event itself. In most cases, Command did not have the necessary information to make an appropriate decision, even though field agents knew the information. Command was able to recognize the informational disconnect in these cases, and addressed the problem by requesting information from field agents. Although the decisions were eventually made with all of the necessary information, they took longer than they might have if Command had known the information before it was necessary.

Figure 5 shows an example dialogue from one event that demonstrates an informational disconnect. Command asks a coordinator when they should close the roads, to which they received an incorrect answer. Only through clarifying the information with field agent 603 was Command able to answer the question. In this dialogue, Command is speaking with both field agent 603 and the coordinator over different radio frequencies.

> **Command (to coordinator):** Are you in communication with road closure people? What time should we close the roads?
>
> **Coordinator (to Command):** Yes, we're closing at 5:30.
>
> **Command (to coordinator):** That sounds pre-mature, normally they close later…
>
> **Command (to field agent 603):** Are you near an auxiliary police officer? Is 5:30 too early for road closure?
>
> **Field agent 603 (to Command):** Shut down in 10 minutes from now.
>
> **Coordinator (to Command):** So, 20 minutes to 6:00?
>
> **Command (to coordinator):** Yeah, that's right.

Figure 5: Dialogue Showing an Informational Disconnect

These common informational disconnects may point to a more important problem of lack of situation awareness. That Command often does not know the whereabouts of their field agents or the state of the event shows that they are not able to maintain accurate situation awareness.

Further indication of situation awareness levels can be found through the analysis of anticipation ratios, gathered through analysis of audio coding. Anticipation ratios, as outlined within Chapter 3 are a representation of how well members on a team anticipate the needs of others. An anticipation ratio higher than 1.0 is considered an indication of “good” teamwork and communication amongst teams (Entin & Entin, 2001). During the events with coded communications, it was found that the anticipation ratios of the communications between the REACT teams was consistent, and revealed interesting information about the way the group shared information and actions.

A comparison of anticipation ratios between the two events is shown in Figure 6. The overall anticipation ratios of both events were above 1.0, as were the information anticipation and action anticipation ratios. These numbers show that anticipation of information and actions is part of Command culture within the REACT command center.

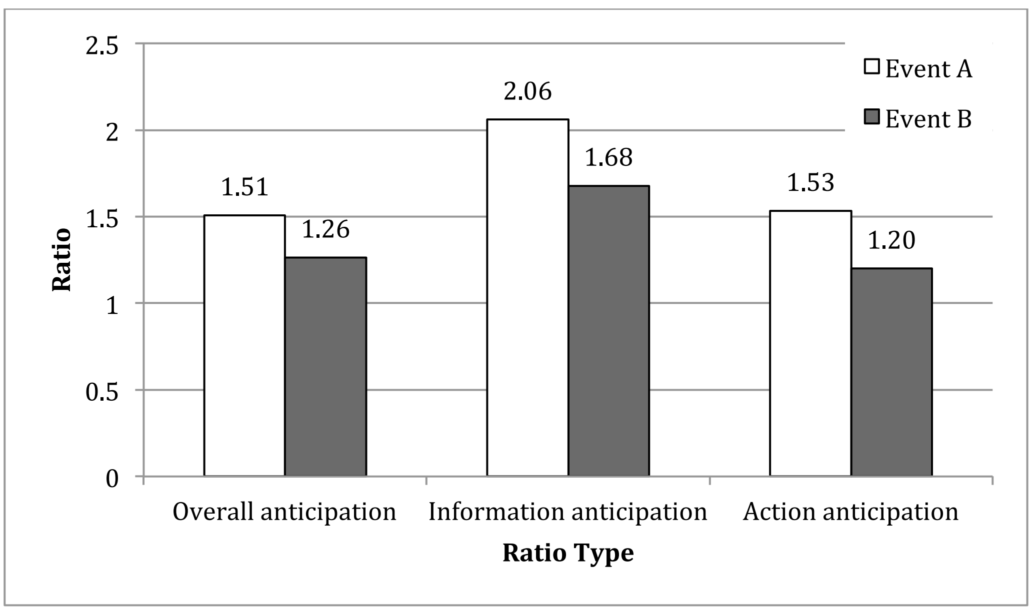

Figure 6: Baseline Anticipation Ratios

The high information anticipation ratios show that the team is very successful in understanding the informational needs across the team. This finding is not surprising when compared to other findings that show many exchanges by field agents and Command that are intended to share information that others may find potentially useful. For example, Figure 7 shows an exchange at the start of one of the parades between field agent #601 and Command. During this dialogue, field agent 601 anticipates that Command needs information about the start of the parade, and relays it accordingly. Command also anticipates that the rest of the team would need to know that the parade started, and communicates that information.

Although field agent 601 did transmit this information over the REACT radio for all field agents and Command to hear, Command anticipated that other field agents might not have heard the transmission, and so relayed it again over the radio to ensure it was heard. In each case shown in Figure 7, the information was transmitted before it was requested, showing a high level of information anticipation. Such interactions were very common during each observed event.

Field agent 601: Stand-by for the start of the parade.

(later…)

Field agent 601: The parade has started.

Command (to all): Just to let you know, the parade has started.

(later…)

Field agent 601: FYI, live coverage starts at 11 so they'll be holding floats at city hall if they arrive early.

Command: Copy that, thanks.

Figure 7: Dialogue Showing Information Anticipation by a Field Agent

Action anticipation ratios were very similar across events. Both Command and field agents consistently gave action commands before they were requested. Although a good sign of teamwork, an action anticipation ratio that is too high could also be an indicator of micromanagement. As the ratio increases, this may be a sign that Command is issuing far more commands than necessary, and is moving towards a higher level of micromanagement.

The collected data showed that Command maintained insufficient levels of situation awareness for immediate response to inquiries. Although anticipation ratios were high, the data still revealed informational breakdowns that indicate that situation awareness is an area that could be improved within the REACT command center.

4.2.3 Wide Variance in Cognitive Workload

The cognitive workload of Command was highly variable, depending entirely on the situation unfolding during each event. During the majority of each event, Command need only dedicate a small portion of their cognitive capacity to their command role. This limited cognitive load results in boredom, distractions, and the ability to monitor other organizations' needs throughout most events. However, when a medical emergency or other important incident arises, Command's cognitive workload increases to a very high level and they are unable to pay attention to other tasks or information. At some points, this workload was unmanageable.

No direct measures of Command's perceived cognitive workload were collected. However, the observational data did provide some insights into what they might be experiencing. Primarily, Command often stated that they were bored, and that the job of being Command was quite easy. They noted this in every event during discussions with researchers.

However, this boredom was only seen when nothing went wrong during the event – those events with medical emergencies or other serious situations were not so easy. In asking other field agents to stay off the radio during emergencies, and in asking researchers to stay quiet, Command demonstrated that they had no spare cognitive resources to dedicate to any other tasks. In discussions after the fact, they confirmed this by stating they did not have the spare capacity for distractions during these times.

To further support these claims of boredom and low cognitive workload, observations were noted about the level of distraction being exhibited by Command. During long events, some of which were eight hours in length, there are often long periods of time in which there are no communications from field agents. To add to these potentially boring conditions, Command is often operating alone. This environment results in long periods of boredom punctuated by short bursts of activity. Command was observed multiple times, in every event, using the command center computer to occupy their time.

These distractions, although not interfering directly with command activities, did seem to affect the situation awareness of Command. When Command returned to command activities following one of these distractions, they did have to re-acquaint themselves with the locations of field agents and re-develop their picture of the situation. Additionally, multiple cases of informational breakdowns in decision-making did occur after one of these sessions of boredom caused by low workload.

The workload placed on Command was also observed through analyzing attention paid to secondary tasks. During some events, REACT was the only organization using radios. This meant that Command was responsible for monitoring only one stream of information. In larger events, Command had up to seven different radios on the desk, all of which were to be monitored at the same time. These extra radios were from community organizers, different emergency services, or other organizations, and provided a means for inter-agency coordination. However, monitoring these radios was less important to Command than supporting REACT operations, making it a secondary task. This meant that examining the way Command dealt with extra radios provided some indication of the amount of available cognitive resources.

Observational data revealed that during times of high workload they would turn down the volume on these extra radios. Command was then able to still peripherally listen to the radios, sensing when something urgent was being discussed, but they did not actively listen to the discussion. This coping strategy stopped Command from being overloaded with information, but it meant that important information could have been missed. This management of a secondary task showed that command operations during any kind of incident required almost all of Command's cognitive resources, leaving little-to-no resources for monitoring extra radios. During the rest of the event, Command was able to monitor all of the radios, showing that the normal command activities did not require very much cognitive capacity.

4.3 Chapter Summary

This chapter described the baseline study that was conducted to gather data about the REACT operations prior to any technology deployment. The data collection methods described in previous chapters were used to learn about the operations currently conducted within the REACT context, and to understand how command operations worked during different events.

The data analysis revealed that the culture within REACT is one that allows field agents a high level of freedom, and puts great value on independence and low levels of micromanagement. This was observed through both the communications and actions of many different REACT members. To maintain this low level of micromanagement, Command did not attempt to maintain contact with all field agents at all times, resulting in some difficulties maintaining situation awareness. This was seen through the observed informational breakdowns in decision-making, and an apparent lack of complete knowledge on the part of Command. Additionally, the cognitive workload of Command varied greatly, as times in which no incidents occurred were extremely boring for Command, while incidents resulted in very high workload as Command attempted to regain complete situation awareness and manage the incident.

These observations about REACT provided direction for the design of the controlled technology study, as well as the actual technology built for use within the REACT command center.

Chapter 5

Controlled Technology Study

In order to investigate how providing high-fidelity information could impact micromanagement and situation awareness in REACT command center operations, a controlled technology study examined changes in participant behaviour with and without a high-fidelity GIS tool. Participants conducted coordination tasks with access to technology with varying levels of information fidelity, and the changes in their behavior were documented.

In studying the differences between the ways participants behaved as information fidelity changed, it was found that micromanagement, situation awareness, and cognitive workload were all affected. Within the high-fidelity information condition, participants engaged in a higher level of micromanagement, were able to maintain better levels of situation awareness, and maintained more stable levels of cognitive workload.

This chapter describes the technology used to provide higher-fidelity information during the study; it then describes the study design, procedure, data collection and analysis, and key findings.

5.1 Increased Location-Based Information Fidelity Display

To assist REACT in their operations within the community, technology was developed for deployment within their mobile command center. The technology was designed to increase the fidelity of available location-based information about field agents by presenting the location of each field agent on a large map display.

The tool was designed is to assist Command in their role of directing the actions of the field agents. In addition, it was designed as a method of planning operations for events by providing a visual supplement to briefing activities. Using the display, command is able to see the locations of field agents at all times, and always has access to a complete visual picture. Figure 9 shows a sketch of how the technology deployment within the REACT trailer may look after the project is completely finished; pictured are the display, a computer monitor, papers for use on the desk, and three small radios (shown, bottom right).

Figure 8: Sketch of Potential Technology Deployment in REACT Command Centre

The technology being used within this study was an adapted version of that which was intended for deployment within the REACT mobile command center. It was a simplified interface that used a large display to show the locations of REACT field agents, thereby increasing the fidelity of the location-based information available to command, but did not include any other features (such as annotations and note-taking) that were planned for deployment within the REACT command center. The design of the interface used by participants, and the hardware with which they could interact with the display is described below to give a better understanding of what the participants were experiencing during the high-fidelity condition.

5.1.1 Interface Design

The interface of the technology used within the study was created to be as simple as possible. The information displayed was intended to increase the fidelity of the location-based information, without distracting participants with other features. Figure 9 shows the interface in the state that all participants experienced. The interface provides a basic map showing the locations of field agents during the simulated events.

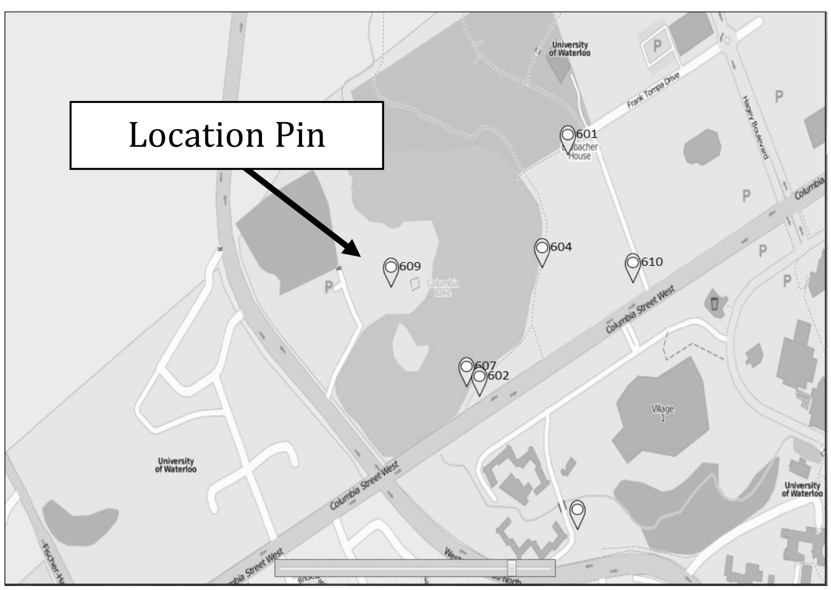

Figure 9: Interface for High-Fidelity Condition in Study 2

The location pins on the map indicate the location of each individual field agent, and are labeled with the radio call number of that field agent. Consistent with real-world operations, the radio call number was the number that the field agents used to identify themselves over the simulated radio as they communicated with each participant. With their mouse, participants could pan and zoom the map. No other interactions were available.

5.1.2 Physical Setup

The physical setup in which the previously described high-fidelity information display was created to closely mimic what will be deployed in the REACT mobile command center, but allow for empirical evaluation in a controlled setting (see Figure 10). The display was projected onto a wall for the study participants to view. Participants were situated at a table directly in front of this projected display, so that they could also use the provided paper maps.

Figure 10: Simulated Command Centre Setup

5.2 Experimental Design

The experiment was designed as a single factor (level of information fidelity) repeated measures design that accounted for learning effects and potential differences in participant experience and knowledge. The following sections describe these conditions more fully, and the design of the experiment.

5.2.1 Conditions

To determine how a change in information fidelity affected those in a command role, participants were asked to complete a coordination task under two different conditions: with high-fidelity location-based information, and with low-fidelity location-based information. Each participant experienced both conditions, so that the effect of participant experience and command style could be considered and accounted for. By looking at changes that occurred between conditions for each participant, overall effects of these conditions were isolated.

5.2.1.1 High-Fidelity Condition

In this condition, participants were able to complete the experimental task using the large format information display system previously described. Other information was received through simulated radio contact with field agents. Participants also had access to a paper map that showed the location of the simulated event, as well as an event brief that described the planned location for each field agent, and the rules for the event. The coordination task completed by the participants in the high-fidelity condition is described in the Task Design section below.

5.2.1.2 Low-Fidelity Condition

In this condition, participants did not have any information display system at their disposal. Participants had access only to a radio system, through which they received the same type of radio information as was available over radio in the high-fidelity condition. Identical to the high-fidelity condition, participants were provided with a paper map and event brief. Participants performed the same coordination task as in the high-fidelity information condition (described in the Task Design section below).

5.2.2 Learning Effects

As the order that participants conduct the coordination tasks may affect their ability to coordinate, or may cause change in their command style as they learn how to better coordinate their field agents, conditions were balanced between participants. Half of the participants were presented the high-fidelity condition first, and half were presented the low-fidelity condition first. Observed changes in the same direction across participants in both orders could then be assumed to be a result of the change in information fidelity, rather than order or learning effects.

Learning effects were also addressed by providing training sessions before each condition trail. By practicing both the technology and the coordination task over radio, participants should learn enough about both to allow for limited learning effects between different conditions. This training is outlined further in the Procedure Section.

5.2.3 Participants

Twenty graduate students were recruited from the University of Waterloo population. Within this participant pool, there were 12 males and 8 females. Half of the males and half of the females participated in the experiment with the high-fidelity coordination task first, and the other half participated with the low-fidelity coordination task first.

The participants were assumed to have some knowledge of how emergencies might be handled, and some knowledge of the area geography that was referred to within the tasks (it was local to the university campus).

5.2.4 Experimental Task

The experimental task was designed to mimic the types of tasks routinely encountered by Command within the REACT mobile command center and was based on observations from the baseline study which highlighted some specific types of incidents that occur on a regular basis within REACT operations. Specifically, participants were asked to monitor a radio and coordinate field agents as they encounter different types of incidents at a simulated event. Problems such as lack of support and need for different types of resources were presented, and participants were instructed to solve these problems and ensure the field agents carried out the appropriate solution.

A different variation of the coordination task was designed for use in each condition. To make these two coordination tasks directly comparable, each event and communication from field agents within the high-fidelity information task directly corresponded with another event or communication in the low-fidelity information task. Specifically, these corresponding communications were written such that the type of information or request, and the expected response, would be of the same type of content, but with a different theme or topic. In this way, the tasks were directly comparable while still feeling unique to the task participants.

The coordination tasks were also designed to account for both what participants could reasonably handle, and what would be most comparable to real-world REACT circumstances. If the tasks were too difficult for participants to understand, or if the learning curve was too steep, it would be difficult to determine which changes in collected data were due to the change in information fidelity, and which changes were due to participants changing their understanding of how to handle emergencies. In creating tasks and circumstances that closely mimic what someone working as Command within the REACT mobile command center would actually encounter, the data and conclusions could better be extended to the REACT environment. Rooting the circumstances in real-life was the method through which this was accomplished.

To best ensure that the participants could be reasonably expected to know how to respond to the circumstances as they develop, care was taken to make sure that terminology used was common to an average graduate student. In addition, situations and incidents were selected that could happen in an everyday environment, and that required no special actions on the part of Command – the focus could be put on coordination of field agent resources and information distribution, rather than understanding exactly what must be done to handle the incident. Additionally, steps were taken to ensure that Command knew that field agents were able to handle the emergencies properly without needing detailed medical instructions from command.

Each task involved the coordination of seven field agents. The field agents were played by the same researcher over the radio, however each identified themselves by a specifically radio call number. Participants directed their instructions at specific field agents in the same manner, by addressing them by their radio call numbers. This use of radio call numbers kept the experiment easy to run, yet still maintained the feel of coordinating multiple field agents.

5.3 Procedure

The procedure that was used for each experiment was identical to ensure that the data collected would be directly comparable. The procedure incorporated methods, described previously, to counter concerns such as learning effects and different interpretations of command roles.

Table 6 briefly describes the procedure used during this study. The two coordination tasks varied depending on the order the participant was completing the study to address learning effects. All of the procedures and the artifacts used for these steps can be found in Appendix B.

Table 6: Study 2 Procedure

Step	**Description**
Introduction	Each participant was introduced to the study with the same script. The script outlined the procedure, what was expected of them during each task, and how to handle different types of situations. Any questions were answered at this time.
Training 1	Participants completed a 5-minute training task that directly mimicked the types of incidents and communications they could expect in the experimental tasks. They then had an opportunity to ask any questions about aspects they were unsure of, and could request to repeat the training task if they did not yet feel comfortable with their role.
Coordination Task 1	The first coordination task was conducted for each participant directly following his or her training task. This task took 20 minutes to complete.
Questionnaire 1	Participants were then asked to immediately complete the questionnaire regarding the first coordination task.
Interview 1	The researcher conducted the interview regarding what the participant experienced during the first coordination task.
Training 2	The training task was then conducted again with the different information fidelity, taking 5 minutes to complete.
Coordination Task 2	The second coordination task was then conducted, again taking 20 minutes to complete.
Questionnaire 2	Participants were asked to immediately complete the questionnaire again, this time regarding their experiences during the second coordination task.
Interview 2	The researcher then conducted the same interview with the participant, this time regarding the second coordination task.
Wrap Up	Participants were asked if they had any other comments or questions that they would like to discuss. These were discussed before providing the participant with remuneration and completing the study.

