

A Model Based Design Framework for Interoperable Communication Systems

Gyu Hyun Kwon

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Tonya L. Smith-Jackson, Chair
Charles W. Bostian
Brian M. Kleiner
Woodrow W. Winchester

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ABSTRACT

The need for interoperability in emergency communication systems has hastened the development of cognitive radio technology. However, even though a cognitive radio system technically interconnects participating agencies, interoperability depends not only on technical matters but also organizational issues related to the different individuals, working contexts and types of cooperative work involved. In order to support public safety workers such as police, firefighters, and Emergency Medical Service (EMS) providers appropriately, it is vital to consider the dynamics of the way they interact in any collaborative situation.

The purpose of this study is to develop an in-depth understanding of interoperability and construct a new model based on this understanding, along with a working model of an interoperable communication system to serve as a design framework that (1) supports effective public safety communication and (2) incorporates cognitive radio capabilities to ensure optimal semantic interoperability. An adequate model for interoperability must include multiple dimensions to explain both the concept of interoperability in the public safety domain and its relationships with task characteristics and information needs. This model focuses primarily on the requirements for communication systems. The value perspective reflects the evaluation criteria for effective team communication such as semantic interoperability, task routineness, and information processing aspects. The design framework incorporates the proposed model into Work Domain Analysis (WDA).

To achieve these research objectives, a series of studies was conducted. The first was a qualitative exploratory study that identified how the concept of interoperability is manifested in the public safety work domain. Through the use of semi-structured interviews, communication patterns in

terms of interoperability were placed in a real world context. The responses from the participants were categorized in terms of the dimensions of interoperability and reinterpreted using sensemaking as a theoretical framework. The dimensions of interoperability identified consisted of information sharedness, communication readiness, operational awareness, adaptiveness, and coupledness. Based on these findings, a new instrument was proposed to measure interoperability for communication systems. This instrument was then statistically validated. The second study identified the effects of different types of operation and types of organization on interoperability, as well as investigating the relationships among interoperability, task routineness and information processing using Structural Equation Modeling (SEM). Based on this understanding and theoretical perspective, a new interoperable communication structure was delineated in the model. A prototype of a public safety cognitive radio communication system was then developed based on the proposed framework and examined using a focus group in order to validate the proposed model and design framework and highlight any usability issues that may affect the prototype's operational effectiveness.

DEDICATION

This dissertation is dedicated to my beloved wife, Kyunghui, and my little angel, Yoonhye.

for your constant support, encouragement, and love

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1. INTRODUCTION

1.1. Background

When a natural disaster occurs, the ability of public safety services to communicate with each other fast and effectively is critical. For example, during Hurricane Katrina, the collapse of public communication systems precipitated a catastrophic information asymmetry and a massive disconnect within and between emergency service groups and citizens (Comfort & Haase, 2006). Louisiana Governor Kathleen Babineaux Blanco complained that “the big problem [in managing the disaster response] was that the communications network was down. The day after the storm, cell phones, blackberries, and landlines were useless at the moment when coordination among many branches of government was critical” (Maggi, 2005, p.A10). The lack of electrical power meant that all 911 services ceased to function and those in the affected area had no way to communicate with the outside world. Radio technology was the only surviving means of communication; the American Radio Relay League (ARRL) President Jim Haynie provided written testimony to the US Congress in 2005 that “1000 Amateur Radio volunteers were or have been serving in the stricken area to provide communication for served agencies such as the American Red Cross and The Salvation Army and to facilitate interoperability between agencies” (Haynie, 2005).

From daily patrol tasks to large-scale emergency control events, public safety workers must collaborate to solve life-critical problems (Smith & Tolman, 2000). They must collect information related to an incident at the scene and pass it on to the dispatchers on duty, who, in turn, share it with their working partners or other agencies as needed. All levels require strong teamwork, which can be defined as cooperative and coordinated work in a group performing complementary tasks and contributing resources towards a shared goal (Andersen, 2000; Langan-Fox, Anglim, & Wilson, 2004; Terrell, 2006; Yen, Yin, Loerger, Miller, Xu, & Volz, 2001). In this context, the importance of communication cannot be overstated since collaboration is time- and safety-critical. Communication needs have dramatically increased

over the past few decades, but the inherent limitations of the currently available communication technology and the general lack of understanding of how the design space functions have restricted the task performance of public safety workers.

1.2. **Research Problems**

1.2.1. *Situation Specific Functions and Tasks*

The work carried out by public safety personnel is diverse, ranging from simple patrol tasks to large-scale disaster management. Although there are differences of degree, all public safety work ultimately deals with emergency and life critical situations. Situations that are unknown and uncertain may involve some level of danger and may therefore be considered risky and time-pressured (Manning, 2003). Westrum (2006) categorized three different kinds of threats according to their frequency. The first and most common of these categories consists of regular threats, which occur often enough to trigger certain standard response procedures. In these cases, public safety workers can respond based on their standard training. They can fully identify and understand the situation from the initial dispatch, and can thus handle the situation. Most communication in this phase follows a familiar pattern and is part of their regular organization. The second of Westrum's categories consists of irregular threats, which represent more challenging situations and are more difficult to prepare for. These large scale disasters fit the description of a so-called "wicked problem set" (Rittel & Webber, 1973), which is ill-defined and unique in every situation. There is no absolute solution that can be applied to deal with such problems and extensive collaboration among agencies is necessary. The final type of threat category is the totally unexpected event; the terrorist attacks on 9/11 are a prime example of such an event. In this case, public safety workers must undergo a radical shift in their mental framework in order to perform effectively. In the case of Hurricane Katrina, which falls into the second of these categories, most of the agencies involved in the disaster relief effort engaged in multi-tasking with heavy collaboration in order to save many lives. However, the nature of the tasks they were carrying out and the environments in which they were working severely restricted the communication alternatives that were available to help them to achieve their shared goals.

1.2.2. *Individuals in Public Safety Work Contexts*

Where public safety is concerned, the public expects swift execution of emergency protocols by relevant agencies at all times. It is widely accepted that the police use the concept of ‘a situational rationality’ that takes into account the particular times and places of events, rather than a set of firm rules, regulations, or laws (Manning, 1992). In a very similar vein, a naturalistic decision making model attempts to explain decision making in the public safety domain (Uttaro, 2002; Zsombok & Klein, 1997).

The general features of a threat in the *Naturalistic Decision Making* (NDM) framework, as delineated by (Klein & Klinger, 1991) are: ill-defined goals and ill-structured tasks; uncertainty, ambiguity, and missing data; shifting and competing goals; dynamic and continually changing conditions; action-feedback loops (real-time reactions to changed conditions); time stress; high stakes; multiple players; organizational goals and norms; and experienced decision makers.

Research into the human decision making process in public safety work environments such as firefighting, combat control, and aircraft control has resulted in insights supporting the claim that experts make decisions by pattern matching with their experience (Kaempf, Klein, Thorsden, & Wolf, 1996; Klein, 1989). The *Recognition Primed Decision* (RPD) model, the predominant hypotheses that has emerged from these studies, has been widely applied to develop both training systems and guidelines for decision support systems, notwithstanding the fact that the RPD model as a descriptive model suffers from many limitations. For example, RPD focuses on individuals, rather than groups; it is domain specific; it is limited by the expertise of the participating agencies and workers; and it gives no consideration to individual differences (Klayman, 2001; Soh, 2007). In concordance with other decision making models, the RPD model also highlights the need to comprehend the situation in order to recognize a pattern (Endsley, 1997). In this framework, the comprehension process must distinguish four types of information: goal, cues, expectancies and actions (Klein, 1989).

In summary, a decision model within NDM may produce an appropriate model with which to understand a public safety worker’s decision making process. However, both NDM and RPD focus on an individual’s decision making rather than that of a group or team (Terrell, 2006).

1.2.3. Dynamic Collaboration and Sensemaking

Cannon-Bowers and Salas (2001) state that with respect to public safety, especially in the crisis management domain, the nature of the work is so complex that it would be impossible for any single team member to hold all the relevant knowledge required to accomplish their tasks. The concept of distributed cognition emphasizes team and group cognition (Hutchins, 1995). Most public safety work consists of collaborative efforts to achieve the shared goal in an emergency situation (McNeese & Hall, 2003). Weick (1995) has researched the concept of sensemaking at the organizational level to provide insight into the factors related to situation assessment, understanding, and decision making under uncertain or ambiguous situations. Based on the concept of sensemaking, the Department of Defense (DoD) have espoused the concept of Network Centric Warfare (NCW), which emphasizes information sharing based on the use of information technology to support collaborative works in combat situations (Alberts, Garstka, & Stein, 2000). The many points of similarity between military and public safety operations suggest that sensemaking may offer a suitable theoretical framework with which to explain public safety communication.

During an incident, public safety workers communicate with one another to share as much information as possible. In this context, one of the main problems is the dynamic nature of the team composition. Normally, working teams are defined by the organizational structure of the agency, but in an emergency situation the group composition is improvisational. For instance, at a fire scene, firefighters, police officers and EMS personnel may work together to rescue a wounded person. Volunteers, such as amateur radio operators, may also help within the incident organization. In such cases, the emergency agency workers may need to frequently change their communication networks: the police must communicate with each other using a primary channel but the change the channel to communicate with the EMS, while EMS must ask the police to check a crime scene to ensure it is safe for them to enter. Thus, inter-personal communications, as well as inter-organizational communications, are frequently needed and those working the incident must continually change between their primary channel and the predefined tactical or operational channel in order to communicate with each other.

1.2.4. Information Overload during Communication

Individuals, including public safety workers, under information overload are unable to absorb all the required information and sometimes make critical mistakes performing their primary task due to missing important information. This was demonstrated during a major football game day at Virginia Tech in 2007, when a field test of an interoperability gateway, the ACU 1000, was conducted. The test failed due to high levels of radio traffic and consequent information overload; many agents had turned off their radio systems to avoid being distracted by information irrelevant to their situation. A great deal of research has been devoted to the technical aspects of interoperability in public safety situations (Dilmaghani & Rao, 2006; Interoperability, 2003; Smith & Tolman, 2000). Based on the findings of these studies, a major goal of interoperability research is to reduce information overload and hence make communication possible with everyone in the network. Thus, it is important to support naturalistic dynamic team composition in the interface and system levels. Understanding the communication patterns of public safety workers and organizational issues in naturalistic contexts opens the way to solving the problem of information overload.

1.2.5. Interoperability in Public Safety Communication Systems

Interoperability is defined as “the ability of public safety personnel to communicate by radio with staff from other agencies, on demand and in real time” (Public Safety Wireless Network [PSWN], 2002, p.2). Interoperability is critical to ensure cooperation among team members or different agencies charged with dealing with large operations such as simultaneous incidents, a massive public event, or a natural disaster.

Public safety agencies have used radio communications systems since 1928 (IEEE, 2009). So far, however, most of these systems have been limited in terms of range and although they enable communication within a particular group or agency they do not function across agencies as each agency has its own system and the systems are incompatible. Virginia Tech (VT) police officers, for example, can talk amongst themselves over their radios, but cannot speak directly with Emergency Medical Service (EMS) providers or fire fighters, and sometimes not even with the Town of Blacksburg police officers or other agencies from neighboring towns. This situation

severely curtails the utility of radio communications, especially in situations that demand large-scale immediate interagency communication and coordination.

Designing communication systems always presents challenges due to the need to incorporate adaptiveness and appropriate representation (Woods, 1991). In today's environment of unprecedented IT development, it is imperative to understand how new technologies can meet the needs of this important user group. For the past few decades, there have been many efforts to develop communication systems that support interoperability among agencies. Since the concept was first presented by Mitola and Maguire (1999), cognitive radio has been highlighted as the key technology in solving interoperability issues. Ideally, a full cognitive radio will consider every possible observable parameter of a wireless node or network in order to address interoperability issues (Smith & Tolman, 2000). It is important to note, however, that the current concept of interoperability focuses primarily on the importance of exploiting the technical communication potential among devices and a previous ethnographic study identified the limitations of the current concept of interoperability (Imran & Smith-Jackson, 2005). Thus, it is critical to understand the characteristics of how dynamic communication groups devoted to public safety can function most effectively in the light of recent advances in communication technology and to redefine the concept of interoperability considering organizational, operational and contextual aspects in order to enhance cognitive radio capabilities in the public safety domain.

1.2.6. Task-Artifact Cycle

Public safety agencies have been attempting to customize their various radio systems for several decades, but their communication tasks are still constrained by the available technologies and systems. This problem is critical whenever a new technology is being introduced. Typically, since the designer introduces a new design based on the requirements provided by an analysis of current practice, the user adapts that proposed system so the introduction of the new design creates a new practice.

Carroll and Rosson (1992) captured the interdependence between current practice and the design of new devices and suggested the concept of the *task-artifact cycle*. Descriptive studies enable

designers to better understand their assigned task and apply the knowledge gained as they create a new artifact. This new artifact, in turn, creates a new task, which serves as a trigger for a new design and perpetuates the cycle. To address this issue, (Carroll & Rosson, 1992) suggested the use of a scenario-based design framework. Scenarios provide a means for analytically evaluating “simulated future work” (Kyng, 1995) and encourage designers to simulate a future system by developing scenarios and iteratively evolving novel systems with the aid of prototypes. Vicente (1999) suggested an alternative way to overcome this cyclic effect using a model-based design framework called Cognitive Work Analysis (CWA). He identified two main pitfalls of the current design framework, namely device-dependence and incompleteness, and suggested a constraints-based approach to designing sociotechnical systems. Figure 1 describes the task-artifact cycle in communication systems.

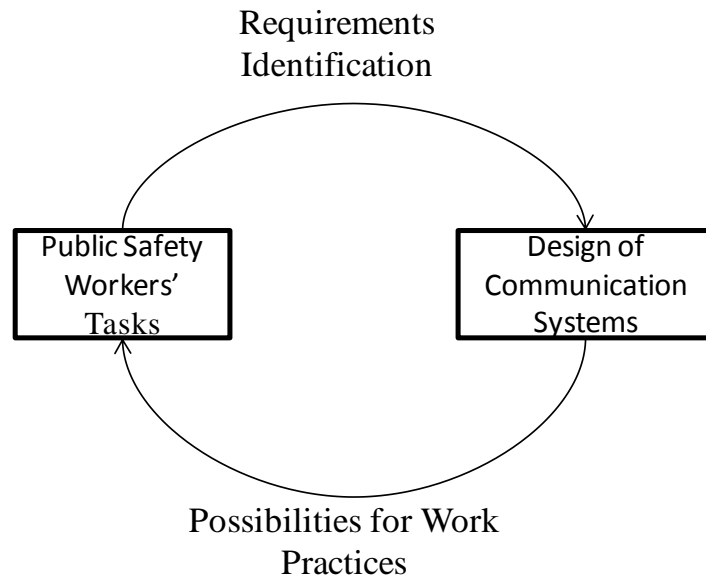


Figure 1. The Task-Artifact Cycle (adapted from Carroll & Rosson, 1992)

1.2.7. Summary of the Problem

Public safety work is often harsh and tough, but it is one of the most important tasks needed to sustain human society. The working conditions are uncertain, risky and subject to time-pressure and workers must collaborate to achieve shared goals. Although the role of communication systems in public safety work has been emphasized for a long time as a vital component supporting the various tasks of all the parties concerned, technical and operational limitations still hamper interoperability among agencies. The introduction of cognitive radio now makes it possible to imagine the full potential of seamless communication. However, problems such as a lack of understanding of the communication structures under cognitive radio environments continue to hamper efforts to develop effective systems. This understanding should be modeled to shed new light on the problems involved and break open the task artifact cycle.

1.3. Motivation for This Research

1.3.1. Defining Dimensions of Interoperability

Despite the many discussions of the concept of interoperability, there is as yet no measure of semantic interoperability in the context of the public safety domain that extends beyond a technical perspective. As previously mentioned, interoperability is currently one of the most important issues in communication system design. Since the concept of network centric operation has been emphasized in disaster management events, there is a strong need to define interoperability in terms of its socio-cognitive aspects. Socio-cognitive research (Hemingway, 1998; Sharples, du Boulay, Teather, Teather, & du Boulay, 2002) should therefore be used to describe the integrated cognitive and social properties of interoperability. Sensemaking (Weick, 1995) provides a convenient framework for this endeavor.

1.3.2. Need for a Model of Interoperability

Semantic interoperability in the public safety communication domain is intended to more effectively support team communication. Even though this research sought to identify the

dimensions of the concept of interoperability, it was still necessary to statistically validate the identified dimensions. In addition, it was important to identify the relationships between the dimensions of interoperability and other variables in order to explain organizational performance.

1.3.3. Need for a Model of Interoperable Communication Systems

Traditional design approaches emphasize the concept of cognition as a predictive model. *Goals, Operators, Methods, and Selection rules* (GOMS), *Task-Action Grammar* (TAG) and other task analysis techniques focus on how the individual action interacts with computer systems. However, in the public safety context, many tasks are situated within an intricate network of social interactions. These communication and collaboration tasks overlap and generally occur between people, machines/computers, artifacts, and organizations in the environment (Rogers & Ellis, 1994). In order to design a new communication system, it is necessary to first understand the relevant context, system functions and tasks, as well as the underlying communication structures that reflect static or improvisational relationships among people, teams, and organizations. As previously mentioned, interoperable communication systems would be highly advantageous in the public safety domain to more effectively support intra- and inter-agency operations.

The *Abstraction Hierarchy* (AH) approach is a useful way to model interoperable structures of communication systems. In addition to the structure, it is also important to identify the values of the communication system in terms of the criteria that should be used to measure communication system performance. This value perspective provides evaluation criteria that iteratively review the system purpose and completeness of general function levels. Complex public safety communication patterns that consider how each of the organizations involved in dealing with an incident also need to be modeled to support interoperability among agencies.

1.3.4. Design Framework for a New Communication System for Emergency Contexts

When new technologies are introduced, the number of design alternatives available to the designer increases. The designer then has more opportunities to improve the system and needs to optimize current practice as well as consider new possibilities that arise from implementing the new technology. Research on current practice is valuable but suffers from limitations that obscure

potentially valuable but as yet unexplored new ways of working. In addition, the result of descriptive studies shows a strong dependency on existing devices. To overcome this shortcoming, Vicente (1999) suggested a formative approach focused on intrinsic work constraints. The previously performed work on domain analysis, however, has mostly focused on system functionality rather than system properties or values. Particularly, when we consider human behaviors and organizations as an important design component, human values should be an axis of design direction. In terms of this perspective, Friedeman (1996) suggested value-sensitive design framework. In an interoperable communication system, values of the systems, such as interoperability, have been critical regardless to different operations and organizations.

Thus, there is a need to enhance the current work domain analysis to encompass a highly human value-oriented system. The model proposed in this study is expected to contribute a critical part of this design framework.

1.4. Scope of the Study

The main objective of this study was to provide a design framework for communication systems that support dynamic public safety work in different types of emergency situations. A design framework represents a design theory that is used as the basis for an effort to design and validate a technology. For the purpose of this study, the target collaborative group will be referred to in this dissertation as “the incident organization” and includes the police, EMS providers, firefighters, hazmat and any other federal agencies involved in dealing with an emergency. Although the needs of other agencies such as firefighters, hazmat and federal agencies were widely investigated through archival research, two agencies—the police and EMS—were exhaustively reviewed. Using data gathered from semi-structured interviews and a survey, this research sought to identify the patterns of communication within multiple agencies in real contexts.

This study focused primarily on the role of cognitive radio-enabled communication systems, although many other communication systems are also used by public safety organizations, such as internet-based communication, land-line telephone and WiFi-based communication. In particular,

the advanced cognitive radio technologies developed by Cognitive Wireless Technology at the Center for Wireless Technology (CWT²) at VT has the potential to significantly enhance communication capabilities (Le, Rondeau, & Bostian, 2007). This research provides a model of an interoperable communication system based on these capabilities.

1.5. Research Objectives and Questions

As stated previously, the primary goal of this study was to develop a new design framework for a communication system based on a new dynamic communication system model. To achieve this goal, it was important to first examine current communication patterns and identify plausible future patterns under different contexts. Also, this research proposes a novel model with multi-dimensional perspectives for interoperability in public safety communication systems. The proposed model is firmly based on our current understanding of communication and organizational structures. To review the characteristics of interoperability as an important property supporting inter-organizational decision processes, the concept of sensemaking was applied as a theoretical framework. Further, based on the proposed system model, new approaches were adopted in the design of an interoperable communication system. The proposed design framework ensures completeness, thus necessitating the introduction of novel interoperable communication system features. The objectives guiding this research were therefore as follows:

- Provide a greater understanding of the concept of interoperability in the context of public safety;
- Statistically validate the identified dimensions of interoperability;
- Identify the relationships between the concept of interoperability and other variables that are related to organizational structure and performance;
- Develop a model of an interoperable communication system, as described by the multi-dimensional perspectives, to overcome the task-artifact cycle effect;

- Determine how the proposed communication system supports the values of interoperable communication systems such as the concept of interoperability and overall performance; and
- Design a prototype of a new communication system based on the proposed model.

The following list shows the research questions associated with these objectives. Both a descriptive analysis and modeling exercise were performed to address the research problems in order to provide an in-depth exploration of the research objectives stated above.

RQ1: What is the concept of interoperability in the context of the public safety domain in terms of socio-cognitive aspects?

RQ2: Which relationships exist between and among the concept of interoperability and other variables to describe organizational structure and performance?

RQ3: How can communication systems intended to support interoperability be modeled?

RQ4: What types of design recommendations can be helpful in supporting dynamic communication groups more effectively?

Ultimately, this study aimed to provide a set of recommendations to guide the design of an effective communication system for dynamic situations that improves the task performance of public safety workers.

1.6. **Overview of Research Methodology**

The overarching goal of this research was to investigate the concepts of interoperability and develop a model based on newly identified interoperability concepts. This research goal was achieved through four main studies: 1) understanding the concept of interoperability in the context of the public safety domain, reviewing the properties of sensemaking, and developing an instrument to measure understanding in the work domain; 2) validating the instrument to measure the concept of interoperability and hence construct a model of interoperability; 3)

modeling an interoperable communication system based on a model of interoperability; and 4) reviewing and evaluating the model and prototype. For studies 1 and 2, a mixed method approach was used in which different but complementary data was collected (Creswell & Clark, 2007).

The first study identified dimensions of semantic interoperability in the public safety communication domain and elicited user requirements for the communication system to support interoperability in public safety contexts. Sensemaking was used as a framework to describe instances and themes from participants' responses. To address this goal, semi-structured interviews were employed to collect qualitative data in a phenomenological study. A phenomenological study is a unique qualitative research genre that explores the meaning of individual live experiences (Rossman & Rallis, 2003).

The second study involved the construction and validation of an instrument that could be used to measure interoperability and to highlight the interactions of interoperability with other variables. A survey was conducted to collect quantitative data. By combining the qualitative and quantitative approaches from studies 1 and 2, this research provided a better understanding of the research problems than each qualitative or quantitative research method could do alone.

The aim of the third study was to provide a model of an interoperable communication system based on a model of interoperability *per se*. A modeling framework was employed using Cognitive Work Analysis (Vicente, 1999). Based on this newly developed model of interoperable communication systems, a prototype of an interoperable public safety communication system was then produced.

The fourth study evaluated the proposed model and prototype and constructed a set of recommendations for interoperable communication systems. A focus group was convened to review the model and prototype. With the aid of an exit questionnaire, the usability and completeness of the proposed systems was evaluated. The overall methodology is shown in Figure 2.

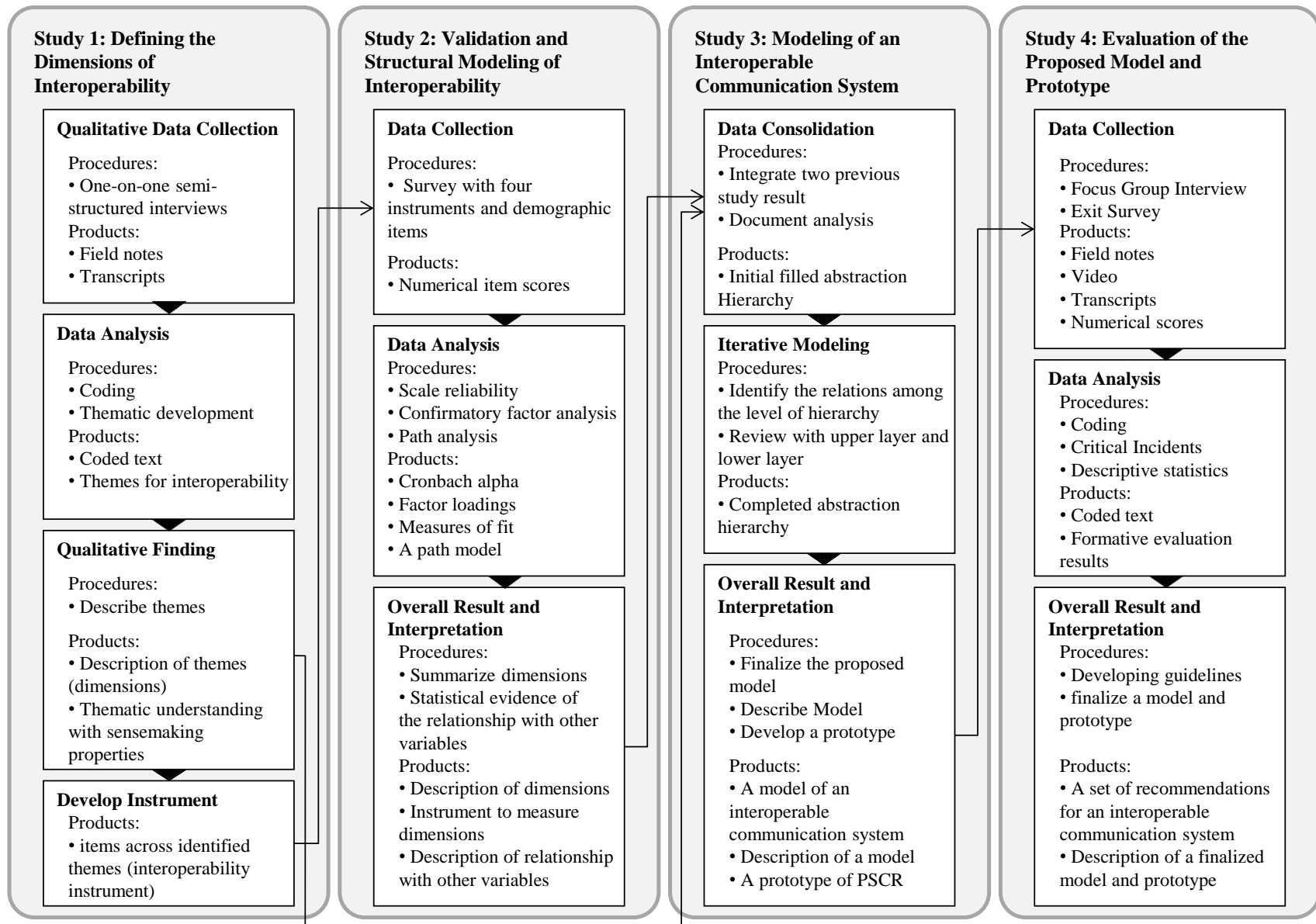


Figure 2. Overview of Research Methods

1.7. Summary of Outcomes and Contributions

This research effort contributed to the knowledge domain of designing and modeling communication systems as follows:

- Provided a description and discussion of the dimensions of interoperability in the context of public safety communications;
- Reconceptualized the dimensions of interoperability, applying seven properties of sensemaking as a theoretical framework;
- Validated the dimensions of interoperability with a comprehensive statistical analysis;
- Identified the relationships between interoperability and the organizational structural variables that affect organizational performance;
- Provided details and discussion of the systems perspective of interoperable communication systems and interoperability issues in knowledge representation at different system levels;
- Described and discussed the value perspective of interoperable communication systems. The lessons learned as a result will facilitate the expansion of the model to encompass other aspects of the Public Safety Cognitive Radio (PSCR) communication system;
- Described the application layers of PSCR communication systems in terms of a set of functional purposes, values, general functions, physical functions and physical forms;
- Developed a novel design framework based on theory that reflects the above mentioned model of the PSCR. This design framework will circumvent the task-artifact cycle through the adoption of the CWA framework. The proposed design framework also has the benefit of completeness to compensate for this otherwise descriptive approach;
- The development of a prototype PSCR interface. This interface demonstrates the operation of an interoperable system for public safety communications;
- The proposed model was validated and a usability evaluation conducted using the prototype. The validation process included a review of the values perspective in communication systems and an in-depth focus group interview to collect feedback related to the proposed system.

2. LITERATURE REVIEW

2.1. Overview of Literature Review

This literature review provides an in-depth understanding of the problem domains as well as the theoretical background related to this research effort. Personnel subsystems and technical subsystems will be discussed separately. The old Tavistock studies recommend that organizational aspects be considered in order to jointly optimize work systems when introducing new technologies. Hendrick and Kleiner (2001) emphasize that both personnel and technical subsystems should be analyzed when designing a sociotechnical system. In this context, the first part of the literature review will deal with what should be included in the model and takes into account the general characteristics of public safety organizations as well as technical availability issues. Understanding both the technical and personnel subsystems provides a set of constraints that are relevant to efforts to model interoperable communication systems.

As a major application domain, the emergency response system and structures of incident organizations are reviewed. The factors affecting team performance are an important consideration when communication systems are being designed. This part of the review therefore highlights the contribution of the dynamic team composition and cultural issues in the public safety domain. In addition, the review will look at the general characteristics of networking and network structure in terms of communication.

The second part of the literature review focuses on the technical subsystems. Interoperability issues are one of the biggest problems in current public safety communication systems, and these will be reviewed in terms of their technical aspects. Cognitive radio, as an enabling technology to solve the interoperability issues, will also be reviewed.

2.2. Personnel Subsystems

2.2.1. Emergency Response

Emergency situations require speedy and appropriate responses from a multi-organizational group of professionals from several different disciplines. Coordination and communication are dynamic processes among those involved, ranging from the two police officers who arrive first at the scene to the multiple organizations that then contribute, including hospital staff and volunteers. These public safety personnel must assess the incident, comprehend the situation, and project future events immediately (Endsley, 1997). When the incident is larger in scope, those processes tend to be less complete (Klein, 1989; Kristensen, Kyng, & Palen, 2006). Public safety personnel need to be able to make local decisions in the absence of a global assessment of a dynamic situation. Smaller-scale events are naturally easier to manage since their communication and tasks are limited within the organization. The larger and more critical the situation is, the more complex the collaboration. Emergency responders' work inevitably includes a combination of improvisation and standard procedures, depending on the situation (Quarantelli, 1997).