5.4 Data Collection and Analysis

As previously discussed in Chapter 3, the data collected within this study were chosen in order to answer specific questions about how information fidelity impacted different aspects of command processes and decision-making. The questions and the sources of their answers are summarized in Table 2 in Chapter 3. The method of data analysis for each type of data collected is summarized in Table 7 and detailed in the following subsections. The method of collecting and analyzing the audio coding and qualitative observations is described in depth in Chapter 3, while the workload ratings and secondary task analysis is described in the following sub-sections.

Table 7: Data Analysis Methods for Study 2

Data Source	Analysis Method
Audio Coding	Graphing the changes in average number of communications in each code gave preliminary indications of changes in communication, which were further analyzed through Repeated Measures Analysis of Variance (ANOVA) procedures to determine significance.
Qualitative Observations	Qualitative observations were analyzed using affinity-diagramming techniques, which provided central themes to report. The field notes were also read carefully to look for patterns in behavior or to support or deny preliminary findings from other data sources.
Artifact Analysis	The artifacts collected after each session were examined specifically to look for offloading of memory tasks, and to determine whether participants had to rely on the maps to remember location information. Use of maps for offloading was also analyzed with a Paired t-Test to determine significance.
Questionnaire Responses	Questionnaire responses were compared using graphs that showed the distributions of responses for each question in each condition. The changes seen in those graphs were further analyzed with a Wilcoxon Signed-Ranks Test to test for significance.
Interview Responses	Interview responses were analyzed using affinity-diagramming techniques to isolate themes in responses. These themes were used to support other findings and to provide some insight as to why certain data patterns were being seen in other analysis.
Workload Ratings	Workload ratings were compared using graphs that showed the distribution of all responses over each task, and were further analyzed for significance using a Wilcoxon Signed-Ranks Test.
Secondary Task Performance	Secondary task performance was measured as time-to-respond, and was analyzed be examining the average time to respond for each condition. The significance of that change was evaluated using a Paired t-Test.

5.4.1 Cognitive Workload Self-Assessment

The cognitive workload being placed on participants in this study was captured partially through subjective ratings of workload throughout each session. This was accomplished through the use of a program that prompted participants to rate their workload periodically and logged the results. These log files of subjective workload ratings provided a way to quantifiably measure the cognitive workload of participants throughout the activity.

The ratings of workload by participants indicated both how their workload changed within each task, and how their workload changed between tasks as a result of the available technology. In examining the distribution of ratings indicated by participants and how the distribution changed, a picture of the effect of increasing information technology was developed. The dialogue used to collect this subjective workload rating is shown in Figure 11.

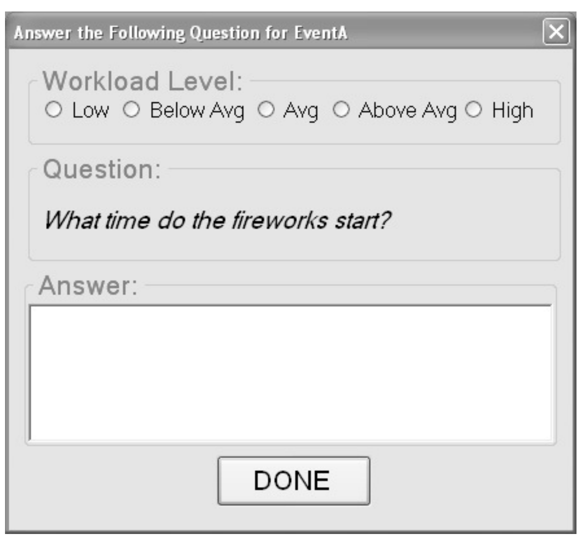

Figure 11: Dialogue to Collect Intermittent Rating of Perceived Workload

5.4.2 Cognitive Workload Secondary Task Performance

Although subjective workload ratings were collected, it was also important to collect objective data about workload. One method that can be used to assess cognitive workload is the use of a secondary task (Ogden et al., 1979). Participants were asked to answer a simple question, but only in a way that did not interfere with their primary task of making command decisions. The time it took to answer indicated the amount of workload being experienced at the time of the question. Questions were asked every two minutes, at the same time and using the same dialogue as the subjective workload rating shown in Figure 11. Similarly, secondary task performance was only measured where the interruption would not have the potential for affecting real-world emergency response operations. The questions posed can be found in Appendix B.

To analyze the data collected from this secondary task measure, the average time to answer was compared both within each task, and across the different technology conditions. A shorter time to answer indicated that more cognitive resources were available to dedicate to the secondary task (Ogden et al., 1979). Conversely, when participants needed more time to answer the question, it was assumed that more cognitive resources were needed to complete the primary task at that time.

5.5 Results

Analysis of each data source was used to understand how the increase in information fidelity impacted different aspects of command processes and decision-making. The data were examined with respect to the areas of concern found in the baseline study.

The results of this study elucidate how increasing information fidelity moves command towards a more micromanagement-type style of command, increases their situation awareness, reduces the extremes in their cognitive workload, and increases their confidence in command decisions.

5.5.1 Evidence for Increasing Micromanagement

To determine if there was an increase in micromanagement during the high-fidelity condition, audio from each session was coded. The ratio of commands (coded here as Action Transfers) to other types of transmissions and a quantification of how often participants actually corrected field agent actions were examined. Although there was little change in the makeup of the communications as seen in the coding data, there was strong evidence of an increase in micromanagement in the way participants managed field agents.

Analysis of participants' responses to field agents deviating from assigned roles showed that micromanagement did increase in the higher-fidelity information condition. During each condition, the same number of field agents deviated from their known roles. For example, in each condition, one of the field agents wandered away from their posts to help with a small crowd control issue before returning. They did this without informing Command (something that occurs within the REACT context as field agents do not want to bother Command with mundane issues). Participants were far more likely to respond verbally to these deviations when they were in the higher-fidelity information condition; none of the participants in the low-fidelity condition responded to any of the deviations, while in the high-fidelity condition 16/20 participants responded to the first deviation and 12/20 participants responded to the second. These responses to deviations showed how participants were more likely to micromanage their field agents when in the high-fidelity condition.

The pattern illustrated in responses to deviations was consistent with participant interview responses about managing field agents when there were issues, and their concerns about whether field agents were properly carrying out instructions. One of the most common themes that arose from the analysis of these responses was that participants were aware that they were micromanaging their field agents more in the high-fidelity condition, but only when they noticed incidents that were abnormal. For example, Participant 12 noted, "if you see them moving around you can ask them what they're doing, which I did from time to time." Participant 12 also mentioned that "it was easier to remember and make sure your strategy is actually being followed" when referring to the higher fidelity coordination task.

On the other hand, participants took more of a back-seat role, and put more responsibility in the hands of field agents, when they were in the low-fidelity condition. Without the available geographical information, it was far more difficult to preemptively give instructions, or to notice correctable mistakes on the part of the field agents. Additionally, participants did not want to try to gain this information over the radio, as it could potentially distract the field agents from their tasks. As Participant 4 described, "there were a few instances where 604 and 601 didn't really do much at all, so I wasn't sure of their status throughout the entire thing. And I didn't want to cloud up radio with questions or just status updates."

Data was coded using the coding scheme described in Chapter 3. This coding scheme provided insights as to what proportion of transmissions by command were actions. As shown in Figure 12, there was little change in the composition of transmissions during each condition session and statistical analysis showed that any changes that did occur were not significant. Although there does appear to be a trend to increasing action requests and decreasing levels of communication in all other categories, no immediate conclusions can be drawn from these data.

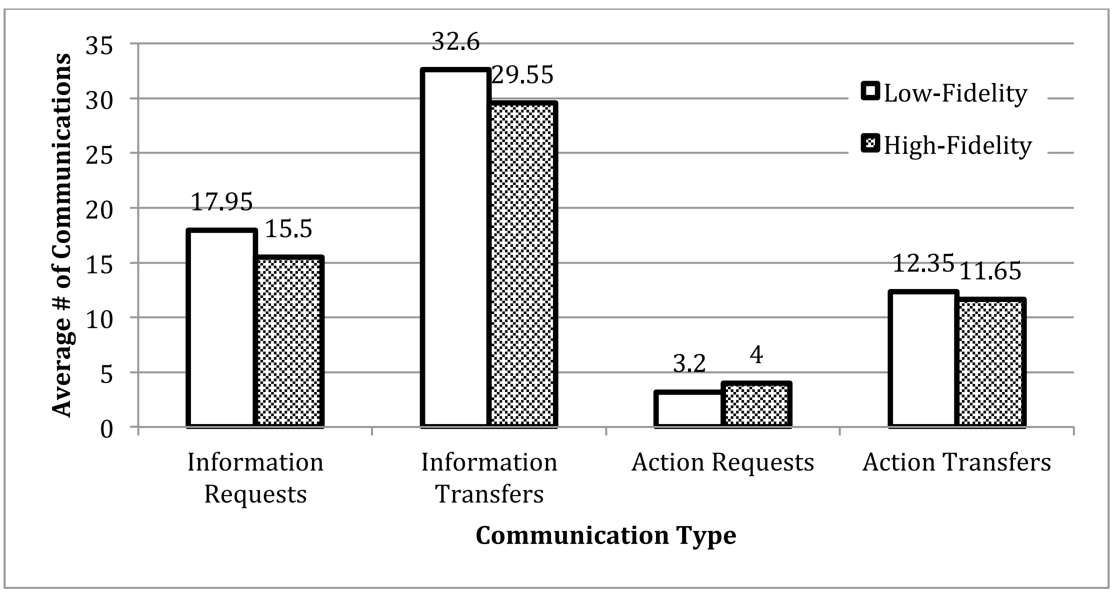

Figure 12: Coding Communication Types - Comparing Conditions

Overall, the collection of qualitative observations and audio coding data show that there was a higher level of micromanagement in the high-fidelity information condition. Although the audio coding did not show a statistically significant change in micromanagement, observations of responses to deviations and interview responses provided evidence to support this finding.

5.5.2 Increasing Temptation to Micromanage

To understand why the participants had an increased level of micromanagement in the high-fidelity condition, an analysis was conducted to learn about the temptation to micromanage experienced by the participants. To specifically understand the temptation to micromanage, and how that temptation changed with the varying of information fidelity, data from both questionnaire responses and interview answers were considered. These sources did not directly ask about micromanagement – instead they focused on the participants' desires to correct field agent actions and their command style. Both of these sources provided insights as to how much motivation there was to micromanage the field agents, based on the level of trust and confidence the participants had in their field agents.

5.5.2.1 Evidence for Increasing Temptation to Micromanage

It was found that participants felt more desire to micromanage their field agents, and specifically to correct or manage their actions, when they had access to higher-fidelity information. This is supported by both questionnaire and interview data.

Figure 13 shows how participants' level of agreement with the statement "I felt some desire to correct the actions of the field agents" increased with higher-fidelity information. A Wilcoxon Signed Ranks Test showed that there was a statistically significant change in response from the between the two conditions (Z = -2.460, P = .014). The responses to this question are shown in Figure 13.

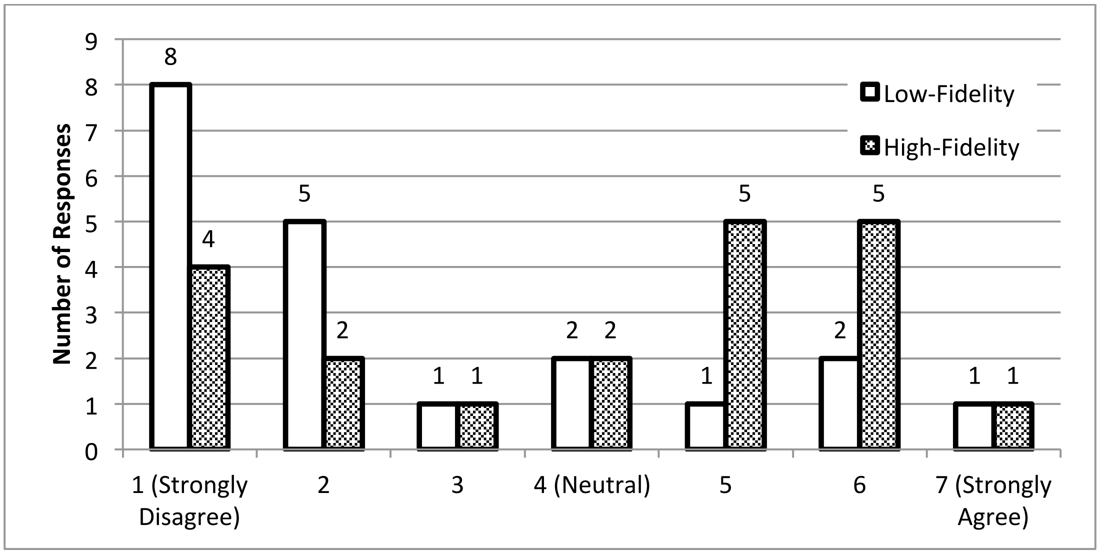

Figure 13: Questionnaire Answer Distribution for Agreement with "I felt some desire to correct the actions of the field agents"

The shift in the responses between the high-fidelity and low-fidelity condition is more specifically seen in the numbers of responses below or above neutral. As seen in Figure 14 in the low-fidelity information condition, 14 participants responded with disagreement of some kind, and only 4 responded with agreement. In the high-fidelity information condition, 7 responded with disagreement, while 11 responded with agreement. As a greater number of participants indicated that they felt desire to correct the actions of field agents during the high-fidelity condition, the questionnaire responses showed that participants experienced a greater temptation to micromanage during the high-fidelity condition when compared to the low-fidelity condition.

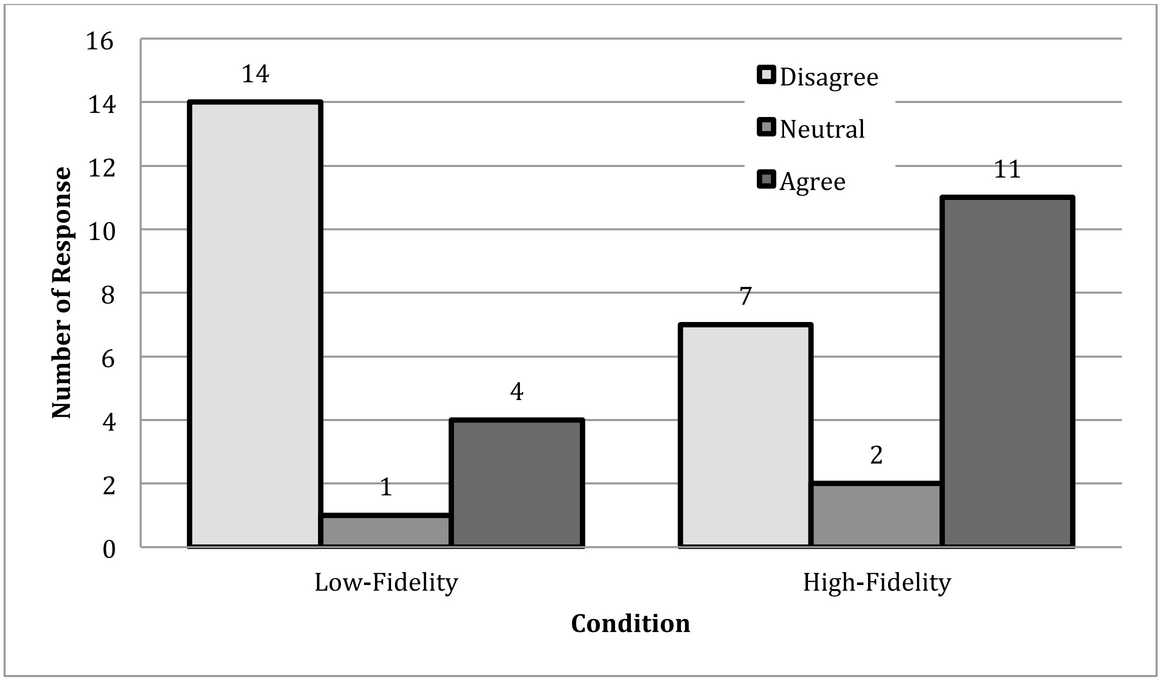

Figure 14: Level of Agreement with "I felt some desire to correct the actions of the field agents"

Many participants also reported this desire to micromanage during the interviews following the high-fidelity condition. Even though an increase in micromanagement was seen in the high-fidelity condition, participants often described not acting on their temptation to micromanage. Participant 13 noted, when discussing if he wanted to correct field agent actions, "Yeah, I suppose when they were out of position [I did]. I felt tempted to ask them about it. I was kind of tempted a couple of times. I guess I didn't want to be a jerk." This and other similar interview answers provided evidence to show that participants experienced temptation to micromanage, and shows that there were many instances in which they resisted temptation to micromanage. If participants had been more motivated to response to that temptation, the increase in micromanagement would have been even greater.

These observations provide evidence to show that there was an increase in the temptation to micromanage when participants were in the high-fidelity condition. This increase in temptation was most likely the cause for the increase in micromanagement described previously.

5.5.2.2 Reduced Trust in Field Agents

The increased temptation to micromanage in the high-fidelity condition was directly related to participants' trust in the field agents. Participants' level of trust depended on the order in which they completed the conditions, and was affected greatly by the increase in information fidelity. The high-fidelity condition reduced participants' trust in their field agents, and that effect lasted into the subsequent low-fidelity condition if participants experienced the high-fidelity condition first. These observations came from patterns that emerged during analysis of qualitative interview data.

Participants who experienced the higher-fidelity information display first found that they noticed field agents acting somewhat differently than expected, and that knowledge translated into lower trust in their field agents when they subsequently completed the low-fidelity condition. Participants who completed the low-fidelity condition first did not realize discrepancies in field agent behavior unless they specifically inquired about it over radio, something only one participant did. This meant that their trust level fell permanently once they were exposed to the higher-fidelity information display and could see those discrepancies. As Participant 9 described, participants were willing to trust field agents because they had not considered that field agents could be doing something unexpected. Seeing the field agents positions change on the screen completely changed how they thought about and trusted their field agents: "When 602 and 607 went off and did their things - that's the sort of stuff I couldn't pick up on before without the display. But at the same time, as far as personnel management, there is the potential with that to become obnoxious and not let the agents do stuff or trust their judgment. So, 602 didn't necessary need to radio in, but as soon as I saw [them move away from their post] I was like 'oh, what's happening?'"

This reduction in the level of participant trust in field agents was directly related to the increased information fidelity and the additional information provided by the display. The increasing fidelity of information about field agent whereabouts changed the way participants thought about field agents, and likely was one of the reasons micromanagement increased in the high-fidelity condition.

5.5.3 Better Maintenance of Situation Awareness

The study results showed that, overall, participants were better able to maintain an adequate level of situation awareness during the high-fidelity condition. Interview questions directly inquired about perceived situation awareness, and showed that participants felt they had much better situation awareness when using the higher-fidelity information display. This was further corroborated by a reduction in decision-making breakdowns when the higher-fidelity information display was available. As situation awareness was a key factor in how well participants were able to anticipate the needs of their field agents, anticipation ratios were also used as an indicator of situation awareness, and specifically the ability of participants to use that situation awareness in a way that benefitted their coordination abilities. The analysis of the anticipation ratios showed no significant change in anticipation, but did show that anticipation levels were appropriate in both conditions.

5.5.3.1 Perceived Increase in Situation Awareness

Participants perceived an increase in situation awareness during the high-fidelity condition. This was support through interview responses and questionnaire responses, both of which showed an increase in perceived situation awareness due to more easily available information.

An example of the perceived increase in situation awareness can be seen in Participant 12's responses, who completed the low-fidelity condition first, and the high-fidelity condition second. After the first, low-fidelity condition, he described feeling unsure about where his field agents were: "A few times, I tried to ask people what's going on to try to keep in touch. I guess it's sufficient, I suppose it could be better. You don't always know exactly where everybody is." However, after the second, high-fidelity condition, he had a completely different experience: "It's nice to see where they are, you don't have to worry about that. But then I guess if they do stray off the path you're more likely to talk to them. Maybe it's good, maybe it's a waste of your time. I don't know. But I think it makes the coordination very easy to see where everyone is and not have to remember... I don't think my strategy changed much, but it was easier to remember and see if your strategy is actually being followed." Participants consistently reported this perceived increase in situation awareness due to higher fidelity information. Participant 17 highlighted why it was so easy to maintain situation awareness in the high-fidelity information condition: "The best thing was that I could see where the agents are and I didn't have to ask them again and again about their location".

Responses to questionnaire questions regarding situation awareness were consistent with the self-reporting results described above. Participants indicated their level of agreement with the statement "I was always aware of what was happening outside of the command center". As shown in Figure 15, participants' agreement with that statement, an indicator of situation awareness, increased in the high-fidelity information condition. In the low-fidelity condition, there was wide variation in the responses of participants. In the high-fidelity condition, all the participants indicated at least some agreement above neutral with the statement. A Wilcoxon Signed Ranks Test found a statistically significant change between the two conditions ($Z = -3.404$, $P = .001$).

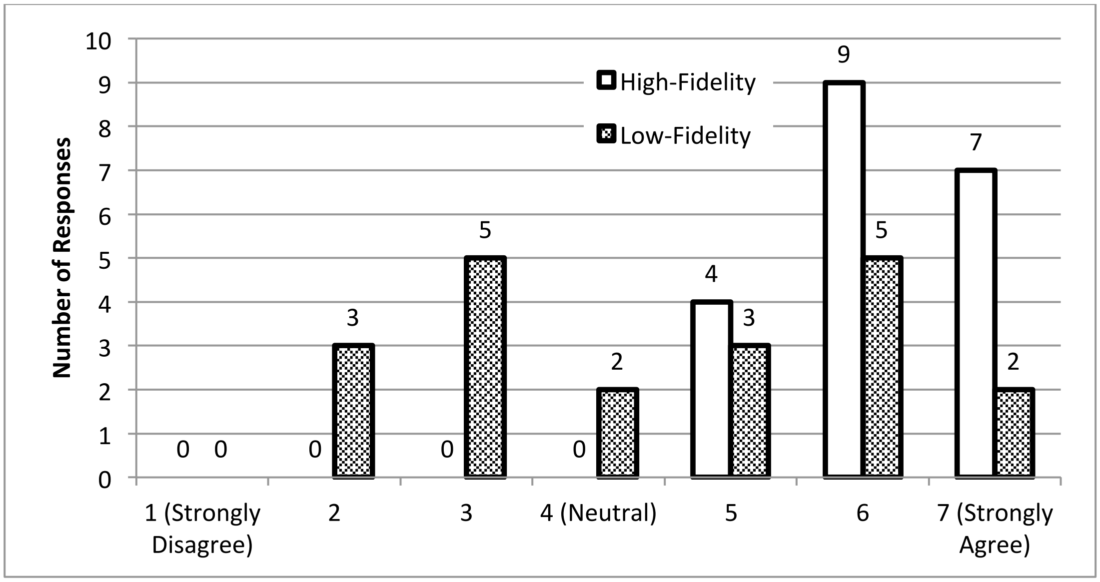

Figure 15: Questionnaire Answer Distribution for Agreement with "I was always aware of what was happening outside of the command center"

Results from both interview and questionnaire analyses show that participants perceived an increase in situation awareness during the high-fidelity information condition. They felt they were better able to maintain situation awareness with the high-fidelity information display.

5.5.3.2 Perceived Increase in Anticipation of Field Agent Needs

Qualitative analysis of the interviews showed that participants felt that they were better able to anticipate the needs of the field agents in the high-fidelity condition. Measured anticipation ratios showed no significant change, but did show that anticipation ratios were adequate for both conditions.

Many participants expressed that the high-fidelity condition caused them to feel better able to help their field agents because they were better aware of what was occurring outside of the mobile command center. For example, Participant 11 noted: “I felt it was more manageable [with the display], I could respond a little quicker.” When asked why he could respond quicker, he discussed how difficult it was to maintain situation awareness that he trusted: “I guess not being able to see immediately if there were reactions to my directions, and not being able to see what people were doing when they were talking to me. Whether they were in the right area or if they wandered off or were in the totally wrong area on the map, I didn't really know that. People that did check in, you knew where they were for that second where they checked but you couldn't actually know if they were really in the fireworks launch area. By [the field agent] just saying ‘I'm in my position’, you don’t know if where they think they are is where they're supposed to be.”

Analysis of anticipation ratios during the study showed that anticipation of field agent needs was at a level that provided “good teamwork” throughout both conditions, but showed no statistically significant changes between conditions. Figure 16 shows the overall anticipation ratios in both conditions. According to Entin and Entin (2001), an anticipation ratio over 1.0 indicates good teamwork and is an effective level of anticipation. Similar to the analysis results of the baseline study, the overall anticipation ratio for the participants was always considerably above 1.0.

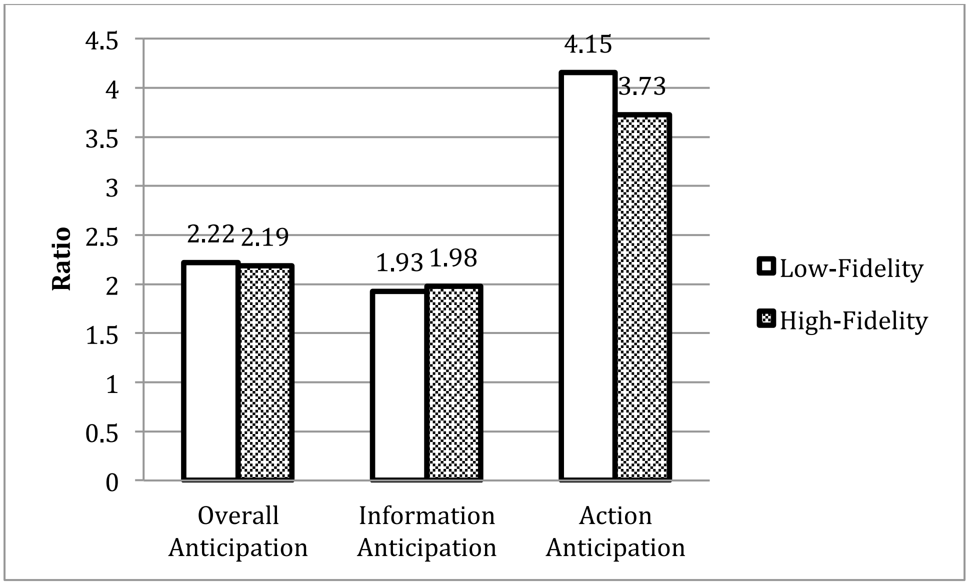

Figure 16: Comparing Anticipation Ratios

The interview responses of participants showed that they felt their situation awareness was increased during the high-fidelity condition, causing an increase in their ability to anticipate the needs of their field agents. Analysis of anticipation ratios did not support this change. However, this information was enough to conclude that participants felt they were better able to anticipate field agent needs.

5.5.4 Reduction in Cognitive Workload

The cognitive workload placed on participants acting as command was measured using a number of different data sources. Participants' perception of their workload was measured both during and after each coordination task, showing consistently that participants felt they were under a reduced workload when using the higher-fidelity information display. At the same time, participants completed a secondary task throughout each coordination task, although this measure was dominated by an order effect. An additional finding about participant boredom showed that the other extreme of cognitive workload was also affected by the increase in information fidelity. These findings are described below.

5.5.4.1 Reduction in Reported Cognitive Workload

Subjective ratings of cognitive workload during coordination tasks and interview responses after coordination tasks showed that participants felt their cognitive workload decreased during the high-fidelity information condition.

During each coordination task, participants were prompted to rate their workload at two-minute intervals. Participants rated their workload during these tasks on a scale from 1-5, with 5 indicating a very high workload. These ratings showed that participants felt their workload was reduced during the high-fidelity condition. Figure 17 shows the total number of times participants selected each rating during both the high-fidelity and low-fidelity conditions. It can be seen that, in both cases, cognitive workload was rated as neutral to very low, but in the high-fidelity condition, more of the rating of cognitive workload were neutral or lower. A Wilcoxon Signed Ranks Test showed that there was a statistically significant change in response between the two conditions ($Z = -2.141$, $P = .032$).

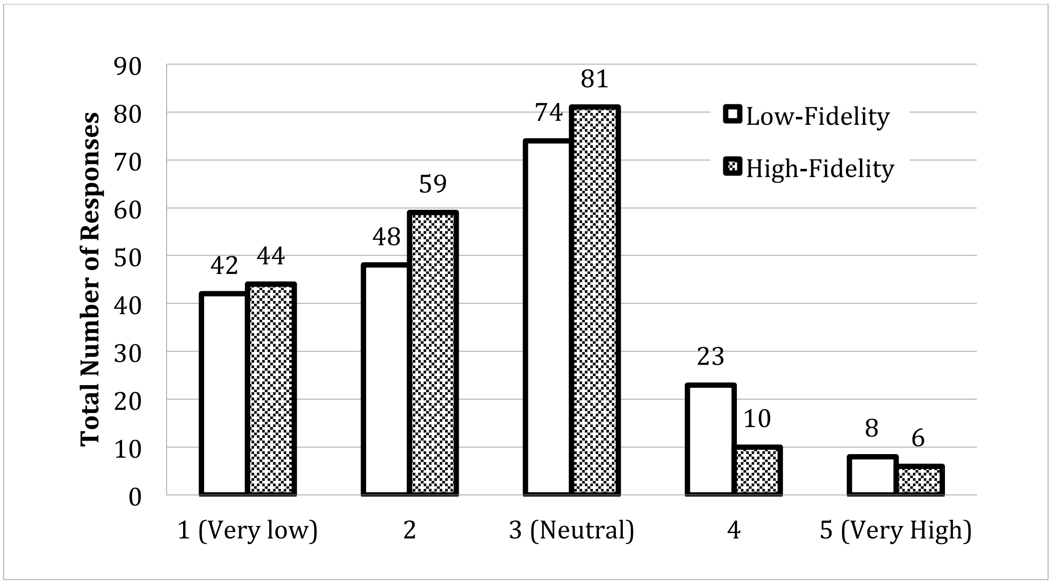

Figure 17: Average Workload Rating during Tasks

Within interviews, participants reported that they experienced lower workload during the high-fidelity information task. A number of participants also reported their perceived reason for this reduction in workload. For example, Participant 11 explained, "It was still manageable throughout [the low-fidelity condition]. But it was much easier with the video. It was just more calming to have more knowledge about the field situation in the low-fidelity condition." The decrease in information fidelity increased the amount of cognitive effort participants dedicated to remembering what was happening, and to gathering extra information to complete their situation awareness. Participant 2 mentioned how much more work it was to maintain awareness of the situation: "Basically I just keep asking questions to see what's going on and since I don't know if they're still in their station area, I have to keep asking if something goes wrong, or 'where are you guys right now at this moment?'" In the higher-fidelity condition, the cognitive tasks of information gathering and remembering were offloaded naturally to the information display, reducing the workload.

On the post-session questionnaire, participants were asked to rate their level of agreement with the statement "My workload was manageable". Figure 18 shows how the responses indicated by participants changed between the low-fidelity and high-fidelity conditions. In both the low and high-fidelity conditions, all participants indicated agreement with the statement. A Wilcoxon Signed Ranks Test found no statistically significant change in response between the two conditions, indicating that participants felt their workload was manageable through both conditions.

These data sources showed that participants experienced a reduced level of cognitive workload during the high-fidelity condition. The interview responses serve to further corroborate these findings by showing that participants were also able to articulate their perception of a much lower cognitive workload.

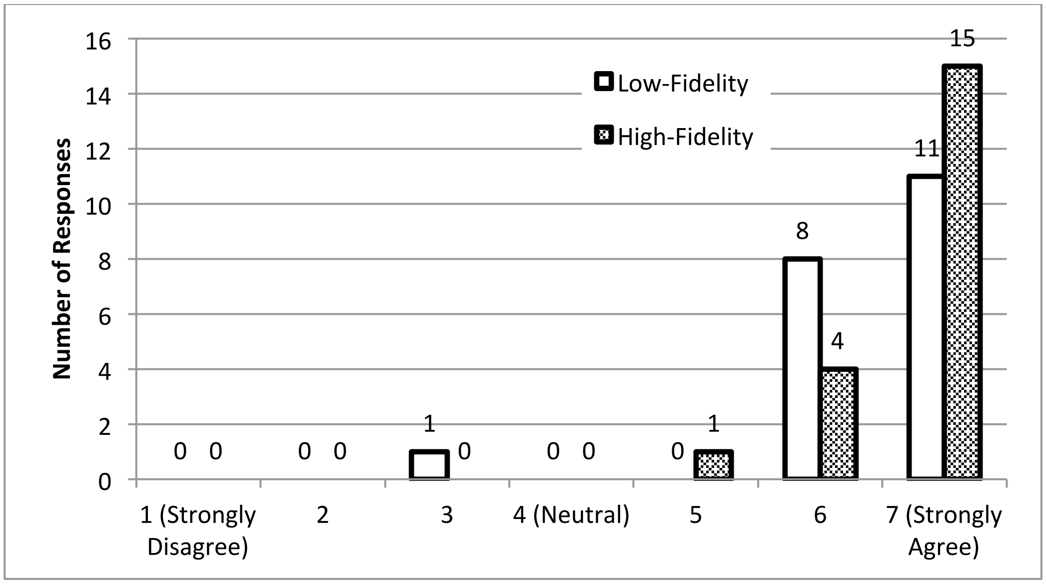

Figure 18: Questionnaire Answer Distribution for Agreement with "My workload was manageable"

5.5.4.2 External Indications of Reduced Workload

Along with self-rating of cognitive workload, external measures of workload were observed. The use of paper maps to offload cognitive functioning provided further evidence that participants experienced a lower level of cognitive workload during the high-fidelity information condition. Secondary task measures showed no significant change.

The artifacts collected after each coordination task were examined for cognitive offloading. Participants used markings on the paper maps to offload their memory tasks when they did not have the high-fidelity display. Figure 19 shows an example of offloading conducted by participants in the low-fidelity condition. This offloading is an indication of a higher workload in this condition, as it shows that the workload necessary for remembering the situation outside the command trailer was too high for participants to handle. Primarily offloaded was positional information about field agent whereabouts, which was exactly what the high-fidelity information display provided. As the information that was offloaded by participants was specifically this location-based information, there was no need for offloading in the high-fidelity information display. This shows that the majority of the contribution to cognitive workload was remembering the location-based information, providing an explanation for why the perceived cognitive workload for participants was much lower in the higher-fidelity information display condition.

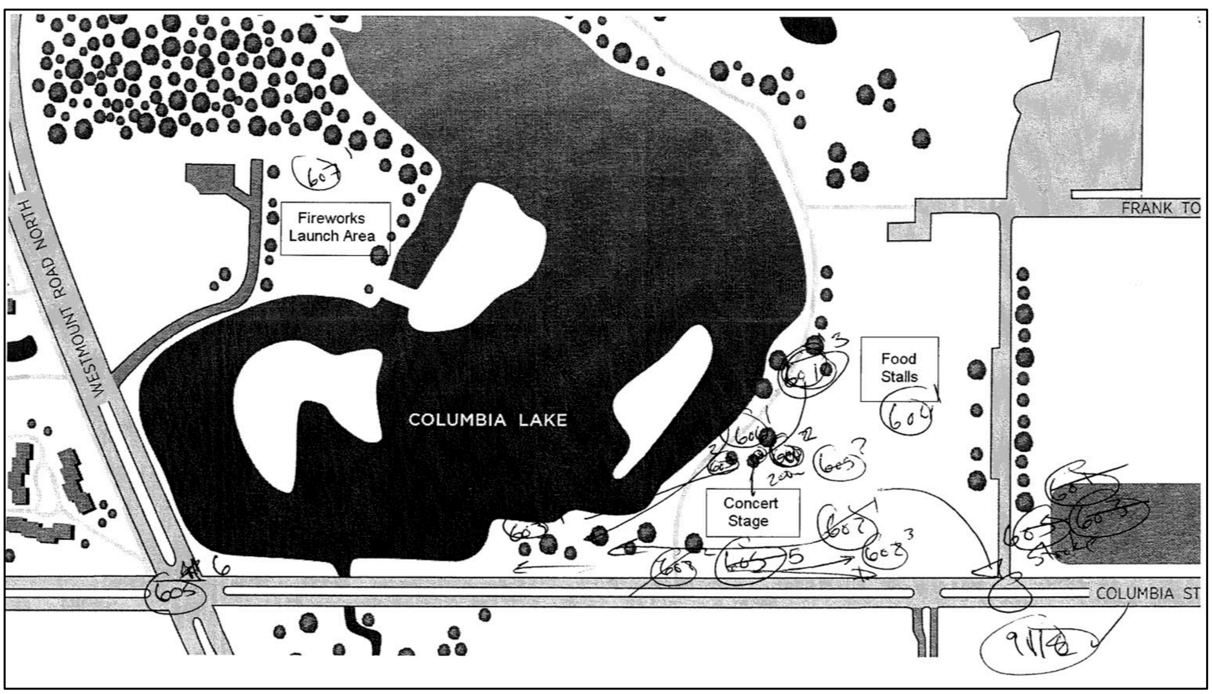

Figure 19: Complex Offloading of Positional and Movement Information in the Low-Fidelity Information Condition

Figure 20 shows the number of participants in each condition that used the paper maps for offloading of information. Participants were far more likely to use offloading techniques in the low-fidelity condition. In the high-fidelity condition only 8 participants used the maps to offload memory tasks, while in the low-fidelity condition 13 participants used the same technique. A Wilcoxon Signed Ranks Test showed that there was a statistically significant change in the use of maps for offloading between the two conditions (Z = .20449, *P* = .014).

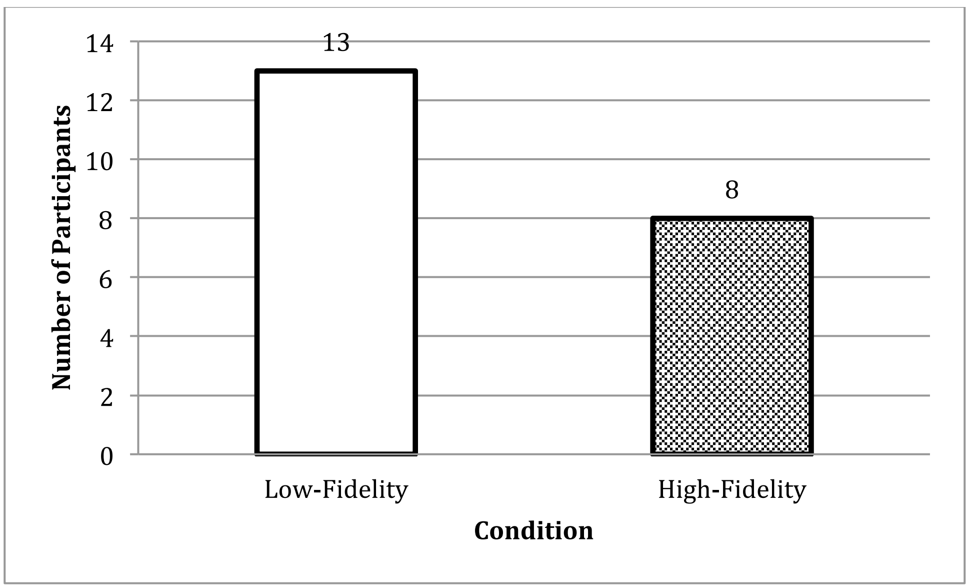

Figure 20: Participants using Maps to Offload Memory Tasks

At the same time as workload ratings that occurred during each condition, participants were also asked to answer a brief question about information that was listed on a paper resource. The answering of these questions was a secondary task, of which the time-to-answer can be taken as an indication of available cognitive resources (Ogden et al., 1979).