Major incidents require a multi-agency response in order to adequately address such problems as mass-traffic accidents, train and subway accidents, chemical spills and natural disasters. In the 1970s, there were several natural disasters in California that revealed significant weaknesses in the U.S. national incident management system. These weaknesses were found to be due to the following: (1) a lack of accountability, (2) poor communication, (3) the lack of a systematic planning process, (4) overloaded incident commanders, and (5) the lack of a method for integrating interagency requirements (Department of Homeland Security [DHS], 2004).

Accountability is defined as the ability to understand and consider incident contexts and incident personnel (DHS, 2004). Effective accountability at all organizational levels is critical. Moreover, individual functional areas during incident operations should be aware of the responsibilities of all participating agencies. In particular, the following principles in each category must be adhered to (DHS, 2004, p.12):

- *Check-In:* All responders, regardless of agency affiliation, must report in to receive an assignment in accordance with the procedures established by the incident commander;
- *Incident Action Plan:* Response operations must be directed and coordinated as outlined in the incident action plan;
- *Unity of Command:* Each individual involved in incident operations will be assigned to only one supervisor;
- *Span of Control:* Supervisors must be able to adequately supervise and control their subordinates, as well as communicate with and manage all resources under their supervision;
- *Resource Tracking:* Supervisors must record and report resource status changes as they occur.

Communication is the key to effective incident organization and has been shown to reduce the psychological distance between the members involved in the operation (Olson & Olson, 2000). For effective communication, information management and information sharing, the National Incident Management System has established and maintains a common operating picture and systems interoperability schema that provides a framework for the following:

- Formulating and disseminating indications and warnings;
- Formulating, executing and communicating operational decisions at an incident site, as well as between incident management entities among organizations;
- Preparing for potential requirements supporting incident management activities;
- Developing and maintaining overall awareness and understanding of an incident within and among functional agencies activities (DHS, 2004, p.49).

The planning process has been developed over several decades. To facilitate an effective planning process, the national incident management system provides an Incident Action Plan (IAP) template that guides the initial and collective planning activities of the incident management team. The planning process should provide the following:

- Current information that accurately describes the incident situation and resource status;

- Prediction of the probable course of events;
- Alternative strategies to attain critical incident objectives;
- An accurate, realistic, Incident Action Plan for the next operation period (DHS, 2004, p.97).

The high mental workload experienced by incident commanders is closely related to the characteristics of incident organizations such as span of control, task routineness, and information uncertainty. Since the integrated interagency requirements for public safety communication systems depend on the structure of incident organizations, the next section will review the general structures of incident organizations.

2.2.2. Organization and Team

a) Incident Organization

A team can be defined as two or more people working together adaptively and interdependently as a unit within a large organization to reach a specific common goal (Brannick & Prince, 1997). Even though multiple factors such as availability, functionality, and task objectives affect team composition, public safety incident organization is highly dependent on the precise nature of each individual emergency situation. In most cases, tasks are performed within a regular public safety organization such as a police, fire or EMS department. When dealing with emergencies, however, the team structure and organization can change depending on the time, location, and operation. Here, the operation refers to the temporal interaction at the incident site. The goals for emergency situations may emerge unexpectedly. In a normal operation such as a routine administrative task, this type of emergent characteristic, namely a spontaneous goal, is not likely to happen. The nature of the communication within a team in an emergency situation, however, differs from normal situations and is emergent, geographically distributed and abnormal in nature (Vicente, 1999). Usually, the incident command organizational structure develops in a top-down, modular structure based on the severity and complexity of the incident, as well as the degree of danger due to the environment (DHS, 2004).

In general, an incident organization is not correlated with the administrative structure of any single agency or organization. The individual serving as the head of a regular organization will not necessarily act as the incident commander when deployed at the emergency site. The Incident Command System (ICS) organization consists of four primary functional areas: operations, planning, logistics and finance, and administration. Table 1 shows a detailed description of each function.

Table 1. Incident Command System Organization (Adapted from DHS, 2004)

Functions	Description
	Directs and coordinates all incident tactical operations
	Is typically one of the first organizations to be assigned to the incident
The Operations Section	Expands from the bottom up
	Has the most incident resources
	May have Staging Areas and/or Labor Pools and other special organizations
The Planning Section	Variables impinging primarily from sources external to the team, but may include some internal to the team (e.g. team organization)
The Logistics Section	Variables inherent to the team itself
The Finance/Administration Section	Variables impinging from sources internal and external to the team

The ICS organizational structure is extensible to all the elements such as divisions, branches and sections depending on the type, size, scope and complexity of a given incident (DHS, 2004). Whenever the need arises, the incident organization can be composed of as many as four separate sections, all of which may have their own staff. Depending on the size of the incident, an individual sometimes manages all major functional areas, or a group within the organization can be assigned to perform a specific function.

b) Operation Section

In incident management, the role of the operations section is to manage a tactical operation at the incident site and mitigate the immediate hazards, save lives and property, control the situation, and attempt to restore a normal condition. People in an operation section are primary users of the radio communication system. Understanding the organizational structure of an operations section in this research is crucial to providing a set of effective design constraints for radio communication.

Although the operation section may be organized in many different ways depending on the situation, the primary organizational structure consists of the chief, branches, divisions, groups and resources.

c) Operations Section Chief

The operations section chief is responsible for managing all incident tactical operations. The operation section chief may have one or more deputies at his or her disposal, depending on the size of the incident. The operation section chief collects all relevant information from the deputies and communicates with all the tactical branch directors or supervisors in the division and group.

d) Operations Section: Divisions and Groups

When the size of an incident needs more resources than the Operations Section Chief can manage alone, divisions and groups are organized. Divisions can be defined as physical or geographical areas of operation within the incident area, whereas groups relate to the functional areas of operations for the incidents. Both divisions and groups can be organized in the context of a single incident. An example of a typical incident organization is shown in Figure 3.

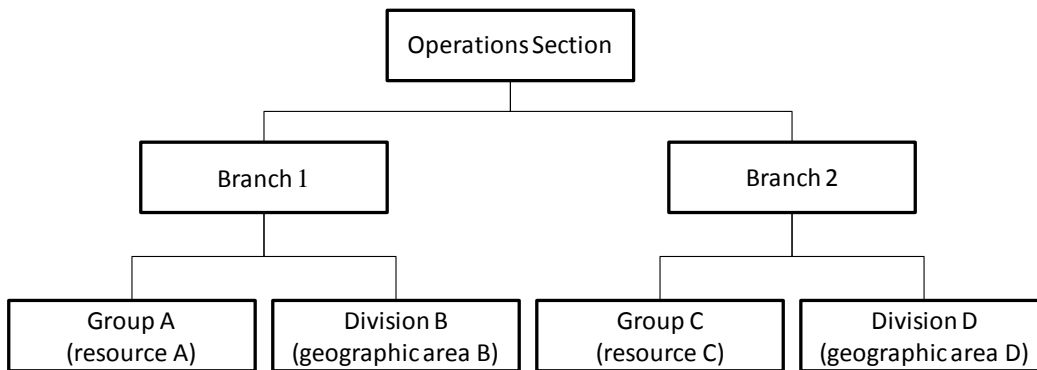


Figure 3. Divisions and Groups

A division can be created to mark out an area according to physical, geographical, or other prominent features. In the case of a football stadium, for example, the stands on each side of the field and the gates would be good criteria for establishing separate divisions. Based on the span of control, the appropriate size of the division would be decided by the Operations Section Chief. Figure 4 shows the organizational structure established as division-oriented operational sections.

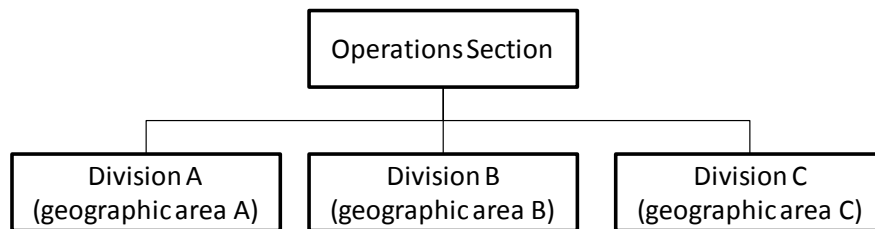


Figure 4. Use of Geographic Divisions

Functional groups may be established according to the functional needs in the operational section. Based on their functional purpose for the incident, a group can be created to deal with a particular aspect. Emergency medical services, an investigative group, and a suppression group are good examples of this sort. These can be assigned without any geographical limitations (see Figure 5).

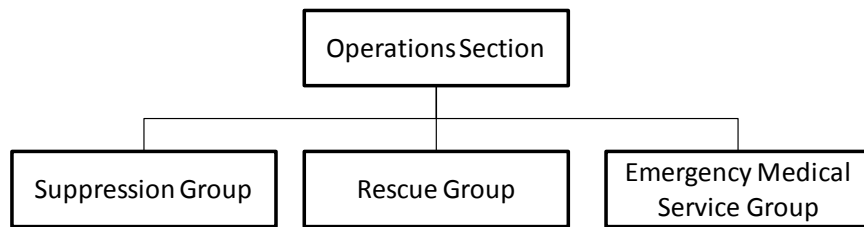


Figure 5. Use of Functional Groups

e) *Branches*

If an incident exceeds the span of control, the incident command system may establish a branch that comprises a number of divisions or groups. This will depend on the size and type of the incident. Branches can be separated either geographically or functionally. Some incidents involve multi-jurisdictional needs that require a combination of federal, state or county resources. In this case, a group such as the one shown in Figure 6 may be utilized.

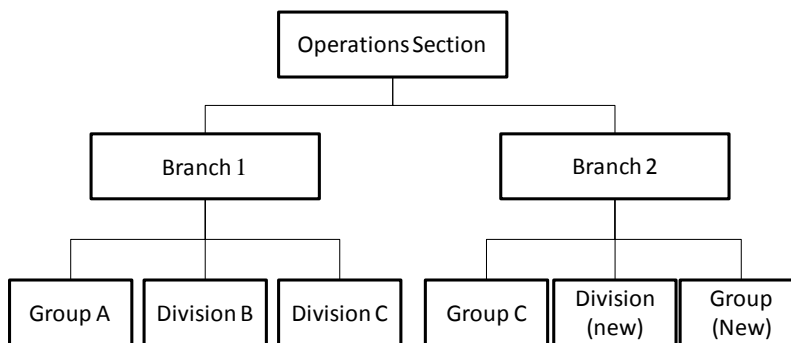


Figure 6. Two-Branch Organization

2.2.3. *Factors Related to Team Performance*

The initial response to most small incidents is typically handled by local emergency responders within a single organization. Effective emergency response requires working together at the team level within an organization or between different organizations. Although group

effectiveness is hard to define, Guzzo and Dickson (1996) listed the following criteria: (a) group-produced outputs (quantity or quality, speed, customer satisfaction, and so on), (b) the consequences a group has for its members, and (c) the enhancement of a team's capacity to perform effectively in the future. Another approach is to express team performance measures in terms of outcome vs. process. Although in general teams in industrial organizations are valued largely by their outcomes, an assessment based on outcomes is limited if there is no consideration of teamwork and work quality in the process (Brannick & Prince, 1997). As far as the public safety domain is concerned, the teamwork process is more critical in team performance measurement than the team's outcome(s) because the latter is less clear than in industrial organizations and tactical operational goals in emergency situations depend primarily on the team process. In order to function in demanding environmental conditions and perform their given tasks, teams require a wide range of knowledge, skills and attitudes (KSAs) which are called "team competencies" (Cannon-Bowers & Salas, 1997). In addition to team competencies, Paris, Salas, and Cannon-Bowers (2000) summarize a number of external and internal factors that influence team performance, namely contextual factors, structural factors, team design factors, process factors, and contingency factors, along with a set of applicable interventions. Table 2 shows the factors known to influence public safety team performance.

Table 2. Taxonomy and applicable interventions of variables influencing team performance (adapted from Paris et al., 2000)

Factor(s)	Description	Examples	Applicable intervention(s) for personnel subsystems	Applicable intervention(s) for technical subsystems
Contextual factors	Variables that pertain to the environment in which the team activity is embedded	Culture within an organization or among public safety group Climate within an organization Training/education systems Reward systems Information systems	Team selection in emergency situations Communication task design Training of communication procedures Training of cognitive architectures	Development of ontology for Identification of the context models based on the task situation
Structural factors	Variables impinging primarily from sources external to the team, but may include some internal to the team (e.g. team organization)	Physical environment Organizational arrangements Technological systems	Communication task design reflecting on organizational structure Training	Presentation of organizational structure, communicative group, and technical readiness
Team design factors	Variables inherent to the team itself	Work design Task interdependence Team size/composition Leadership	Team selection Task design Training	Displaying interface flows based on team task procedures Support communication inter- and intra team
Process factors	Variables inherent to the team itself and the way in which it functions	Boundary management Task cohesion Performance norms Communication Team interactions Potency/team self-efficacy Team spirit	Team selection Task design Training	Supporting customized communication boundary according to dynamic operational boundaries
Contingency factors	Variables impinging from sources internal and external to the team	Team application/mission Resource availability Procedural requirements Rules of operation, managing, or decision-making	Task design Training	Customizable and adaptable communication system for public safety events

2.2.4. Team Composition and Cultural Factors

Team composition is an important issue in a multi-agency operation. In practice, even if the importance of cooperation and collaboration is emphasized in public safety work, cultural diversity in an incident organization hampers working together. The composition of a diverse group can affect the following issues in public safety work:

- Problem-solving and the decision-making process;
- The development of status hierarchies;
- Patterns of participation and communication;
- The development of cohesiveness;
- The group's ability to perform and implement decisions (Jackson, 1996, p.55).

In the context of teams consisting of multiple public safety organizations, team composition can be a very important determinant of ability to respond effectively to a large-scale disaster. For example, in a mass-disaster such as Hurricane Katrina, instantaneous team composition can be a major problem. In the case of Katrina, numerous federal, state, and local agencies had to come together to respond to rescue and recovery needs and address the material damage caused by the hurricane and its aftermath. From the earliest stages, it was clear that the leadership of the Federal Emergency Management Agency (FEMA) was incapable of organizing a multi-organizational effort in a culturally diverse environment. In particular, even though there were some specialists belonging to non-governmental organizations involved, for example the Red Cross and the Salvation Army, working with the volunteers was very difficult because most of the volunteers were not trained when they joined the Katrina response effort and their regular organizational culture was different from that of the emergency organizations. Diversity affected short-term cooperation at the scene as well as the long-term recovery process for the victims. Hurricane Katrina revealed a timeworn, but still controversial, problem, namely the lack of integration of the emergency services.

In the past twenty years, the notion of organizational culture has provided important tools for understanding organizational behavior (O'Reilly, Chatman, & Caldwell, 1991). listed seven major factors that could be used to describe a firm's culture:

- *Innovation/Risk Taking*: Degree to which employees and the firm are encouraged to take risks and the degree of creativity involved;
- *Stability*: Predisposition to maintain the status quo;
- *Respect for people*: Management's emphasis on the effects of decision-making on people;
- *Outcome orientation*: Management's focus on results or outcomes as opposed to processes;
- *Attention to detail*: Expectations to display precision, analysis, detail, and specificity;
- *Team orientation*: The tendency to emphasize teamwork rather than individual work;
- *Aggressiveness*: The degree of competitiveness.

These characteristics are an outgrowth of Hofstede's famous five dimensions of national and regional cultures (Hofstede, 1983; Hofstede & Bond, 1984). In addition to providing a set of constraints for the communication practice, these characteristics offer another rationale as to why public safety personnel currently communicate with each other in the ways they do.

Stinchcomb and Ordaz (2007) compared the cultures of the two main emergency services, namely the police and fire services. Based on their investigation of work-related identity, person–environment fit (cultural alignment), and employer–employee reciprocity, they found that the two organizations have significantly different cultural characteristics, particularly with regard to group-orientation and organizational structure. Thus, understanding organizational culture in emergency operations is important for several reasons:

- Integrating and composing incident organizations;
- Organizing team operations in an emergency situation;
- Designing work procedures;
- Establishing communications protocols;
- Fostering cooperation.

2.2.5. Incident Organization as a Network Structure

The previous sections in this chapter examined the emergency organizational structures and the factors that affect the performance of organizations and teams. This section reviews the general concept of networking and network structures, which can explain the phenomena of networking issues within the public safety communication domain.

According to the Merriam Webster Dictionary, even though “network” can be defined several ways, the most relevant definitions are the following:

- an interconnected or interrelated chain, group, or system
- a usually informally interconnected group or association of persons (as friends or professional colleagues)

Networks are established when links among a number of people or teams become formalized (Keast, Mandell, Brown, & Woolcock, 2004). Networking is a more formal way of maintaining links with others who share the interests, needs or goals in a certain situation. For instance, a captain in the police force, a dispatch supervisor and an officer at a scene, must coordinate their efforts in order to achieve their shared objectives and their tactical goals. However, a network structure is different from a network *per se*; it arises from a strong need for cooperation. A network structure is formed when individuals or units working separately are insufficient and the individuals concerned realize that it may not be possible to solve problems or achieve goals independently (Gray, 1989). Although a network structure may include linkages, coordination or goal-oriented actions, it involves more than just these characteristics. It may be less formal than a network, but people in a network structure actively work together to solve the problem that they face (Mandell, 1999). For example, firefighters and EMS providers cooperate to save a life at a fire scene. In this case, although the personnel do not belong to the same organizations, they work together to address what they all recognize to be the problem. Network structures are distinguished from traditional organizational structures since there are no typical power structures and the authority or power only emerges based on the situation (Keast, et al., 2004). In this context, the emergent incident organization previously reviewed will be the best example of a network structure.

2.2.6. *Measures of Networks and Network Structure*

There has been considerable attention devoted to understanding networks and the development of appropriate metrics in the field of social networks. Three different types of analysis have been applied: Variable analysis, Typological analysis, and Network analysis (Scott, 2000). Social network analysis can be done with relational data, which shows connection, group attachment, and degree of gathering. In terms of public safety communications, this network analysis can reveal the relationships between agencies, grouping, and organizational structure as well as the process of communication itself. Papa and Papa (1992) suggest the use of two major network variables to measure communication network patterns:

- *Network Activity*: This can be measured by two indices—interaction frequency and network size;
- *Network Integrativeness*: This refers to the degree to which the members of an employee's personal communication network are linked to each other.

2.2.7. *Parameters of a Communication Model*

Under the concept of distributed cognition, Hutchins (1995) suggested a minimum of four parameters to describe the functioning of a communication system among a group of people. This approach is effectively an expansion of the behavior of a single constraint–satisfaction network, which is defined as “a network in which each unit represents a hypothesis of some sort (e.g., that a certain semantic feature, visual feature, or acoustic feature is present in the input) and in which each connection represents constraints among the hypotheses” (Rumelhart, Smolensky, McClelland, & Hinton, 1986). Philosophically, this concept comes from connectionism, which considers thought or human behavioral phenomena to be an emergent process of interconnected networks of simple units. Hutchins likened a human network to a constraint–satisfaction network. In this context, Hutchins (1995) suggested communication parameters in a human network should be understood as follows:

- Pattern of interconnections among the nets in the community;
- Pattern of interconnectivity among the unit of communicating nets;
- Strength of connections between nets that communicate;

- Time course of communication.

In public safety communications, it is vital to understand these parameters in order to identify the characteristics of a network and elicit the intrinsic requirements for a new communication system design.

2.3. Technical Subsystems

2.3.1. *Need For Interoperability*

From the Columbine High School massacre and Hurricane Katrina, to the 2007 massacre at Virginia Tech, many news media and official reports on those disasters have indicated the lack of interoperability among the relevant agencies. As mentioned in the introduction, interoperability is generally discussed in terms of technical issues and there have been many conferences on interoperability among the various public safety entities in recent years. The United States Congress has stated its intention to resolve the interoperability issues that have been so evident in national disasters as the tragedy of the 9/11 attacks (House Committee, 2004).

2.3.2. *Definitions of Interoperability*

Interoperability means different things to different people. Enterprise information systems, communication systems, and military operations all have different expectations for interoperability, for example. However, in the context of communication systems it is closely related to technical issues that apply to specific types of hardware or systems. The Alliance for Telecommunication Industry Solutions (ATIS) defines interoperability in five different ways (ATIS, 2007):

1. The ability of systems, units or forces to provide services to and accept services from other systems, units, or forces and to use the services so exchanged to enable them to operate effectively together;

2. The condition achieved among communications-electronics systems or items of communications-electronics equipment when information or services can be exchanged directly and satisfactorily between them and/or their users. The degree of interoperability should be defined when referring to specific cases;
3. The state of affairs which allows applications executing on separate hardware platforms, or in multi-processing environments on the same platform, to share data and cooperate in processing it through communications mechanisms such as remote procedure calls, transparent file access, etc.;
4. The ability of a set of modeling and simulation processes to provide services to and accept services from other modeling and simulation activities, and to enable the services to operate effectively together;
5. The capability to provide useful and cost-effective interchange of electronic data among agencies, e.g., different signal formats, transmission media, applications, or performance levels.

ATIS developed these definitions for the American National Standard Institute (ANSI), who set the communication system standards for the United States and they replace ANSI T1.523, the previous version of these definitions. The International Organization for Standardization (ISO) (ISO/IEC 2382-01), the Institute for Electrical and Electronics Engineering (IEEE) (IEEE Standard Computer Dictionary: Interoperability) and the Federal Communication Commission (FCC) (FCC 1307C) have all adopted standards that are identical to the ANSI guidelines. To ensure interoperability, there are three main principles governing the performance of an interoperable radio communication system:

- *Same operating parameters*: the radio communication system should have appropriate transmitting/receiving frequencies, modulation format and other parameters to support interoperable communication;
- *Adequate signal coverage*: the power of the radio should cover the operational region where the incident organization works to solve tactical problems.

- *Scalability*: The communication network should be scalable, which means the communication network can span to any size based on the span of control or the size of the incident.

In addition to these principles, a workable interoperable network requires that gateway functions be supported (FCC, 2009), thereby not only bridging the member radio networks, but also providing an interface with the internet and other wide area networks.

Beyond this technical definition, the limitations of the current concept of interoperability were identified by an ethnographic study (Imran & Smith-Jackson, 2005). Thus, there is a strong need to reconceptualize interoperability in terms of the organizational and operational aspects in order to enhance cognitive radio capabilities in the public safety domain. The new approach to interoperability should therefore support information exchange procedures among the agencies, as well as the decision making process. Consequently, the human factor aspect of interoperability is emphasized in the next step of this study.

2.3.3. *Cognitive Radio*

The Department of Homeland Security (DHS) announced the first national emergency communication plan in July 2008. Their report enumerated current efforts for future interoperable communication systems, including the establishment of communication and technology standards and the development of new technologies. Towards this goal, the Association of Public-Safety Communications Officials (APCO), the National Association of State Technology Directors (NASTD), and the Telecommunications Industry Association (TIA) are currently building a set of communication standards that incorporates the standards adopted by the digital Land Mobile Radio (LMR)-Project 25 and the Emergency Data Exchange Language and Common Air Interface. In addition to these efforts, the Office for Interoperability and Compatibility (OIC) has established the SAFECOM program to support the research, development and evaluation of communication related technology to support interoperability. Through the OIC, the Department of Homeland Security, the Department of Defense and the Department of Justice have organized several projects to develop new technologies such as Voice over Internet Protocol, Vocoder, Software Defined Radio, and Cognitive Radio technology.

Cognitive Radio is generally defined as a technology that, in principle, is capable of sensing every possible observable parameter and processing the data to meet user needs (Mitola & Maguire, 1999). Cognitive Radio technology is expected to be the new enabling technology that will ensure interoperability. For example, CWT² has developed core cognitive radio technologies as its contribution to the CommTech program of the National Institute of Justice. Ultimately, cognitive radio technology will contain many capabilities beyond spectrum sensing, accessing the currently available spectrum, reconfiguration and gateway functions.

Virginia Tech's CWT² system incorporates environmental awareness mechanisms in its cognitive architecture. In the context of environment awareness, this research group defines three main domains: the user domain, the policy domain, and the security domain (Figure 7). More specifically, the user domain is defined as "both the operation preferences and performance requirements of both the service provider and end user. It encapsulates performance optimization objectives like access availability, service type, and service quality. A CR needs to understand the QoS requirements and adapt to meet them" (Le et al., 2007, p.1041). However, although the VT CWT² describes environmental awareness as "understanding required information and developing the ability to sense the environment" (Le et al., 2007, p.1041), their user domain does not yet adequately reflect work-related situational issues.

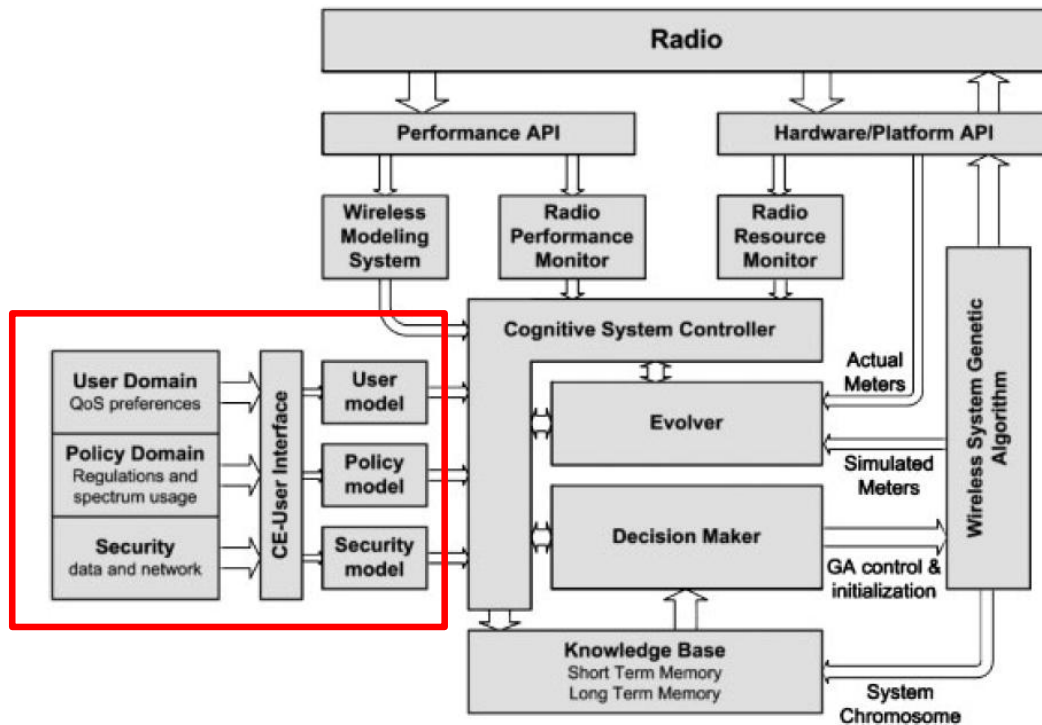


Figure 7. A Cognitive Architecture Model of the Cognitive Radio (adapted from Le et al., 2007)

Nolan (2005) took a different approach, subdividing external input data into five domain categories, namely environmental, radio, user, social, and policy. In terms of work-related situations, three domains are of particular interest here:

- Environmental Domain: local internal and external sensing, location-awareness;
- User Domain: number of users/devices, abilities, requirements, patterns, forecast of requirements, Man-Machine Interface (MMI) complexity;
- Social Domain: collaboration, marketing and payment models.

2.3.4. The Measures and Evaluations of Communication Systems

In the previous section, suitable measures and metrics for characterizing and evaluating networks and network structures were identified. Communication systems are tools that are used to connect

people or groups and form networks and network structures. While the metrics of network structure delineate the topological or organizational characteristics of a network and the network structure, the metrics of a communication system are closely related to the performance of the system. A great deal of research has thus focused on the evaluation framework in accordance with group and organizational issues (Jarvenpaa & Leidner, 1999; Olson & Olson, 2002; Olson & Teasley, 1996). In general, the performance or effectiveness of a collaborative work system can be influenced by individual and group characteristics, situational factors, task properties, and task processes. Concept-oriented evaluation frameworks describe how the system can be measured by conceptual attributes such as effectiveness, awareness and trust (Neale, Carroll, & Rosson, 2004). Olson and Olson (2002) suggest the use of four main concepts to evaluate computer-aided collaborative work systems:

Common Ground: Common ground can be defined as the extent to which the participants are mutually aware of the knowledge that the participants have in common (Olson & Olson, 2002). This is not just shared knowledge of communication topics, but also knowledge that the participants have about their interlocutors. Effective communication among people or agencies requires that the communicative exchange take place at some level of common ground (Clark, 1996; Kraut, Fussell, & Siegel, 2003).

Work Coupling: Olson and Olson (2002) defined the concept of work coupling as the extent and kind of communication required by the task. Tightly coupled work is work that strongly depends on the cooperation of the participants, whereas loosely coupled work is work that is less interactive but still needs some level of collaboration.

Collaboration Readiness: This concept refers to the willingness of the participants to share information concerning the work at hand (Olson & Olson 2002). Typically, the collaboration occurs in different fields, organizations and work settings. This willingness to share will impinge on the effectiveness of the communication system.

Technology Readiness: Technical systems may affect work structures and the procedure adopted to perform the work. The current practice of collaboration could be affected by technical

limitations. The adoption of appropriate technology can enhance collaborative and cooperative work performance.

2.4. Summary of Literature Review

Public safety communication systems are indispensable in dealing with emergency situations. As new technologies have been introduced, communication practices and incident organizational structures have both changed to maximize the capabilities of these new technologies. Public safety communication systems depend on both organizational and technological constraints. This section therefore looked at general incident organizational structures and technical issues related to communication systems in the public safety domain. Based on the results of this literature review, a theoretical framework based on sensemaking was adopted for this research in order to refine the concept of interoperability. The review also showed that work domain analysis is a useful tool with which to model an interoperable communication system.