The time to answer the questions is charted in Figure 21, shown separated by the order in which participants completed the two information fidelity conditions. There was no statistically significant change in available cognitive resources as indicated by change in time to answer. However, this was likely because any change was dominated by an order effect that showed a decrease of 3.34 seconds.

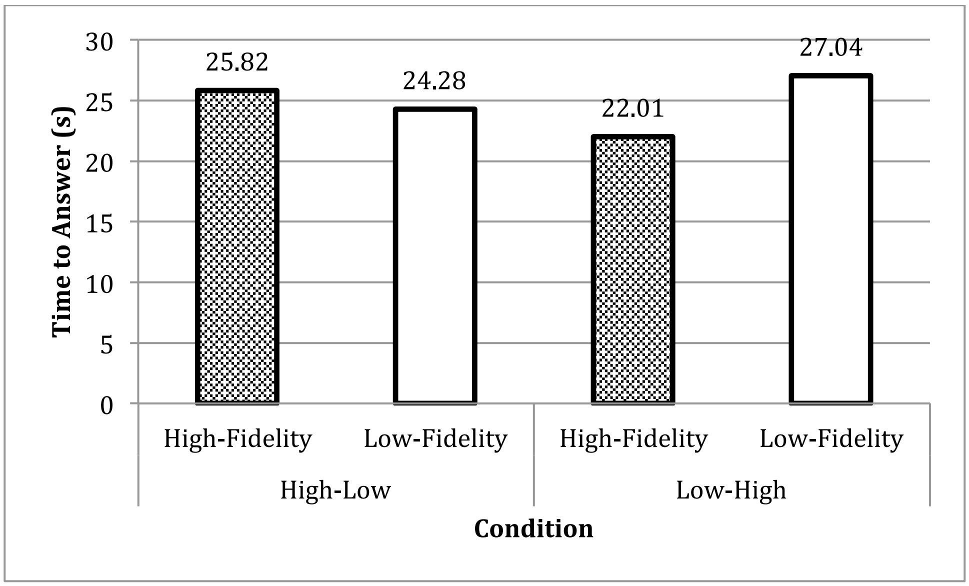

Figure 21: Secondary Task Average Time to Answer, by Order

This order effect could not be removed from the data, so the data from this secondary task serve only to show that participants became better at their secondary task as time progressed. This topic might warrant further study at another time as it could indicate that the impact of high-fidelity information display in a real command environment on secondary task ability may be dependent on the experience Command has with that task.

In summary, the external measures of cognitive workload provided further support for the claim that participants experienced lower-cognitive workload during the high-fidelity information tasks. The reduction in need to offload geospatial information to paper maps in the high-fidelity information condition showed that cognitive workload was reduced, and less cognitive effort was required to maintain awareness of geospatial information.

5.5.4.3 Reduction in Reported Boredom

One of the interesting results from the baseline study was that there were many periods of "downtime" in which command had no communications with field agents, and became distracted due to boredom. Interestingly, boredom was also a common topic brought up by participants during interviews. Participants stated that they found the task fairly boring in the low-fidelity condition, and that the high-fidelity condition was not as boring because they had something interesting to watch during boring periods. For example, Participant 19 stated, "It just gave me something interesting to watch!" while talking about their experience with the high-fidelity information display. It seems that participants enjoyed watching the field agents as they moved around the screen, and found themselves staying aware and paying attention during the high-fidelity condition.

This reduction in boredom may have also played a role in reducing the workload of participants, as they did not need to use resources to remember what had been happening before they became bored. It may have also played a role in increasing the situation awareness of participants in the higher-fidelity information condition, as they were able to maintain that situation awareness rather than having to re-create it after a period of boredom.

5.5.5 Increasing Decision-Making Confidence

Important to the introduction of any technology is how well the users of it feel it accomplishes what it is purported to do. The interview and questionnaire data sources showed that participants felt that both systems provided them with an environment that allowed them to be confident in their decisions.

In the questionnaire, participants indicated their agreement with the phrase “I was confident in my decisions”. Figure 22 shows the distribution of responses to the question in both conditions. As shown in the figure, participants consistently answered with a high level of agreement, regardless of the condition. The figure shows that the most common response in the high-fidelity condition was 7 (strongly agree) while the most common response in the low-fidelity condition was 6. This showed that the confidence of participants did increase in the high-fidelity condition. A Wilcoxon Signed Ranks Test showed a statistically significant change in response between the two conditions ($Z = -2.384$, $P = .005$).

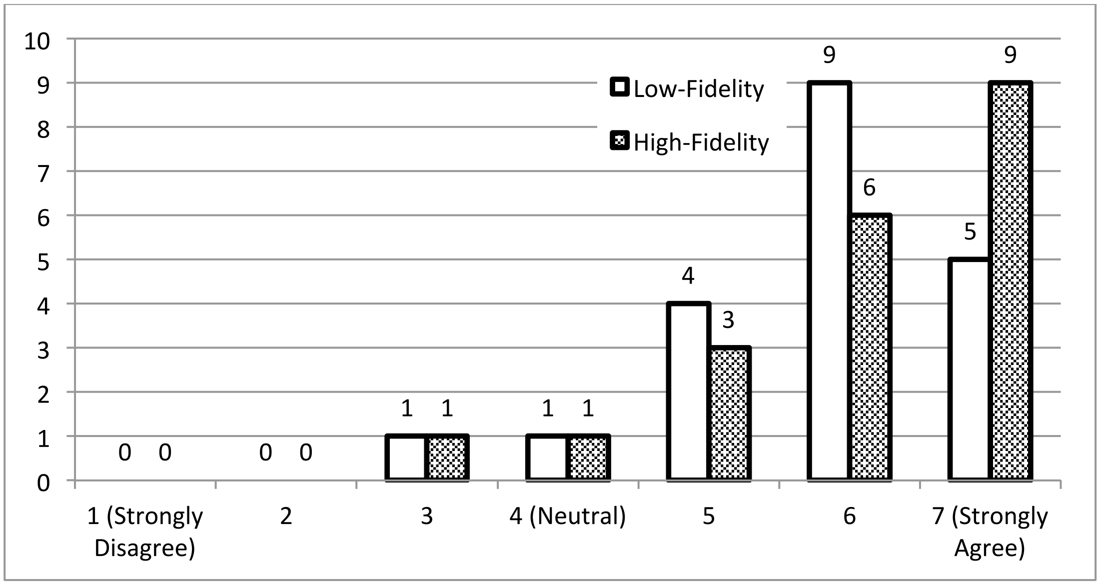

Figure 22: Questionnaire Response Distribution for Agreement with "I was confident in my decisions"

The potential for increased decision confidence caused by the increase in information fidelity is further supported by interview responses from participants. Many participants revealed that they felt that their ability to make decisions and coordinate their field agents was increased when using the higher-fidelity information display. For example, Participant 12 stated that the most advantageous part of using the high-fidelity system was "just that you're more confident in what's going on." Participant 14 saw that his decisions were better because he felt less busy "It didn't feel like I had as much to do. Given a busier situation, I think I could handle it." and Participant 6 noted that "actually seeing the people there made it much easier." This sentiment was shared by many other participants who also expressed similar comfort with not having to rely on memory or memory aids, and having instant feedback.

Similarly, participants expressed more concerns about their decision-making confidence when in the low-fidelity information condition.

5.6 Chapter Summary

The controlled technology study evaluated how the command processes of 20 participants changed as the fidelity of the information available to them was changed. The results showed that participants' level of micromanagement increased as a result of the increased information fidelity, caused by an experienced increase in the desire to micromanage. This was seen through questionnaire and interview responses, as well as analysis of communications during each task. It was also found that participants were better able to maintain situation awareness with the higher fidelity condition, again seen through analysis of questionnaire responses and interviews, as well as analysis of communications. In the high-fidelity information condition, the level of cognitive workload experienced by participants was reduced and overall was more manageable, based on interview and questionnaire responses.

Along with these changes to the main factors described in the initial baseline data study, it was also seen that there was an impact of information fidelity on decision-making confidence: participants were more confident in their decisions when they had access to the large display. This was also seen through both questionnaire and interview responses. These findings and their implications are further discussed in Chapter 7.

Chapter 6

Ecological Validation

The data collected in the preceding baseline and controlled technology studies provide insights into the potential impact of increasing information fidelity in the REACT context. Ecological validation (Brewer, 2000) serves were used to show how the findings in this thesis are applicable in the real context of REACT. To ecologically validate the findings, two studies were conducted. With a beta version of the higher-fidelity information technology available, a field study (McGrath, 1984) was conducted to observe the technology deployment in an initial field test. Additionally, a REACT member participated in a experimental simulation (McGrath, 1984) that used the controlled-laboratory study to learn about how REACT Command's behavior might be different from study participants. The collected data were compared to both the initial baseline data set and the data collected in Study 2 in order to verify whether the changes predicted by the controlled technology study would occur in the real world.

The data collected in the field study and the experimental simulation demonstrated initial support for the expected change in micromanagement. The study showed concern in real-world deployment on the part of field agents who felt they no longer had the same level of independence, and some indication of commands being given without need. The event did provide preliminary support for the findings that the higher-fidelity technology would positively the previously observed issues in maintaining situation awareness and managing cognitive workload. Additionally, observations during technology downtime showed some interesting support for a high level of immediate trust placed in automation and reliance on the new technology. These observations provide only preliminary information and indicate some interesting directions for future research. The methods used to conduct the field study and the experimental simulation are described below.

6.1 Experimental Simulation: REACT Personnel as a Study Participant

One of the REACT personnel, who often acts as Command in the real-world environment, was recruited as an additional study participant. He participated in the full controlled technology study as described in Chapter 6, and performed the low-fidelity condition before the high-fidelity condition (as would occur in the REACT context). The data collected from his participation was compared to the data collected from participants to understand how consistent his behavior was to the other, non-domain expert, participants and in turn understand how well their results might translate to real-world effects.

6.2 Field Study: Data Collection after Initial Deployment

Once a version of the technology was deployed within the REACT mobile command center, there was an opportunity to observe its use. The data was collected using the same procedure as the baseline study, described in Chapter 4, in order to enable comparison between the pre- and post- technology situations. Although only one event, this field study provided preliminary data in which trends could be seen.

The event that was studied for this field study was a large local community gathering, celebrating a national holiday through concerts, food, and fireworks (Canada Day Fireworks event on June 1st 2011). This event, spanning eight hours and involving 50 000 members of the public, is a typical REACT event and made for useful comparison data. During this event, there were several incidents that required attention, such as a missing child and a member of the public falling in and out of consciousness.

6.3 Increase in Level of Micromanagement

The baseline data described in Chapter 4 showed that there was a strong culture within the REACT organization that supported maintaining the independence of field agents while still ensuring successful handling of situations. The findings from the controlled technology study showed that the level of micromanagement exhibited by participants acting as Command increased as the information fidelity increased, so it was expected that there would be some increase in micromanagement within both the results collected from the experimental simulation and field study.

Through qualitative observation in the field study, it was found that Command was interested in knowing more about field agents and spent a lot of time monitoring their activities, and field agents were concerned about the level of monitoring that was now available. Command commented on how the higher-fidelity information provided a better understanding of what all of the field agents were doing, and how to immediately direct them when necessary. Command did not express any concern about potential increases in micromanagement due to this extra information. Similar statements were made about the advantages provided by the high-fidelity display following the experimental simulation.

Interestingly, during the field study, some field agents were also overheard making passing comments about how Command now knew their whereabouts at all times and could correct their actions immediately. Although not an outright concern, it appeared that some tension was caused by the introduction of this system due to the perception that more micromanagement could be experienced.

A shift towards micromanagement was seen in an analysis of the action anticipation ratios of both the experimental simulation and field study. Figure 23 and Figure 24 show the action anticipation ratios as observed in each comparison. These anticipation ratios showed the high-fidelity information condition resulted in a higher percentage of commands (Action Transfers) given by Command without being prompted first by a request. This change showed that, in both studies, Command was making the decision to give instructions to field agents that did not first ask for instructions or guidance. Such a change in communications is evidence that Command is being influenced by the increased temptation to micromanage in both the real world context and the controlled technology study.

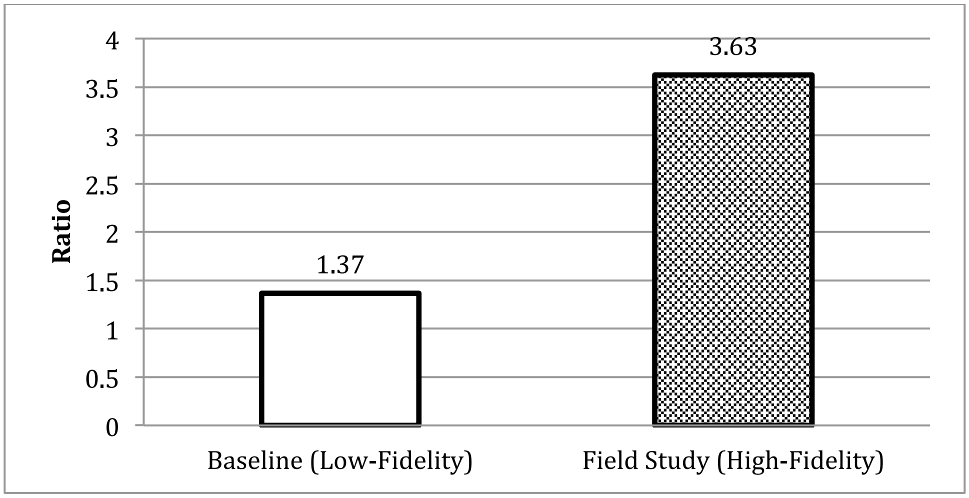

Figure 23: Change in Action Anticipation Ratio in REACT Context

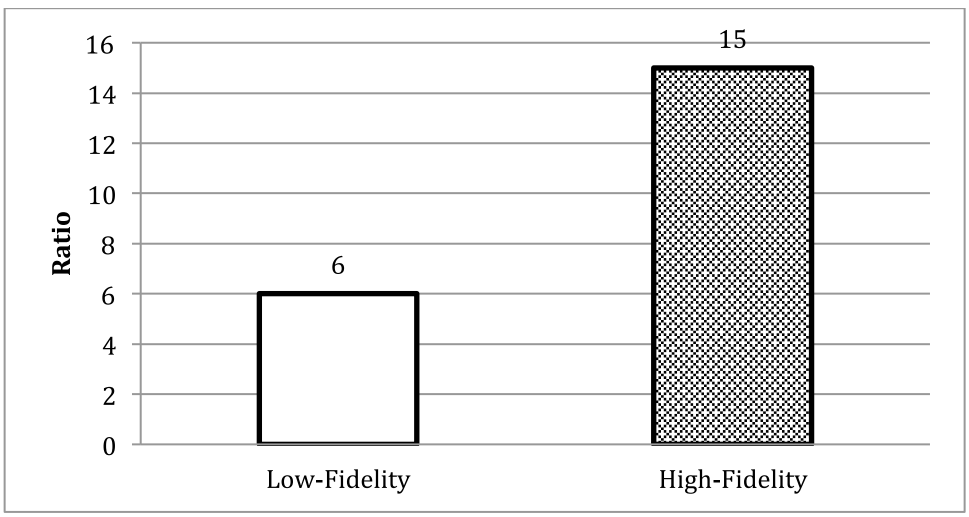

Figure 24: Change in Action Anticipation Ratio by REACT Personnel in Controlled Technology Study

The temptation to micromanage also produced a change in the communications of command in the real REACT context. As described in Chapter 3, micromanagement would be seen in this data as an increase in Action Transfers and/or Information Requests. Figure 25 shows a comparison of communications coding results of those two categories, before and after deployment. The number of Information Requests made by Command increased after deployment of the high-fidelity system, while the number of Action Transfers did not show any decrease. This is consistent with the finding that micromanagement increased with the deployment of the high-fidelity display in the REACT command center. However, as shown in Figure 26, only an increase in Action Transfers was observed in the experimental simulation, while a decrease in Information Requests occurred.

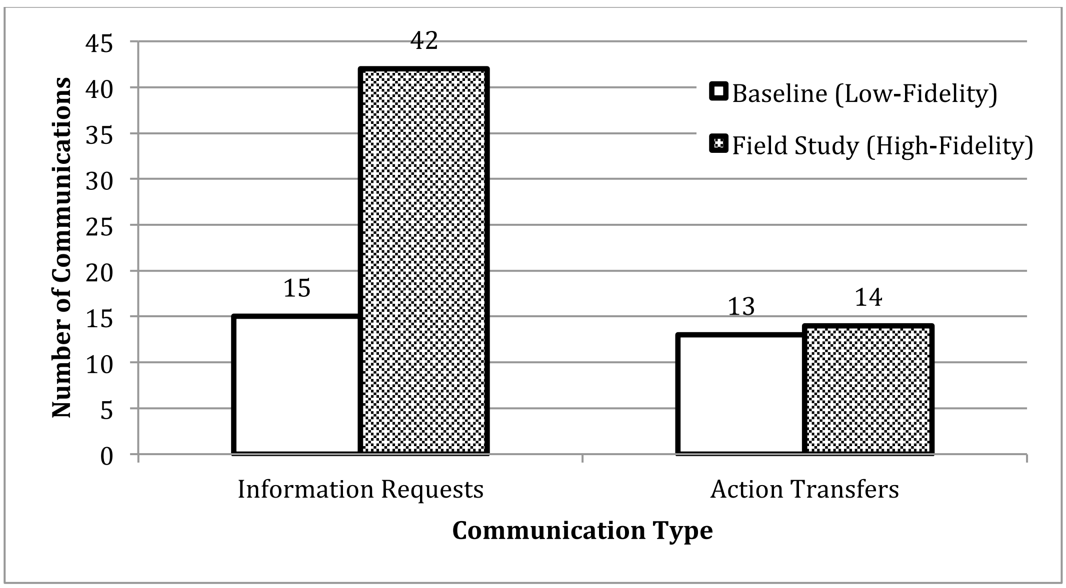

Figure 25: Comparison of Information Requests and Action Transfers made by Command in Baseline and Field Studies

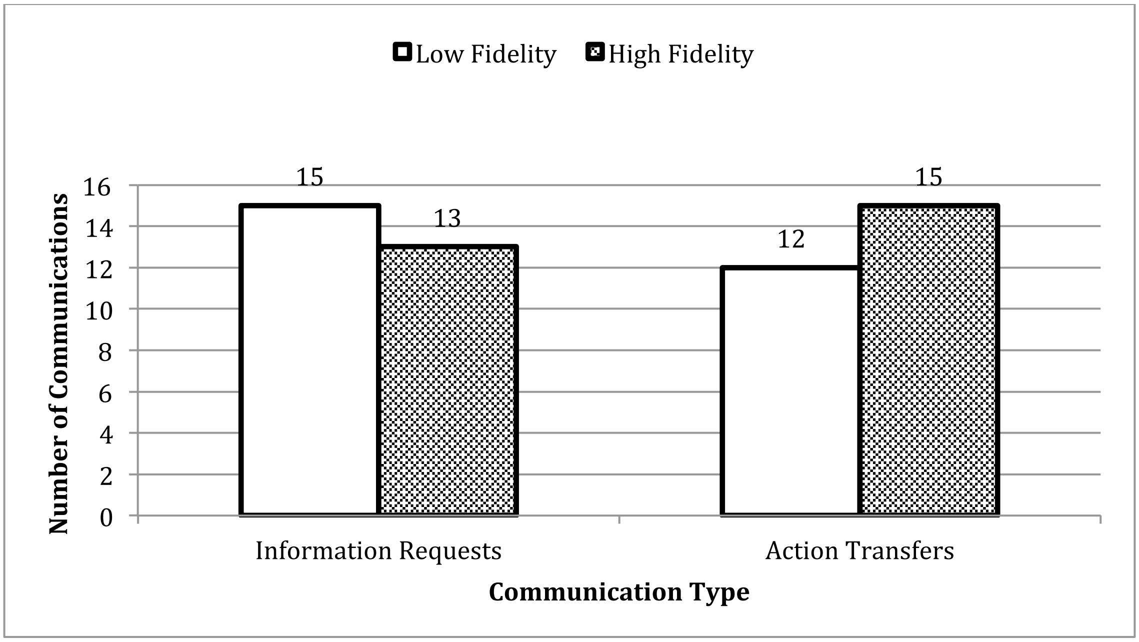

Figure 26: Comparison of Information Requests and Action Transfers made by Command in Controlled Technology Study

The results of both qualitative analysis and examination of communications coding in both ecological validation studies provided further evidence that increasing information fidelity increases both the temptation to micromanage, and actual micromanagement. Additional challenges were raised by the observation of field agents' concern about micromanagement in the REACT context, something that warrants further research as described in Chapter 8.

6.4 Ease of Maintaining Situation Awareness

The ecological validation studies showed that situation awareness was more easily maintained by Command when using the high-fidelity information technology both in the experimental simulation and field study. This was consistent with evidence found in the controlled technology study with non-expert participants.

Qualitative observations showed that Command frequently described an increase in situation awareness as a result of the increase in information fidelity, in both ecological validation studies. They were now completely aware of where field agents were at all times, and were excited about how they did not need to continually ask about their whereabouts to have that knowledge. During the field study, Command discussed with Police visitors how they could now see extensive information about agent locations in the event, often referencing how they no longer had to ask to keep track of what was going on. In the controlled technology study, Command said: "This system is great. It gives me the picture. Before this I would just try to keep my mind clear to mentally track where everyone is, but mostly I wouldn't know where these guys [points to the screen] are." This showcased how much easier it was for them to maintain situation awareness about field agent locations with the use of the high-fidelity information display.

Additional qualitative analysis showed that, in both studies, Command did not dedicate as much time or effort to gathering information in the high-fidelity condition. Before making a decision, Command was able to gather the necessary information in a manner that did not require as much inquiry, especially if the decision was based on the locations of field agents.

These qualitative observations showed that Command felt they were better able to maintain situation awareness with the use of the high-fidelity display. This is consistent with findings from the controlled technology study as described in Chapter 5.

6.5 Lower Variance in Cognitive Workload Levels

As discussed in Chapter 4, there was a wide range in the level of cognitive workload being placed on Command within the baseline study. During many periods, boredom and very low levels of workload were observed. Yet, during an emergency, Command experienced such high levels of cognitive workload that they were unable to pay attention to any other secondary tasks. In the controlled technology study, both of these extremes were reduced by the presence of the high-fidelity information display; boredom was relieved through providing something to maintain the attention of Command, while emergency scenarios required less workload to manage. Similar decreases in workload extremes were observed in ecological validation.

Indications of a decreased variance in cognitive workload collected during the experimental simulation. Figure 27 shows the time taken by the REACT personnel to perform the secondary task. There was a significant difference in secondary task performance between the low-fidelity and high-fidelity conditions ($t(18)=3.16$, $p <.05$). Additionally, there was an interesting difference in the standard deviation of the two conditions. In the low-fidelity condition, times varied from 9 seconds to 30 seconds (a standard deviation of 7.15), while in the high-fidelity condition, times varied only from 8 seconds to 16 seconds (a standard deviation of 2.59). This showed a distinct change in both the cognitive workload, and in the variance of cognitive workload between the two conditions.

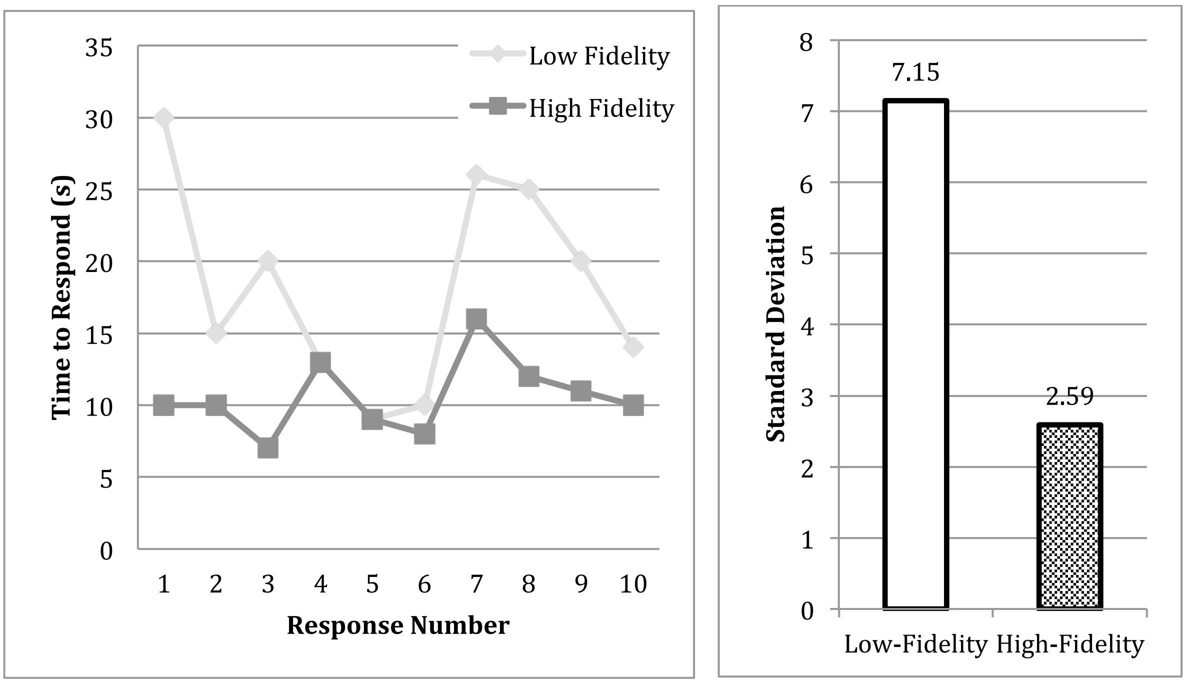

Figure 27: Secondary Task Performance for REACT Personnel

This type of change in variance of time to respond was not seen in the original controlled technology study. The change in variance of secondary response time might be due to the more extensive experience of the REACT personnel. The average time to respond for the REACT personnel compared to the average time to respond for the non-expert participants is shown in Figure 28. This shows that, across the board, the REACT personnel had much lower workload and was able to complete the secondary task faster. However, it is also possible that this change stemmed from a learning effect as the REACT personnel learned to better complete the lab-based tasks. In either case, the limited sample size meant that the finding is only preliminary.

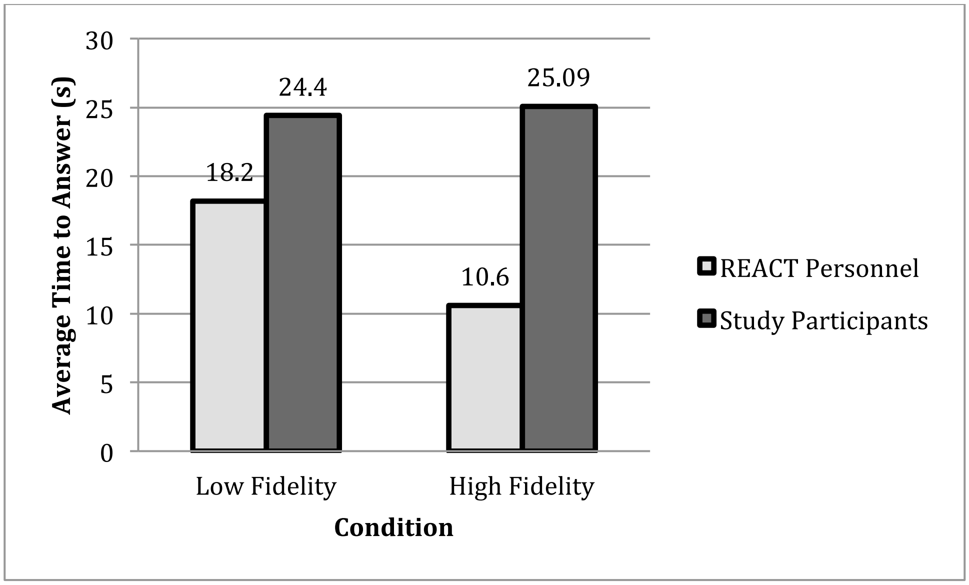

Figure 28: Comparison of Secondary Task Performance

This change in extremes of cognitive workload is consistent with the analysis of qualitative observations taken during the field study. Observations of the way Command dealt with secondary tasks in the REACT command center field deployment showed, similar to within the baseline study, Command removed extra stimulus so that secondary tasks were not present. However, the incidents encountered in the field deployment were of a lesser severity than many of those seen in the baseline study and may have contributed to this effect.

Additional artifact analysis during the experimental simulation provided further evidence of a decrease in cognitive workload during the high-fidelity condition. Figure 29 and Figure 30 show the offloading by the REACT personnel onto the provided maps. In the low-fidelity condition, they offloaded information about locations, tasks, and incidents. In the high-fidelity condition, less information was offloaded and the maps had a small amount of geospatial information. This is consistent with map usage by non-expert participants in the controlled technology study, indicating a lower level of cognitive workload.

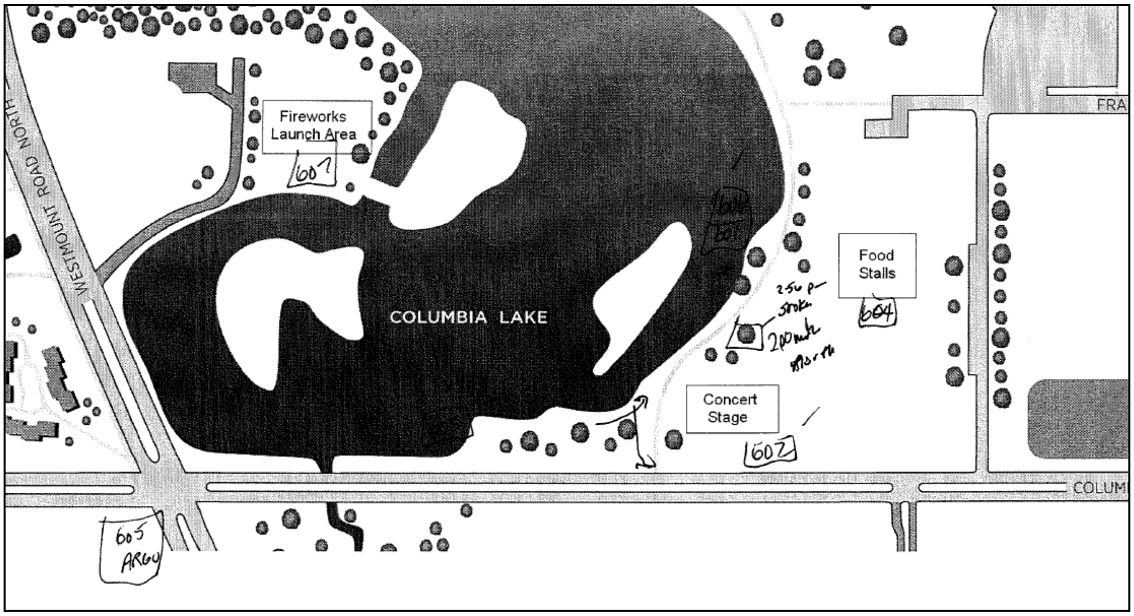

Figure 29: Offloading by REACT Personnel during Low-Fidelity Condition

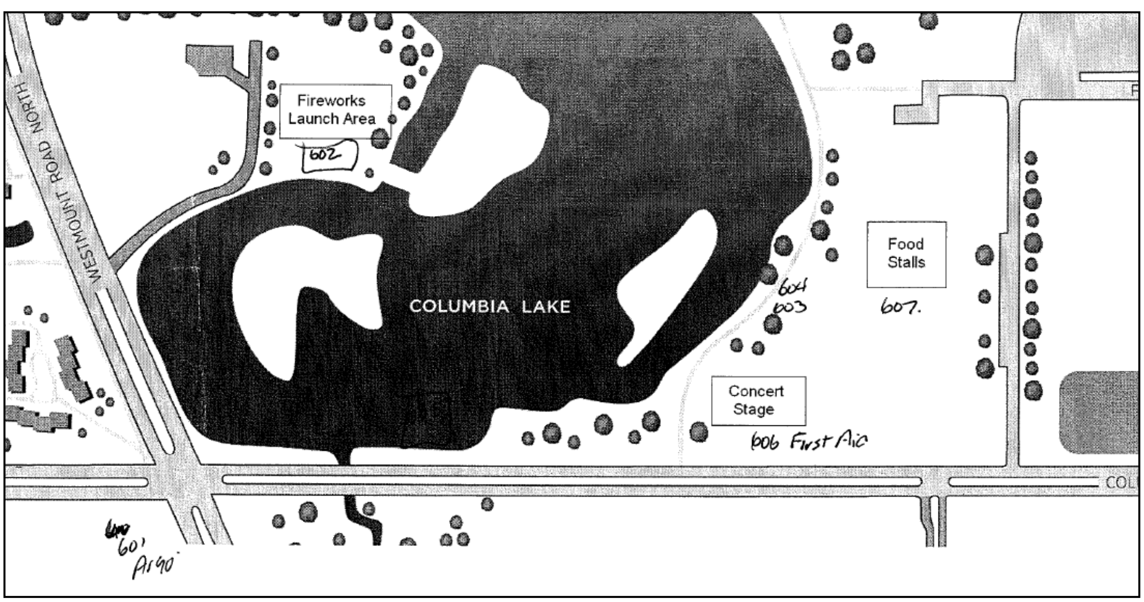

Figure 30: Offloading by REACT Personnel during High-Fidelity Condition

These changes in both the real-world deployment and REACT Command participation in the controlled technology study corroborated previous findings of a decrease in Command's cognitive workload due to the high-fidelity information display. Additionally, a general decrease in the range in cognitive workload was seen in the REACT personnel's participation in the controlled technology study, as the standard variation in their secondary task response time was significantly different.

6.6 Increasing Reliance and Trust in Technology

Although not seen within the experimental simulation, there were strong indications that Command immediately placed a great amount of trust in the technology they were using during the field study, immediately allowing themselves to rely heavily on its features. This was prominently highlighted within the field study when the technology experienced a failure, and Command was forced to switch back to operating without the high-fidelity information. Building up new situation awareness took time and effort, and showed that Command had offloaded most memory tasks related to location information to the display itself. These observations showed that there was a high level of decision-making confidence afforded to Command when using the high-fidelity information system. The observations were also supported by quotes from the interview with the REACT personnel in the experimental simulation that indicate how positive they felt about the system.

In the field study, although Command had been warned that the display was a still a prototype and was not yet robust enough to be relied upon, they had immediately trusted that the system would not fail and were comfortable with leaving the important task of remembering field agent positions to the system. Indeed, Command exhibited symptoms very often observed in technology and automation research – they placed a high level of trust in the system and immediately relied very heavily on the display for completing tasks (Muir & Moray, 1996). These observations raise potential directions for future research, as outlined in Chapter 8, about reliance and trust in automation within emergency and command and control settings.

This trust and reliance in the system may have come from, or contributed to, the increased decision-making confidence that was seen in both ecological validation studies. Although the REACT personnel's response to the questionnaire question "I felt confident in my decisions" did not change in the experimental simulation, they expressed their positive reaction to the system and their ability to make better decisions.

6.7 Chapter Summary

Ecological validation studies were conducted to understand how findings from the controlled technology study were applicable in a real-world context. It was found that the changes due to increasing information fidelity in the controlled technology study, collected from non-expert participants, were also seen when the expert REACT Command personnel participated in a experimental simulation. Additionally, many of the same changes were observed in a real-world deployment of the technology in the REACT mobile command center in a field study.

Both temptation to micromanage, and actual micromanagement, were observed in both ecological validation studies. This was seen through qualitative observations, as well as analysis of audio coding data that showed evidence of increasing micromanagement and situation awareness. The increases in which were seen in both ecological validation studies.

The cognitive workload of Command in the experimental simulation was seen to vary less in the high-fidelity condition, providing further corroboration of the finding that cognitive workload at both extremes was improved by the increased information fidelity.

Finally, in the field study, trust in automation was observed to a point that it affected Command's operations when the deployed system experienced an outage. This was not seen in the controlled technology study, but provides direction for future research.

The combined findings and implications of the baseline study, the controlled technology study, and the ecological validation studies outlined in this chapter are further discussed in Chapter 7.

Chapter 7

Discussion

This thesis has described the results of three research activities, each aimed at investigating how increased information fidelity changes the processes within a mobile command center. To better understand what these results mean as a cohesive whole, the guiding research questions described in Chapter 3 are discussed below.

7.1 Question 1 – How does the increase in information fidelity impact the level of micromanagement on the part of Command?

Findings from the controlled technology study showed that the study participants experienced a much greater temptation to micromanage during the high-fidelity condition. They were able to monitor minute changes on the part of the field agents, and were tempted to react to changes that they might not have even known about in the low-fidelity condition. These findings were supported by both questionnaire and interview data in the controlled technology study. The limited field study did not show these trends.

The increase in temptation to micromanage was important because of it's potential to affect Command's actions. In the ecological validation studies, where evidence of an increase in micromanagement could be found, Command still reiterated that they felt it was important to try to limit micromanagement and to make sure field agents felt independent. This supports, in a limited way, some of the findings from NCW research that suggest that temptation to micromanage may become too great to ignore, despite training or doctrine (Boila et al., 2006; Hakimzadeh, 2003). In addition, concerns about the impact of outside factors such as pressure from embedded media or world scrutiny (Boila et al., 2006; Hakimzadeh, 2003) may mean that an operator's ability to resist this temptation to micromanage is, in part, determined by the environment in the command center. In this case, an existing understanding of Command's role may have prevented a severe increase in micromanagement. At the same time, this could mean that different circumstances in the REACT mobile command center may result in completely different changes to the level of micromanagement. The addition of outside observers such as Police or other emergency response agencies may result in a greater shift in micromanagement through changing the perceived pressure to perform. Indeed, a change in the Command personnel themselves might completely change the extent to which temptation to micromanage is felt and acted upon. Further investigation is needed to fully understand these factors.

Although micromanagement itself was only observed in some data sources after technology deployment, other unpredicted social effects were observed that might prove to be just as important. The reaction of the field agents to the deployment of the system was that of slight suspicion, and they expressed concern about losing their independence. These field agents, although not specifically informed about the study focus, provided insight into how important an issue micromanagement is to volunteer organizations. Unlike paid organizations, REACT is able to retain volunteers primarily through offering a sense of pride and independence. In changing the dynamic of the organization, it is possible that the deployment of the high-fidelity information system will impact the ability of REACT to maintain the volunteer base, regardless of whether it actually results in any measurable increase in micromanagement.