As shown in the first section of this chapter, Incident Command System (ICS) organizations vary greatly depending on the types of operations. The literature reveals that there are various forms of sub-organization in the ICS organizations. A division can be created to delineate an area according to physical and location separations of terrain or other prominent features. Functional groups may then be established according to the functional needs in the operational section. If there is an incident that exceeds the span of control, the incident command system can establish a branch that is composed of a number of divisions or groups. As a primitive unit, an emergency team will be formed and managed by a higher level of authority. In general, workers in the public safety domain are highly stressed and often need to make time and life-critical decisions. Communication is one of the most important factors governing incident organizational performance.

Interoperability has become a core concept in the public safety domain, primarily as a result of the increased number of multiple jurisdictional operations. Cognitive radio technology has emerged within the past decade as an enabling technology to support interoperability in various areas. While most research has focused on the technical aspects of interoperability, the need to

understand semantic interoperability in the public safety domain has recently begun to be more widely appreciated and this aspect will provide the focus for the research reported in the remainder of this dissertation.

3. SOCIO-COGNITIVE ASPECTS OF INTEROPERABILITY: UNDERSTANDING PUBLIC SAFETY COMMUNICATION TASK ENVIRONMENTS

Abstract. Emergency Communication Systems are a key element in collaborations among different public safety organizations. The need for interoperability in emergency communication systems has hastened the development of cognitive radio technology. However, even if a cognitive radio system satisfies the technical aspects involved in interconnecting participating agencies, organizational issues remain an issue due to the need to include different individuals, different working contexts and cooperative work. This chapter examines the socio-cognitive dimensions of interoperability, which equal the technical dimensions of the problem in importance. The existential-phenomenological study reported here used semi-structured interviews to reconceptualize interoperability in the public safety communication domain. Based on the interviews, five important factors were identified that have a major impact on the effectiveness of interoperable groups. First, information sharedness is problematic for asymmetry of information, overload, and synchronicity among agencies. Second, Operational awareness describes how public safety workers identify the scope of operation and organization. Third, communication readiness is about willingness to share and technical readiness. Forth, adaptiveness characterizes self-organization in Incident Command Systems as well as technical adaptability. Finally, coupledness illustrates highly distributed decision making processes and tentative coupling in terms of functions and procedures in an operation. Based on these main concepts, high-level suggestions are provided to guide the design of a new public safety communication system.

3.1. Introduction

Public Safety Emergency Response Service (PSERS) tasks must function using highly complex communication systems, including computer-aided dispatch systems, handheld diagnostic tools, GPS, radios, and mobile data terminals. Since the introduction of cognitive radio, it is now possible to imagine the possibility of seamless communication or interoperability. However, those designing technologies to facilitate communication must still overcome major challenges due to the complexity of the work environment and organization-specific communication needs. Interoperability has become a critical concept supporting cooperation within a team or between different agencies in large operations such as unexpected simultaneous incidents, crowd control at a massive public event, or a natural disaster.

Employing new communication technologies such as cognitive radio has led to considerable improvements and ensured technical interoperability among devices on the frequencies reserved for public safety agencies (Mitola III & Maguire Jr, 1999; Smith & Tolman, 2000). Even though technical interoperability issues can be resolved by applying new technology, there remain a significant number of operational interoperability issues (Department of Homeland Security [DHS], 2006; Smith & Tolman, 2000).

The main purpose of this study was to reconceptualize interoperability to support the socio-cognitive aspects of communications between Police and Emergency Medical Service (EMS) providers. The socio-cognitive perspective when applied to Police and EMS focuses on the interdependences within social groups and the means by which these groups receive, process, and transmit information to make decisions. In particular this study was expected to: 1) gain a better understanding of the public safety domain and their responses in emergency situations, 2) identify dimensions of the concept of interoperability among agencies, 3) develop a measurement for interoperability, and 4) frame the concepts of interoperability in terms of the seven properties of sensemaking. To address these issues, a series of interviews were conducted with local police and Virginia Tech (VT) EMS providers. Content analysis revealed five dimensions that explained the concept of semantic interoperability and led to a series of

suggestions for designing better public safety communication systems that incorporated cognitive radio technology.

3.2. **Methods**

3.2.1. *Semi-Structured Interview: Existential-Phenomenological Approach*

Interviews, especially semi-structured interviews, are a key technique for knowledge acquisition. The semi-structured interviews conducted for this study combined a structured agenda under three scenarios, with the flexibility to ask follow-up questions. Structured questions guide the boundaries of a topic, while open-ended questions are posed to the participant based on their responses to previous questions. Here, the interviewer sought to acquire a deep understanding of a personal experience and how each participant (first responder) explained these experiences. Researchers engaged in this type of phenomenological research generally focus on the in-depth meaning of participants' reflections and dialogues, which reveal the essence of the experience (Rossman & Rallis, 2003). Holstein and Gubrium (1994) regarded language as the primary symbol system through which meaning is both constructed and conveyed in a phenomenological study. Since phenomenology as a philosophy assumes that perception is highly related to the object perceived and the object of experience affects human epistemology, the interview was chosen as a good method to holistically understand the essence of public safety workers' experience in context-specific settings (Thompson, Locander, & Pollio, 1989). This research was an exploratory study that identified appropriate measures for interoperability and refined the concepts of interoperability in terms of the properties of sensemaking. It was therefore important to understand the main contexts as well as the current practices in emergency communication and to address this, the narrative research explored the story of certain individuals. Each interview session lasted around one and half hours, and 15-20 questions were typically asked. Since the scenarios that were dealt with in the interview could be too sensitive to be recorded, at least two interviewers took notes at each interview to ensure accuracy, anonymity and confidentiality. No one other than the researchers was aware of the identities of those who took

part in the interview process. In addition, the researcher assured the participants that they could stop at any time if they began to feel uncomfortable during the interview.

3.2.2. *Semi-Structured Interview Questionnaire*

When designing the questions for an interview, two important issues should be considered (Milton, 2002):

- The general research issues of self-understanding and self-change;
- The aim of developing various ways of representing people's knowledge in order to both analyse the interviews and use in subsequent techniques.

The first issue was to elicit the participants' views on their tasks and situations, what limitations there were on each of them, and how they interacted. In the context of the public safety domain, participants' experience with public safety events and their communication in such situations was examined. Participants' understanding and how they adapted to situations reflected their individual perspectives about current practice and the technology they used in the work domain. A descriptive approach was important in order to review the current practice and explain how it functions in a real situation, where events do not always proceed as expected. To account for the second issue, this study designed the interview in such a way that it would elicit both event-based and belief-based knowledge (Milton, 2002). Thus, large-scale questionnaires such as the biographical inventory should contain the following parts (De Waele & Harré, 1979):

- Microsociological framework;
- Time perspective;
- Social ecology;
- Socioeconomic living conditions;
- Social psychological life-patterns;
- Family and groups;
- Cultural patterns of values, norms, expectations, and roles;
- The institutional situation;
- Individual characteristics: self and personality;

- Self-description and interpretations;
- Interests, occupational and leisure-time activities;
- Goals, aspirations, and conflicts.

To address these issues, a pilot study was conducted to develop the interview scenarios. The preliminary interview provided information regarding how the participants understood the communication system to operate, which aspects of events could be reviewed during the interview, and a glossary of technical vocabulary used in the work context. This effort provided an equal or quasi-equal understanding of the work between the interviewee and the interviewer, as well as some level of completeness of the interview questionnaires in which the main topics were singled out for further exploration. The main topics raised in the interview are shown in Table 3. Although these categories were not exhaustive, they provided a good basis for the semi-structured interview used in this study.

Table 3. Main Topics for Semi-Structured Interview

Categories	Topics
Operational Aspects	Dispatching Operating Settling Other emergency response procedures Barriers of the individual/group in the working context
Informational Aspects	Information needs in terms of the types of incident Presentation of information Input methods of information
Technological Aspects	Limitation of current technology during given tasks Appropriateness of technology at each communication situation Identification of the failure and recovery of system Adaptation at the specific situation with technology Usage pattern of the technology
Organizational Aspects	Characteristics of incident organizations Role allocation within the division/group/branch/organization Collaboration and coordination within the organization Structure and size of the organization

Another issue was the situatedness of the interview. The main claims of situated cognition are that human knowledge is not isolated from a situation or the contexts in which it is experienced. Their perceptions, thoughts about their actions, and the actions themselves are closely related to and interact with their environments (Clancey, 1997). Since appropriate scenarios could evoke situation-specific knowledge, three different scenarios were developed based on the preliminary interviews. These three different scenarios represented different working contexts, namely day-to-day, taskforce, and mutual aid situations, as specified by the Public Safety Wireless Advisory Committee (PSWAC) (Irving, 1996). Based on each scenario, the above-mentioned aspects for specific operations were reviewed. These scenarios are described in Appendix A.

3.2.3. Recruitment

In this research, the main sampling strategy was purposeful sampling, which is defined as intentionally selecting participants who are specifically related to the event, process or technological issues of the main topic (Patten, 2002; Rossman & Rallis, 2003). In particular, the criterion sampling method was adopted here. Criterion sampling involves selecting cases that meet some predetermined criterion of importance (Patton, 2002, p.238). Criterion sampling is particularly useful for identifying and understanding cases that are information rich (Robert Wood Johnson Foundation [RWJF], 2009). The main criteria of the selection were as follows:

- Participants should be familiar with public safety communication systems (at least one year working experience with portable communication systems);
- Participants should be either a police officer or have some experience with police tasks, OR
- Participants should be either medical emergency service providers or have some experience with the emergency medical service tasks, OR
- Participants should have experience with a large-scale disaster or emergency operation (at least one year working experience at a local judicial organization or EMS); In addition,
- At least one participant with experience as an incident commander;
- One of the participants should have experience as an emergency dispatcher.

Based upon the above criteria, regional judicial organizations, or emergency medical service providers were contacted. Both the telephone and email were utilized as the primary methods for recruiting participants.

Many researchers (Crabtree et.al, 1993; Kuzel, 1992) recommend that the total number of participants in studies of this type should be six to eight in order to achieve maximum variation. This study therefore recruited 11 participants from the Virginia Tech Police Department and the VT Rescue Squad.

3.2.4. Interview Procedure

The interviews were conducted between June 2007 and July 2008 with members of the VT Police Department and the VT Rescue Squad who had sufficient experience in all the different types of operations of interest: day-to-day, taskforce, and mutual-aid. Before starting the interview, the researcher briefly introduced the objectives and summarized this research and explained how confidentiality and anonymity would be ensured. The participant was then asked to read and sign the informed consent document for the interview (Appendix D). Once the participant had completed the form, the interviewer introduced three different scenarios and scenario-relevant questions related to (a) a football game day, (b) a fire in a large shopping mall, and (c) a case of alcohol poisoning (Appendix A).

The session began with a short introduction to the PSCR and its proposed uses. The primary method for knowledge elicitation was the Sensemaking Critical Incident Method (SCIM) developed by Klein, Moon, and Hoffman (2006). This interview method focuses on eliciting information regarding a critical incident where the interviewee experienced some surprise or a growing sense of doubt with respect to how those involved in the incident had understood the situation. The interviewer asked about the participant's familiarity with the scenarios provided. In the context of the provided scenarios, the participants were asked to describe a surprise or violated expectancy and their subsequent information seeking activity. Relative to the specific event in the scenario, they were asked how they prepared in order to recover situation awareness. Based on their responses, additional probe questions were used to explore the information sources, information exchange with current communication systems and face-to-face

communications, and information integration would be utilized by the participant to assess the given problems. The interview continued until the technical issues related to effective sensemaking had been identified, as well as any procedural problems in communications, and the alternatives currently available for effective communications and to overcome barriers to sensemaking.

After reviewing all the scenarios, the participants were asked if they had any kind of wish list for their communication practices. The participants were asked to discuss what an “ideal” radio / communication device would be like, given the situation, with “ideal” meaning a usable, effective, efficient and satisfactory device in their work context. They were also asked to draw upon previous experiences related to informational, operational, technological, and organizational issues. All questions were open-ended and explored the participants’ in-depth experience based on their prior responses.

At the end of the interview, the participants were given the opportunity to review sessions about the interview or cognitive radio technology. All interviews were recorded by hand to ensure confidentiality. This also provided a more comfortable environment for the participants. Each interview lasted until the point of theoretical saturation was reached (Glaser & Strauss, 1967; Lindlof, 1995), generally after about one and half hours.

3.2.5. Content Analysis

In line with a Grounded Theory approach (Charmaz, 1995; Glaser & Strauss, 1967), two independent coders reviewed the data with no pre-assumptions concerning the results, as recommended by Thompson et al. (1989). Atlas.ti (Ver. 5.5) for initial review, Microsoft Word 2007 and Microsoft Excel 2007 were used as another analytic tools. The analytic procedures were based on Miles and Huberman’s (1994) suggestions for encoding qualitative data. First, the coders carefully read the transcripts to obtain the overall flavor of the interviewees’ responses. During the reading of the transcripts, each coder inserted codes as labels in appropriate places (Figure 8).

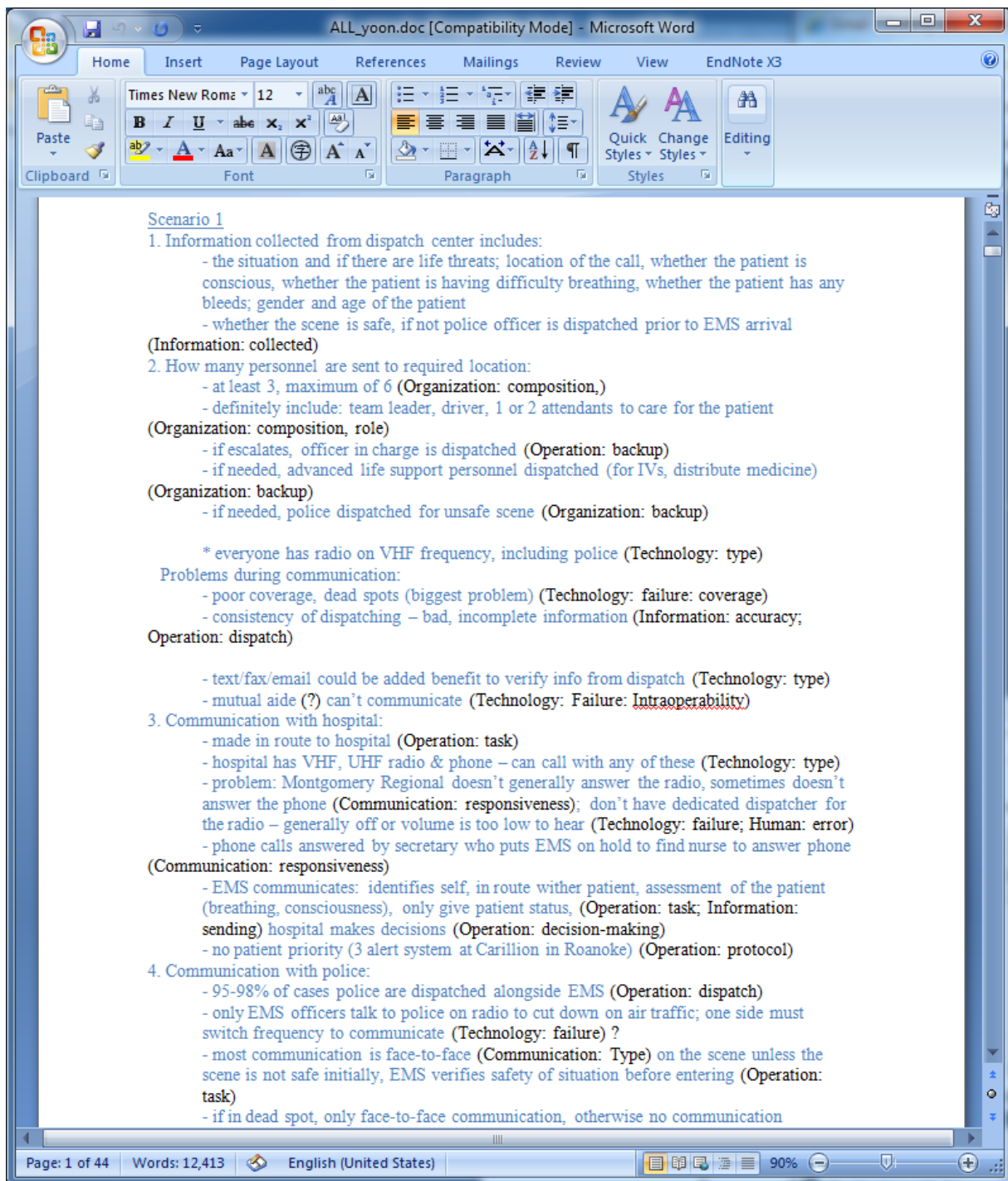


Figure 8. Screenshot of coding

From these labels, each analyst developed a general category scheme of the participants' responses. For the second phase of analysis, the coders tried to identify the themes from the identified

categories and sub categories. The categorization reflected the similarity of responses and frequency of responses (Myers & Oetzel, 2003). At least half the participants will have to identify an initial theme if it can be included. The analysts will identify themes based on the concepts as follows:

- Themes are an expression of focus, of meaning of points;
- Theme formulations are at best a simplification;
- Themes are not objects one encounters at certain points or moments in a text;
- Themes are a form of capturing a phenomenon one is trying to understand (Van Manen, 1990, p. 87).

Finally, the coders had a review session to reread the responses and identify themes to ensure goodness of fit. After all steps had been completed, the researcher determined which of the themes used to describe the concept of interoperability adequately reflected the responses provided by the participants.

3.3. **Results**

First, in accordance with the study objectives this study identified a set of themes that could be used to explain the concept of interoperability in the context of public safety communications. These themes were related to the collaboration and coordination required for effective team communications. Table 4 shows the codes used in this analysis and their description; note that the codes emerged from the interviews.

Table 4. Identified Themes

Themes	Sub-Themes	Description
Information sharedness	Information asymmetry	Existing differences of information among stakeholders
	Information overload	Difficulties in decision making caused by too much information
	Communication synchronicity	The experience of two or more communications occurring simultaneously and degree of sharing of the information at the same time
Communication Readiness	Technical readiness	Trouble with hand-held radios or other equipment due to hardware problems
	Willingness to share	Attitude to sharing collected information with other people at the same operation
Operational (group, team, network) awareness	Dynamic operational boundaries	Ability to change the operational boundaries depending on the emergency situation
	Social awareness	Knowing the person who has the right information and being aware of the existence of the right person
	Copresence	The sense of being together or awareness of the involvement of a remotely located person
Adaptiveness	Self-organization	Emerging and self-formed organization without any previous structure
	Technical adaptability	Existing alternatives or option to modify current technology to communicate with each other
Coupledness	Work coupling	Degree of functional and sequential relationship of task or work
	Distributed decision-making/Duality of centralization	Degree of centralization of decision making or relationships among decision makers

3.3.1. Information sharedness

a) Information Asymmetry

Information asymmetry was prevalent in the interaction between the dispatcher and workers at the scene. They wanted to transfer what they knew. Most participants who were working at incidents complained that they experienced insufficient information regarding the incident that they were involved in due to a lack of communication capability. The dispatcher sometimes provided only part of the information available or the participants had not memorized all the information transferred from the dispatcher. Consistency of dispatching was important in gaining a better understanding of the situation. Human errors occurred frequently, in spite of the VT dispatchers having a list of 100 common terms to support consistency when explaining situations. Since the VT police dispatchers were not trained as emergency medical dispatchers, they had some limitations when trying to obtain accurate information (the VT police dispatch center dispatched VT Police, VTRS and the Blacksburg Fire Department). This issue was also mentioned in a previous study that focused on interoperability in police communication (Kwon et al, 2009). To make matters worse, sometimes the dispatchers failed to realize the importance of collecting information. Also, they did not always ask for important information since each agency had its own perspective of the same incident. Another information asymmetry existed in the communication between emergency service providers and hospitals. Perceptions and comprehension of the situation was different at each place, which led to different prognoses for the next task.

b) Information Overload

In general, individuals, including experienced police and EMS providers, under information overload cannot absorb all the required information and sometimes make vital mistakes when performing their primary task due to missing important information. For example, a field test for interoperability was conducted at the interoperability gateway on campus using the ACU 1000 Model at a VT home football game in 2007. The interviewees mentioned that test was

unsuccessful due to excessive radio traffic and information overload. Many agents had turned off their radio systems since they were continually distracted by hearing information irrelevant to their situation. It is not uncommon for operators to eliminate stimuli in their environment, especially when the stimuli are overloading their ability to process information.

c) Communication Synchronicity

One of the main roles of public safety communication is to synchronize and share information with other team members. In an emergency operation, they need to be able to communicate with each other at the same time and to share the same understanding of the operation, which were the characteristics of the public communication systems initially designed and developed to support real time synchronicity. However, interviewees suggested that there was a need to asynchronously refer to information. Especially in non-emergency situations such as administrative communications, they wanted to receive the information via text messages. A VT police officer mentioned that many communications were initiated to confirm past communications since their handheld communication devices did not have a function to store their communication history. Since their working situation is time-critical and very stressful, they sometimes miss information and also suffer from information overload. Another issue in synchronicity is prioritizing information. Public safety workers received all their information through the communication systems in real time because their communication systems were synchronized. If multiple incidents occurred simultaneously, the ability to receive only relevant information is critical to prevent information overload, as previously mentioned. Thus, in addition to considering the importance of information, the degree of synchronicity needs to be optimized.

3.3.2. Communication Readiness

a) Technical Readiness

The pattern of public safety communication is highly associated with the communication infrastructure and devices used. The interviewees commented that they usually carry two more communication devices when on duty, for examples mobile phones, Nextel, and police or EMS

radios. Each device is used for a specific purpose. Their official communication tool is, of course, their radio and in most cases, their communications is conducted wholly within the organization that they belong to. However, if they do need to collaborate with a different organization, the communication is usually done through a dispatch center due to the technical limitations that hamper direct communications. For example, Blacksburg EMS and Blacksburg police use different frequency bands so their communication systems are not compatible even though they frequently collaborate with each other. Consequently, they usually prepare cache radio systems to communicate with other organizations involved in an incident.

Moreover, the use of alternative communication devices is sometimes related to privacy issues. The regular communication system can be scanned by the public, so EMS sometime use a mobile phone for sensitive medical information. There are also practical reasons to use alternative forms of communication; if there is a blind spot or a partner does not respond through regular the communication network, public safety workers usually use a personal communication device such as a cellular phone. In addition, for less formal communications they frequently use their cellular phone for privacy because their formal communication is automatically recorded at the dispatch station when they communicate with each other.

b) Willingness to share

Every organization has its own culture. During the interview, police and EMS showed different attitudes to sharing information. One police interviewee commented that sharing information was not easy since it was related to responsibility. For example, the dispatch center collects all the information provided by callers who could be the victim or a friend of the victim. They often provide very sensitive information, raising privacy issues. Thus, sometimes, police hesitate to share all their information with other organizations. Similarly, EMS also deal with highly sensitive medical information that is very personal and are thus reluctant to share it with others. On the other hand, for some emergency cases, agile sharing of information is critical since it may well be related to safety issues. Responders therefore prefer to use both private and public modes to share information and maintain organizational responsibility. Thus, a permission function regarding sharing information would be necessary.

3.3.3. Operational (group, team, network) awareness

a) Dynamic Operational Boundaries

Operational boundaries are often flexible based on contextual information. For example, on a football game day, when some 65,000 people gather at the same location, the public safety team is in charge of allocated sections. As usual, their operational boundary is defined by geographical constraints. However, if a large incident should occur, the operational boundary would change dynamically. In the case of multiple incidents at the same approximate location, police officers could be overloaded with the communication they are sending and receiving. Most of this information might be irrelevant or less important. In this case, it is necessary to assign different networks for each incident to avoid information-overload. In the event of an emergency case, these officers operate more than two tactical channels simultaneously. However, sharing the information provided by the tactical channels with other relevant personnel often becomes problematic. There are many usability problems involved in changing communication channels and identifying which channel a particular officer is on. Thus, if the officer has certain operational information, for example the geographical boundary, the number of people involved and the name of the appropriate channel, it may help them to be aware of their current boundary of operation.

b) Social awareness

Unlike structured collaborations occurring in regular organizations, public safety work is intrinsically based on local and emergent organizations. Thus, it is necessary to maximize the potential advantages of being 'local'. There is a reason for public safety personnel to be at a certain place, and this physical presence indicates more than just the fact of a person being there. Thus, the study participants suggested that knowing the identity and the expertise of the person at the scene would be very helpful when collaborating with each other. If the person can be aware of on-going activities or can know 'who' to contact about 'what', particularly at a large event, it is likely that the worker can establish a closer involvement with the event and engage in more effective interactions with the other

members of the team.

c) Copresence

The era of computer mediated communication has emphasized the importance of maintaining a presence on the scene capable of gathering information quickly and accurately and then disseminating this information to where it is needed, depending on the media capacity and channels available. In public safety communications, a presence is critical because information from the scene may deal with the status of patients or life-critical incidents. The interviewees noted that there was sometimes a problem with explaining the symptoms and status of a patient to doctors. If there were some additional provision for transmitting images or videos at the scene, this could be very helpful for those involved at the scene.

3.3.4. Adaptiveness

a) Self-Organization

Public safety teams, especially police teams, tend to self-organize at the scene. Long-term and extensively planned operations such as football game days are performed by the formal organization. However, in some emergency situations, their organizational structure must emerge as the incident progresses on the basis of physical and contingent constraints. For example, incident command teams may consist of volunteers, firefighters and emergency medical service providers. It is not necessary that a decision maker should be the highest-ranked person present at the scene; rather this will depend on the situation. Once the situation becomes more settled, the emergent organization reverts to the formal organization.

b) Technical Adaptability (Device Dependency of Communication Task)

For several decades, public safety agencies have been attempting to customize their various radio systems to suit their needs but their communication tasks have been constrained by the available technologies and systems. This problem became critical whenever a new technology was

introduced, as their existing operational procedure was optimized with the then-current technology and had to be adapted to use the new equipment. The study participants hesitated to directly contact other agencies except through the dispatcher since they were not trained to do so and did not know how direct communication might disrupt organizational protocols. Not surprisingly, therefore, when the idea of cognitive radio technology was introduced during the interview, the interviewees showed some level of concern about incompatibility with their current practices.

3.3.5. Coupledness

a) Work Coupling

The public safety communication boundary is highly limited by context. Their normal and planned operations are performed according to their formal organization. However, in emergency situations, their organizational structure was instantaneously formed by physical and contingent constraints. Interviewees noted that although the members of VTRS and the VT police were highly functionalized, when they were dispatched to the scene of an incident, they often changed their role based upon the situation they found. For example, the incident commander was not necessarily a high-ranked person in the organization, but varied by situation. Thus, functional coupling becomes looser and tentative relationships may be established. Weick (1976) labeled these phenomena as a loosely coupled system, which he characterized as:

- situations where several means can produce the same result
- a lack of coordination
- the absence of regulations
- highly connected networks with very slow feedback times

Two coupling types in public safety operations often discussed are technical couplings (between technology, task, and role) that are task-induced and authority couplings (positions, offices,

rewards, sanctions) that somehow hold the organization together (Weick, 1976; Orton & Weick, 1990).

Once the situation is settled, an emergent organization turns into a formal organization. In addition, operational boundaries are flexible based on contextual information. Normally, operational boundaries are defined by geographical constraints. However, if multiple incidents occur at the same location, both the operational boundaries and the degree of coupling can change as necessary.

b) Distributed Decision Making/Duality of Centralization

At the scene of an emergency, public safety workers' decision-making is critical to help save lives or prevent major disasters. Like any other police force, the VT police attempt to make quick decisions based upon the local information they already have or can obtain. They try to gather as much information as possible from all available sources. Dispatchers, people in vehicles, or people at the headquarters can collect information from the entire police database system, including data from other people in relevant places. Police organizations are very hierarchical by nature. Thus, decision makers are usually high-ranked persons in the organization. Nevertheless, at the scene, they sometimes make locally optimized decisions in response to the situation. Due to the limitations of their current radio communication systems, the police can only transfer highly abstracted information by voice. In the scenario cases, the police officers interviewed stated they have on occasion had trouble in transferring the information that they collect and in making decisions based on incomplete information. The intrinsic characteristics of police tasks and communication capacity have rendered their decision-making distributed. In contrast, an EMS organization is highly functionalized, which means their decisions are distributed to people in-situ. In addition to communication capacity, there are many barriers to effective collaboration, including environmental issues such as blind spots or noise, organizational issues such as individual and organizational culture, and privacy issues.

3.4. Theoretical understanding of interoperability

In the results section, this study reviewed the dimensions of interoperability based on the results of the qualitative study. This section reviews the dimensions of interoperability from the point of view of organizational sensemaking. Recently, Alberts and Hayes (2003) discussed the four domains of warfare: physical, information, cognitive, and social domains. In this perspective, the concept of interoperability should incorporate these four levels of domain. Interoperability has a major role in the battlefield, enabling troops to share information and maintain situational awareness. Making information more available to all participants is, in fact, the main purpose for introducing the concept of interoperability. However, this notion has been extended as a concept to support coordination and cooperation in intra- and inter-organizational operations. In such contexts, both concepts of interoperability and sensemaking have become crucial to support military organizational performance (Alberts & Hayes, 2003). In addition, Weick, Sutcliffe, & Obstfeld have said, “The image of sensemaking as activity that talks events and organizations into existence suggests that patterns of organizing are located in the actions and conversations that occur on behalf of the presumed organization and in the texts of those activities that are preserved in social structures” (Weick, Sutcliffe, & Obstfeld, 2005, p.413). This treats communication as a core component of sensemaking and organizing. Thus, the concept of sensemaking provides a good theoretical framework to reconceptualize semantic interoperability in the public safety domain.