Trust was implicated in the controlled technology study as one of the causes of increased temptation to micromanage. Trust, being so important, may have an impact on how the findings about micromanagement in the controlled technology study can be extended to real-world contexts. In the lab, participants did not know their "field agents", nor did they have any way of knowing the field agents' trustworthiness, other than observed actions. Potentially, the observed change in trust levels due to the high-fidelity information display was partly caused by these new and untested relationships. In real contexts, command teams may know each other well enough that their trust will not be so drastically changed based on the information presented by the high-fidelity display. Without this negative effect on trust, it is likely that the display's impact on temptation to micromanage will not be as pronounced.

This thesis has shown that increasing information fidelity increases the temptation to micromanage on the part of Command, and may actually increase that level of micromanagement in real-world contexts. It would appear that outside influences may also have an important role in determining how much Command is able to resist that temptation. This is something that must be considered by designers of systems for similar agencies, if they are intending on implementing a high-fidelity information system.

7.2 Question 2 – How does the increase in information fidelity impact the level of situation awareness maintained by Command?

It was found that the situation awareness of Command in the baseline study was sometimes not high enough to avoid information breakdowns. In the subsequent studies, it was found that the increase in information fidelity caused an increase in Command situation awareness.

From both interview responses and observations of the way Command was using the high-fidelity information to maintain situation awareness, it seemed that the cause of this increase was the better accessibility to timely information. Many of the information breakdowns observed during the low-fidelity condition in the controlled technology study and during the baseline study were due to the inability of Command to maintain an up-to-date picture of the event. Although possible to gather a high level of situation awareness at any point in time, it is time consuming and disruptive for Command to maintain that situation awareness for any extended period of time, due to the number of radio calls that are necessary. The provision of the high-fidelity information, logically, made it easier and much less obtrusive for Command to maintain situation awareness. Although awareness about actual events and happenings had to still be collected over the radio, maintaining awareness about locations was made considerably easier.

An important consideration in the design of the high-fidelity system was that it only increased the fidelity of information that was already being collected, and that was easy to display in a graphical format. Command already attempted to maintain some level of situation awareness about the geographical location of field agents in the baseline study, but they were not very successfully at keeping that situation awareness accurate. Thus, in similar systems, providing a higher fidelity version of information already collected and required, at a manageable level, will likely increase the situation awareness of the user. It is not, however, known whether increasing the fidelity of other types of information will be a useful or effective method for increasing situation awareness. This issue requires further investigation.

7.3 Question 3 - How does the increase in information fidelity impact the cognitive workload placed on Command?

The baseline study showed that REACT Command experienced periods of very high workload, and of very boring low workload. Both of these situations negatively affected Command's ability to maintain proper situation awareness or coordinate incidents in the fastest and most appropriate manner. Although at no point did these issues cause serious operational problems, it was an area identified for potential improvement.

The resulting controlled technology study and ecological validation studies showed that increased fidelity effectively reduced the perceived workload of study participants and REACT Command. Additionally, the incidents of boredom and extremely low workload were reduced. Participants in the controlled technology study indicated that watching the screen was interesting, while REACT Command in the field study spent less time being bored or attempting to occupy downtime with other activities.

It would appear that the provision of the high-fidelity information display reduced these extremes of cognitive workload through two different mechanisms. The periods of high cognitive workload were considerably reduced because of the aforementioned increased situation awareness afforded by the display. As Command had a more complete picture of what was happening, they did not have to spend as much of their cognitive resources on compiling situation awareness when an incident occurred. This, in turn, meant that their cognitive workload was reduced during those crucial times. At the same time, the display helped to improve the extremely boring periods by providing some mental stimulation. Rather than having nothing to do, Command could look at the display to see the high-fidelity information. This appeared to have enough of an impact to change the level of boredom experienced both by study participants and by REACT Command themselves.

Presumably, this effect may only occur at certain levels of information fidelity. At some point, the level of information fidelity provided may overwhelm Command, and instead create an increased level of workload during high-stress incidents. Additionally, the type of information provided will likely determine whether cognitive workload levels are improved. The baseline study showed that Command was having some trouble collecting and maintaining situation awareness pertaining to the location of field agents. Increasing the fidelity of available information about location field agents was therefore quite helpful. If the information being provided had not been directly related to the cause of increased cognitive workload, the same improvements likely would not have occurred.

Overall, the deployment of high-fidelity information displays may be advantageous in many different contexts. Because it appears to improve workload levels both during high stress events and during uneventful periods, a display of this type may be useful in contexts with cognitive workload requirements very different from that in the REACT command center. However, proper selection of the type of information to display in high-fidelity, as well as attention to what level of fidelity to provide that information, is likely to also be important.

7.4 Question 4 – How does the increase in information fidelity impact the confidence Command has in their decisions?

The information fidelity increase was perceived, by both participants and REACT Command, as something that provided much greater confidence in decision-making. However, this increase in decision-making confidence had an unforeseen effect when the system was deployed within the actual REACT context during the field study. The users of the system appeared to immediately place (perhaps unwarranted) trust in the automation of the system, and relied on it to a point that a failure in the system caused some difficulty transitioning back to the use of low-fidelity information.

There is an interesting effect when considering the trust being placed in systems. On one hand, if the user does not trust the system enough, they will not use the system and will not be able to gain the benefits afforded by that system (Carver & Turoff, 2007; Muir, 1987). Alternatively, too much trust (as appeared to be the case in this instance) often occurs, and can lead to complacency and an inability to properly intervene when the system fails (Carver & Turoff, 2007; Muir, 1987). This appears to be especially true because of the unpredictable nature of emergency response situations (Carver & Turoff, 2007).

This is an important consideration for designers of similar systems. Perhaps, in using a system that appeared “high-tech”, REACT personnel did not consider that it might not be reliable. Had it appeared in a less polished state, the level of trust may have been lower and Command may have paid more attention to maintaining sufficient understanding to be able to quickly recover during a failure. Conversely, too little trust would negate many of the important improvements that occurred during the deployment of the system. Balancing the user’s trust and ability to recover from failure is an important consideration, even when creating a simple display to increase the fidelity of one type of information.

7.5 Utility of Selected Measures

An important contribution of the thesis was the designed measurement suite, used to gather a wide range of information to answer the previously discussed questions about the effect of information fidelity. The measures were applied in their entirety within the course of the three studies outlined, and it was found that they, for the most part, proved useful. Some of the measures appeared to be more useful in a real-world setting, while others were more useful in the controlled technology setting. In the end, the combination of all of the measures, and the balance of their strengths and weaknesses, helped to provide richer insight than if only one type of data had been collected. Specific considerations for the selection of measures are discussed below.

7.5.1 Qualitative Observations and Interview Data

Potentially the most useful data came from the qualitative observations and from the interviews conducted. Both of these sources provided insights into the other collected data, and were sources that were not necessarily aimed at answering one specific question. In being able to collect a wide variety of information, they also provided additional information about some conclusions that were not anticipated during the study design. Specifically, they were very helpful in collecting the baseline data to help structure the subsequent studies and they allowed for learning about reliance and trust in technology during the ecological validation studies.

7.5.2 Audio Coding and Anticipation Ratios

The audio coding methodology and anticipation ratios proved to be less useful than originally expected. During the controlled technology study, care was taken to make the two coordination tasks similar enough that they could be directly comparable. However, this may have contributed to the inconclusive evidence that was collected during that study from the audio coding and anticipation ratios. Participants may not have had the prior knowledge to have a defined command style, and perhaps were too inexperienced to allow their communication patterns to change significantly. However, during the ecological validation studies, the audio coding and anticipation ratios were a very useful way to capture the differences between completely different events.

Additionally, the comparison of anticipation ratios when a REACT personnel participated in the controlled technology study showed that there was potential for these measures to produce potentially interesting results, given the right level of expertise.

7.5.3 Questionnaire Data

The questionnaire used in the controlled technology study provided useful information about participants' perception of different effects. Collecting this information allowed a comparison of participant perception to participant action. Additionally, it enabled some quantification of the feelings being experienced by participants, to better capture changes in those feelings caused by the increase in information fidelity. Specifically, temptation to micromanage was important to collect, and provided a useful finding, even though less evidence was found for participants actually acting on that temptation.

7.5.4 Workload Measures

Workload was measured in the controlled technology study through the use of a secondary task and workload ratings. In having participants complete these tasks and rate their workload every two minutes, a comprehensive view of the experience of the participant was collected throughout the conditions. However, there was a lack of conclusive evidence from both of these measures in the controlled technology study. This was in conflict with reported feelings of workload and use of offloading techniques, and highlights how it is important to use a comprehensive set of data collection tools.

Without the other measures, it would have been difficult to determine how workload was actually affected by the increase in information fidelity.

7.6 Chapter Summary

This chapter explored how the objectives were addressed, and what the findings presented in this thesis might mean in a real-world context. Most salient was that the context of deployment might drastically change the way the high-fidelity information impacts Command. Indeed, trust causing temptation to micromanage, type of useful information, and intensity of cognitive workload requirements all will directly impact how the findings from this thesis translate to the deployment context. Additionally, the measurement suite utilized in this thesis was found to be useful in similar contexts, although some measures may be more directly impacted by the controlled task than any change in command process.

Chapter 8

Conclusions and Future Work

The use of high-fidelity information displays in emergency response environments is not new. However, an understanding of how these systems affect the contexts in which they are used was an important but missing piece of the research literature. This thesis was motivated by this lack of empirical evidence for the impact of increased information fidelity in command environments.

This thesis developed a baseline data set within a specific emergency response context (REACT), experimentally determined the changes that might occur within that context, and used ecological validation to verify these findings.

It was found that the increase in information fidelity caused an increase in both temptation to micromanage and actual micromanagement. Additionally found were increases in situation awareness, reduction in cognitive workload, and in increase in decision-making confidence. These findings support previous literature that implicates information fidelity in micromanagement increases and in other decision-making changes, and provide information for designers of high-fidelity information displays in command contexts.

8.1 Research Findings

The objectives around which this thesis was structured were to develop a measurement suite for analysis of decision making changes in the REACT context, develop a baseline set of data that describes the Command processes in the REACT context, and empirically evaluate the changes in Command processes due to increasing information fidelity.

The objective to develop a measurement suite was addressed through the careful selection of a number of measures that would be most useful in the REACT context, as detailed in Chapter 3. Specifically selected was a combination of qualitative and quantitative measures that were comparable across different real-world events. These measures were used within the subsequent studies.

The baseline data set was collected within the REACT context, and is described in Chapter 4. This data showed a culture that discouraged micromanagement, highlighting the importance of learning how increasing information fidelity affects micromanagement levels. Additionally, there were observed difficulties maintaining situation awareness, and a very wide variation in cognitive workload levels.

The collected baseline data was then compared to data collected in the controlled technology study (Chapter 5) and two different ecological validation studies (Chapter 6) to understand the changes caused by the increase in information fidelity. In addressing these three objectives, four main effects were caused by the increase in information fidelity: increased micromanagement, increased situation awareness, reduction in cognitive workload, and increased decision-making confidence.

8.2 Future Work

This thesis has highlighted a number of areas that warrant further investigation related to the use of high-fidelity information in command environments. Additional field studies to further understand the ecological validity of the main findings in the controlled technology studies. Future research should gather more information about REACT Command operations after deployment of the high-fidelity information system, for better comparison to the baseline data set.

Additionally, qualitative observations within the REACT context after the deployment of the system indicated that field agents were concerned about the potential for micromanagement. Future research should observe field agents to learn more about the impact of the high-fidelity information on their experience. This is especially important for the use of these types of systems in volunteer organizations where independence is even more important to many members of the team.

Finally, further empirical investigations should examine the applicability of the findings of this thesis to other real-world contexts. The REACT context is different than many other command contexts, so it would be advantageous to learn how the change in information fidelity affects other types of command operations. Additionally, many high-fidelity displays for use in command contexts are designed with other features such as annotation, note taking, and additional data layers. Future work should also learn how the addition of those features affects the findings found in this thesis by replicating study procedures with these features.

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Appendix A

Study Materials for Baseline Studies

Procedure for Observations

On-site unobtrusive observations
-The research team will attend for several events identified by the REACT executives as potentially good representative activities to observe (e.g. Manulife Bike & Hike for Heart on 6 June 2010, Columbia Lake Fireworks on 1 July 2010) and observe the use of the command centre of the REACT organization by its personnel as well as other users like public and emergency services.
-Before the start of each event, the research team will place an audio recording device on the desk of the command centre. The REACT personnel acting as command will be informed of this recorded device and instructed as to how the device can be turned off. They will be informed of their option to turn the device off or ask a researcher to turn the device off at any time during the observation.
-The research team will be looking specifically at the use of current technology and other resources within the command centre.
-At any point in time, should the research team be required by the personnel to leave the command centre, or at any point become aware of private and/or confidential information being discussed, the researchers will exit the command centre until the situation has been resolved and they are invited back in.
-Extreme efforts will be made by project team members to be as non-disruptive as possible, and all members are well aware of the important nature of the services being observed.
-Photos of technology or resources use, in a manner which render any persons unidentifiable may be taken occasionally for requirements development purposes. No photos involving children will be taken.
-No personal data will be collected.

Appendix B

Study Materials for Controlled Technology Study

Recruitment Email

Hello, my name is Katie Cerar and I am a Master's student in the Department of Systems Design Engineering. I am currently working on a project with Professor Jonathan Histon to evaluate a prototype digital wall display computer interface, for use in a mobile command centre,that has been developed in the Collaborative Systems Lab, and would like to invite you to participate in a study to test this interface.

This study will take no longer than 2 hours of your time. If you volunteer to participate in this study, you will be asked to coordinate activities of field agents from a mock mobile command centre using different technology. Following each coordination activity, you will be asked to participate in an interview and complete a questionnaire.

You may volunteer to participate in this study as an individual. The studies are expected to take place from April 1-30, 2011.

For your participation in this study, you will be remunerated at the rate of 10$/hr.

We would like to assure you that this study has been reviewed and received ethics clearance through the Office of Research Ethics at the University of Waterloo. However, the final decision about participation is yours.

If you are interested in participating, please email kcerar@uwaterloo.ca with your availability.

Thank you.

Informed Consent

Title of Project: Examining potential changes in decision-making process in a mobile command centre caused by increasing information fidelity.

Principal Investigators:

Dr. Jonathan Histon, Systems Design Engineering, 519-888-4567 Ext. 37730

Student Investigators:

Katie Cerar, Systems Design Engineering, kcerar@uwaterloo.ca.

Summary of the Project:

The purpose of this study is to evaluate how changes in information fidelity in a mobile command centre will change the decision-making processes that happen within.

Study Participation and Tasks:

Participation in this session is voluntary.

Throughout the study, you will be working by yourself to coordinate the actions of field agents at an event from a mock mobile command center. Before beginning, you will be given a short training session on the technology you will be using and the types of coordination tasks you may encounter. You will then will be given an opportunity to practice using the technology and responding to a couple mock events.

You will be presented with two different technology set-ups in the mock command centre, with which you will act as command to coordinate your field agents. For each, the task will be explained to you, at which point you may ask any questions that you have. You will then be given time to complete the coordination task. At the end of each task, you will be asked to complete a short questionnaire with questions about the task and the technology you used. You will also be asked to participate in a quick interview about the coordination task. This part of the study will take you approximately 2 hours to complete.

Throughout the study, video and audio recordings will be collected, and your interactions with the technologies will be automatically logged.

You may withdraw from this study at any time by advising the researcher.

Confidentiality and Data Security:

All information provided is considered completely confidential. Your name will not appear in any publication resulting from this study; however, with your permission anonymous quotations from the interview (or conversation during the session) may be used. In these cases participants will be referred to as Participant 1, Participant 2, … (or P1, P2, …) Data collected during this study will be retained indefinitely in a locked cabinet or on password protected desktop computers in the Collaborative Systems Laboratory at the University of Waterloo (DC2583).

You will be asked to explicitly consent to the use of video and audio data captured during the study for the purpose of reporting the study's findings. If and only if consent is granted, this data will be used only for the purposes associated with teaching, scientific presentations, publications, and/or sharing with other researchers. Participants will not be identified by name.

Risks and Benefits:

There are no known or anticipated risks from participation in this study. There are no direct benefits to you from participation.

Remuneration:

Upon completion of this study, you will be paid $10 for every hour that you participate in this study, up to $20.

Research Ethics Clearance:

We would like to assure you that this study has been reviewed and received ethics clearance through the Office of Research Ethics at the University of Waterloo. However, the final decision about participation is yours. Should you have comments or concerns resulting from you participation in this study, please contact Dr. Susan Sykes in the Office of Research Ethics at 519-888-4567, Ext. 36005, or ssykes@uwaterloo.ca

Questions and Contacts:

If you have any questions about participation, or would like additional information to assist you in reaching a decision about participation, please contact the principal investigator Professor Jonathan Histon in Systems Design Engineering, University of Waterloo at (519) 888-4567, Ext. 37730 or jhiston@uwaterloo.ca

Thank you for your assistance in this project.

University of Waterloo Project: Examining potential changes in decision-making process in a mobile command centre caused by increasing information fidelity.

I have read the information presented in the information letter about a study being conducted by Professor Jonathan Histon and Katie Cerar of the Department of Systems Design Engineering at the University of Waterloo. I have had the opportunity to ask any questions related to this study, to receive satisfactory answers to my questions, and any additional details I wanted.

Sometimes a certain image and/or segment of video recording clearly shows a particular feature or detail that would be helpful in teaching or when presenting the study results at a scientific presentation or in a publication.

I am aware that I may allow video and/or digital images in which I appear to be used in teaching, scientific presentations, publications, and/or data sharing with other researchers with the understanding that I will not be identified by name. I am aware that I may allow excerpts from the conversational data from this study to be included in teaching, scientific presentations and/or publications, with the understanding that any quotations will be anonymous.

I am aware that I may withdraw my consent for any of the above statements or withdraw my study participation at any time without penalty by advising the researcher.

This project has been reviewed by, and received ethics clearance through, the Office of Research Ethics at the University of Waterloo. I was informed that if I have any comments or concerns resulting from my participation in this study, I may contact Susan Sykes, Director, Office of Research Ethics at 519-888-4567 ext. 36005 or ssykes@uwaterloo.ca.

	Please Circle One	Please Initial Your Choice
With full knowledge of all foregoing, I agree, of my own free will, to participate in this study.	YES NO	____
I agree to be video and audio recorded	YES NO	____
I agree to let my conversation during the study be directly quoted, anonymously, in presentation of the research results	YES NO	____
I agree to let the video recordings, digital images, or audio recordings be used for presentation of the research results	YES NO	____

Participant Name: ____ (Please print)

Participant Signature: ____

Witness Name: ____ (Please print)

Witness Signature: ____

Date: ____

Participant Feedback Letter

University of Waterloo

Date

Dear Participant,

We would like to thank you for your participation in this study. As a reminder, the purpose of this study is to determine the impact of changing information fidelity on the decision-making strategies used within a mobile command center.

The data collected during the study will contribute to a better understanding of the appropriate direction of future development of our technology to be used within a mobile command centre.

Please remember that any data pertaining to you as an individual participant will be kept confidential. If you are interested in receiving more information regarding the results of this project, or if you have any questions or concerns, please contact Professor Jonathan Histon using the contact information listed at the bottom of the page. If you would like a summary of the results, please let the researcher know now by providing your email address. When the project is completed, the results will be sent you. The project is expected to be completed by May 1, 2012.