Sensemaking is a broad concept that can be used to explain how best to understand and project a situation characterized by high complexity or uncertainty. Sensemaking has been researched in both individual (Dervin, 1983) and organizational aspects (Weick, 1995). In this research, sensemaking mainly refers to the research in organizational contexts and is defined as the ongoing effort to understand events that are usually unexpected or highly complex in organizational contexts (Klein et al., 2006b; Weick, 1995; Weick et al., 2005). According to Weick (1995), sensemaking consists of seven interconnected properties that serve as a useful framework in a research area such as command and control in the military. Similarly, the following seven properties would also be applicable in the public safety domain:

Grounded in identity construction: Making sense of the environment influences everything, including one's self-understanding. For example, how public safety workers define their own mission and capabilities depends on their personal identity and includes aspects such as the organization they belong to and their role in the organization. This shapes how they interpret events and is strongly related to operational awareness as well as coupledness. The identity would be established through long-term involvement in the organization and emergency operations and could be the basis of their cultural perspective towards public safety operations.

Retrospective: Making sense of the present event is always grounded in past experience. Past decisions affect current decisions to adopt certain strategies and objectives. For example, how public safety workers make sense of an emergency situation will be shaped by their experience. A police officer familiar with drug investigations is likely to collect the evidence related to drugs at a homicide scene and make decisions based on that past experience.

Enactive of sensible environment: Making sense involves the construction of reality by interactively assigning attention to the context of an event. For example, instead of attempting to get as much information about an emergency situation as possible, a commander may focus only on those aspects of the emergency situation that interactively fit certain patterns of thinking derived from his or her past experience. Cognitive radio technology may facilitate their interactions with the operational environment and provide sensible information to the commanders.

Social: Making sense relies on what other people related to tasks are thinking and doing. In this case, it emphasizes creating shared meanings and experiences that guide commanders in their organizational decision-making. This is one of the most important concepts of sensemaking and is related to most dimensions of interoperability. For example, a public safety incident organization involves many decision makers at various levels, all of whom affect each other's decision making. They need to share their respective goals and vision for the situation. Coupledness explains the degree of coupling among decision makers. This is also related to the type of operational awareness that identifies the boundaries of operation as well as social awareness.

Ongoing: Making sense is a continuous process that causes individuals to perceive, comprehend, take action, and repair a given situation. For example, a public safety worker's tasks are likely to

involve understanding, goal-directed planning, sharing information and executing it in a dynamic environment. Information sharedness refers to the ongoing activity of sharing information to make decisions at the scene.

Focused on and by extracted cues: Sensemaking is based on cues that are extracted and noticed from the environment. The people involved in the situation contextually interpret those cues according to certain experiences, mental models and patterns. For example, particularly when facing time stress and situational ambiguity, experts in the public safety domain will intuitively focus on key events and patterns they can see and make decisions to develop the course of the operation.

Driven by plausibility rather than accuracy: Sensemaking seeks to find feasible solutions rather than the optimal solution. For example, when faced with a situation of uncertainty or information overload, public safety workers try to understand their cues at an executable level, thus helping them to make a timely decision in order to maintain momentum and gain an advantage over uncertainty.

3.5. Implications

Highly distributed decision-making processes are problematic for situations involving multiple communication channels. Decision-making in this context is geographically and organizationally distributed. It can be made by people at the scene, dispatch centers, vehicles and other control centers at different levels of organization. In every decision-making task, the communication group shares situational knowledge. Consequently, this study characterized the concept of interoperability as a unit of decision-making in terms of the joint cognitive systems involved (Cannon-Bowers & Salas, 2001; Hollnagel & Woods, 2005; Hutchins, 1995). Each unit needs to have sufficient capacity to collect and transfer the information in order to yield a seamless decision-making process. A cognitive radio communication system therefore needs to be able to support the transfer of multi-modal data, including texts, images or videos. In addition, device usability is important when the situation becomes increasingly complex.

Direct communication with appropriate personnel can address many of the time critical issues in emergency communication. However, this should be done in parallel with appropriate contextual information such as the people who are part of the current communication network, information related to the incident commander, and the physical and contextual boundaries of the current operation. Appropriately prioritizing networks and displaying channel information may be a solution that will enhance the efficiency and effectiveness of emergency communications.

In interoperable work systems, information asymmetry is an inevitable problem. Decision making in this emergency context is geographically and organizationally distributed, which is one of the main reasons for distributed decision making. At present, synchronous communication is the default mode, but asynchronous communication may help users to retain information and make it easier to compare past information with current information in real time. The expansion of communication capacity in terms of multi-modality should also help to reduce information asymmetry.

Information overload remains a serious problem. Emergency responders require access to pertinent information but at the same time isolation from irrelevant information. Thus, it is important to support dynamic team composition at the interface and system levels.

Understanding the communication patterns of public safety workers and organizational issues in context-specific settings may be a way to solve the problem of information overload.

The context of an incident can determine the best configuration for the interoperable communication group, which may be a decision-group, incident command organizational group, or a geographical-operational group, as appropriate. Based on the parameters of operational boundaries, it is possible to prioritize communication networks that support interoperable groups with cognitive radio devices. This type of divided communication facilitates building more valid and relevant decision-making process models that are compatible with joint cognitive systems. In this context, a communication system should identify current operational boundaries. The police, for instance, use three or four communication networks for a single operation. In general, communication networks support the communication within an organization. Yet, even though the police have dedicated tactical channels, they are not often utilized. The people directing the

operation need to know who is involved in this particular operation and how to contact them. Therefore, the communication system should present the boundaries of operation geographically as well as organizationally.

When it comes to introducing new technology, designers tend to start their design from analyses of current practices, with new practices being created based on current devices. This circular logic eventually prevents innovative design in new communication systems.

Finally, interoperability can be described in terms of self-organization characteristics, which is emerged by operations, highly distributed, and non-specific (Vicente, 1999). It is essential to present the organizational information clearly in their communication devices in order to support effective communication. For example, people in the operation need to be able to identify the person who is in charge of the case. This may be critical, especially, in the case of multi-group operations. In addition, the functional unit also needs to be represented in their communication system to support direct communication between stakeholders (Vicente, 1999).

3.6. Conclusion

In spite of the huge amount of research that has been devoted to the technical aspects of interoperability in public safety situations (Dilmaghani & Rao, 2006; National Task Force on Interoperability [NTFI], 2003; Smith & Tolman, 2000), this remains an unsolved problem and there is as yet no effective approach that supports interoperability in the context of public safety. Consequently, this research focused on the socio-cognitive aspects of interoperability. Five themes were identified that explain the socio-cognitive aspects of interoperability and could potentially be applied to improve public safety communication task performance.

The study explored how those responding to an incident identify the appropriate unit to communicate with and what information they try to share with the team or partner at the scene. Based on the results of the interviews, themes were identified related to the concept of interoperability within teams or among organizations. Based on the identified themes, an

instrument to measure interoperability in the context of public safety was developed (Appendix B). Each item represented the identified dimensions of interoperability. A further study was conducted to validate the developed instrument and is presented in the next chapter.

The interviews also identified user needs related to the first and minimal form representing problems that prevented the users from achieving their goals or provided opportunities to improve the likelihood of the users' achieving their goals (Kujala, Kauppinen, & Rekola, 2001). For example, in this public safety context, the current technological and task procedural limitations were investigated in order to achieve the shared goals in emergency situations as well as opportunities to integrate future technological advances to enhance their performance from the users' perspective. Based on these user needs, user requirements were elicited. User requirements consist of the description of any function, constraint, or other property to meet the user needs (Kujala, et.al., 2001). This will be organized into a systematic framework in a later chapter.

The other major outcome of this study was a thematic review of the identified concepts of interoperability from the perspective of sensemaking. The interoperability themes identified were reinterpreted with respect to major aspects of sensemaking that could explain organizational decision behaviors under conditions of uncertainty and high complexity. The main dimensions in sensemaking were the following: Grounded in Identity Construction, Retrospective, Enactive of Sensible Environments, Social, Ongoing, Focused on and By Extracted Cues, and Plausibility (Weick, 1995; Weick et al., 2005).

3.7. Limitations of the Study

This phenomenological study was based on an in-depth understanding of the experience of the participants. Thus, the results of the study depended on those individuals who participated in this research; their level of experience was an important aspect of this study, as well as the time they had spent in post and the position they held. To ensure a minimum level of experience and some

variety in the positions held by the participants, criterion sampling was used as a type of purposeful sampling. The other limitation was the situatedness of their working condition (Nardi, 1996). As previously stated, a pilot study was conducted to collect a set of three scenarios that reflected the breadth of their communication tasks in the context of day-to-day, task force, and mutual aid, respectively (Irving, 1996). Although scenarios were provided, the results may include superficial answers to the phenomenon related to the synthetic experience. Finally, there may be a subjective bias during the analysis. To avoid this, this study used an interpretative group based on the recommendations by Thompson et al. (1989).

4. EXPLORING THE DIMENSIONS OF INTEROPERABILITY IN PUBLIC SAFETY COMMUNICATION: CREATING AND VALIDATING A MEASURE

Abstract. The purpose of this study was to develop and validate a measure for interoperability in the context of public safety. Interoperability refers to the ability of different organizations or systems to work together or exchange information directly and satisfactorily. Members of local and state judicial organizations and emergency medical service organizations participated in this research. In the previous chapter, interviews with 11 participants suggested five dimensions of interoperability: (1) information sharedness, (2) operational awareness, (3) communication readiness, (4) adaptiveness, and (5) coupledness. This chapter analyzed a survey completed by 64 participants (186 valid instances) that attempted to validate these five dimensions. The discriminant validity of the interoperability index was tested using a confirmatory factor analysis and the convergent validity was reviewed through the use of two other scales: task routineness and work unit information processing. Five factors model had better fit than single factor model, which showed the discriminant validity of the interoperability index. The results confirmed the existence of a correlation among the constructs of interoperability. In addition to this correlation, task analyzability and variety were also positively correlated to organizational awareness as a dimension of interoperability. These correlations were evidence of convergent validity. Interestingly, work unit information processing was not highly correlated to the interoperability dimensions.

4.1. Introduction

In the first phase of this study, reported in Chapter 3 of this dissertation, 27 items were developed to represent the five dimensions of interoperability for an emergency operation. Based on these findings, a survey was developed to measure the dimensions of interoperability for three different

types of operation within two different public safety organizations. The study reported in this chapter was designed to validate the utility of the new instrument for measuring interoperability. Based on the participants' responses, this study reviewed the reliability of the scales. Discriminant validity describes the degree to which the elicited dimension is not similar to other dimensions but rather has its own unique features (Campbell & Fiske, 1959). To confirm discriminant validity, if the five factors model has a better fit than a single factor model, it is safe to assume that each of the five *a priori* dimensions has explanatory power with respect to interoperability. Convergent validity means that a dimension should in fact be similar to other dimensions that it is theoretically related to. Thus, this study investigated the correlations among five *a priori* dimensions and two additional scales that are related to the characteristics of technical systems in an organization. Task routineness and information processing are widely used to identify the relationship between technical systems and organizational aspects. Woodward (1969) showed relationship between organizational structure and technology. Perrow (1970) suggested two distinctive dimensions in task routineness, task analyzability and task variety, and these dimensions have been widely accepted. Task routineness is also related to the organizational sensemaking process (Fulk & Boyd, 1991). According to Alberts, Garstka, Hayes & Signori (2001), interoperability is a core enabler for organizational sensemaking with respect to the concept of network centric warfare. Both warfare and public safety operations are very similar in terms of stressful environments and strong needs for collaboration among stakeholders. Similarly, Daft and Macintosh (1981) indicated that the work unit information processing affect task routineness as well as organizational structure. Therefore, this study assumed that interoperability might be related to information requirements as many research projects have identified the information requirements and effective performance (Daft & Lengel, 1983; Daft & Lengel, 1986; Robert & Dennis, 2005).

The above-mentioned expectations have thus led to two hypotheses:

H1: The dimensions of interoperability correlate positively with task routineness.

H2: The dimensions of interoperability correlate negatively with information requirements.

Identifying any correlations with existing scales would provide evidence for the convergent validity of the interoperability scales.

4.2. **Participants**

To create a generalizable measure of interoperability for members of varied organizations, 63 public safety workers in two distinctly different public safety organizations were recruited to participate in a study to explore intra-organizational and inter-organizational communication issues. The organizations contacted included regional judicial organizations and emergency medical services, as follows: Virginia Tech Police Department, Virginia State Police, Blacksburg Police Department, Christiansburg Police Department, Radford University Police Department, Montgomery County Sheriff's Office, San Antonio Police Department, University of Virginia Police Department, Virginia Tech Rescue Squad, Blacksburg EMS, University of Virginia EMS, Radford Carilion EMS, and Radford University EMS. Since the data were collected repeatedly in terms of type of operation, this study had 186 valid data instances. Overall, 33 police officers, 29 EMS providers, and two unidentified organization workers responded. Their detailed information is shown in Table 6 below.

Table 5. Participants' Demographic Information

		n	%
Organization	Police	33	52.4
	EMS	29	46.0
	Not specified	1	1.6
Experience	>15	8	12.7
	10-15	10	15.9
	3-10	25	39.7
	<3	18	28.6
	Not specified	2	3.2
Gender	Male	49	77.8
	Female	14	22.2
Location of Organization	Urban	10	15.9
	Suburban	16	25.4
	Rural	33	52.4
	Not specified	4	6.3

4.3. Procedures

Two domain experts from different public safety organizations reviewed the questionnaire in terms of terminology and expressions in their respective fields. The questionnaire was revised on the basis of their recommendations. Notices describing the study were mailed electronically to the chief or the communication officer concerned. As needed, telephone calls were made to explain detailed information related to this research. Since the topics of the research dealt with sensitive issues, this research was conducted with the approval of the chief or communication officer of the individual public safety organization that the participants in this research belonged to. This study was deployed in three ways: (a) a printed version was delivered if they requested a hard-copy version; (b) an email with an attached Microsoft Word document, and (c) an online survey using the survey.vt.edu tool were used simultaneously. The participants could choose whichever method they preferred. They could complete the questionnaire in approximately 25-35 minutes. The Virginia Tech Institutional Review Board (VT IRB) approved the study prior to any data collection. To minimize recall bias, the study provided the participants with a complete explanation

including some examples for each type of operation (Appendix A). The data were collected between October 2009 and April 2010.

4.4. Instruments

Five survey instruments were compiled to form an “Interoperability Questionnaire.” The main questionnaire was generated based on five emerging themes from the results of the previous study. Each item reflected the specific content of the identified themes. The instruments had four additional scales: (1) task routineness, (2) work unit information processing, (3) organizational characteristics, and (4) demographic information. The data for this study were collected using a Likert-scale survey as a self-reporting questionnaire. The set of questions, except for the demographic information, were deployed in terms of three different types of operation types: day-to-day, task-force, and mutual-aid cases. The PSWAC final report (Irving, 1996) suggested these three types of operations would constitute a pertinent category to review the interoperability requirements. (See Appendix B.)

Interoperability measurements: Interoperability measurements were developed based on the results of the previous qualitative pilot study. The five themes identified explained the concept of interoperability. Each theme was measured with several items. “Information sharedness” included information asymmetry, information overload and communication synchronicity aspects. “Communication readiness” included technical readiness and collaboration readiness, that is, willingness to share their information with other agencies. “Operational awareness” included dynamic operational boundaries, social awareness, and copresence. “Adaptiveness” consisted of self-organization, distributed decision-making, and technical adaptability. “Coupledness” included distributed-decision making and work coupling characteristics. All these items were presented under the interoperability category in the questionnaire. They were not grouped by theme but rather were presented as sub-categories under the themes based on the recommendations of the Subject Matter Expert (SME) reviewer. In the analysis phase, the items for the statistical analysis were regrouped.

Task Routineness: The relative routineness of the three operations was measured based on perceptions of the public safety workers. Since Woodward (1965) reported the first empirical evidence of the relationship between technology and organizational structures, organizational researchers have regularly used measures of technology in models of organizational structure and processing. Ahuja and Carley (1999) also investigated the relationship between task routineness and structural issues in virtual organizations. In particular, task routineness affects the use of technology and is related to sensemaking (Fulk & Boyd, 1991). Both Maguire (2003) and Langworthy (1986) investigated the relationship between task routineness and structural issues within police organizations. Task routineness consists of task analyzability and task variety. To determine the perceptions in terms of task analyzability and variety, Daft and Macintosh's (1981) scales were used in this study.

Work Unit Information Processing: The relative amount and equivocality of information in a particular operational context was examined. Various researchers have shown that many aspects of structure in organizations may be related to information processing requirements (Daft & Macintosh, 1981; Galbraith, 1977; March & Simon, 1958; Weick, 1969). Hypothetically, when tasks become highly complex and nonroutine, the level of uncertainty increases. Their information requirements become greater to ensure effective performance (Daft & Lengel, 1983; Daft & Lengel, 1986; Robert & Dennis, 2005). Hence, work unit information processing was assumed to be closely related to interoperability characteristics. This study adopted the scales suggested by Daft and Mackintosh (1981).

Incident Organization Characteristics: The general organizational characteristics of incident organizations in terms of type of operations were measured, namely the size of the incident organization, its complexity (including differentiation and integration), its centralization, and its formalization.

Demographic Information: The respondents' demographic information was collected, including general information about their organization, work experience, gender, channels that they have used in specific operations, and frequency of specific operations they have been involved in.

4.5. Results

Questionnaire responses were scored according to a five-point rating scale: (i) Strongly Disagree, (ii) Disagree, (iii) Neutral, (iv) Agree, and (v) Strongly Agree. Prior to any subsequent statistical tests, all measures were tested for normality using Shapiro-Wilk's Statistic. Since the normality assumption was not met, this study checked for skewness and kurtosis to evaluate the symmetry and shape of the distribution. To establish discriminant validity of the *a priori* dimensions, this study conducted a confirmatory factor analysis. To identify convergent validity, the study also adopted a correlation analysis between the proposed dimensions and pre-existing instruments related to organizational-technical characteristics.

4.5.1. Reliability

These developed items should each have homogeneous content. Cronbach (1951) suggested using coefficient alpha to measure the internal consistency reliability among the items. After removing items that were not consistent with other items, Cronbach's alpha values for each factor ranged from 0.413 to 0.869. As a rule of thumb, Nunnally (1978) suggested that alpha levels for new scale values are good as low as 0.6, and acceptable alpha levels should be larger than 0.5. Operational awareness (0.869), adaptiveness (0.620) and coupledness (0.804) all had acceptable levels of reliability. On the other hand, communication readiness (0.574) barely exhibited acceptable reliability. Summary statistics for interoperability are presented in Table 7. Although information sharedness had a relatively low alpha level, this study retained it for further analysis since it was an *a priori* dimension from the qualitative study.

Table 6. Summary of Interoperability Scale Results

Construct	Items	Cronbach's α
Information Sharedness	<ul style="list-style-type: none"> • I have experience to turn off radios due to information overload. • I need to communicate with people in real- time. 	0.413
Operational Awareness	<ul style="list-style-type: none"> • What I know is the same as what the people in the group know. • I know the person who has relevant information. • I know the people who are currently involved in this operation. • I can identify my current communication group. • I know the people who should listen to my message. • I know who is saying the current message. • I know how many people are in the current tactical team. 	0.869
Communication Readiness	<ul style="list-style-type: none"> • I am willing to share the information in the network. • I am ready to share the information that I have collected at the scene with other agency. • Communication technology can easily support to collaborate with other agency. 	0.574
Adaptiveness	<ul style="list-style-type: none"> • I have many chances to work with other agencies without planning. • I need to communicate within my organization as well as with other people from different organizations at the scene. • The structure of incident organization frequently changes as time goes. • Communication methods depend on the environmental constraints. 	0.620
Coupledness	<ul style="list-style-type: none"> • I can easily know who the decision makers are in this situation. • I can easily communicate with decision makers. • Decision makers can easily communicate with their team members. • My tasks are functionally related to other people's tasks. 	0.804

4.5.2. *Discriminant validity*

The AMOS 3.7 with maximum likelihood estimation was used in testing the confirmatory factor analysis model. Previous studies (Muthen & Kaplan, 1985; Curran, West, & Finch 1996; Schumaker & Lomax, 2004) showed that maximum likelihood estimation for factor analysis is fairly robust in non-normal Likert variables. In particular, Curran et al., (1996) reported that the maximum likelihood estimation for factor analysis is robust if skewness and kurtosis are smaller than 2.0 and 7.0, respectively. Table 8 shows the results of the normality test and skewness and kurtosis of the items.

Table 7. Statistics for Constructs

Construct	Items (Variable)	Mean (n=185)	Standard Deviation	Normality (SHAPIRO- WILK Test: pr < W)	Skewness	Kurtosis
Information	IS02	3.380	1.124	$p < 0.001$	-0.047	-0.846
Sharedness	IS03	4.443	0.806	$p < 0.001$	-1.354	1.052
Operational	OA01	3.665	1.003	$p < 0.001$	-0.429	-0.605
Awareness	OA02	4.098	0.965	$p < 0.001$	-0.974	0.526
	OA04	3.535	1.156	$p < 0.001$	-0.449	-0.714
	OA05	3.735	1.088	$p < 0.001$	-0.632	-0.341
	OA06	3.768	1.066	$p < 0.001$	-0.803	0.076
	OA07	3.649	1.133	$p < 0.001$	-0.590	-0.493
	OA08	3.497	1.319	$p < 0.001$	-0.475	-0.917
Communication	CR01	4.362	0.849	$p < 0.001$	-1.578	2.953
Readiness	CR02	4.022	1.073	$p < 0.001$	-1.030	0.419
	CR03	3.849	1.122	$p < 0.001$	-0.583	-0.780
Adaptiveness	AD01	3.173	1.176	$p < 0.001$	-0.159	-0.951
	AD02	4.243	0.927	$p < 0.001$	-1.166	0.882
	AD03	3.189	1.208	$p < 0.001$	-0.033	-0.998
	AD05	4.038	1.007	$p < 0.001$	-1.011	0.537
Coupledness	CO01	3.859	1.054	$p < 0.001$	-0.757	-0.058
	CO03	3.870	1.040	$p < 0.001$	-0.940	0.517
	CO04	3.876	0.873	$p < 0.001$	-0.350	-0.602
	CO06	4.005	0.970	$p < 0.001$	-1.060	1.046

To provide evidence for the discriminant validity of the five dimensions of interoperability, this study compared a single factor solution with the five factors model. A single factor solution implies that the items represent a single construct. This analysis hypothesized that each dimension has explanatory power with regard to interoperability if the five dimensions model has a better fit than a one-dimensional model. In fact, this single factor model provided a poor fit to the data [$\chi^2(170, N=183) = 603.351, p < .001, GFI = 0.735, AGFI = 0.672, RMR = 0.105$] and the five factors model fit to the data was much better [$\chi^2(160, N=183) = 439.608, p < .001, GFI = 0.819, AGFI = 0.762, RMR = 0.091$]; the smaller ratio of chi-square to degrees of freedom represents a better fit. Marsh and Hocevar (1985) suggested that the expected ratio of chi-square to degrees of freedom is 1 and that a ratio as high as 5 to 1 indicates a good fit. Kline (1996), on the other hand, reported 3 to 1 could be better. The ratio of chi-square to degree of freedom for a single factor model was 3.351 and for the five factors model was 2.415. For most of the indices, the five factors model had a better fit. Thus, it was reasonable to reject the assumption that a single factor underlies these measures.

4.5.3. *Convergent Validity*

This study hypothesized that the dimension of interoperability would correlate positively with task routineness, which means that the degree of interoperability would be low and the needs of interoperability would be increased if the operation was nonroutine. Similarly, the dimension of interoperability would correlate negatively with work unit information requirements. The degree of interoperability would be low if information equivocality and information amount were high (Table 9 shows the correlation matrix). There was a significant, positive relationship between task analyzability and four interoperability dimensions: operational awareness, communication readiness, adaptiveness and coupledness. Task variety significantly correlated positively with operational awareness and coupledness. Two dimensions of information processing and five dimensions of interoperability both had low correlation coefficients. However, information amount and equivocality had statistically significant correlations with adaptiveness. Thus, hypothesis one was statistically supported and provided further evidence of the convergent validity of the proposed instrument of interoperability.

Table 8. Correlation Matrix

	IS	OA	CR	AD	CO	TRA	TRV	IPA	IPE
IS	1								
OA	0.020 0.786	1							
CR	0.128 0.083	0.544 <.001	1						
AD	0.146 0.048	0.051 0.487	0.212 0.004	1					
CO	0.075 0.314	0.788 <.001	0.475 <.001	0.183 0.013	1				
TRA	0.060 0.418	0.690 <.001	0.480 <.001	0.204 0.005	0.681 <.001	1			
TRV	0.117 0.113	0.402 <.001	0.108 0.143	-0.171 0.020	0.324 <.001	0.230 0.002	1		
IPA	-0.008 0.913	0.228 0.002	0.151 0.041	0.196 0.007	0.170 0.021	0.231 0.002	-0.053 0.474	1	
IPE	0.264 <.001	0.062 0.405	0.081 0.273	0.367 <.001	0.194 0.008	0.219 0.003	0.133 0.071	0.150 0.042	1

* IS = Information Sharedness, OA= Operational Awareness, CR= Communication Readiness, AD = Adaptiveness, CO= Coupledness, TRA= Task Analyzability, TRV=Task Variety, IPA= Information Amount, and IPE = Information Equivocality

The dimensions of information processing correlated significantly with few of the dimensions of interoperability. The correlation coefficient among adaptiveness and the dimensions of task routineness and information processing was relatively low but statistically significant, which suggests the dimensions of interoperability may account for some part of the variance in organizational-technical characteristics.

4.6. Discussion

The purpose of this study was to validate a measure of interoperability. This section discusses the findings of a statistical analysis and shows how the analysis fulfills the predetermined purpose. The implications, limitations, and future direction of the study are also outlined here.

4.6.1. Dimensions of interoperability

All the dimensions are acceptable except for information sharedness, which had a relatively low alpha level (0.413). One of the reasons for this low alpha level may be the number of items employed. This study tried to minimize the number of items; the subject matter experts recommended reducing the number of items because the participants might not complete all of the questions due to lack of time. Even though the sub-categories were intended to disclose relevant information, they represented a wide range of information sharing issues such as individual overload due to sharing information, degree of synchronicity, and degree of information differences among stakeholders. In terms of communication readiness, the previous study had classified both technical readiness and social readiness as communication readiness. Thus, the correlation among the items in communication readiness was somewhat lower than that of the other constructs. The number of items was also kept as small as possible, as advised by the subject matter experts, who were concerned that higher numbers of questions would likely reduce the rate of response. Under organizational awareness and coupledness, the number of items was relatively high since these included more subcategories. In sum, given the exploratory nature of the study and the relatively small number of questions in these five dimensions, the reliability of the scales was considered adequate.

The first factor involved issues related to *information sharedness*. Public safety workers in such operations have historically suffered from severe information overload under time-pressure conditions. This comes from the limitation of information sharing among the different stakeholders, each of whom has different information from the others, in accordance with Alberts and Hayes's (2003) description of interoperability. In addition, real-time communication and

retrieving and saving of the communication information are also critical issues when the public safety workers try to share information.

The second factor was *operational awareness*. When public safety workers are involved in an operation, they are aware of the physical and abstract boundaries. The workers need to know who is involved in the current operation and how much information they have (Cannon-Bower & Salas, 2001; Hutchins, 1995; Klein & Klinger, 1991; Weick et al., 2005).

The third factor, *communication readiness*, involves both the willingness to share information and technical readiness. In the previous chapter, the existence of cultural, legal, and administrative barriers among the different organizations was identified. Technical readiness has been highlighted for the past few decades and many problems in technical readiness have already been solved. However, willingness to share has been underrated, and even disregarded at times.

Adaptiveness, the fourth factor, includes organizational adaptability and the technical aspects involved in performing an operation. Even though incident organization was described in NICS (National Incident Command Systems), the size, differentiation, and formalization were determined based on a specific operation. Thus, many self-organizational characteristics were revealed during a specific operation.

Finally, the previous study suggested *coupledness* as the fifth factor. The results showed that coupledness was highly correlated with organizational awareness. Theoretically, if incident organizations are highly coupled, operational awareness should be high and vice versa.

In sum, the proposed instruments were designed to measure five distinct and empirically verified aspects of interoperability: (1) information sharedness, (2) operational awareness, (3) communication readiness, (4) adaptiveness, and (5) coupledness. Using a series of statistical analyses, this study demonstrated the reliability of the items, discriminant validity, and convergent validity. Although each dimension itself provided valuable information, the full instrument could more efficiently offer a whole range of data to organizations about communication or collaboration among the different teams, decision groups, and organizations.

4.7. Implications

This study has contributed to our understanding of the public safety communication activities aspects of interoperability and created an instrument with which to measure it. The need for a deeper understanding of interoperability in the context of the public safety domain has been emphasized, as collaboration is essential for effective operations. In this study, the concept of interoperability was fairly new and had to be explained to the participants as a major facet for collaboration performance, along with other social variables.

Designers of socio-technical systems may be particularly interested in four implications of this study. First, these findings may be applicable to separate system modes based on the degree of interoperability. When users confront different emergency situations, designers can provide different communication modes based on how much of the situation they or the communication systems are aware of. Each mode may require a unique interface in order to fully support organizational collaboration.

Second, an awareness of the current degree of interoperability may assist an incident commander to control an emergency situation. An incident commander can assign a special purpose team for the collaboration or select an alternative way to facilitate communication if the current communication device is not adequate to support the collaboration.

Third, the results of this study may be used to design incident command organizations and to support their training. As previously discussed, an incident command organization is not a regular organization but an emerging organization based on the situation. The dimensions of interoperability in this study were the essential characteristics of the incident command organization. Thus, according to the degree of interoperability, different incident command systems and training practices can be established to effectively collaborate with other team/organization members.

Finally, this instrument is undoubtedly applicable to similar domains involving public safety. As the need for collaboration among military divisions continues to increase, the capabilities of

communication operations must become ever more versatile. The concept of interoperability will accordingly provide direction for future communication systems in military operations.

5. INTEROPERABILITY AS AN IMPORTANT VARIABLE FOR ORGANIZATIONAL TECHNICAL SYSTEMS DESIGN

Abstract: The previous chapter reported on a study that validated the measurement index for interoperability developed from a qualitative study. The research reported in this chapter had two main purposes: to identify the effects of task types and organization on the dimensions of interoperability and to explore the relationships among interoperability, task routineness and information processing using structural equation modeling. Using nonparametric mean comparison methods, this study reviewed the effect of type of organization and type of operation on the dimensions of interoperability and the effect of type of organization and type of operation on task routineness and information processing. A structural equation model was used to describe the relationships among interoperability, task routineness, and information processing.

Operational awareness and coupledness were significantly different depending on the type of operation. Information sharedness and adaptiveness were significantly different for different types of organizations. In addition, task analyzability and task variety were significantly different for different types of operation, and depending on the type of organization, task variety and amount of information were significantly different. The hypothesized structural equation model found minimal relationships among task routineness, information processing, and interoperability. However, the correlation between operational awareness and the dimensions of task routineness was very high.

Interoperability differs by type of operation and type of organization, which suggests that systems designers should consider different interfaces or organizations to address different problems. Even though interoperability has little relationship with task routineness and information processing, the high correlation among operational awareness, coupledness and task routineness provides some evidence that interoperability may explain other aspects of the organizational characteristics.

5.1. Introduction

In the previous chapter, the instrument of interoperability was statistically validated. Discriminant validity was reviewed by comparing one and five factors models. The five factors model was a much better fit than the single factor model, which indicates that each of the factors identified from the first study had their own meaning. To show convergent validity, the previous study checked the correlations among the dimensions of interoperability, task routineness and information processing. Operational awareness and coupledness were highly correlated with task analyzability and task variety as dimensions of task routineness. This meant dimensions of interoperability might also explain the aspects of organizational performance that were explained by task routineness.

In this chapter, this study considered the dimensions of interoperability more deeply. Irving (1996) suggested three types of operation related to interoperability. Thus, this study hypothesized that interoperability might function differently if the type of operation is different and the proposed instrument of interoperability may serve to measure different values for different types of operation. Based on the results of the previous qualitative study, each organization communicates differently in the same operation since the organizational purposes and practice of each are essentially different. Hence, this study hypothesized that the dimensions of interoperability might be different depending on the type of organization.

As previously mentioned, task routineness could explain the organizational sensemaking process and interoperability is a major concept for the organizational sensemaking process (Alberts & Hayes, 2003; Fulk & Boyd, 1991). Thus, the concept of interoperability may also be related to task routineness and work unit information processing. This study has suggested a hypothesized structural model that links interoperability, task routineness and information processing. In addition, the findings of this study highlight the collaboration among loosely coupled systems such as different organization and different teams that have their own unique objectives as well as overall goals. Hence, this study implies that other aspects of interoperability may explain the collaborative aspects of organization beyond the task routineness and information processing aspects. The specific questions raised were as follows:

Research Question 1: Are there differences in the dimensions of interoperability depending on the types of operation and types of organization?

Research Question 2: Are there differences in task routineness and information processing for different types of operation and types of organization?

Research Questions 3: What are the relationships between interoperability, task routineness, and information processing?

To answer these questions, a self-report questionnaire was administered to study participants in order to describe the characteristics of interoperability, task routineness, and information processing in a public safety context. The aspects measured in this study were: 1) the dimensions of interoperability, 2) task analyzability and variety, 3) information equivocality and amount, 4) organizational characteristics, and 5) demographic information. The results of this study are presented in two separate analyses in this chapter to answer the three research questions above.

5.2. Participants

This study used the same data set described in the previous chapter. In the previous study, 64 public safety workers in two distinctly different public safety organizations were recruited to explore intra-organizational and inter-organizational communication issues. They responded to questions designed to elicit information on the dimensions of interoperability, task routineness measurement, and information processing measurements in three different cases. As explained previously, more than 10 public safety organizations were contacted and agreed to allow their workers to participate in this study. Overall, 33 police officers, 29 EMS providers, and one unidentified organization worker responded.

5.3. Data Analysis

The previous study examined the reliability and validity of the instrument of interoperability. In this chapter, two separate data analyses were performed using SAS and SPSS AMOS to reveal how interoperability may differ by type of operation and type of organization and any relationships that may exist among interoperability, task routineness, and information processing.

The objective of Analysis 1 was to investigate the effects of different types of operation and types of organization on interoperability, task routineness, and information processing. A five-point Likert style rating scale was used to collect responses. Mean comparison analysis, consisting of Analysis of Variance (ANOVA) or nonparametric mean-comparison tests, was intended to identify any differences related to interoperability in each situation or organization. Prior to any subsequent statistical tests, all measures were tested for normality using Shapiro-Wilk's Statistic. If normality assumptions were not met, this study applied nonparametric statistical analysis. For all dimensions that did not satisfy the normality assumption, the Wilcoxon signed-rank test (Wilcoxon, 1945) and Kruskal-Wallis one-way analysis of variance by ranks (Kruskal & Wallas, 1952) were adopted.

The Wilcoxon signed-rank test is a non-parametric statistical hypothesis test that is used to compare two means on a single sample. When this study examined the effects of types of organization on interoperability, task routineness, and information processing, the Wilcoxon signed-rank test was used to compare differences in interoperability for two representative public safety organizations, in this case the police and emergency medical service. Kruskal-Wallis one-way analysis of variance by ranks is a test to compare three or more means on a single sample. This test was used to investigate the effect of types of operation on interoperability, task routineness, and information processing.

The objective of analysis 2 was to identify the relationship among interoperability, task routineness, and information processing using structural equation modeling. Structural Equation modeling consists of factor analysis and path analysis. Before any further analysis was performed, normality was checked and not all the variables satisfied the normality assumption. Following the suggestion of previous studies for non-normal factor analysis (Muthen & Kaplan, 1985; Curran et al., 1996;

Schumaker & Lomax, 2004), the data was checked for skewness and kurtosis and all the variables met the criteria (smaller than 2.0 and 7.0 respectively; see Table 8 in the previous chapter).

5.3.1. Factor Analysis

Factor analysis is a statistical technique that is often used to examine how observed variables (identified themes) cluster together in patterns based on other unobserved variables (interoperability). Factor analysis is a good way of measuring abstract theoretical variables that cannot be measured directly using estimation based on one or more measurable variables (Johnson, 1998). To test the construct validity of the instrument, a confirmatory factor analysis was conducted and the results were reported in the previous chapter. In confirmatory factor analysis, the researcher specifies the expected relationship and validates the theoretical model based upon how well the data fit the model. The identified themes that were directly measured explained the degree of interoperability (Figure 9).

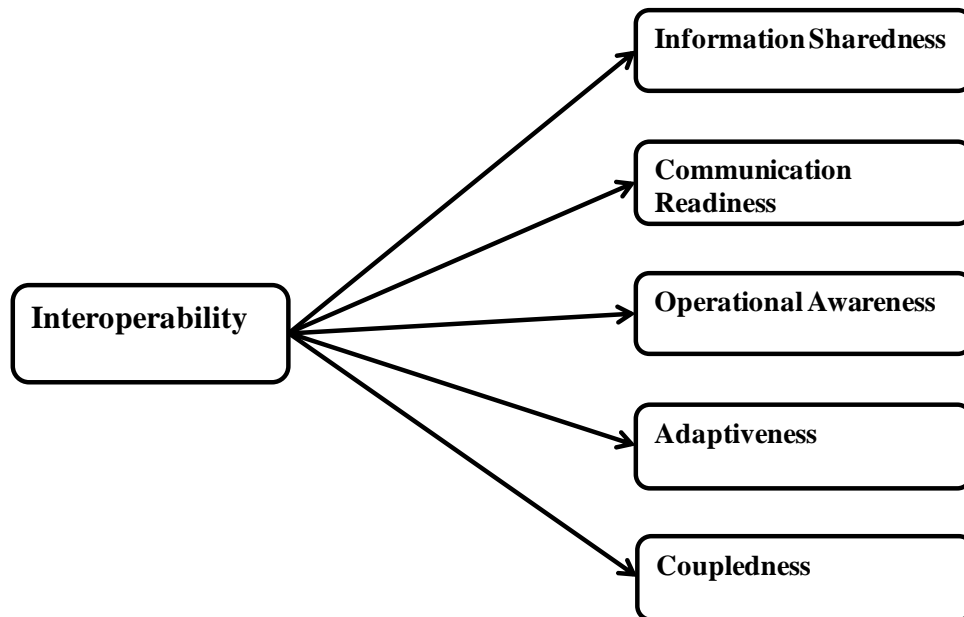


Figure 9. A model of interoperability

In this case, the latent variable, interoperability, was composed of five measured indicators. Hence, in this model interoperability cannot be directly measured since it is an abstract theoretical concept. However, it can be estimated by measuring the individual themes identified.

5.3.2. Path Analysis

Path analysis is used to describe the directed dependencies among a set of variables using a graphical representation. This analysis, initially introduced by Wright (1921), has become influential in the social sciences since the 1960s (Maguire, 2003). Figure 10 shows a hypothesized path model for interoperability.

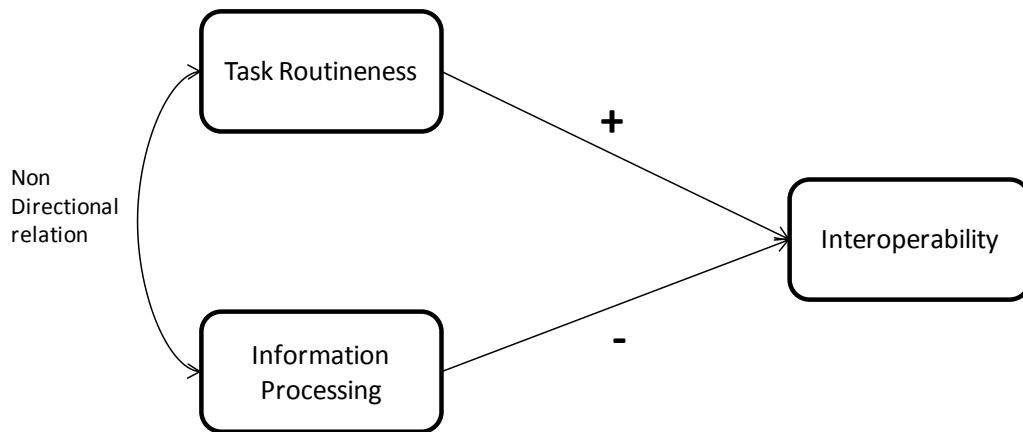


Figure 10. A hypothesized path model for interoperability

The path from “task routineness” to “interoperability” represents the direct effects of task routineness and information processing on interoperability. The curved arrow between “task routineness” and “information processing” represents the unanalyzed correlation. Path coefficients can be derived from the values of standardized partial regression coefficients and/or Pearson product-moment correlation coefficients (Hoyle, 1995). Since those variables were not directly

measured in this research, this study combined path analysis with factor analysis to create a full SEM model.

5.3.3. Combining Factor and Path Analysis

A full SEM model is a combination of path analysis and confirmatory factor analysis. In order to practically estimate structural equation models, the covariance structures are referenced.

Covariance is a measure that summarizes the linear relationship of two variables. In an SEM diagram, latent variables are represented as circles and observed variables are represented as rectangles. Each of these variables can incorporate error terms such as measurement error or a component of prediction equations.

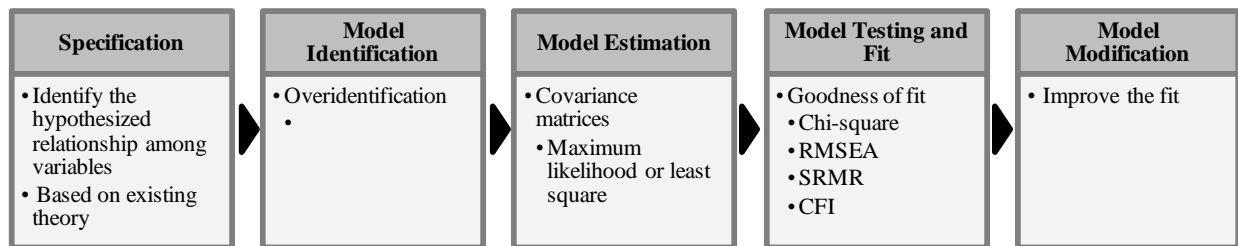


Figure 11. Steps of SEM Analysis

This study followed five generally accepted steps within SEM analysis process (Figure 11). The first step was specification. In this phase, the initialized hypothesized model was defined. The relationship among latent variables and observed variables was specified. Since SEM was intended to be a confirmatory study, it was critical that the hypothesized relationships within the model were based on existing theory and relevant knowledge. According to the prior research described above, both task routineness and information processing would be hypothesized to correlate positively with interoperability. Figure 12 shows a hypothesized full SEM model for interoperability. The second step was model identification. In SEM, researchers usually prefer an over-identified model that has positive degrees of freedom, which thus allow for more than one possible solution to fit the data and a chi-square test for model fit. The third step was model estimation. In this step, parameters were estimated for the relationships between variables in the model. Maximum likelihood was used to estimate the parameters, providing a very robust

estimation for non-normal variables (Curran & West, 1996). The fourth step was model testing and fit. The Chi-Square test is a fundamental measure of fit used in the calculation of many other fit measures. Goodness of Fit Index (GFI), Adjusted Goodness of Fit Index (AGFI), Parsimony Goodness of Fit Index (PGFI), Root Mean Square Error of Approximation (RMSEA), Comparative Fit Index (CFI), Normed Fit Index (NFI), Incremental Fit Index (IFI), and Standardized Root Mean Residual (RMR) were all used to evaluate overall goodness of fit (Hatcher, 1994; Hoyle, 1995; Schumacker & Lomax, 2004). The final step was model modification, where the tested model was adjusted in order to improve the fit. However, all modifications had to be firmly based on a theoretical rationale.

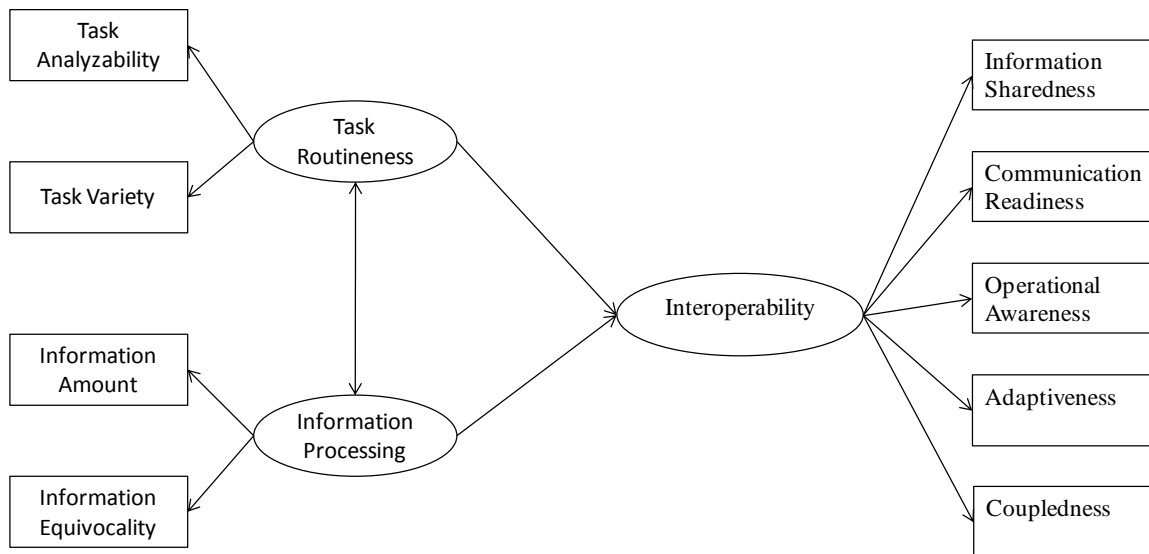


Figure 12. A hypothesized full SEM model for interoperability

A detailed hypothesized SEM model (Figure 12) was generated after identifying the themes of interoperability. The path shows the relationship among variables. The analysis of residuals and the relationships among residuals should reveal the implicit structures among variables or provide opportunities to introduce new variables into the model.

5.4. Results of Analysis 1

5.4.1. Effects of types of operation and types of organization on interoperability

Based on the previous study, the dimensions were statistically validated. Thus, for the analysis the average values of the items in the dimensions were used.

A Kruskal-Wallis test indicated that there were significant differences among the average ratings of operational awareness [$\chi^2(2, N=183) = 45.181, p < .001$] and coupledness [$\chi^2(2, N=183) = 32.714, p < .001$] for the three types of operation. For day-to-day operations, operational awareness and coupledness were relatively higher than in other taskforce or mutual-aid operations (Figure 13). However, the other three dimensions, namely information sharedness, communication readiness, and adaptiveness, were not statistically different for different types of operation (Table 10).

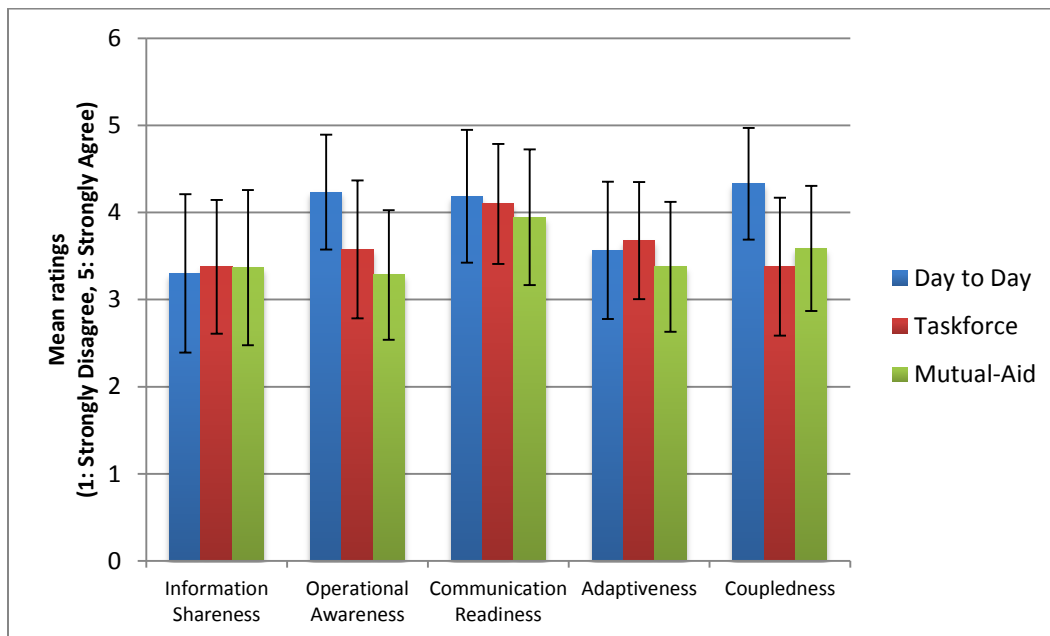


Figure 13. Differences in the Dimensions of Interoperability by Types of Operation

Table 9. Results of Kruskal-Wallis Test (* = significant at $p < .05$)

	Chi-Square ($df = 2$)	Prob>ChiSq
Information Sharedness	0.189	0.910
Operational Awareness	45.181	<.001*
Communication Readiness	3.966	0.138
Adaptiveness	1.211	0.546
Coupledness	32.714	<.001*

A Wilcoxon signed-rank test was used to identify the effect of the types of organizations involved. Information sharedness, [$\chi^2(1, N=183) = 3.978, p = .046$] and adaptiveness [$\chi^2(1, N=183) = 30.299, p < .001$] were significantly different between EMS and police organizations (Figure 14). In contrast, no effect due to the type of organization was found for operational awareness, communication readiness or coupledness (Table 11).

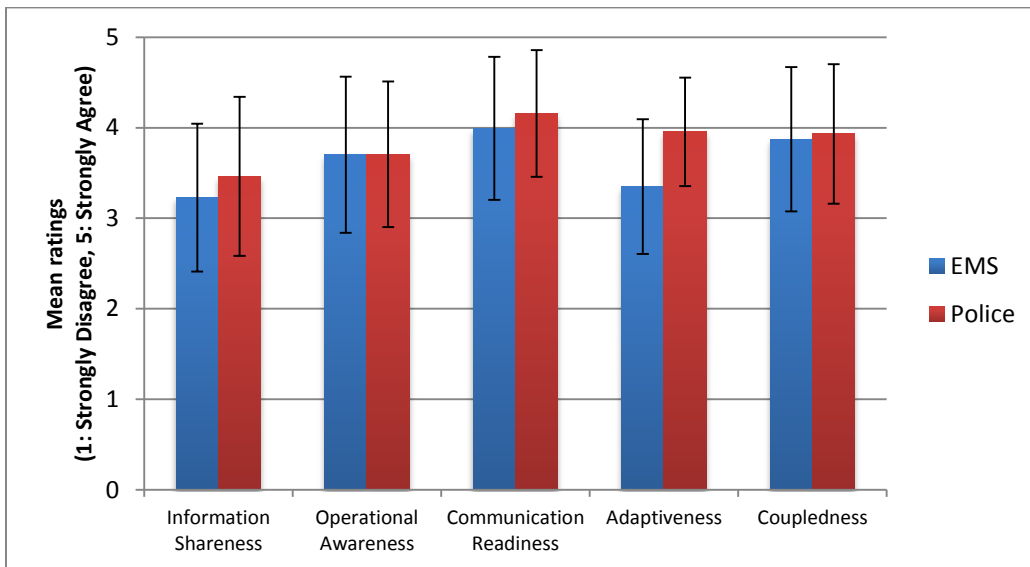


Figure 14. Differences in the Dimension of Interoperability by Types of Organization

Table 10. Results of Wilcoxon Test (* = significant at $p < .05$)

	Chi-Square ($df = 1$)	Prob>ChiSq
Information Sharedness	3.978	0.046*
Operational Awareness	<.001	0.986
Communication Readiness	1.576	0.209
Adaptiveness	30.299	<.001*
Coupledness	0.409	0.523

5.4.2. *The effect of types of operation and types of organization on task routineness and information processing*

Figure 15 shows the mean ratings of task routineness and information processing for different types of operations. A Kruskal-Wallis test indicated that there were significant differences among the average ratings of the task analyzability [$\chi^2(2, N=183) = 18.274, p < .001$] and task variety [$\chi^2(2, N=183) = 13.107, p < .001$] for the three types of operation. For types of operation, task routineness is a critical characteristic that defines the nature of the operation, while information processing aspects were not statistically different by type of operation (Table 12).

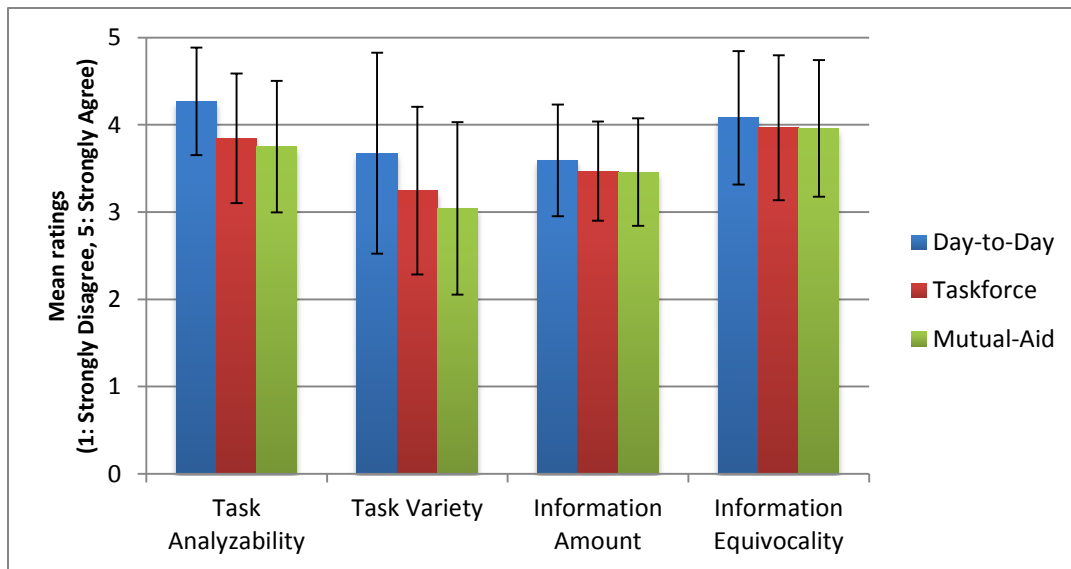


Figure 15. Differences in the Dimensions of Task Routineness and Information Processing by Types of Operation

Table 11. Results of Kruskal-Wallis Test (* = significant at $p < .05$)

	Chi-Square ($df = 2$)	Prob>ChiSq
Task Analyzability	18.274	<.001*
Task Variety	13.107	0.001*
Information Amount	2.565	0.277
Information Equivocality	1.234	0.540

The effect of types of organization on task routineness and information processing was also reviewed using Wilcoxon signed rank tests. The average ratings of the task variety [$\chi^2(1, N=183) = 14.992, p < .001$] and information amount [$\chi^2(1, N=181) = 7.915, p < .001$] were significantly different by type of organization (Figure 16). In terms of task analyzability, the results of the test were not statistically significant, although they did show a pattern between different types of organization to some extent. Information equivocality was no different for the two organizations (Table 13).

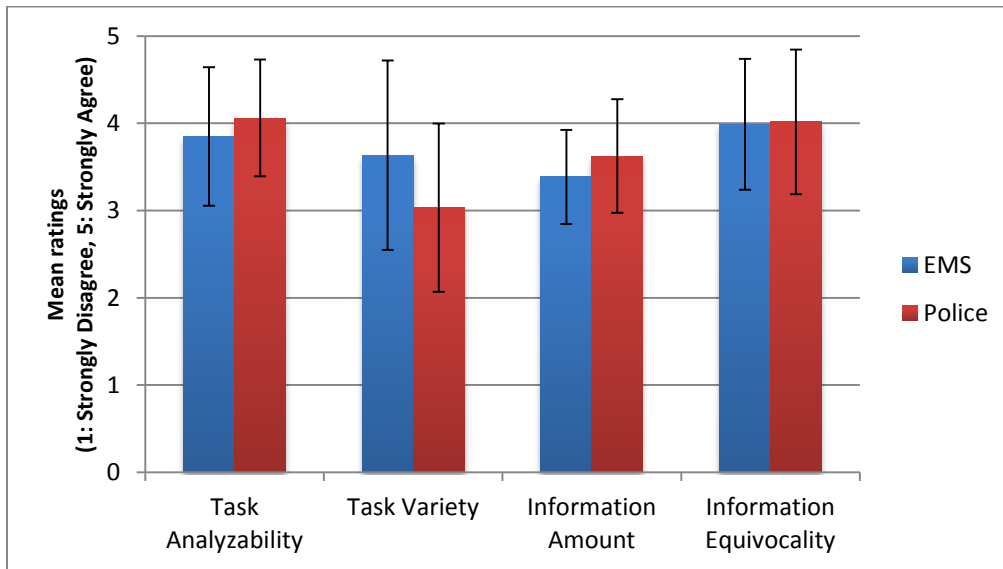


Figure 16. Differences in the Dimensions of Task Routineness and Information Processing by Types of Organization

Table 12. Result of Wilcoxon Test (* = significant at $p < .05$)

	Chi-Square ($df = 1$)	Prob>ChiSq
Task Analyzability	3.196	0.074
Task Variety	14.992	<.001*
Information Amount	7.915	0.005*
Information Equivocality	0.502	0.479

5.5. Results of Analysis 2

The relationship among interoperability, task routineness, and information processing was hypothesized and tested. Figure 17 presents the structural model and estimated coefficients. Overall model fit was not acceptable [$\chi^2(25, N=185) = 107.406, p < 0.001$] (see Table 14). The total number of data points was 181, an acceptable number compared to Hoelter's critical number of 65 ($p=0.05$) in this hypothesized model.

Table 13. Goodness of Fit Indices for the Theoretical Model

Index	Guideline	Theoretical Model
Chi-square statistic		104.059
Degrees of freedom		24
Chi-square statistic/ df	≤ 3.00	4.336
Goodness of fit index (GFI)	≥ 0.90	0.886
Adjusted goodness of fit index (AGFI)	≥ 0.90	0.787
Parsimony goodness of fit (PGFI)	≥ 0.50	0.473
Root mean square error of approx. (RMSEA)	≤ 0.08	0.135
Comparative fit index (CFI)	≥ 0.90	0.841
Normed fit index (NFI)	≥ 0.90	0.808
Incremental fit index (IFI)	≥ 0.90	0.845
Standardized root mean square residual (RMR)	≤ 0.05	0.060

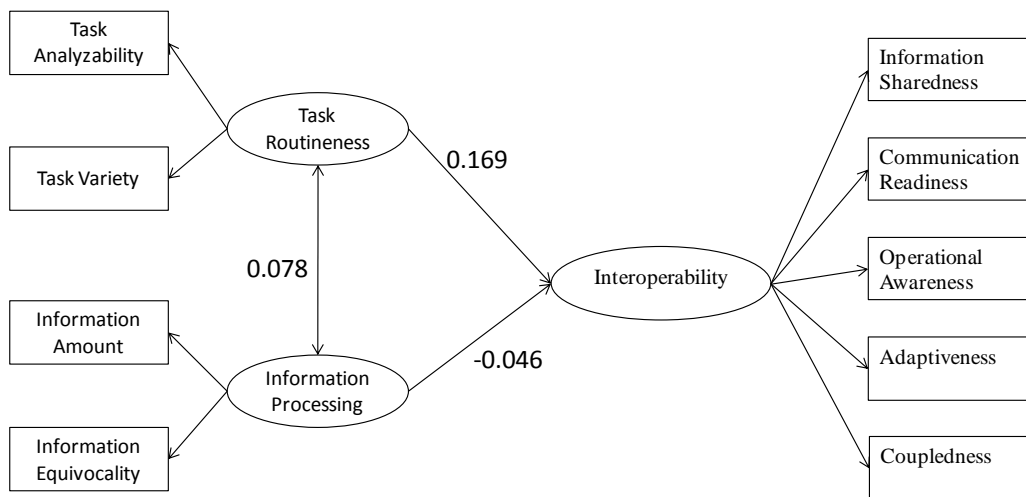


Figure 17. The relationship of Theoretical Model

Although task routineness had a positive effect on interoperability in the model, in accordance with the theoretical assumptions, the coefficient were not statistically significant ($p=0.379$). Similarly, information processing seemed to have a negative effect on interoperability but was also not significant ($p=0.492$). However, the patterns of relationship among task routineness, information processing, and interoperability corresponded to those in the new theoretical model.