As with all University of Waterloo projects involving human participants, this project was reviewed by, and received ethics clearance through, the Office of Research Ethics at the University of Waterloo. Should you have any comments or concerns resulting from your participation in this study, please contact Dr. Susan Sykes in the Office of Research Ethics at 519-888-4567, Ext., 36005 or ssykes@uwaterloo.ca

Principal Investigator:
Dr. Jonathan Histon
Systems Design Engineering
519-888-4567 Ext. 37730
jhiston@uwaterloo.ca

Student Investigators:
Katie Cerar
Systems Design Engineering
kcerar@uwaterloo.ca

Post-Trial Questionnaire

Subject ID: _______________

Please fill out this questionnaire as accurately as possible. None of the information will be personally linked to you in any way. Please do not write your name anywhere on the questionnaire.

Please circle the number on the scale from 1 to 7 to indicate how much you agree with each of the following statements. A "1" indicates that you strongly **disagree** with the statement, and a "7" indicates that you strongly **agree** with the statement.

	Strongly Disagree			Neutral			Strongly Agree
I was able to properly coordinate the activity during this session.	1	2	3	4	5	6	7
My activities were well supported by the technology available to me.	1	2	3	4	5	6	7
I was always aware of what was happening outside of the command centre.	1	2	3	4	5	6	7
I was confident in my decisions.	1	2	3	4	5	6	7
The field agents always carried out my instructions properly.	1	2	3	4	5	6	7
I felt some desire to correct the actions of the field agents.	1	2	3	4	5	6	7
My workload was manageable	1	2	3	4	5	6	7

(Semi-Structured) Interview Questions

Guiding Questions:

1. How did you feel about your activities during that session?
2. Can you describe your strategy for managing what happened during this session?
3. Do you think the technology available to you was sufficient for your needs?
4. What did you like best about the technology that you used?
5. What did you dislike the most about the technology you used?
6. What are your feelings about the field agents you were coordinating for this session?
7. How did you feel your workload changed through the event? Where there cases when your workload was unmanageable?

Scripts

Training Event

Time	Field Agent	Dialogue
0:00		
0:10	602	Where am I heading again?
0:20	603	I'm in location now
	604	605 and I are in position
0:30		
0:40		
0:50	605	There is a report that a girl has broken her arm just by the food tent, I'm going to go investigate.
1:00		
1:10		
1:20	605	I've found the girl, can I have some assistance to help with crowd control? I also need the first aid kit.
1:30		
1:40		
1:50		
2:00		
2:10		
2:20		
2:30		
2:40		
2:50		
3:00	605	Mother is OK with taking her to the hospital herself, but we will need the argo to drive them to their car.
3:10		
3:20		
3:30		
3:40		
3:50	604	Mother and daughter safely in their car on the way to the hospital. I'll head back to my position now.
4:00		
4:10		
4:20	601	My battery is about to lose charge, can I have a spare?
4:30		
4:40		
4:50		

5:00		

Event #1

Time	Field Agent	Dialogue
0:00		
0:10		
0:20	602	Where is my position?
0:30	604	Who am I partnered with?
0:40		
0:50		
1:00	605	Can you explain what I need to look out for with regards to swimmers in the water?
1:10		
1:20		
1:30		
1:40	605	I don't see anyone near the road closures, should I go supervise that instead?
1:50		
2:00		
2:10	602	I'm in position
2:20	603	I'm in position now
2:30		
2:40		
2:50	603	We've started patrolling the waterfront
3:00		
3:10		
3:20	607	Are the public allowed to have sparklers?
3:30		
3:40		
3:50		
4:00		
4:10		
4:20	607	Where is the concert stage?
4:30		
4:40		
4:50		
5:00	605	I'm hearing reports of someone getting a fishhook stuck in their face, I'm going to go see what's happening.
5:10		
5:20		

5:30		
5:40		
5:50		
6:00		
6:10	605	I've found the girl with a fishhook in her neck. Can I have help from someone with the first aid kit?
6:20		
6:30		
6:40		
6:50	602	When do the fireworks start?
7:00		
7:10		
7:20		
7:30		
7:40		
7:50		
8:00		
8:10	605	Looks like we'll need 9-1-1 support for this, I don't want to take out the hook.
8:20		
8:30		
8:40		
8:50		
9:00		
9:10		
9:20		
9:30		
9:40	605	Where should I meet the ambulance?
9:50		
10:00		
10:10		
10:20		
10:30		
10:40	605	Have met with the ambulance, girl is on her way to the hospital
10:50		
11:00		
11:10		
11:20		
11:30		
11:40		

11:50	607	My battery is running out of charge, is there a spare I can have?
12:00		
12:10		
12:20		
12:30		
12:40		
12:50		
13:00		
13:10		
13:20		
13:30		
13:40		
13:50		
14:00		
14:10		
14:20	606	I have a child here who has fallen and bumped his head.
14:30		
14:40		
14:50		
15:00		
15:10		
15:20		
15:30	606	The boy seems to be OK, but his mother is demanding that we call 9-1-1 to take him to the hospital anyways. Can you call 9-1-1?
15:40		
15:50		
16:00		
16:10	606	Can we have the Argo come here to bring the woman and her child to meet the ambulance?
16:20		
16:30		
16:40		
16:50		
17:00		
17:10		
17:20		
17:30		
17:40		
17:50	602	The fireworks are starting!

18:00		
18:10	601	Where are we meeting the ambulance again?
18:20		
18:30		
18:40		
18:50		
19:00		
19:10		
19:20	601	Mother and child successfully handed off to the ambulance
19:30		
19:40		
19:50	602	Fireworks finished!
20:00		

Event #2

Time	Field Agent	Dialogue
0:00		
0:10		
0:20	601	Who am I patrolling with?
0:30	603	Where am I going again?
0:40		
0:50		
1:00	605	Can you explain what the rules are for people on the roads?
1:10		
1:20		
1:30		
1:40	602	Is someone supposed to be stationed in the food area? Don't see anyone.
1:50		
2:00		
2:10	604	I'm in position
2:20	607	I'm in position now
2:30		
2:40		
2:50	605	I've started patrolling the roadways.
3:00		
3:10		
3:20	602	Are they allowed to have sparklers?
3:30		

3:40		
3:50		
4:00		
4:10		
4:20	604	Where is the fireworks launch area?
4:30		
4:40		
4:50		
5:00	601	Someone is reporting that a man may be having a stroke. I'm going to go with them to find out what's going on.
5:10		
5:20		
5:30		
5:40	601	I've found the man, he may have had a stroke. Is someone available with the first aid kid to bring the O2? We're also going to need 9-1-1 assistance on this.
5:50		
6:00		
6:10		
6:20		
6:30		
6:40		
6:50		
7:00		
7:10		
7:20	601	Looks like I need we'll need the argo to transport him to meet the ambulance, are they nearby?
7:30		
7:40		
7:50		
8:00		
8:10		
8:20		
8:30		
8:40		
8:50		
9:00	607	When do the fireworks start?
9:10		
9:20		
9:30		

9:40		
9:50	605	Where should I meet the ambulance?
10:00		
10:10		
10:20		
10:30		
10:40		
10:50		
11:00	605	Have met with the ambulance, man is on her way to the hospital
11:10		
11:20		
11:30		
11:40		
11:50		
12:00		
12:10		
12:20		
12:30	603	My first aid kit needs more supplies now, is there a spare I can have?
12:40		
12:50		
13:00		
13:10		
13:20		
13:30		
13:40		
13:50		
14:00		
14:10		
14:20		
14:30	602	I have reports of an adult here who has gotten a burn from stepping on a sparkler in sandals. I'm investigating now.
14:40		
14:50		
15:00		
15:10		
15:20	602	The adult seems to be OK, but he'd like to head to his car to go home. I'll escort them.
15:30		

15:40		
15:50		
16:00	602	Can we have the Argo come here to bring the man to his car? He's having trouble walking.
16:10		
16:20		
16:30		
16:40		
16:50	607	The fireworks are starting!
17:00		
17:10		
17:20		
17:30		
17:40		
17:50		
18:00		
18:10		
18:20		
18:30		
18:40	605	Have dropped off the man and his family at his car, heading back now.
18:50		
19:00		
19:10		
19:20		
19:30		
19:40	607	Fireworks finished!
19:50		
20:00		

Appendix C

Studied Baseline Events

Manulife Bike and Hike for Heart

The bike and hike for heart was a two part athletic event to raise money for charity. It included both walking routes and a bike route. REACT's involvement in this event was to provide emergency support for participants should a medical issue occur. They also patrolled the routes to ensure that participants were safe on the roadways.

Cambridge Tour de Grand

This event was a series of bike races, ranging in distance from 10km to 160km. REACT's responsibilities were to provide emergency support for accidents, and to follow the race routes to ensure the safety of participants on roadways. As eight different races occurred at the same time, command was responsible for monitoring the progress of multiple sequences at the same time.

University of Waterloo Canada Day Celebrations

Canada Day celebrations were monitored by REACT field agents during this event, which included live bands and food during the day, followed by a fireworks display after dark. Primary responsibilities included providing medical assistance to members of the public, directing traffic, assisting organizers in running the event, and monitoring restricted areas to ensure public safety. During this event there was a missing person incident, and two medical incidents requiring 9-1-1 assistance.

Waterloo Aviation Expo & Air Show

The air show took place at an airport, where various planes and flying vehicles demonstrated acrobatics for over 25,000 members of the public. The observed event was the training run, as the researchers were not allowed to observe the actual event due to safety concerns. Primarily, REACT was responsible for monitoring the perimeter for members of the public entering restricted areas, providing medical assistance should there be an emergency in the crowd or during the performance, and to assist the organizers as necessary. During this event, EMS also operated out of the REACT mobile command center.

Kitchener-Waterloo Oktoberfest Parade

An event attended by over 150,000 members of the public, this parade covered a distance of 5km and involved over 130 parade floats. REACT's responsibilities included escorting floats, assisting with parade direction, blocking off traffic, providing support in the case of medical emergency (in this case, a heart attack victim), and directing traffic after the parade conclusion.

Kitchener-Waterloo Santa Claus Parade

Similar to the Oktoberfest parade, this parade covers 5km with over 100 parade floats. REACT's responsibilities included assisting with parade direction, blocking off traffic, providing support in the case of medical emergency, and directing traffic after the parade conclusion. No major medical incidents occurred within this event.

Cambridge Santa Claus Parade

This parade took place on a smaller route with fewer floats than the other two parades described, however it took place during the evening, in the dark. REACT responsibilities included assisting with parade direction, blocking off traffic, providing medical support, and directing traffic after the event concluded. The dark, cold conditions meant that the field agents had to pay specific attention to public safety due to decreased visibility, and also had an unwelcome side effect of lowering the ability of radio batteries to hold a charge. The specific location of the parade also caused traffic direction after the event to be particularly difficult.

Appendix D

Statistical Test Results

Wilcoxon Signed Ranks Test (Questionnaire Data)

Ranks

		N	Mean Rank	Sum of Ranks
LF1 - HF1	Negative Ranks	4[a]	4.00	16.00
	Positive Ranks	3[b]	4.00	12.00
	Ties	13[c]		
	Total	20		
LF2 - HF2	Negative Ranks	11[d]	6.77	74.50
	Positive Ranks	1[e]	3.50	3.50
	Ties	8[f]		
	Total	20		
LF3 - HF3	Negative Ranks	15[g]	8.83	132.50
	Positive Ranks	1[h]	3.50	3.50
	Ties	4[i]		
	Total	20		
LF4 - HF4	Negative Ranks	6[j]	4.25	25.50
	Positive Ranks	2[k]	5.25	10.50
	Ties	12[l]		
	Total	20		
LF5 - HF5	Negative Ranks	7[m]	7.29	51.00
	Positive Ranks	5[n]	5.40	27.00
	Ties	8[o]		
	Total	20		
LF6 - HF6	Negative Ranks	12[p]	8.58	103.00
	Positive Ranks	3[q]	5.67	17.00
	Ties	5[r]		
	Total	20		
LF7 - HF7	Negative Ranks	6[s]	4.08	24.50
	Positive Ranks	1[t]	3.50	3.50
	Ties	13[u]		
	Total	20		

a. LF1 < HF1
b. LF1 > HF1
c. LF1 = HF1
d. LF2 < HF2
e. LF2 > HF2
f. LF2 = HF2
g. LF3 < HF3
h. LF3 > HF3
i. LF3 = HF3
j. LF4 < HF4
k. LF4 > HF4
l. LF4 = HF4
m. LF5 < HF5
n. LF5 > HF5
o. LF5 = HF5
p. LF6 < HF6
q. LF6 > HF6
r. LF6 = HF6
s. LF7 < HF7
t. LF7 > HF7
u. LF7 = HF7

Test Statistics[b]

	LF1 - HF1	LF2 - HF2	LF3 - HF3	LF4 - HF4	LF5 - HF5	LF6 - HF6	LF7 - HF7
Z	-.378[a]	-2.834[a]	-3.404[a]	-1.098[a]	-.975[a]	-2.460[a]	-1.897[a]
Asymp. Sig. (2-tailed)	.705	.005	.001	.272	.330	.014	.058

a. Based on positive ranks.
b. Wilcoxon Signed Ranks Test

Wilcoxon Signed Ranks Test (Workload Ratings)

Ranks

		N	Mean Rank	Sum of Ranks
LowFid - HighFid	Negative Ranks	41[a]	48.00	1968.00
	Positive Ranks	60[b]	53.05	3183.00
	Ties	99[c]		
	Total	200		

a. LowFid < HighFid

b. LowFid > HighFid

c. LowFid = HighFid

Test Statistics[b]

	LowFid - HighFid
Z	-2.141[a]
Asymp. Sig. (2-tailed)	.032

a. Based on negative ranks.

b. Wilcoxon Signed Ranks Test

Repeated Measures ANOVA (Audio Coding)

Within-Subjects Factors

Measure	Fidelity	Dependent Variable
InfoTrans	1	HFInfoTrans
	2	LFInfoTrans
InfoReq	1	HFInfoReq
	2	LFInfoReq
ActTrans	1	HFActTrans
	2	LFActTrans
ActReq	1	HFActReq
	2	LFActReq
Ack	1	HFAck
	2	LFAck

Descriptive Statistics

	Mean	Std. Deviation	N
HFInfoTrans	29.5500	6.83239	20
LFInfoTrans	32.6000	7.74868	20
HFInfoReq	15.5000	4.18644	20
LFInfoReq	17.9500	7.13387	20
HFActTrans	11.6500	5.68724	20
LFActTrans	12.3500	5.70572	20
HFActReq	4.0000	1.83533	20
LFActReq	3.2000	.95145	20
HFAck	30.9500	6.77049	20
LFAck	33.4000	9.50014	20

Multivariate Tests[b]

Effect			Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Between Subjects	Intercept	Pillai's Trace	.993	439.247[a]	5.000	15.000	.000	.993
		Wilks' Lambda	.007	439.247[a]	5.000	15.000	.000	.993
		Hotelling's Trace	146.416	439.247[a]	5.000	15.000	.000	.993
		Roy's Largest Root	146.416	439.247[a]	5.000	15.000	.000	.993
Within Subjects	Fidelity	Pillai's Trace	.194	.722[a]	5.000	15.000	.617	.194
		Wilks' Lambda	.806	.722[a]	5.000	15.000	.617	.194
		Hotelling's Trace	.241	.722[a]	5.000	15.000	.617	.194
		Roy's Largest Root	.241	.722[a]	5.000	15.000	.617	.194

a. Exact statistic

b.
Design: Intercept
Within Subjects Design: Fidelity

Mauchly's Test of Sphericity[b]

						Epsilon[a]		
Within Subjects Effect	Measure	Mauchly's W	Approx. Chi-Square	df	Sig.	Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Fidelity	InfoTrans	1.000	.000	0	.	1.000	1.000	1.000
	InfoReq	1.000	.000	0	.	1.000	1.000	1.000
	ActTrans	1.000	.000	0	.	1.000	1.000	1.000
	ActReq	1.000	.000	0	.	1.000	1.000	1.000
	Ack	1.000	.000	0	.	1.000	1.000	1.000

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b.
Design: Intercept
Within Subjects Design: Fidelity

Multivariate[b,c]

Within Subjects Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Fidelity	Pillai's Trace	.194	.722[a]	5.000	15.000	.617	.194
	Wilks' Lambda	.806	.722[a]	5.000	15.000	.617	.194
	Hotelling's Trace	.241	.722[a]	5.000	15.000	.617	.194
	Roy's Largest Root	.241	.722[a]	5.000	15.000	.617	.194

a. Exact statistic

b.
Design: Intercept
Within Subjects Design: Fidelity

c. Tests are based on averaged variables.

Univariate Tests

Source	Measure		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Fidelity	InfoTrans	Sphericity Assumed	93.025	1	93.025	1.754	.201	.085
		Greenhouse-Geisser	93.025	1.000	93.025	1.754	.201	.085
		Huynh-Feldt	93.025	1.000	93.025	1.754	.201	.085
		Lower-bound	93.025	1.000	93.025	1.754	.201	.085
	InfoReq	Sphericity Assumed	60.025	1	60.025	3.721	.069	.164
		Greenhouse-Geisser	60.025	1.000	60.025	3.721	.069	.164
		Huynh-Feldt	60.025	1.000	60.025	3.721	.069	.164
		Lower-bound	60.025	1.000	60.025	3.721	.069	.164
	ActTrans	Sphericity Assumed	4.900	1	4.900	.398	.536	.021
		Greenhouse-Geisser	4.900	1.000	4.900	.398	.536	.021
		Huynh-Feldt	4.900	1.000	4.900	.398	.536	.021
		Lower-bound	4.900	1.000	4.900	.398	.536	.021
	ActReq	Sphericity Assumed	6.400	1	6.400	3.416	.080	.152
		Greenhouse-Geisser	6.400	1.000	6.400	3.416	.080	.152
		Huynh-Feldt	6.400	1.000	6.400	3.416	.080	.152
		Lower-bound	6.400	1.000	6.400	3.416	.080	.152
	Ack	Sphericity Assumed	60.025	1	60.025	2.091	.164	.099
		Greenhouse-Geisser	60.025	1.000	60.025	2.091	.164	.099
		Huynh-Feldt	60.025	1.000	60.025	2.091	.164	.099
		Lower-bound	60.025	1.000	60.025	2.091	.164	.099
Error(Fidelity)	InfoTrans	Sphericity Assumed	1007.475	19	53.025			
		Greenhouse-Geisser	1007.475	19.000	53.025			
		Huynh-Feldt	1007.475	19.000	53.025			
		Lower-bound	1007.475	19.000	53.025			
	InfoReq	Sphericity Assumed	306.475	19	16.130			
		Greenhouse-Geisser	306.475	19.000	16.130			
		Huynh-Feldt	306.475	19.000	16.130			
		Lower-bound	306.475	19.000	16.130			
	ActTrans	Sphericity Assumed	234.100	19	12.321			
		Greenhouse-Geisser	234.100	19.000	12.321			
		Huynh-Feldt	234.100	19.000	12.321			
		Lower-bound	234.100	19.000	12.321			
	ActReq	Sphericity Assumed	35.600	19	1.874			
		Greenhouse-Geisser	35.600	19.000	1.874			
		Huynh-Feldt	35.600	19.000	1.874			
		Lower-bound	35.600	19.000	1.874			
	Ack	Sphericity Assumed	545.475	19	28.709			
		Greenhouse-Geisser	545.475	19.000	28.709			
		Huynh-Feldt	545.475	19.000	28.709			
		Lower-bound	545.475	19.000	28.709			