5.5.1. Testing the revised model

One of the main reasons the theoretical model was not acceptable may be that the variables were actually composites. Before the analysis, this study combined the measured values for each variable to highlight the relationships among task routineness, information processing, and interoperability. However, when the measured value is composited to a variable, the variability of each measurement error is likely to be diluted. Thus, it is necessary to establish a measurement model at the item level. Considering the correlation matrix (see Table 9 in the previous chapter), a measurement model was therefore established that included all the dimensions of interoperability as well as the dimensions of task routineness. Since the dimensions of information processing were not highly correlated to other variables, the relationship between interoperability and

information processing was excluded (Figure 18) [χ^2 (285, $N=185$) = 821.642, $p < 0.001$] (see Table 15).

Table 14. Goodness of Fit Indices for the Measurement Model and Revised Model

Index	Guideline	Measurement Model	Revised Measurement Model
Chi-square statistic		821.642	706.083
Degree of freedom		285	244
Chi-square statistic/ <i>df</i>	≤ 3.00	2.883	2.894
Root mean square error of approx. (RMSEA)	≤ 0.08	0.101	0.101
Comparative fit index (CFI)	≥ 0.90	0.759	0.779
Normed fit index (NFI)	≥ 0.90	0.681	0.705
Incremental fit index (IFI)	≥ 0.90	0.766	0.785

In the measurement model, all dimensions of interoperability were assumed to be correlated with each other. However, the results showed some estimates were not statistically significant (Table 16).

Table 15. The Estimates of Correlation in the Measurement Model (* = significant at $p < .05$)

Variables	Estimate	S.E.	<i>p</i>
Communication Readiness and Coupledness	.052	.019	.006*
Communication Readiness and Information Sharedness	.023	.037	.527
Communication Readiness and Adaptiveness	.075	.036	.035*
Communication Readiness and Operational Awareness	.163	.040	<.001*
Information Sharedness and Coupledness	.002	.004	.628
Information Sharedness and Adaptiveness	.030	.047	.527
Information Sharedness and Operational Awareness	.005	.010	.587
Adaptiveness and Coupledness	.003	.015	.838
Adaptiveness and Operational Awareness	-.040	.035	.252
Coupledness and Operational Awareness	.275	.062	<.001*
Coupledness and Task Analyzability	.173	.042	<.001*
Operational Awareness and Task Analyzability	.381	.062	<.001*
Task Variability and Coupledness	.122	.038	.001*
Task Variability and Operational Awareness	.236	.064	<.001*

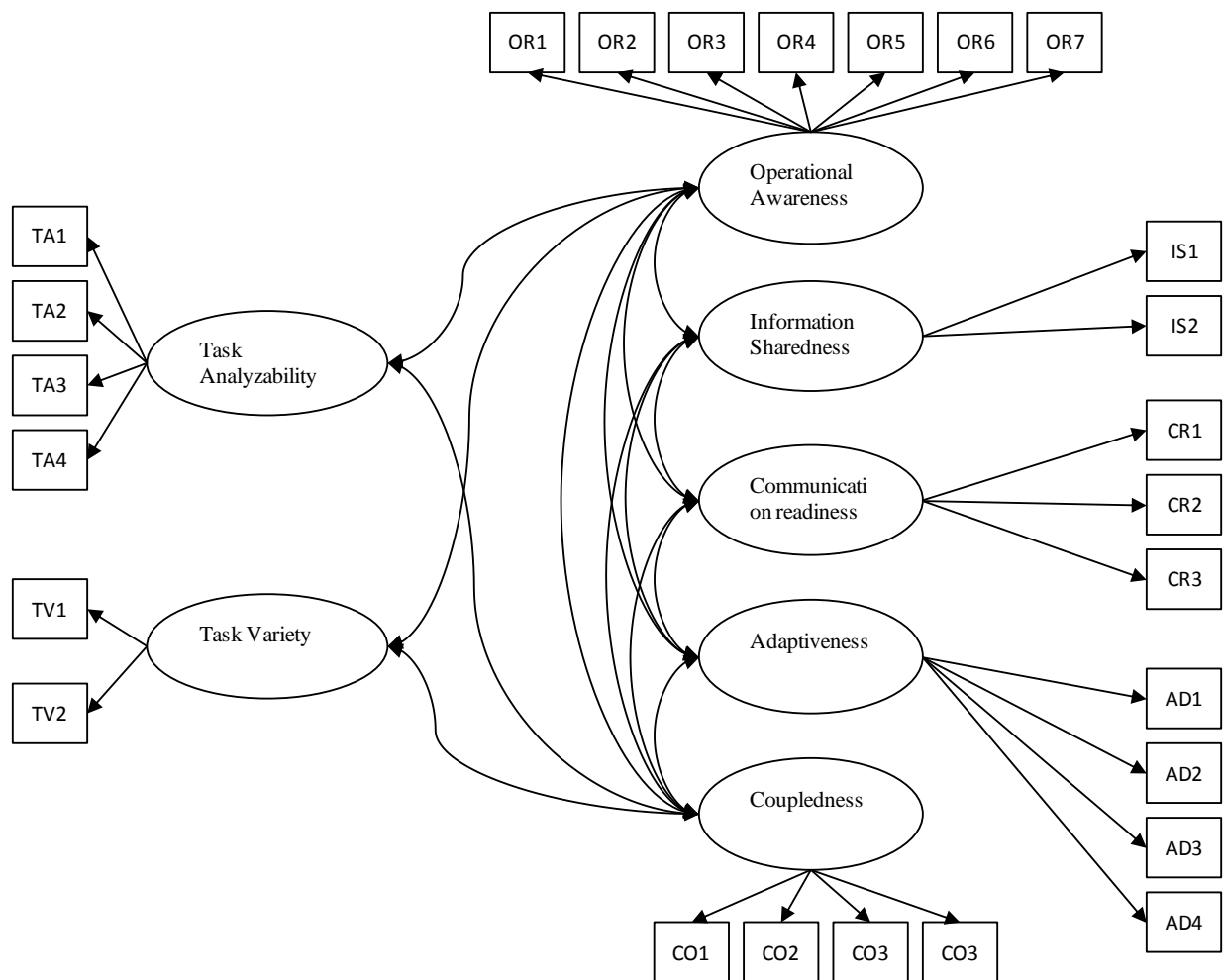


Figure 18. Measurement Model

Thus, the model was revised to remove some correlation links such as the link between communication readiness and information sharedness, the link between communication readiness and adaptiveness, the link between information sharedness and coupledness, the link between information sharedness and adaptiveness, the link between information sharedness and operational awareness, the link between adaptiveness and coupledness, and the link between adaptiveness and operational awareness. In this model, all the estimates are statistically significant (Table 17). Even

though the model fit was not much improved [$\chi^2(244, N=185) = 706.083, p < 0.001$] (see Table 15), the correlations among the variables were statistically significant.

Table 16. The Estimates of Correlation in the Revised Model (* = significant at $p < .05$)

Variables		Estimate	S.E.	<i>p</i>
Communication Readiness	and Coupledness	.046	.017	.009*
Communication Readiness	and Adaptiveness	.093	.037	.011*
Communication Readiness	and Operational Awareness	.165	.041	<.001*
Coupledness	and Operational Awareness	.271	.061	<.001*
Coupledness	and Task Analyzability	.172	.042	<.001*
Operational Awareness	and Task Analyzability	.372	.061	<.001*
Task Variability	and Coupledness	.118	.037	.001*
Task Variability	and Operational Awareness	.252	.066	<.001*

5.6. Discussion

5.6.1. Discussion for Results 1

Operational awareness and coupledness was statistically different depending on the type of operation. Operational awareness was relatively high for day-to-day operations. For example, police attending a traffic accident, which is a day-to-day case, can easily be aware of who is directly involved and how to deal with this type of incident. The coupledness for day-to-day situations is statistically higher than for the other two cases. Once the type of operation becomes larger and more complex, coupledness theoretically becomes loose coupling since more organizations may be involved in the operation. Thus, in order to ensure a certain degree of operational awareness and coupledness in task-force or mutual aid operations, communication systems should display the identity of those currently talking as well as who is involved in the operation. In addition, coupledness includes decision making aspects as well as work coupling. In order to support dynamic decision making, the system needs to support a direct communication mode to decision makers. A functional structure or process of work should also be presented by the communication system.

Depending on the type of operation, the structure of an incident organization can also be customized. This may not be a problem that is related to the size of the incident organization. To increase operational awareness in disaster situations, a sub-division or branch in an incident command system may be grouped into a set of co-located organizations that might have more experience in small operations. In addition, the hierarchical level or formalization for adaptiveness may be an intervention that should be examined in a further study.

In terms of types of organization, information sharedness and adaptiveness were statistically different between EMS and police. This agrees with the results of the previous qualitative study in Chapter 3. The attitude to sharing information between these two organizations was behaviorally different since their function and responsibility at a scene differs markedly. Police showed a tendency to hesitate to share the crime information with EMS or other agencies, while EMS workers were afraid of breaching the privacy issues associated with health information.

Adaptiveness was also different between police and EMS organization. As noted earlier, police generally have more responsibility in emergency operations and their roles are more versatile than those of other organizations. Most policemen have been experienced or trained as EMS and hazmat or other public safety organization. They can perform various roles in emergency situations, even though police organizations are usually very hierarchical and structural. In contrast, EMS organizations are quite functional. Their workers are highly specialized and usually focus on their own tasks.

As this study theorized, the task variety and analyzability were statistically different for different types of operation. Day-to-day, task-force, and mutual aid operations all had different task characteristics. Frequency and uncertainty were the most critical variables separating those operations (Irving, 1996). Thus, task variety and analyzability should be different for different types of operation and this was reflected in the data. These results also confirmed the reliability of this questionnaire study.

Information amount and task variety also differed by type of organization. Interestingly, the task variety of EMS was higher than police attending the same incident site. This might be the reason why the perception of task unit for each organization varies. In an emergency operation, each

EMS unit performs a different role since their organization is highly functionalized. However, most police officers do similar work, even though their role and scope of task might be different. In terms of information amount, the police deal with more information than EMS at the same event.

5.6.2. Discussion for Result 2

The relationships among and between interoperability, task routineness, and information processing was not statistically significant at a structural equation model. However, as the correlation matrix shows, there were significant correlations among the dimensions of interoperability and task routineness. Using this measurement model, this study tried to identify other structural relationships. Even though the model fit increased only slightly when the model was revised, the estimates of correlation coefficient were statistically significant in the final revised model. Theoretically, task routineness was assumed to be positively linked to interoperability (Alberts et al., 2001; Fulk & Boyd, 1991). Operational awareness was positively correlated with task analyzability as well as task variety. Similarly, coupledness was positively correlated with both task analyzability and task variety. These findings imply that task routineness might positively affect certain aspects of interoperability. Daft and Macintosh (1981) demonstrated a positive relationship between information amount and task variety. However, although Weick (1961) theorized unequivocal information might positively affect task analyzability, this study found little evidence to support this.

These results demonstrated how the dimensions of task routineness were correlated with the two dimensions of interoperability. The earlier study by Daft and Macintosh (1981) focused primarily on a single organizational context. Since interoperability deals with collaborative contexts, the results of their study might not be directly comparable to those reported here. The findings also indicate that the dimensions of interoperability are more likely to explain the characteristics of a multiple organizational context than aspects such as task routineness and information processing. In particular, the dimensions of interoperability could be a good way to explain a loosely coupled system (Ordon & Weick, 1990).

In addition, some correlations among residuals were considerably high ($0.1 < |r|$) in the revised measurement model, but smaller than 0.3. They revealed that there might be hidden relationships among items. Hence, the item-level relationships need to be specified at a future study, which may emerge as new constructs to measure different perspectives of the system/organization performance.

5.7. Conclusion

This study consisted of two main analyses: (1) a statistical analysis to identify the effect of type of operation and type of organization on interoperability, task routineness, and information processing, and (2) an exploratory study to find relationships among the dimensions of interoperability, task routineness, and information processing.

First, a Kruskal-Wallis test identified the effect of the type of operation on the dimensions of interoperability, task routineness and information processing. Operational awareness, coupledness, task variety, and task analyzability was statistically different for different types of operation. A Wilcoxon signed rank test indicated the effect of type of organization on the dimensions of interoperability, task routineness, and information processing. Information sharing, adaptability, information amount, and task variety was statistically different between EMS and police. Based on these results, the technical and social systems requirements can be listed and specified.

Second, factor analysis identified appropriate measurable relationships among the identified themes and interoperability. As previously stated, a latent variable, interoperability, was indirectly measured via a set of items within the identified themes. The results of this analysis identified which items had more explanatory power to describe or measure interoperability. The full SEM model produced a graphical relationship, complete with path coefficients. Based on this analysis, the relationships between the dimensions of interoperability and other measured variables were identified. Even though the relationships were statistically not significant, a pattern of relationships became apparent, which may be a topic for future study. Correlation coefficients to represent their linear relationships were identified. More specifically, operational awareness and

coupledness were both highly correlated with task analyzability or variety. In addition to task routineness, the relationship between interoperability and work unit information processing was specified. These results indicated that the relationships between the identified themes and the properties of work unit information processing were negligible.

Finally, this study suggested a model of interoperability that took into account the relationships with other measurable variables. A graphical representation incorporating nodes and arcs was used to present the relationships and a covariance matrix was provided to show the coefficients of the linear combinations of the relationships.

6. MODELING OF AN INTEROPERABLE COMMUNICATION SYSTEM

Abstract:

The purpose of this study was to provide a model-based design framework to support interoperable communication systems. A model of interoperable communication systems was delineated using the requirements and interoperability concepts identified in the previous chapters. In this model, the specific values related to an interoperable communication system were identified and decomposed. The initial values provided the starting point for specifying system functionality. An Abstraction Hierarchy (AH) was used as a basic tool to describe multiple levels of knowledge for the target system. Based on the Work Domain Analysis (WDA) framework, other levels of abstraction were decomposed. The final outputs of this study were a prototypical Abstraction Hierarchy for interoperable communication systems and a prototype based on the suggested model. This study also yielded a unique example of work domain analysis, starting from the values (in this case, interoperability and relationships with other values) to other levels of abstraction.

6.1. Introduction

There are many ways to describe systems on different levels of abstraction (Burns & Vicente, 2001). As discussed previously, descriptive approaches can be very beneficial in developing an understanding of concepts and people's behavior in real contexts. However, it is then necessary to abstract information from the raw data with which to construct a simple model or a set of axioms as part of the design process (Burns & Vicente, 2001). Although the studies in the previous chapters provided an in-depth understanding of the concepts of interoperability and a model of interoperability, including relationships with other variables, the new model of interoperability is not inherently a systems model, even though it offers invaluable insights into the important property in public safety communication systems. Hence, the study reported in this chapter focused on providing a model of an interoperable communication system based on the previous

findings. To describe the different levels of abstraction in the system, this research adopted the Abstraction Hierarchy as a primary tool for a work-domain analysis (Rasmussen, Pejtersen, & Goodstein, 1994; Vicente, 1999). Five different levels of abstract knowledge related to interoperable communication systems were represented in the Abstraction Hierarchy. In addition, this study provided an instance of an analytic process, starting from abstract functions. A model of interoperability was first located in the abstract function layer and then decomposed by goal-means and whole-part relationships and filled with functions in other layers. Ultimately, the research results provided a completed Abstraction Hierarchy of systems knowledge that supports interoperability in public safety communication systems.

6.1.1. Model-Based Design Framework

Model-based design has a long history dating back as far as the 1920s, when the concept of control systems was first introduced. Although model-based design approaches have now been implemented in many specific fields, its most popular use has been in designing complex control systems for industrial, aerospace and automotive applications. A model refers to a conceptual, mathematical and visual representation of an object, value, system, or abstraction. As a distinct class of work analysis techniques, model-based approaches are widely accepted in the cognitive systems engineering discipline (Burns & Vicente, 2001). Model-based approaches seek to abstract from idiosyncratic details to more simple descriptions, thereby guiding the design process by providing requirements and implementations (Burns & Vicente, 2001). This contrasts with observational approaches, which provide a detailed description of single instances of how people work with a specific device (Suchman, 1996). Descriptive or observational approaches greatly help analysts to understand people's behavior and their thinking in real contexts and gain descriptive insight from real situations. In the design process, however, it is necessary to abstract information from large amounts of data in order to develop a simple model or axiom. Model-based approaches focus on developing a model of a work system and then applying the model to the design process. In particular, three types of models can be specified, based on the object of modeling (Burns & Vicente, 2001; Vicente, 1999):

- (1) *Task models*: models that describe the actions that can or should be performed by one or more actors (human or otherwise) to achieve a particular goal;
- (2) *Work domain structure models*: models that describe the structure of the system being controlled and are independent of any particular worker, automation, event, task, goal, or interface; and
- (3) *Work domain goal models*: models that describe desired (i.e., target) states of the system being controlled and are independent of any particular worker, automation, task, or interface.

All three types of models have their own distinct functions in the design phase. Thus, the identification of the relationship among the models is important. Rasmussen et al. (1994) suggested the basic scope of analysis for targeting the above-mentioned models, while Vicente (1999) developed the *Cognitive Work Analysis (CWA)* framework to incorporate these models. CWA utilizes the models to understand complex socio-technical systems as well as to design those systems. The research reported here applied work domain analysis to describe the structure of interoperable communication systems. As intended, a high level of description of a work domain should be independent of the worker, task, or interface. However, low abstract levels of the work domain are inevitably somewhat related to them. Table 18 shows the type of boundaries or constraints in terms of each analysis. Depending on the scope of study or characteristics of systems, all or some parts of the analysis can be utilized as appropriate when designing a system.

Table 17. Phases of CWA (adapted from Naikar et al., 2005)

Vicente(1999)	Rasmussen et al.(1994)	Type of Boundaries or Constraints	Main approach
Work domain analysis	Work domain analysis	Purposes, value and properties, functions, and physical resources	Abstraction hierarchy
Control task analysis	Activity analysis in work domain terms and activity analysis in decision-making terms	Activity in terms of work situations, work functions, and control tasks.	Decision ladder
Strategies analysis	Activity analysis in terms of mental strategies	Strategies for carrying out the activity	Information flow map
Social organization and cooperation analysis	Analysis of the work organization	Distribution of work, including allocation of work to individuals; organization of individuals into teams; and communication requirements	Role allocation within an abstraction hierarchy
Worker competencies analysis	Analysis of system users	Perceptual and cognitive capabilities of workers	SRK (Skill, Rule, Knowledge) taxonomy

6.1.2. Work Domain Analysis

Since this study was designed to describe the structure of interoperable communication systems related to the model of interoperability, it focused primarily on work domain analysis. The main objective of Work Domain Analysis (WDA) is to model those constraints that relate to the abstract structure of the system, which includes both purposive and physical contexts (Naikar et al., 2005). Vicente (1999) illustrated WDA using a field study in physics, showing how WDA does not describe a specific instance of the activity in a system, but rather the boundary conditions, thus furnishing a general categorical representation of that system. The Abstraction

Hierarchy (AH), the most popular tool for WDA, provides a multilevel knowledge representation format for describing the functional structure of a particular work domain or system (Rasmussen et al., 1994). One particular feature of AH is that it is defined by means-ends relationships between adjacent levels, with higher levels containing purpose-related functional information and lower levels representing more physically implemented information. Typically, five abstraction levels are utilized to describe these complex systems, as follows (from the top level): functional purpose (FP) -> abstract function (AF) -> general function (GF) -> physical function (PF) -> physical form (P). Table 19 shows abstraction function level of abstraction hierarchy and what should be understood at the level.

Table 18. Generic prompts for analyzing the abstraction dimension (Adapted from Naikar et al., 2005)

Level	Prompts
Values and Priority Measures (Abstract Function) -Interoperability -Usability -Quality of service	What criteria can be used to judge whether the work system is achieving its purposes? What criteria can be used to judge whether the work system is satisfying its external constraints? What criteria can be used to compare the results or effects of the purpose-related functions on the functional purposes? What are the performance requirements of various functions in the work system? How is the performance of various functions in the work system measured or evaluated and compared? What criteria can be used to assign priorities to the purpose-related functions? What are the priorities of the work system? How are priorities assigned to the various functions in the work system? What criteria can be used to allocate resources (e.g., material, energy, information, people, and money) to the purpose-related functions? What resources are allocated to the various functions of the work system? How are resources allocated to the various functions of the work system?

6.1.3. Completing Abstraction Hierarchy

This distinction of five levels can be applied to communication systems. An *abstract function* (AF) is different from a *general function* (GF) in that it is independent of a particular family of communication systems. Thus, AF does not address functional characteristics limited to a specific type of communication system; rather, it deals with values or quality features that can be found in any kind of communication system. In this study, an abstract function was taken to be a set of values and their relationships. In the case of communication systems, this level is primarily focused on the quality attributes or priority measures that balance the GF-level functions. The distinction between GF and PF is that the former is about a family of communication systems or patterns, while the latter is about a particular product within a system or domain: GF refers to a purposeful function, and PF refers to an object-related function. Figure 19 shows the relationship between each level. The means or ‘how’ relationship is signified by the top-down arrow from the functional purpose, whereas the ends or ‘why’ relationship is signified by the bottom-up arrow from the physical objects. Each level is scaled according to a high or low level of abstraction and specified by defining adjacent layers. In addition to the abstraction dimension, WDA also provides the decomposition dimension. This dimension has a whole-part relationship for each level of abstraction.

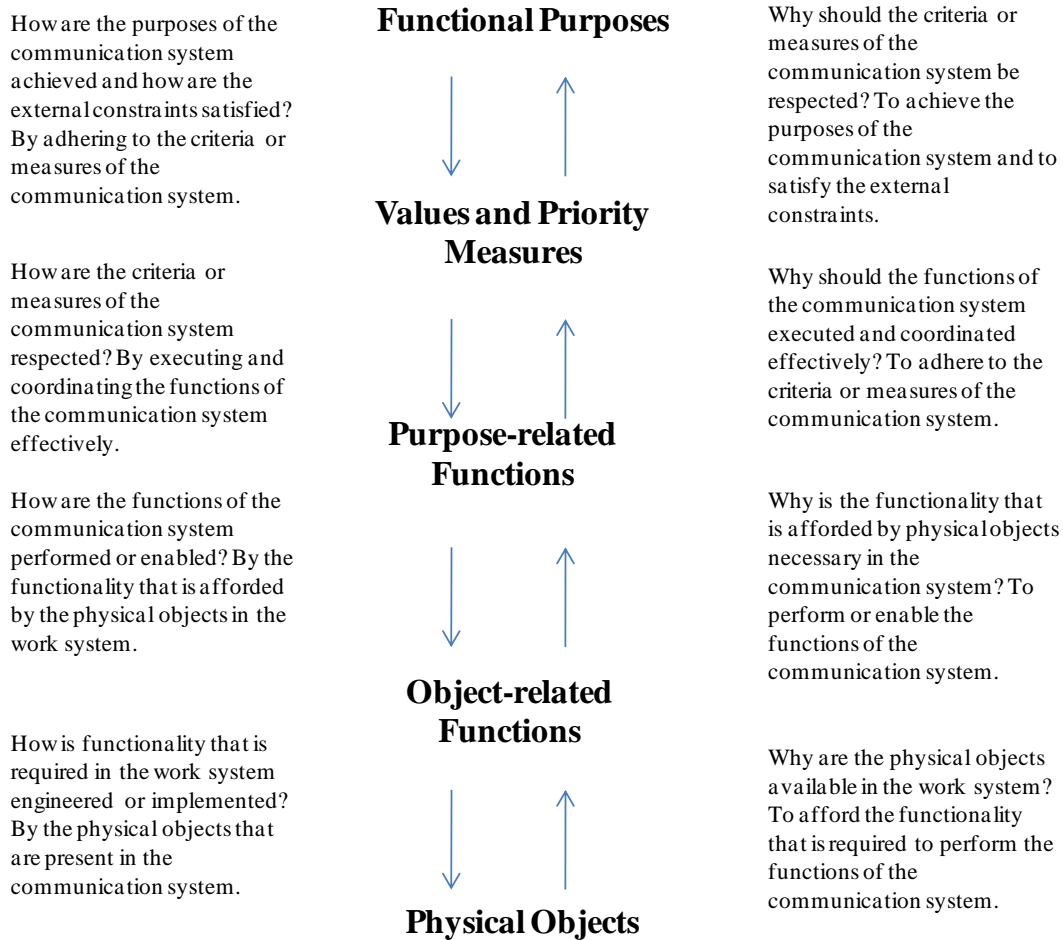


Figure 19. The specific nature of the means-ends relations between adjacent levels of abstraction (Adapted from Naikar et al., 2005)

6.2. Analytic Procedures

The Abstraction Hierarchy (AH) was applied here to analyze the abstraction structure of public safety communication systems that constrains users' conducting tasks in a certain way. The previous studies provided overall goals for the systems and identified values that would support effective communications. This study was therefore based on these value perspectives.

There are no typical ways to fill the Abstraction Hierarchy. The analysis of a work domain usually starts from the identification of functional purposes. In general, this is followed by the identification of a general function because GF is easily identifiable. However, in this study each cell was populated using the following analytic procedure (Figure 20).

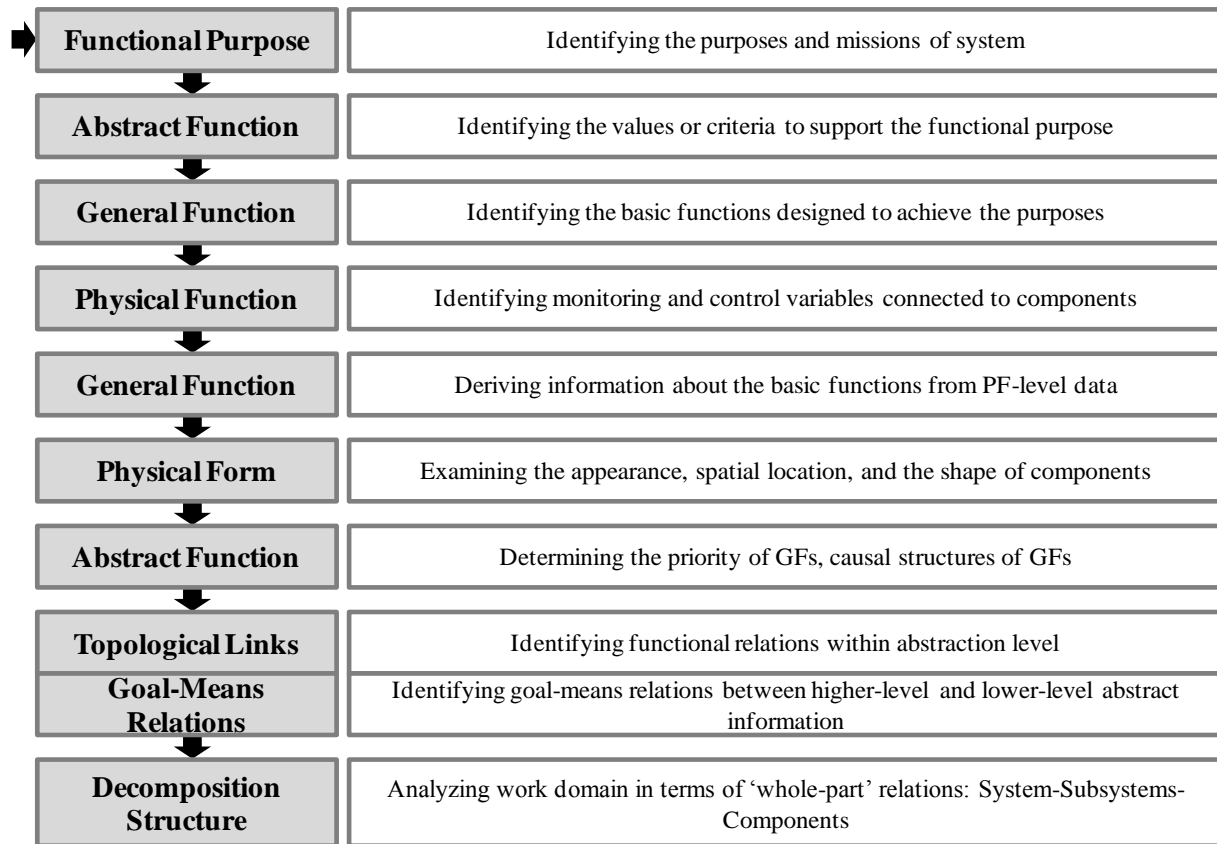


Figure 20. A procedure of goal-means work domain analysis using five abstraction levels

6.2.1. Functional Purposes and Abstract Functions

Effective emergency communication is the core of emergency operations and is directly related to team performance (Paris et al., 2000). In this approach, the main functional purposes of public safety communication systems are to link the team effectively and enable them to share relevant information in emergency situations and to help the personnel to understand and project possible outcomes of those situations.

6.2.2. Values in Communication Systems: Identifying Values and Priority Measures in AH

The main contents at the level of abstract functions are generally derived from the laws of nature (in causal systems), social laws, conventions, and human values (in intentional systems) (Naikar et al., 2005). In this study, interoperability was the main value for communication systems in the public safety domain. A model of interoperability using identified themes and requirements from Study 1(Chapter 3) and other constructing values from Study 2 (Chapter 5) was represented at this level. The values in public safety communication systems are shown in Figure 21.