Tests of Within-Subjects Contrasts

Source	Measure	Fidelity	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Fidelity	InfoTrans	Linear	93.025	1	93.025	1.754	.201	.085
	InfoReq	Linear	60.025	1	60.025	3.721	.069	.164
	ActTrans	Linear	4.900	1	4.900	.398	.536	.021
	ActReq	Linear	6.400	1	6.400	3.416	.080	.152
	Ack	Linear	60.025	1	60.025	2.091	.164	.099
Error(Fidelity)	InfoTrans	Linear	1007.475	19	53.025			
	InfoReq	Linear	306.475	19	16.130			
	ActTrans	Linear	234.100	19	12.321			
	ActReq	Linear	35.600	19	1.874			
	Ack	Linear	545.475	19	28.709			

Tests of Between-Subjects Effects

Transformed Variable: Average

Source	Measure	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	InfoTrans	38626.225	1	38626.225	719.314	.000	.974
	InfoReq	11189.025	1	11189.025	213.988	.000	.918
	ActTrans	5760.000	1	5760.000	109.550	.000	.852
	ActReq	518.400	1	518.400	216.000	.000	.919
	Ack	41409.225	1	41409.225	385.622	.000	.953
Error	InfoTrans	1020.275	19	53.699			
	InfoReq	993.475	19	52.288			
	ActTrans	999.000	19	52.579			
	ActReq	45.600	19	2.400			
	Ack	2040.275	19	107.383			

Estimates

				95% Confidence Interval	
Measure	Fidelity	Mean	Std. Error	Lower Bound	Upper Bound
InfoTrans	1	29.550	1.528	26.352	32.748
	2	32.600	1.733	28.974	36.226
InfoReq	1	15.500	.936	13.541	17.459
	2	17.950	1.595	14.611	21.289
ActTrans	1	11.650	1.272	8.988	14.312
	2	12.350	1.276	9.680	15.020
ActReq	1	4.000	.410	3.141	4.859
	2	3.200	.213	2.755	3.645
Ack	1	30.950	1.514	27.781	34.119
	2	33.400	2.124	28.954	37.846

Pairwise Comparisons

Measure	(I) Fidelity	(J) Fidelity	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
						Lower Bound	Upper Bound
InfoTrans	1	2	-3.050	2.303	.201	-7.870	1.770
	2	1	3.050	2.303	.201	-1.770	7.870
InfoReq	1	2	-2.450	1.270	.069	-5.108	.208
	2	1	2.450	1.270	.069	-.208	5.108
ActTrans	1	2	-.700	1.110	.536	-3.023	1.623
	2	1	.700	1.110	.536	-1.623	3.023
ActReq	1	2	.800	.433	.080	-.106	1.706
	2	1	-.800	.433	.080	-1.706	.106
Ack	1	2	-2.450	1.694	.164	-5.996	1.096
	2	1	2.450	1.694	.164	-1.096	5.996

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Pillai's trace	.194	.722[a]	5.000	15.000	.617	.194
Wilks' lambda	.806	.722[a]	5.000	15.000	.617	.194
Hotelling's trace	.241	.722[a]	5.000	15.000	.617	.194
Roy's largest root	.241	.722[a]	5.000	15.000	.617	.194

Each F tests the multivariate effect of Fidelity. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Exact statistic

Paired t-Test (Avg Time to Answer – Workload Measure)

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	AvgHighFidTime & AvgLowFidTime	20	.491	.028

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	AvgHighFidTime - AvgLowFidTime	-.83500	8.78487	1.96436	-4.94645	3.27645	-.425	19	.676

Wilcoxon Signed Ranks Test (Offloading on Maps)

Ranks

		N	Mean Rank	Sum of Ranks
UsePaperLowFid - UsePaperHighFid	Negative Ranks	0[a]	.00	.00
	Positive Ranks	6[b]	3.50	21.00
	Ties	14[c]		
	Total	20		

a. UsePaperLowFid < UsePaperHighFid

b. UsePaperLowFid > UsePaperHighFid

c. UsePaperLowFid = UsePaperHighFid

Test Statistics[b]

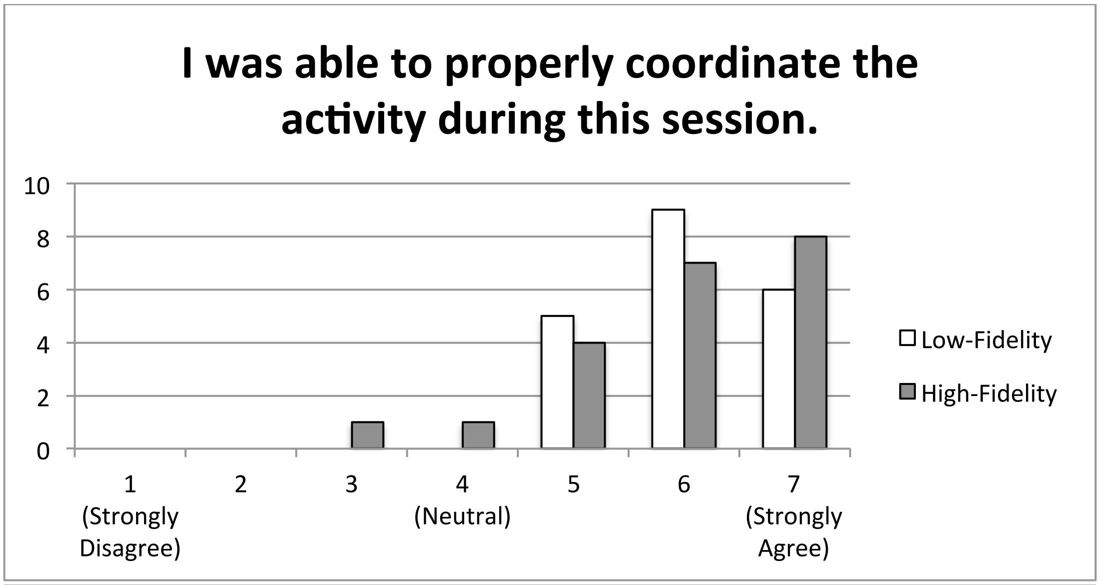
	UsePaper LowFid - UsePaper HighFid
Z	-2.449[a]
Asymp. Sig. (2-tailed)	.014

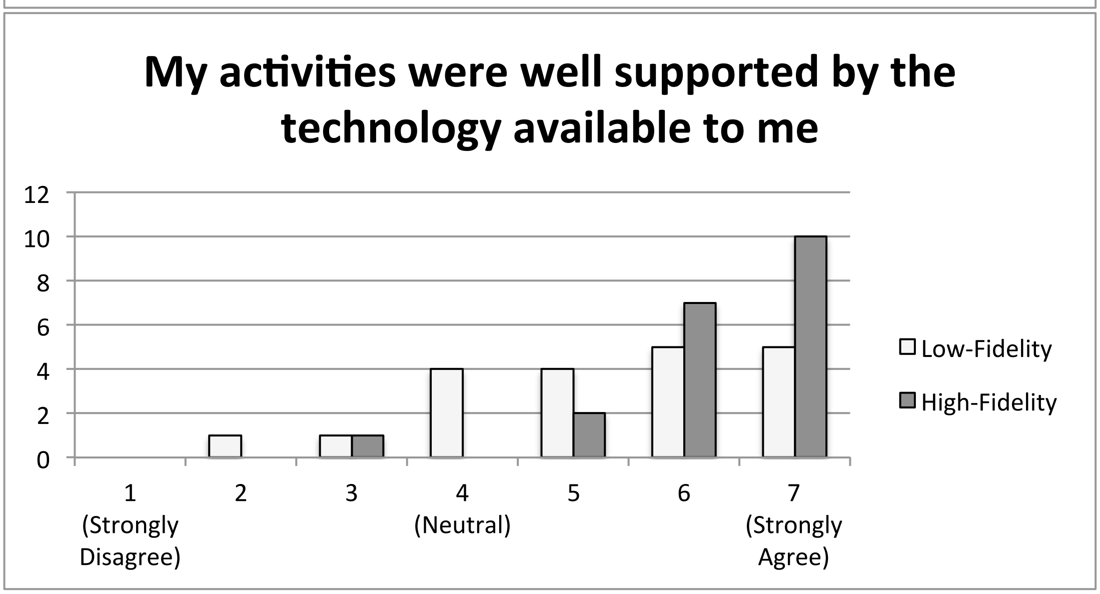
a. Based on negative ranks.

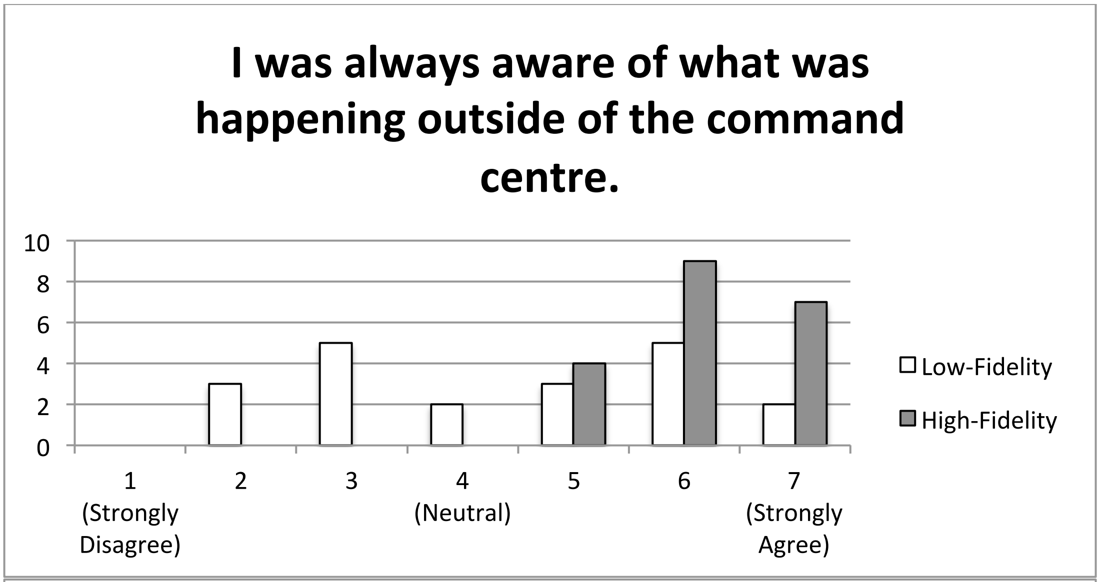
b. Wilcoxon Signed Ranks Test

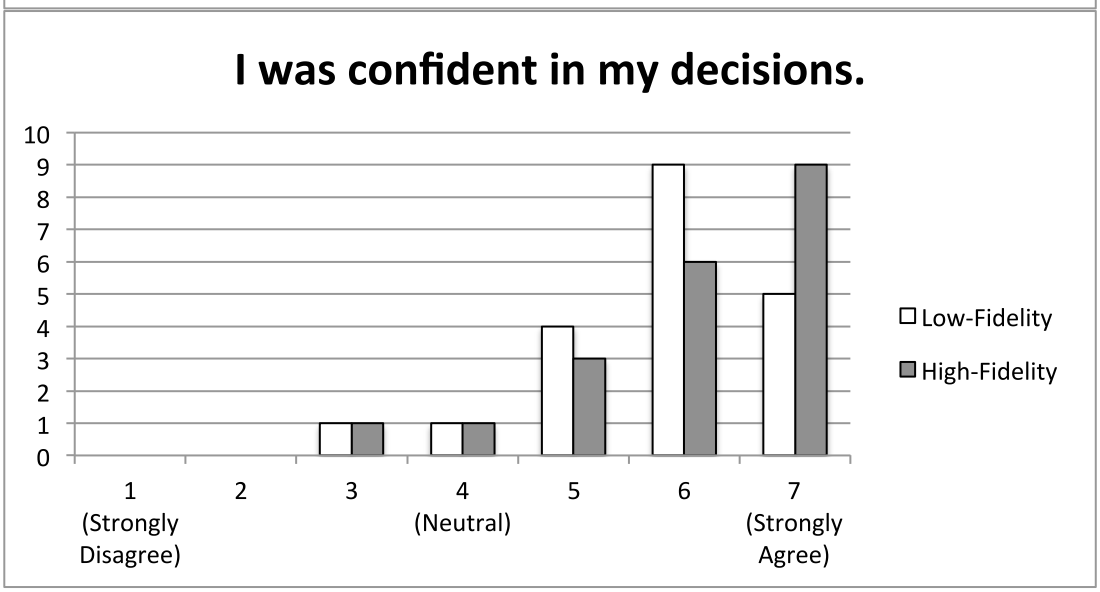
Appendix E

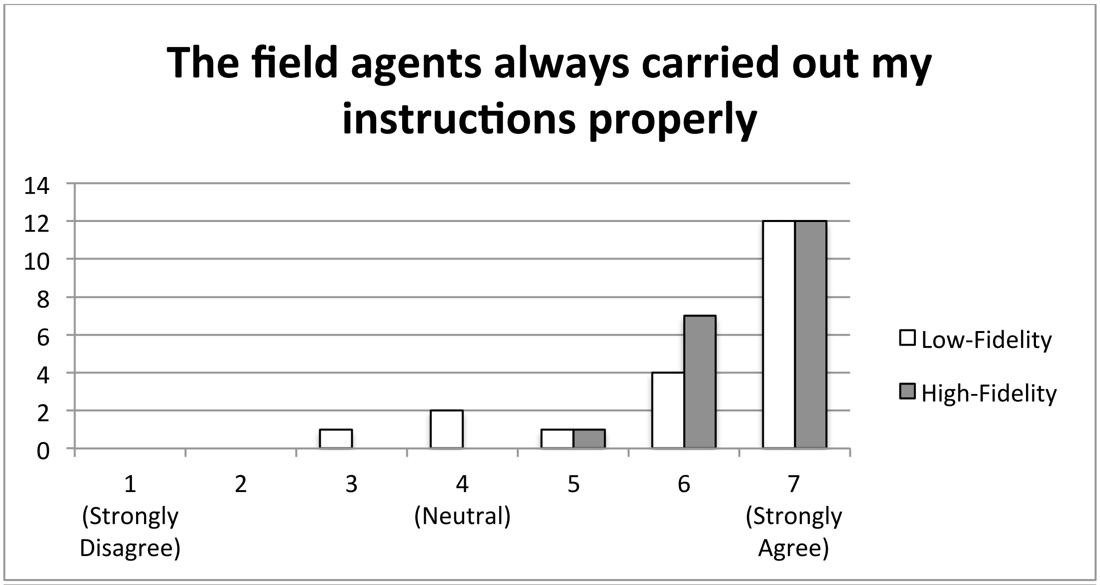
Controlled Technology Study Data

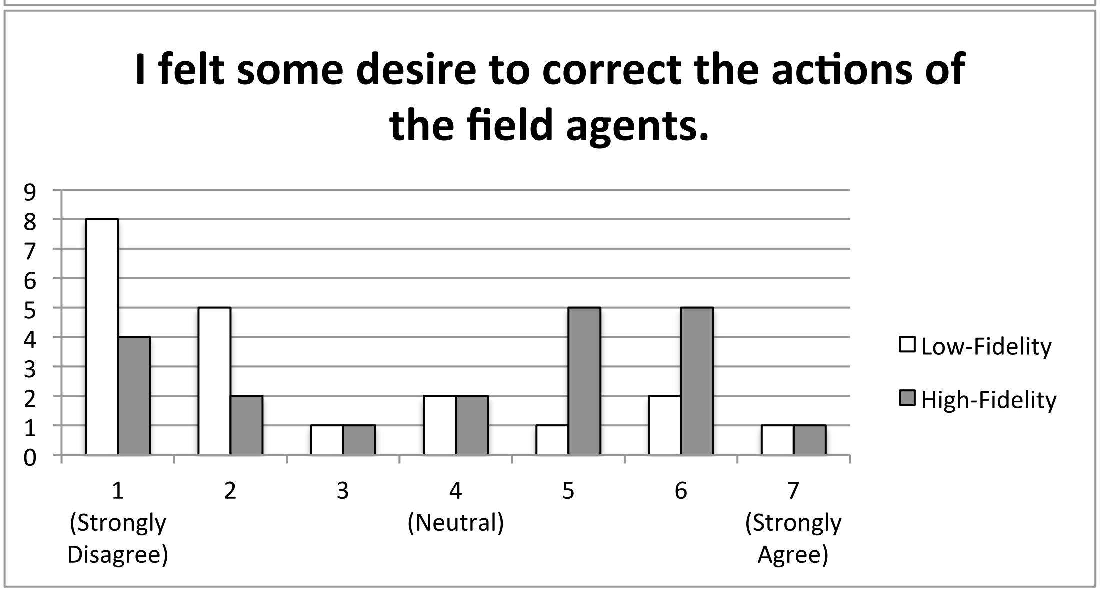


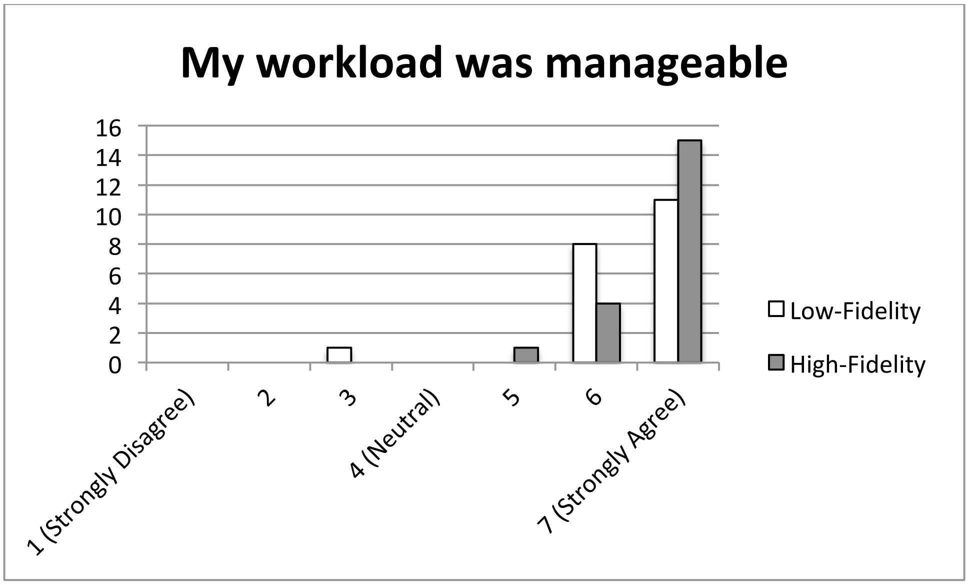



I was always aware of what was happening outside of the command centre.
10
8
6
4
2
0
1 (Strongly Disagree)
2
3
4 (Neutral)
5
6
7 (Strongly Agree)
Low-Fidelity
High-Fidelity


I was confident in my decisions.
10
9
8
7
6
5
4
3
2
1
0
1 (Strongly Disagree)
2
3
4 (Neutral)
5
6
7 (Strongly Agree)
Low-Fidelity
High-Fidelity


The field agents always carried out my instructions properly
14
12
10
8
6
4
2
0
1 (Strongly Disagree)
2
3
4 (Neutral)
5
6
7 (Strongly Agree)
Low-Fidelity
High-Fidelity


I felt some desire to correct the actions of the field agents.
9
8
7
6
5
4
3
2
1
0
1 (Strongly Disagree)
2
3
4 (Neutral)
5
6
7 (Strongly Agree)
Low-Fidelity
High-Fidelity


My workload was manageable
16
14
12
10
8
6
4
2
0
1 (Strongly Disagree)
2
3
4 (Neutral)
5
6
7 (Strongly Agree)
Low-Fidelity
High-Fidelity