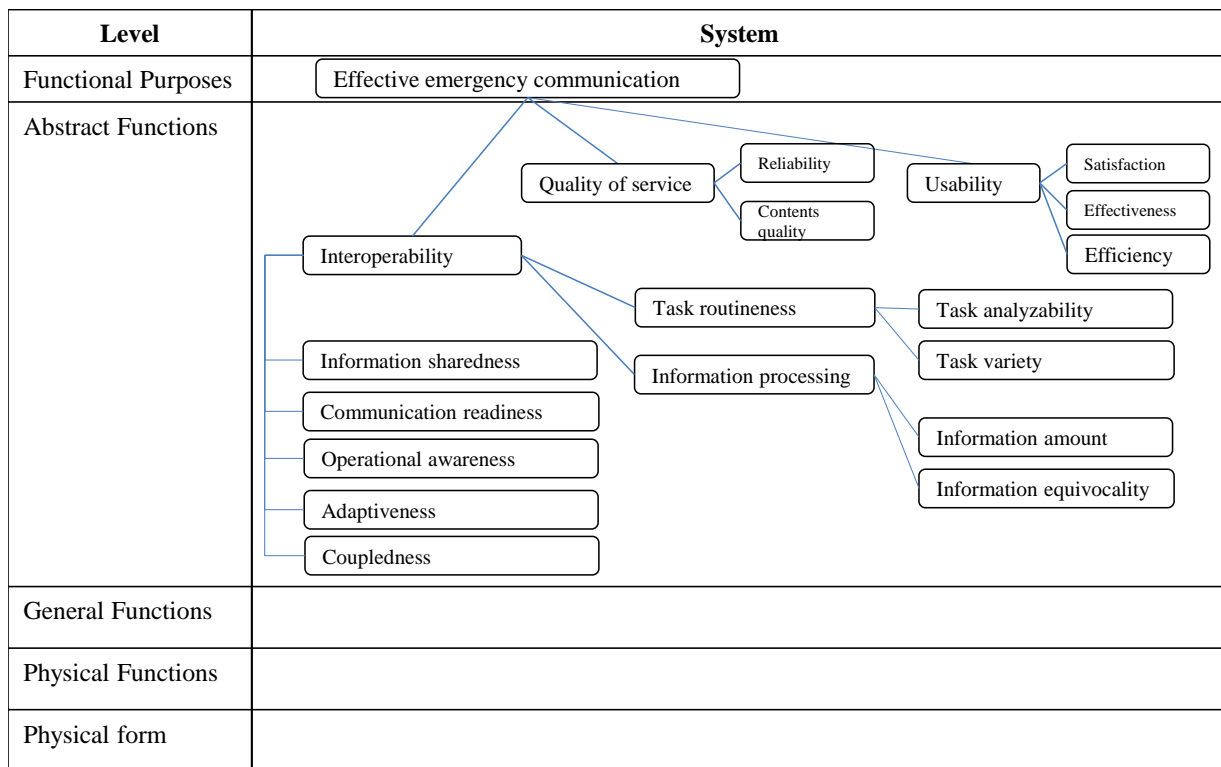


Figure 21. Values for Effective Emergency Communication

As the findings of the previous studies showed, interoperability has five dimensions, each of which has different degrees depending on the types of organization and types of operation involved. In addition to interoperability, the quality of service and usability were emphasized in this research as important properties for communication systems. As a part of the user domain in

a cognitive radio framework, Le et al. (2007) briefly mentioned that quality of service could be considered to consist of reliability and quality of contents. ISO defines usability in terms of three constructs: satisfaction, effectiveness and efficiency (ISO 9241-11). These properties in the abstract functions layer should be correlated with each other in order to sustain effective emergency communications.

6.2.3. Identifying General Functions

In a public safety communication system, a communication structure represents a connection that is designed to relate to certain values or functional purposes. Hence, a communication structure can be considered as a GF in the AH of the public safety communication system. These communication patterns were collected from Study 2 for each of the specific operations considered. This GF could have certain network-related attributes; in turn, these attributes and values would be AF in the AH. GF could be derived from the induction process, given AF, as well as the deduction process, based on PF (Figure 22).

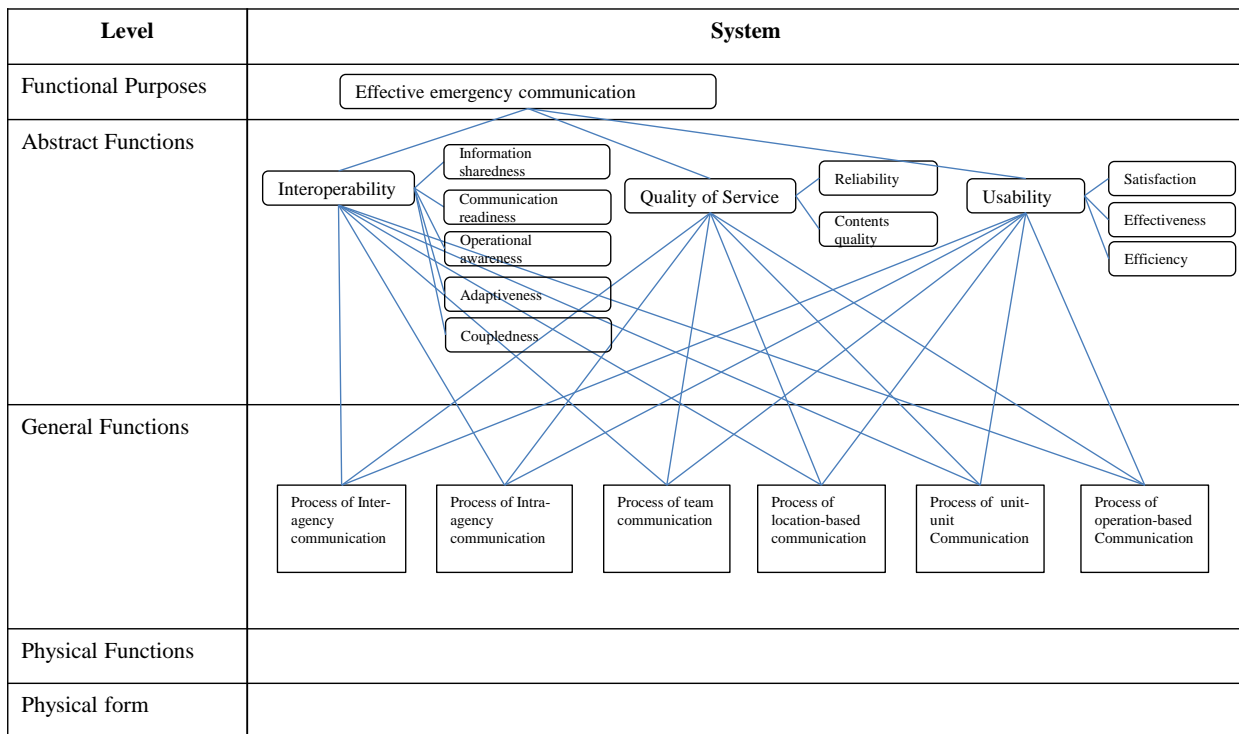


Figure 22. An example of the relationship between AF and GF

The process of inter-agency communication is a communication structure that supports communications between two or more different organizations. For most incidents, agency necessarily needs to collaborate closely with one or more other agencies, since each organization has a different functionality. For instance, many organizations can be involved in controlling a large event such as a football game. The communications among these organizations are usually implemented through dispatcher systems or temporarily established command centers. Depending on the types of operation and types of organization, the degree of interoperability may vary, thus confining the communication structure of inter-agency communication. To support this type of communication, specific identifiers for the organizations concerned and appropriate channel selection are required.

The process of intra-agency communication consists of a structure that supports the communication within an agency, and is one of the most common types of communication in current public safety operations. Officers can talk to all the other members of their organization if the organization communicates by means of a regular channel. This is a very powerful communication structure that supports synchronicity and information sharing. If the size of the organization is not too large, operational awareness will likely be very high using this approach. The officers involved in an operation will probably know each other and easily identify who is currently talking on the channel. The current communication system mostly covers these functions, even though it still needs to support dynamic group communication.

Effective team communication is essential to support multiple incidents. Obviously, the bigger the organization is, the more communication networks are needed. In such cases, public safety workers need to identify which communication group(s) they belong to. Communication groups can be classified by functional divisions or branches with respect to their particular operations. At present, the communication system has tactical channel systems to support additional communication groups within an agency. However, the number and frequency of communication channels need to be predetermined before an agency becomes involved in an operation. The dynamic allocation of the communication group is indispensable under multiple emergency operations. Cognitive radio technology can scan the currently available channels and create a new communication group instantly.

One of the most frequent and difficult cases for public safety workers is the control of a major event, in which multiple incidents frequently happen in very close proximity. Therefore, there is a need to separate channels based on location as well as type of operation. For example, officers at section A in a stadium may be involved in a medical incident. These officers will not need to receive any other information that is not related to their incident. To also receive information from other incidents usually precipitates information overload. However, emergency signals still need to be distributed to anyone near the area in question. This type of communication is very important to ensure interoperability among different teams or organizations dealing with multiple incidents.

The current communication systems are basically one-to-many (1 to n) communication, which is particularly convenient for the simultaneous sharing of information within or between organizations (Figure 23). After the introduction of personal communication systems, the needs of different types of communication in public safety contexts have also increased. Workers want to use unit-to-unit communication to ensure privacy and direct contact. The interviews conducted for Study 1 revealed that many, if not most, public safety workers sometimes use their own cellular phones as ad-hoc communication devices if they think this is warranted. Even though P25 technology provides unit-to-unit communication, the user interface does not fully support it, and thus users may not realize the full functionality of the device. Thus, considering the degree of interoperability among different units, teams and organizations, all these network/communication structures need to be supported at the system level.

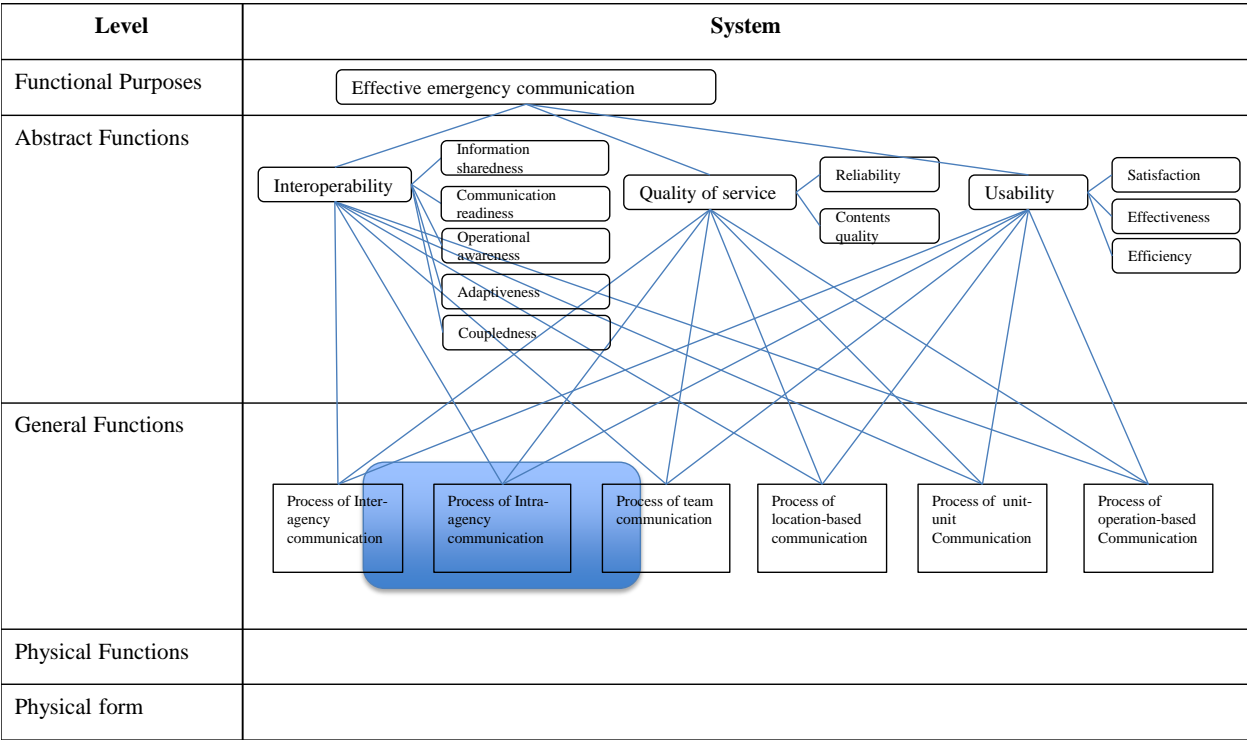


Figure 23. Functional Coverage of Current Communication Systems

In this research, when combining the identified GF and AF, an additional GF was revealed in this phase. For instance, in commander-centered network structures, the communication capability between the decision makers in each team is highly valued and needs to be supported. This communication capability would be classed as a GF (unit-to-unit communication).

Communication structures can consist of a combination of networks and hence are more dynamic than network structures. In the case of regular inter-organizational operations, communication can be performed in small team structures (functional areas) as well as in the incident organizational structure. These system functions do not describe task structure directly but rather define constraints or requirements for the communication task.

6.2.4. Communication Systems: Object Related Functions

In this phase, the general function level was decomposed into object-related functions, the so-called physical functions (Figure 24). For example, the general function ‘Process of inter-agency communication’ can be primitively decomposed into a scan of channels, channel selection, and talk. Other system level functionalities such as user identifier, location identifier, task classifier, group identifier, situation identifier, and motion identifier can be used to support basic communication functions. The cognitive radio platform, including an emergency mode, is incorporated into these functionalities, all of which are ultimately related to the physical interface.

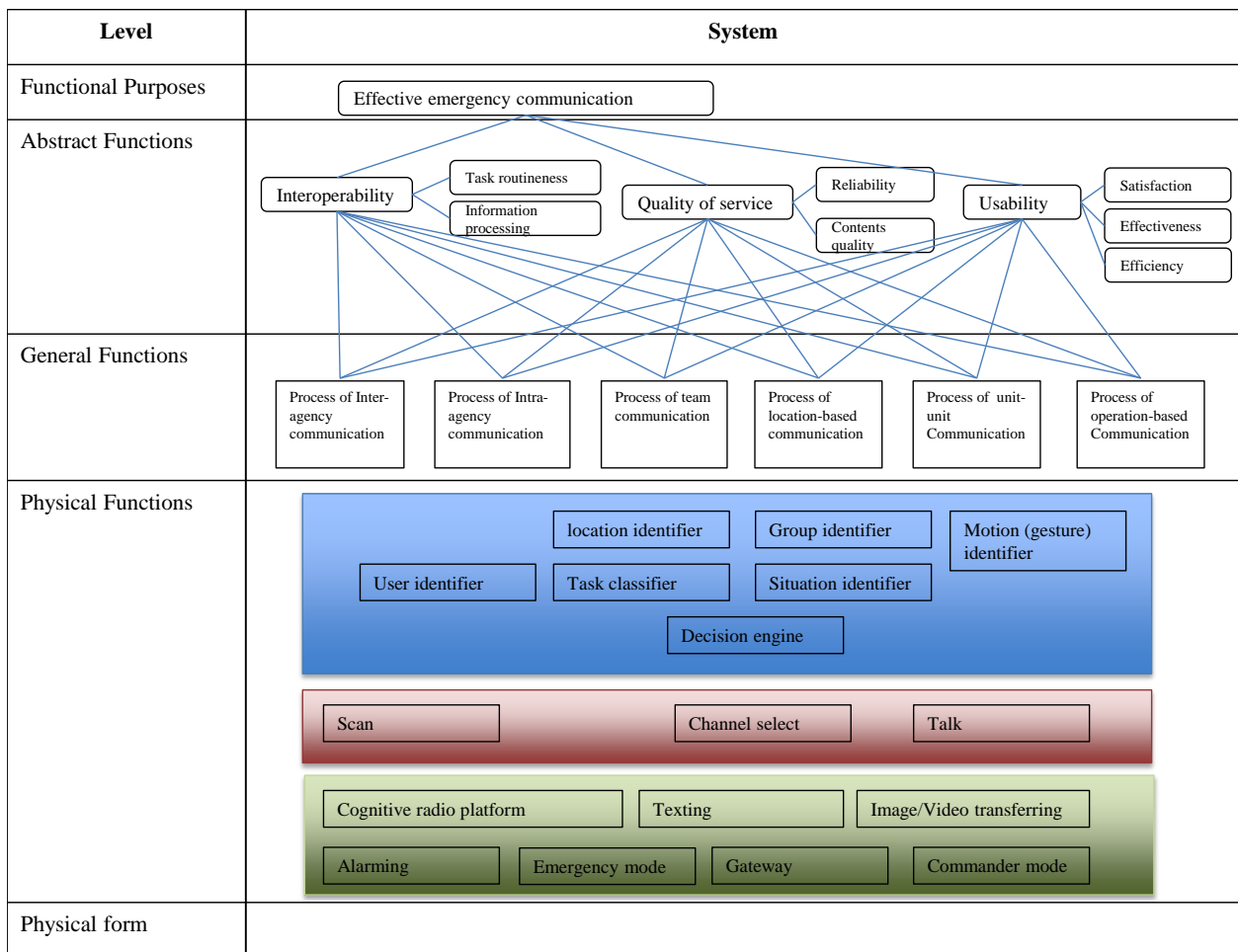


Figure 24. Physical Functions of Interoperable Communication Systems

In this phase, the specific sub-function required to perform a general function is defined in terms of functional objects. The object-related functions defined, namely the Physical Functions, may then be incorporated into a data model of radio communication systems. This data model should be compatible with the pre-developed data model for software-defined radio to ensure compatibility and interoperability by the Department of Homeland Security (DHS) (DHS, 2006).

Another aspect of the data model is the situational aspect, which may be collected instantaneously by public safety communication systems. Based on the relationship with object-related functions and general functions, an updated situation model was therefore also provided. In particular, in this phase, the cognitive radio technology previously developed by VT, CWT², was integrated into the model.

When it comes to the public safety domain, cognitive architecture, especially the user domain and environment domain, should be refined to reflect the specific parameters of the individual user(s), task, organization, and environment. Based on an ecological constraints analysis, the previous study collected most of the functional requirements. The situated information was then categorized on the basis of the macro-ergonomics viewpoints (Hendrick & Kleiner, 2001);

- Information from the technical system: Information from personal communication systems, information from vehicles (number of vehicles, distance and location of the vehicles), information from intelligent buildings, information from other devices (except other CR), etc.
- Information from the environment: temperature, absolute location, building information, distance from the crime/fire scene, incident information, weather, etc.
- Information from the organization: organizational objective, type of organization (federal/local (police, fire, EMS, etc), organizational structure, team structure, cultural information, collaboration pattern, etc.
- Information from the personal subsystem: personal objective(s), short-term task goal(s), physiological data, types of agents, their expertise, interface usage pattern(s), current emotion(s), gestures, motion, etc.

This study classified the level of the situation domain according to the degree of sensing technology. Since modeling is a process of abstraction, it is important to identify suitable abstraction rules and to classify information appropriately. For example, if a firefighter has not moved for some defined time and the outside temperature is high, then the CR hand-held system can notify the nearest agent. The current user's status, such as movement, body temperature, and external temperature, can be input to the cognitive radio as a part of the situation domain. The situation model aggregates this information with abstraction rules. Based on reviews of the situation and cognitive architecture model, this study proposes a level of cognitive architecture which mainly focuses on the situation domain and situation model. Table 20 lists the specific categories used for the situation domain and model.

Table 19. Level of cognitive architecture in terms of the situation domain

Cognitive radio	Technical capabilities	Situation domain	Situation model	Feedback to user (example)
Level 1	Spectrum sensing (radio/policy domain)	Database of organization/person	Matching with database and frequent spectrum	Known user: list of name, organization; Unknown user: Power of spectrum
Level 2	Spectrum sensing, basic environment data (location, temperature, other device), check in (e.g., finger-printer)	Including all the above, environmental data, user preferences (such as frequent menu)	Case-based reasoning for environmental event and user preference model	Notice and communicate with a person whose body temperature suddenly changes (firefighter)
Level 3	Spectrum sensing, basic environment sensing (location, temperature, topology, building, distance from the wall), basic individual sensing (motion, acceleration, direction, physiological data such as EEG, heart rate, EMG)	Including all the above, advanced environmental data; User profiles including physiological data	Computer agent for identifying user intention (gaze, direction, etc.) from the physiological and environmental patterns	If a user indicates a certain group in a disaster situation, show the list of the group.
Level 4	Spectrum sensing Advanced environment sensing (visual pattern recognition) Advanced user sensing (voice recognition, visual pattern recognition)	Including all the above, visual pattern, voice and audio recognition	Natural language processing	Naturally communicate with users
Level 5	Spectrum sensing Advanced environment sensing Advanced user sensing Team/organization sensing	Including all the above, ethical, political, and organizational issues	Political, ethical and cultural policy, organizational policy	Decision aids and advising, background collaboration with other devices.

6.2.5. *Physical Objects or Forms*

The final details of the proposed system are represented in this level. Here, appropriate interface units were investigated to determine how well they could support the object-related functions identified. Public safety communication systems consist of three different types of systems: dispatch systems, mobile systems, and handheld systems. This study focused on optimizing personal communication system functionality, specifically mobile communication systems that will be installed in public safety vehicle systems as well as personal communication devices that will be carried by public safety workers, and therefore a consideration of organizational information systems was outside the scope of this investigation. Figure 25 shows a screen shot of scan, talk, and gateway mode interfaces for hand-held communication devices.

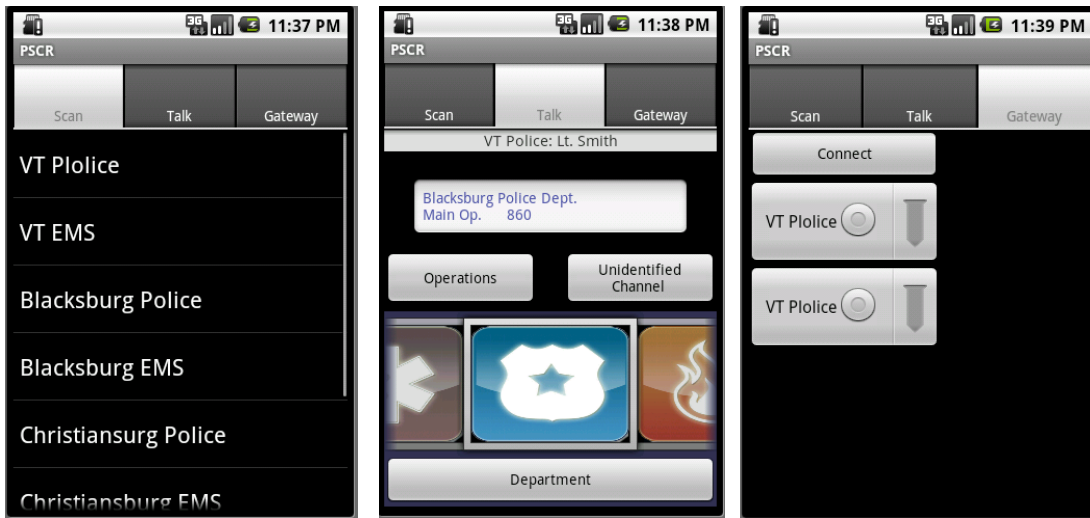


Figure 25. A Screenshot of Handheld PSCR Device

6.2.6. *Social organizations*

Once the system constraints had been identified, both the structure of the technical systems and the social systems could be designed. As Rasmussen et al. (1994) pointed out, many possibilities exist when designing the structure of social organizations. The communication system, as this study has previously identified, is highly depended on the organizational structure. Thus, the current Incident Command System (ICS) and operational process were actually designed based on the current communication systems in order to support effective operations. Nevertheless, the characteristics of the current communication technology have acted as a constraint limiting the performance that is possible for the ICS. Hence, if the technical limitations are forgone, there might be a chance to redesign ICS to maximize the operational performance. This framework thus provides an opportunity to redesign both the technical and social systems simultaneously based on the property of collaboration that is intrinsic to interoperability. For example, the current ICS has two distinctive organizational units, divisions and branches, that represent the functional and geographical aspects of the organization. However, as previously mentioned, the communication systems often utilize more flexible networks such as small groups, unit-unit, or a group of decision-makers. In loosely coupled systems, this flexibility is necessary so that the organizational structure will harmonize with the communication structure.

6.3. **Conclusion**

There were two main outputs produced this phase of the research. The first was the completed Abstraction Hierarchy that represents the different levels of systems knowledge relevant to interoperable communication systems and shows the relationships between each level. Based on this model, the functionalities related to specific values derived during the first two studies were identified. Table 21 shows a summary of the work domain analysis for interoperable communication systems.

Table 20. Summary of Abstraction Hierarchy for Interoperable Communication Systems

Level	Meaning	Contents of AH of interoperable communication systems
Functional Purposes	The purpose for which a communication system is designed	Effective and safe communication for emergency team performance
Abstract Function (Values and Priority Measures)	The values or priorities that must be preserved in carrying out tasks	Themes of interoperability and its relationship with organizational characteristics; for example, relationship between information asymmetry as a theme of interoperability and task variability
General Function (Purpose-related Function)	The purpose-related functions that a communication system is designed to achieve	Functions to achieve a proposed model of interoperability such as dynamic grouping, communication of 1-1, 1-n, 1-specific role in the team, and inter-organizational communication, multi-media communications, etc.
Physical Function (Object Related Processes)	The interface object-related functions designed to achieve the general function	Scanning, Talking, Gateway, Group Identifier, Text Messaging, Video Conferencing, Composing a Communication Group, Saving a Group, etc.
Physical Objects or Forms	The appearance and spatial location of the interface objects	Interface Unit for Scan, Interface Unit for Gateway Mode, Interface Unit for Group Composition, Data Model, etc.

The proposed model includes the design parameters of interoperable public safety communication systems and these have been integrated with the cognitive radio capabilities developed by VT CWT². Based on the integration of the model and the currently available technology (cognitive radio technology), this research has shown that there is indeed a functional gap between the current technologies and an ideal model, which therefore represents a direction for future research.

The second output was a prototype interface, which corresponds to the physical form layer in the AH. The prototype was intended to support the model of interoperability based on the above-mentioned procedures. The physical forms identified here were then organized and structured in a

visual format, for convenience. Prototyping was done with both Microsoft Powerpoint 2007, Visual Basic 2008 with Windows Mobile SDK 6.1, and Eclipse with Android 2.1 SDK. Although no real communication functionality was supported, the level of detail of the prototype was sufficient to evaluate potential usability issues and move on to a review of the proposed model in the next phase, focus group.

7. EVALUATION OF THE PROPOSED MODEL AND PROTOTYPE : FOCUS GROUP

Abstract: The main objective of this phase of the research was to review and validate the completeness and appropriateness of the model and the usability of the prototype described in the previous chapter with the aid of a focus group. This phase was necessary because although many other researchers have suggested a similar design framework for interoperable communication systems, it was possible that other domain-specific characteristics remained to be identified. The focus group deliberations validated the model of interoperable communication systems in terms of completeness and appropriateness from a user's perspective. Participants' comments were treated as design requirements in the physical function layer of the Abstraction Hierarchy and a review score for completeness and appropriateness was subsequently provided. Overall ratings of completeness and appropriateness were good. The byproduct of this focus group interview was a set of design recommendations and alternatives for interoperable communication systems.

7.1. Introduction

A focus group is a form of group interview that capitalizes on communication between research participants and researchers in order to generate themes or review previous results (Kitzinger, 1995). The researcher intentionally facilitates group interaction as part of this method. Listening to the experiences and points of view of the other group members helps participants understand the concepts under discussion and generate critical feedback. The researcher, as a facilitator, provides the main themes or theoretical concepts to the group as a whole rather than asking specific questions of each participant. This method is particularly valuable for exploring people's knowledge and experiences in terms of interactive and generative ways. The main aims of a focus group are the following (Kitzinger, 1995):

- To highlight the respondents' attitudes, priorities, and framework of understanding regarding the system or concept;
- To prompt research participants to generate and explore their own questions and develop their own analysis of common experiences;
- To encourage a variety of communication from the participants, thus tapping into a wide range and many forms of understanding;
- To help to identify group norms and cultural values;
- To provide insight into the operation of group social processes in the articulation of knowledge (for example, through the examination of what information is censored or muted within the group);
- To encourage open conversation about sensitive subjects and to permit the expression of criticism;
- Generally to facilitate the expression of ideas and experiences that might be left underdeveloped in an interview and to illuminate the research participants' perspectives through debate within the group.

In this research, experts assessed how accurately the proposed model explained the dynamic communication and whether the approach was effective or not. Both the newly developed model and the prototype interoperable communication system were presented to the group.

7.2. **Methods**

7.2.1. *Recruitment*

In this research, the main sampling strategy was the purposeful selection, particularly criteria and convenient sampling (Patton, 2002). The main criteria guiding participant selection were as follows:

- Participants should have emergency communication experience that includes experience as a firefighter, an EMS provider, a police officer, a hazmat technician, and/or a federal

emergency agency worker, or served as and volunteer in one or more emergency assistance efforts;

- Participants should have at least one year's experience in dealing proficiently with public safety communication systems;
- One or more of the participants should have served as an incident commander at least once;
- Participants who have had experience with a mass disaster or a large-scale emergency operation would be preferred.

Based upon the above criteria, the regional public safety agencies were contacted. Both telephone and email contact was utilized as the primary recruitment methods. Six participants were recruited for this phase of the study, as recommended by Kitzinger (1995). All participants had more than one public safety work experience, including the emergency medical service, police, search and rescue, and fire service.

7.2.2. Conducting the Focus Group Session

Once the participants had been recruited, the focus group meeting was scheduled at a place and time that was convenient for all. A paper handout and a laptop presentation were used to introduce the proposed model and demonstrate the prototype. At the beginning of the session, the researcher briefly introduced the objectives and summary of this research and discussed how confidentiality and anonymity would be ensured. The participants were asked to read and sign the informed consent document for the focus group (Appendix E).

In the focus group phase, the participants were encouraged to talk to each other rather than addressed themselves to the researcher only. The researcher presented the results of Study 3 (Chapter 6) in as straightforward a manner as possible. At the end of the presentation, discussion was encouraged. During the focus group, the researcher put forward three different operational scenarios in order to enable the group to walk through how the communication procedures would perform in specific contexts using the proposed model and prototype. Focus group questions were developed by the researcher and reviewed in terms of content and readability (Appendix C). A semi structured questioning process was adopted to guide the overall direction of the focus group. The participants were encouraged to freely discuss the effects on their organizational

communication effectiveness and individual effectiveness of using the proposed systems. During this phase, the description of critical incidents was transcribed. The session lasted three hours, with a short break, and was recorded with a voice recorder.

When the focus group discussion drew to a close, the participants were asked to complete a set of questionnaires regarding the completeness and appropriateness of the model and overall usability of the prototype (Appendix F). Based on the results of the comparison study for usability scales (Bangor, Kortum, & Miller, 2008; Tullis & Stetson, 2004), the System Usability Scale (SUS) was used (Brooke, 1996). The exit questionnaires were filled in individually and independently by the focus group participants.

7.2.3. Content Analysis

The analysis of the focus group was basically identical to the previous qualitative analyses in Chapter 3. Transcripts were done using Microsoft Word 7. Excel was utilized to analyze the transcripts. Two coders were involved in the analysis according to the recommendation by Thompson et al. (1989). The interpreters were chosen based on the following criteria to establish reliability:

- The interpreter should have at least one previous experience with conducting a qualitative study;
- The interpreter should have substantial knowledge about the usability and human factors issues; i.e., he/she should have taken at least two classes related to Human Factors/Human Computer Interaction;
- An interpreter who has some knowledge about the public safety work domain would be preferred.

Applying these criteria, two interpreters were recruited. They underwent a two part training session, one of which concerned domain knowledge and the other the skill of analysis. First, they received a one hour training session regarding the public safety domain and the relevant communication systems, before the analysis. The basic material was a modified version of the human factors material originally developed for use in the VT PSCR School program for the

Naval Surface Weapons Lab. in 2007 (Kwon, 2007). In the second part of the training, the interpreters reviewed a randomly selected portion of the focus group interview in a thirty-minute training session. Inter-interpreter reliability was measured using Cohen's Kappa (Cohen, 1960). At least 61% agreement was chosen as the criterion for accepting the interpreters, which is considered as substantial agreement by Landis and Koch (1977). Here, the inter-interpreter agreement was 73.6% and therefore acceptable.

When coding the script of a group discussion, it is often useful to assign special categories for certain types of narrative, such as jokes and anecdotes, and other types of interaction besides discourse (Kitzinger, 1995). In this analytic phase, the completeness of the model and effectiveness of the prototype were reviewed. Firstly, the relationship between the model of interoperability and general function was confirmed based on the results of the content analysis. The coder focused on any missing concepts or functionality during the focus group discussion in order to review the completeness of the suggested model. The general function and object-related function layers were also reviewed. For the prototype, usability aspects were emphasized. The contents were investigated using the perspectives of Efficiency, Effectiveness and Satisfaction as the main properties of usability, as suggested by ISO (ISO 9241-11).

7.3. Results

7.3.1. Need for direct communications

Day-to-Day operation, classified by Irving (1996), refers to frequently performed operations and daily events such as traffic accidents, robberies, or alcohol poisoning incidents. Even though the event is normally small in size, some degree of collaboration with other agencies is necessary in most cases. Participants mentioned that they were expected to go through the dispatch center for political reasons when they needed to collaborate with other organizations. However, in most cases the participants would prefer to connect directly with people from other agencies at the scene:

- “I could talk to the fire person on scene but they don’t allow that and so there’s an issue there.”
- “There are a lot of issues because they don’t even want us talking on the fire department frequency.”

The proposed systems support this direct communication with other agencies at the scene, which is one of the main features of the proposed systems. Most participants were satisfied with this function and interface. They agreed with the aim of communication design even though the system needs to include a function that supports acceptance of communication when other agencies request direct communication with them. For example, if an EMS provider asks to connect to a police channel in order to communicate with a police officer, the police communication network needs to know who is making the request to communicate with their organization. If they are currently discussing confidential issues, the police chief or incident commander may not approve the inclusion of EMS providers in their network, or vice versa.

7.3.2. Reducing the communication traffic

The participants indicated that they frequently suffer from a serious overload of communications in large-scale cases. For example, more than 10 organizations may be involved in controlling a large event such as a college football game. The participants had often suffered from some confusion regarding communication channels and collaboration within certain boundaries. This issue was also raised by the participants in the study reported in Chapter 3. The focus group participants discussed and simulated using the new model in a high communication traffic situation, commenting:

- “There’s no reason that every person in the department needs to hear every call that goes out.”

They provided an example of the communication traffic and the need for separate channels in terms of football game day control:

- “And people were standing and pushing each other. Nobody got seriously hurt but there were a few asthma attacks and things like that, but if it had gotten worse, and you had all those agencies there, you would not have been able to talk to anybody. Mostly you would have been looking for people who needed help and taking them to the hospital without a whole lot of command.”
- “And I assume that’ll be able to be changed on the fly. Like say that talk group starts to get overwhelmed, you can create a subgroup and move them down to some other group.”

The proposed system allows for communication to specific units instead of every person in the organization. The function to select communication group contextually was matched with their needs to create separate channels on demand. Although location-based talk groups must be supported, the participants would like to be able to create different talk groups in cases where multiple incidents occur in close proximity. In addition, alternative media such as texting and video transfers may reduce voice communication traffic. These functions were conceptually suggested in the model but had not yet been implemented in the prototype. The group members expressed strong interest in using the prototype as soon as possible.

7.3.3. Unit-to-Unit communications

During the focus group discussion, the need to use cellular phones for public safety communications was frequently discussed. The current cellular technology often substitutes for public safety communications in terms of unit-to-unit communication. In most cases, it is not necessary for information to be disseminated to the entire organization. Most participants concurred that a new communication system should incorporate unit-to-unit communication just as in a cellular phone network. However, the group also raised concerns about the patchy coverage of cellular communication networks, especially in rural areas:

- “So we’re kind of out there, and relying on cell phones and then when you get into Craig County, which occasionally we go to Craig County, cell phones might not work so then you’re really out there by yourself.”

Since the public safety cognitive radio uses the reserved public safety radio frequencies, if there are enough repeaters good coverage should be available even given the lack of communication infrastructure in some areas.

7.3.4. Identifying who is taking and where he/she is

Public safety communication consists essentially of multiple recipients communicating with each other. The participants actively discussed the problem of identifying communication partners. The communication device itself has a function to indicate the user's identity and even to understand the current situation, including location information:

- “It's like 'where are you ma'am?' 'I don't know where I am, I'm somewhere on the road!’”
- “So they would be able to know Sue was cursing on the radio.”
- “On the other hand, it would be very nice if we knew that. A lot of times it is nice to know where our resources are when you're running a big incident.”

However, they also expressed reservations due to possible privacy issues regarding personal identification. The participants supported including a function to turn off the identification or the incorporation of a stealth communication mode.

7.3.5. Organizational differences

The investigator asked about differences of adaptability among organizations. Beyond simple technical adaptability, the functional structures of the two main organizations, police and EMS, are very different so the two organizations react differently at the same event:

- “You are right, I mean absolutely and your example of any police officer serving in any capacity is very right and EMS generally has a tendency to be more structured than that.”

This implies that the communication systems should be able to reflect the appropriate organizational structure, which includes operational procedure, coupling, and formalization.

7.3.6. *Completeness and appropriateness*

Overall feedback from the focus group participants regarding the new model and prototype was very good. The investigator explained the functions of a new communication system and discussed how the systems would be designed. The participants' responses mostly concerned issue that would be included in the general function layer in the Abstraction Hierarchy (AH). Their discussion provided very good inputs for specifying the physical function layer, which generally consisted of modular functions to support a general function or interface-related functions. They also asked about the functionality of different communication system such as vehicle-based systems or dispatch systems. The investigator explained the previous project using laptop based systems that emphasized the functionality of utilizing talk groups and gateway mode. At the conclusion of the focus group discussion, the participants appeared to be very satisfied regarding the overall directions of the design:

- “You guys definitely are on the right track, you have definitely thought about a lot of stuff. Now the big question is whether there will be any funding for a real system.”

Finally, they suggested the use of Bluetooth capable communication systems in order to enhance functionality and communicate with other medical devices.

7.3.7. *Exit Questionnaires*

The exit questionnaires consisted of two parts. The first part consisted of a completeness/appropriateness scale that was developed by the researcher after finishing the first two studies (reported in the first half of this dissertation). The researcher asked participants to consider the perceived completeness and appropriateness of the proposed systems compared to the current system and the results therefore indicate the relative completeness/appropriateness of the proposed system (Table 22). The results revealed an overall mean of 4.696 and a standard deviation of 0.501.

Table 21. Result of Completeness/Appropriateness Questionnaire

Item	Prompt	Mean	Standard Deviation
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1	I think the purpose of Public Safety Communication Systems is well described	4.6	0.548
2	I think the overall value of this system is well represented	4.6	0.548
3	I think this system can provide support to directly and effectively communicate with incident commanders.	4.8	0.447
4	I think this system can provide support to directly and effectively communicate with partners during an operation.	4.75	0.500
5	I think this system can provide support to directly and effectively communicate with dispatchers.	4.6	0.548
6	I think this system has enough functionality to communicate with your partners within specific boundaries of operation.	4.8	0.447
7	I think this system has enough functionality to notice the emergency situation to your partners	4.8	0.447
8	I think this system can effectively support inter-organizational communication.	4.6	0.548
9	I think this system can support the communication among different teams in an organization	4.8	0.447
10	I think this system can support the communication among decision- makers	4.6	0.548
11	I think this system can support unit- to-unit communication	4.8	0.447
12	I think this system has enough functionality to support the communication in day-to-day operations	4.8	0.447
13	I think this system has enough functionality to support the communication in mutual-aid operations	4.6	0.548
14	I think this system has enough functionality to support the communication in Task-force operations	4.6	0.548

* Item response scale range from 1(Strongly disagree) to 5(Strongly Agree). Higher scores indicate higher completeness/appropriateness.

To check the usability of the proposed prototype, the System Usability Scale (SUS) was utilized and the results are shown in Table 23. However, even though the participants were asked to answer a series of questions about the proposed prototype, there could be problem if the prototype had insufficient fidelity. The participants complained that they could not adequately measure usability issues without access to a working prototype. Nevertheless, the overall usability score was expected to be good ($M = 4.05$, $SD = 1.017$). All the items and prompts are presented here.

Table 22. Result of Usability Questionnaire

Item	Prompt	Mean	Standard Deviation
1	I think that I would like to use this system frequently	4.6	0.548
2*	I found the system unnecessarily complex	3.6	1.517
3	I thought the system was easy to use	3.2	1.643
4*	I think that I would need the support of a technical person to be able to use this system	3.6	1.517
5	I found the various functions in this system were well integrated	4.25	0.957
6*	I thought there was too much inconsistency in this system	4.5	0.577
7	I would imagine that most people would learn to use this system very quickly	4.4	0.548
8*	I found the system very cumbersome to use	4.75	0.500
9	I felt very confident using the system	4	1.225
10*	I needed to learn a lot of things before I could get going with this system	3.6	1.140

* Item response scale range from 1(Strongly disagree) to 5(Strongly Agree). Items 2,4, 6,8, and 10 are reverse coded so higher scores indicate higher completeness/appropriateness.

7.4. Implications

Various discussions related to the functions of public safety radio systems occurred during the focus group meeting. The participants considered several themes related to communications in the field of public safety. In this section, the identified themes are classified in terms of the five layers of the abstraction hierarchy, with attention being paid specifically to the detailed design requirements and physical layout design. The prototypes this study provided here were only an example of design direction that the participants mentioned during the focus group. Table 24 represents the design recommendations and rationales for the prototypes.

Table 23. Abstraction levels and design rationale

Themes (Problems)	Abstract functions	General functions	Physical functions	Design rationale
Needs for direct communications	All dimensions of interoperability, Quality of service, usability	Unit-to-unit communication, intra-, inter-agency communication, operation-based communication	Location identifier, group identifier, situation identifier, motion identifier, channel select	Select an agency or unit at the scene contextually, Identify who are in the operational boundary
Reducing the communication traffic	All dimensions of interoperability, Quality of service, usability	Unit-to-unit communication, inter-team communication, operation-based communication	Location identifier, group identifier, situation identifier, motion identifier, channel select	Separate channel with relevant group, easy to navigate group communication
Unit-to-unit communications	All dimensions of interoperability, Quality of service, usability	Unit-to-unit communication, operation-based communication	User identifier, location identifier, group identifier, situation identifier, motion identifier, channel select	Provide public safety workers' detailed information at the screen, select a unit within an organization
Identifying who is talking and where he/she is	All dimensions of interoperability, Quality of service, usability	Unit-to-unit communication, operation-based communication	User identifier, location identifier, group identifier, situation identifier, channel select	Provide personal information including location, organization as well as rank.
Organizational differences	All dimensions of interoperability, Quality of service, usability	Inter-agency communication, operation-based communication	Group/organization identifier, situation identifier, channel select	Provide organizational function and interface

7.4.1. Needs for direct communications

The function of direct communications can be specified in the physical function of AH. This is related to the processes of inter-organizational communication, location-based communication, unit-to-unit communication, inter-organizational communication, and operation-based communication in the general function layer in AH. For direct communications, one of the most important issues may be the selection process involved in reaching the appropriate communication partner. If the user already knows the partner's name or organization, he/she can select the name of the agent in the unit-to-unit communication list or the name of organization in the inter-organizational communication list. If the user does not know the name of the individuals involved in the operation, he/she can choose the person they need to speak to using the proposed augmented reality interface. When the user goes to AR mode, he/she can see individual people through the camera and PSCR screen (Figure 26). If the user selects "EMS", "Fire" or "Police", he/she receives information on the identities of the police, fire and EMS personnel present. The user can thus identify the partner's organization and name by zooming in on their image on the screen using multi-point finger interaction. This set of interfaces is related to the user identifier and selection process in the physical function layer of AH. In addition, a gesture-based interface can support the prioritization of the preferred network when the user indicates a certain place or person.



Figure 26. Cognitive Radio with Augmented Reality

7.4.2. Reducing the communication traffic

When a public safety worker needs to communicate only with people within a certain range, the system provides a map view that the user can use to select that range. This is particularly effective when multiple incidents occur at the same location or in close proximity. For example, when the user is policing an event such as a large football game, several emergency situations may occur simultaneously at different sections of the stadium. Each section needs a separate talk group in order to minimize information overload and maximize communication efficiency.

The process of location-based communication is designed to support local communication constrained by geographical region. Selecting specific boundaries can facilitate direct communications within that range. Since Public Safety Cognitive Radio (PSCR) can scan the currently available frequencies, it can configure a network based upon the results of the scan. Thus, if all public safety agencies are equipped with PSCR, they can connect to each other

instantly and create a talk group. Figure 27 shows the interface for location-based communication.

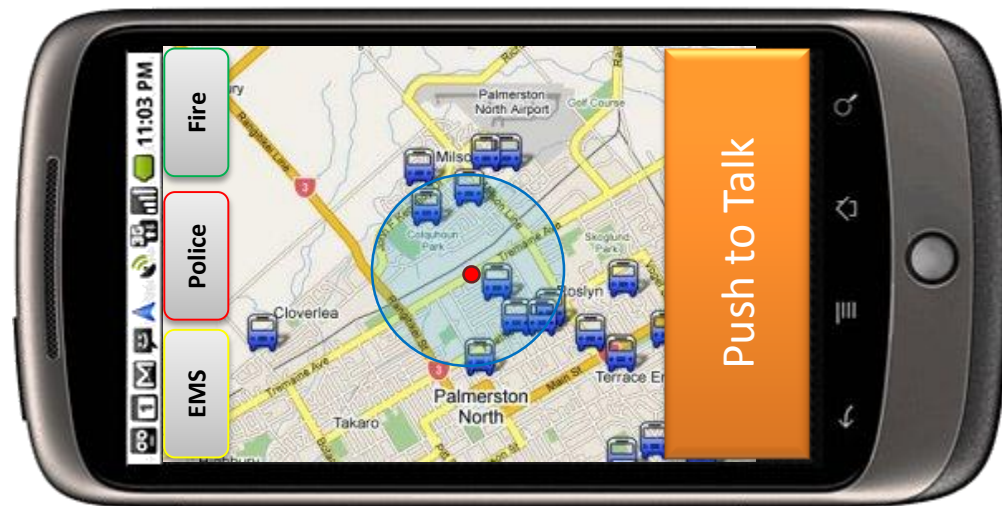


Figure 27. Interface for Location-based Communication

Team or contextual group communication offers another potential solution to reduce communication traffic. Should the user wish to select the specific person serving as the incident commander or EMT specialist, the PSCR needs to be able to provide a list of commanders or specialized agents based on the results of contextual reasoning. For example, if the user pushes the operation button and selects the commander, the PSCR establishes a communication network between the user and the commander.

7.4.3. *Unit-to-unit communications*

Unit-to-unit communication is designed for operations within a single organization. This assumes the user already knows the name of the agent or the identification number of the communication partner, such as a hospital ID. Most of the participants' cellular phone traffic was used to communicate with other team members or pre-defined contacts such as hospitals in the nearby area. In order to replace this cellular phone function, PSCR should support the creation of pre-defined contact lists within an organization. For example, when a user selects the

police department, an interface should come up that provides a navigation button to choose individuals within that department. The default value should be to communicate with all agents in the selected organization. If the user selects an individual, he/she can communicate directly with that person, just as with a cellular phone (Figure 28). As previously mentioned, this is considered an important function by the focus group participants as it provides a way to deal with any privacy issues.

Individual Function

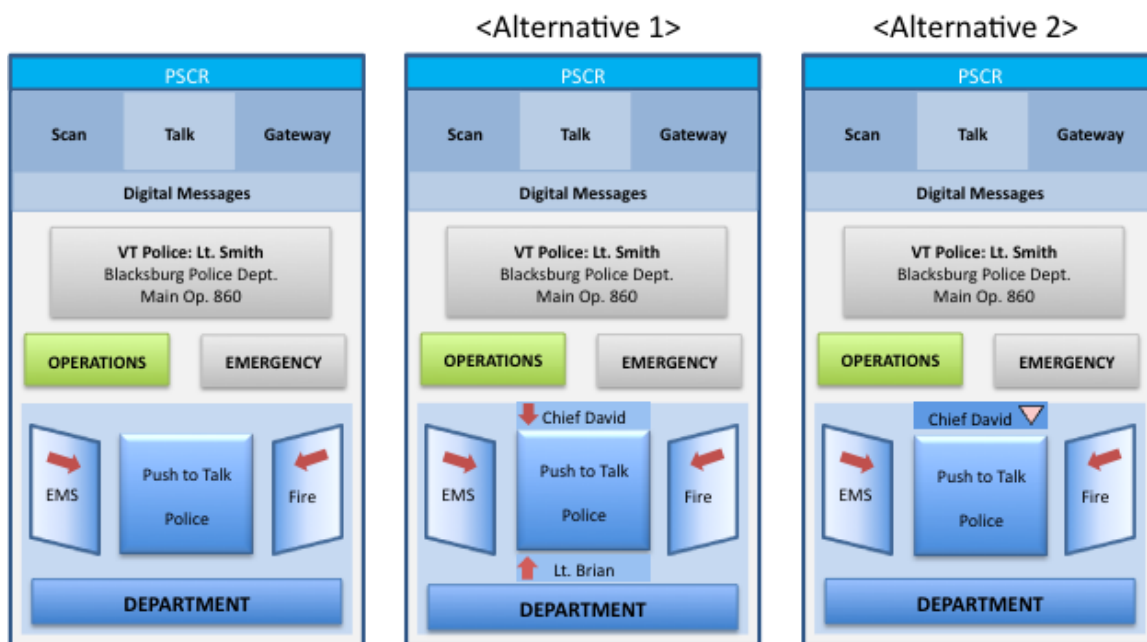


Figure 28. Interfaces for Unit-to-Unit Communication

7.4.4. Identifying who is taking and where he/she is

The interface presented above in Figure 23 includes an information display panel that shows communication information, including identifying those currently talking and which network they belong to. If the communication network changes, the PSCR will provide auditory feedback to prevent the user from accidentally switching networks.

7.4.5. Organizational differences

As the participants noted, each organization performs different roles at an operation. This study also highlighted organizational differences in information sharedness as well as adaptiveness. Those two characteristics may be related to their tasks and the decision making processes involved. For example, most EMS decision making is performed at the scene since the agents present have the vital information regarding patients' symptoms or biomedical signals. They often need to make decisions depending on certain guidelines in life-critical situations. During the focus group discussion, EMS providers noted that it would be helpful to be able to transfer biomedical signals using their communication systems to a doctor who is an expert in a particular area in order to help their decision making. To do this, they would like to integrate communication systems with medical information systems using Bluetooth communication. This contrasts with the approach taken by the group participants who were trained police officers, who recommended the inclusion of digital communication functions such as texting and video/image transfers. This result supports the findings of the study reported in Chapter 3, where police officers also requested the ability to send and receive texts for administrative tasks (Figure 29).

Digital Messages-Text



Figure 29. Interfaces for Texting

Most asynchronous communications will be supported through texting or image transfer functions. This study incorporated unit-to-unit communication with digital communication. Public safety workers using the new system will be able to send text/image/video to anyone/everyone in the organization they belong to as well as sending text to other organizations (Figure 30). However, the ability to send text to all members may need to be limited to commanders or higher-ranked officers in order to reduce communication traffic.

Digital Messages-Photo/Video

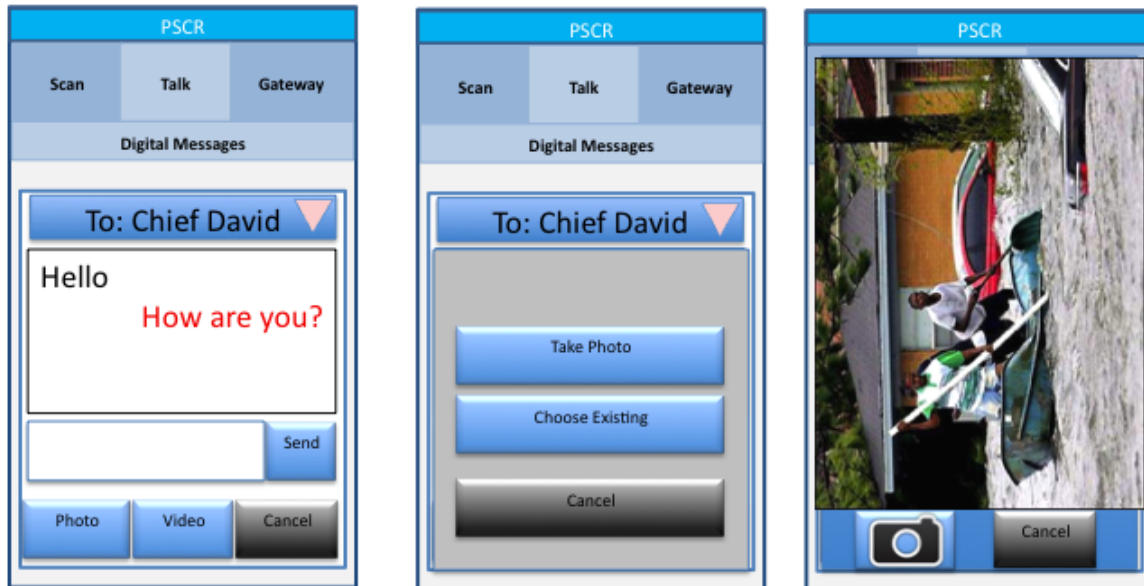


Figure 30. Interfaces for Digital Messages (Photo/Video)

7.5. Conclusion

The purpose of this study was to review the proposed model and prototype in order to develop more concrete proposals for the suggested model and provide formative feedback to the design phase. The content analysis of the participants' behavior and verbalizations during the focus group revealed the completeness and appropriateness of the model. All in all, they appeared to be very satisfied with the proposed model and prototype. The results of the focus group discussion improved the AH considerably, especially the physical function layer. The general functions that were defined in Chapter 6 covered most of the feedback from the participants. However, the additional information provided in the focus group session was particularly important as it helped to identify the detailed design requirements regarding the physical function and physical form layers. The review scores for completeness and appropriateness were collected using a questionnaire. The overall ratings for both completeness and

appropriateness were good. In order to explain clearly the conceptual model, this study utilized a prototype that was an instance of the proposed model. Even though the researcher designed the proposed prototype using the model, it might not completely reflect the system's functionality. Thus, the researcher tried to explain the broader systems concepts with the proposed model during the focus group in order to provide more social elements that are relevant to this operational context.

The second output was the review score for the usability of the prototype. The System Usability Scale represents a potential user's overall satisfaction with the usability aspects of the design. Based on this analysis, a set of design recommendations for an interoperable public safety communication system was developed. These suggestions were categorized in terms of the four levels of abstraction from the abstraction hierarchy theory, except for the functional purpose level. All in all, this study provided certain degree of ecological validity as the real user reviewed the proposed systems under simulated situation.

8. SUMMARY OF THE RESEARCH

8.1. Overall Outcomes and Contributions

This research consisted of four main studies that were designed to develop a comprehensive understanding of the concepts involved in interoperability, along with a model of an interoperable communication system that would enhance communication performance in the public safety domain (Table 24).

The purpose of the first (qualitative) study was to identify the concept of interoperability and understand interoperability, applying sensemaking as a theoretical framework. The final output from this study was a set of themes that could be used to explain the concept of interoperability. These themes and the result of the interviews were delineated according to the seven properties of sense-making. This was an important process designed to identify precisely how interoperability affects organizational decision-making and performance and explaining this by means of the concept of sense-making. Based on the qualitative findings, this study developed a measure of interoperability. This descriptive approach was adopted in order to provide an in-depth understanding of public safety communication tasks and apply the results to design improved technical systems as well as social organizations that can make best use of the new systems. This study also revealed how stressful many communication tasks are to use and how limited the existing systems are in practice. Thus, it is hoped that this better socio-cognitive understanding of interoperability will contribute to research into how the current communication technology influences user behaviors in the context of loosely coupled systems.

The aim of the second study was to validate the instrument to measure interoperability that was developed in the first stage of this dissertation. This study utilized a questionnaire to investigate the relationships among interoperability, work-unit task activities, and information processing. Confirmatory Factor Analysis was used to statistically confirm the instrument's construct validity. This study also revealed relationships with other variables such as task analyzability, task variety, information amount, and information equivocality. Structural equation modeling was used to examine the structural relationships among the variables. The findings of this study were based

on perceptual data from new questionnaire scales and a survey developed by Daft and Macintosh (1981). Only two types of public safety organizations were involved in this project, namely the police force and EMS rescue squad, and sixty four participants responded to the questionnaire. Within these limitations, the data suggested a possible new perspective on interoperability among organizations or within an organization. In terms of organizational theory, task routineness and sense-making were expected to have a direct relationship (Fulk & Boyd, 1991). The relationship between task routineness and information processing was demonstrated by Daft and Mackintosh (1981). When considered in conjunction with these theories, this study implied a close relationship between interoperability as a core enabler of sense-making and task routineness. Even though this study failed to identify any causal relationships among those dimensions, there were significant correlations among the dimensions of interoperability and the dimensions of task routineness.

The third study was designed to develop and describe a model for an interoperable public safety communication system. Using the Abstraction Hierarchy, five different knowledge representations of interoperable communication systems were identified. The model of interoperability identified from the previous studies was the starting point of this analysis. The final output of this study was the completed Abstraction Hierarchy as a model of interoperable systems as well as a prototype from the results of the analysis. During the development of the Abstraction Hierarchy, this study provided an approach to fill it. It was then decomposed and identified from its value/properties layers. Through this study, a unique example of a value-centered design framework was designed.

Finally, the fourth study evaluated the proposed system model and its prototype with the assistance of a focus group consisting of experienced public service professionals who were representative of the anticipated users of the new system. The final output of this study was to consolidate the proposed model and provide overall ratings from the perspective of usability and the completeness/appropriateness of the model. Based on the results of the evaluations, this research provided a set of design recommendations and design alternatives for interoperable public safety communication systems.

Table 24. Summary Outcomes

Study	Expected Outcomes
Defining and Reviewing the Dimensions of Interoperability	<ul style="list-style-type: none"> • Description and discussion of the dimensions of interoperability in the context of public safety communications • Reconceptualization of the dimensions of interoperability applying the seven properties of sense-making as a theoretical framework
Validation and Structural Modeling of Interoperability	<ul style="list-style-type: none"> • Validation of the dimensions of interoperability with statistical analysis • Identification of the relationship between the interoperability and organizational structural variables that affect organizational performance
Modeling of an Interoperable Communication System	<ul style="list-style-type: none"> • Details and discussion of the systems perspective of interoperable communication systems and interoperability issues in knowledge representation of different system levels • Description and discussion of the value perspective of interoperable communication systems; the lessons learned through this will allow the model to be extended to include other aspects of the PSCR communication system • Description of the application layers of public safety cognitive radio (PSCR) communication systems as a set of functional purposes, values, general functions, physical functions and physical forms • Development of a novel design framework based on the theory that reflects the above mentioned model of the PSCR. This design framework avoided the task-artifact cycle through the adoption of the CWA framework. The proposed design framework also had the benefit of completeness that complemented this descriptive approach • Development of a prototype of the PSCR interface. This interface demonstrated the interoperable structure of public safety communications
Evaluation of the Proposed Model and Prototype: Focus group	<ul style="list-style-type: none"> • Validation of the proposed model and a usability evaluation with the developed prototype. The validation process included a review of the values perspective in communication systems and an in-depth focus group interview to collect feedback related to the proposed system • Set of design recommendations for interoperable public safety communication systems

8.2. Implications and Future Studies

As this study has shown, communication among different organizations under stressful environments is a critical function in public safety operations. First and foremost, this study provides a theoretical background to assist in the design of complex collaboration systems under stressful environments. Second, this research has shown that applying the intelligent communication concept will enhance current communication practices by facilitating the implementation of joint cognitive communication systems.

8.2.1. *A theoretical framework for designing man-machine-man collaboration*

Many studies have looked at how people understand the current situation in the study of complex cognitive tasks such as air traffic control, power plant control, and military command control centers (Endsley, 1995; Klein, 1991; Vicente, 1999; Weick, 1995). Utilizing the identified concept of interoperability may shed light on open field shared situation awareness, which is necessarily complex because the information involved is dynamic, depends on the environments, and varies in each case. In the case of open field situation awareness environments such as those experienced by the infantry in combat or firefighters tackling a major blaze, the information source originates directly from a dangerous environment rather than from a closed field system. Although the need for research on situation awareness is high, the task should not be obstructed for research purposes (French, et al., 2004). The cognitive tasks involved in the maintenance of public safety are similar to those performed by the infantry in many ways. At a crime scene or in a disaster area, every situation is unique. As this research has vividly shown, agents in the field will obtain the information they need on their own if necessary, whether from communication with partners or from their personal communication systems. A hand-held system has the potential to gather information from other users, the environment itself, and from different devices. Effectively, the device itself can be considered as a communication partner. Thus, the concept of interoperability can be applied to design man-to-machine communication as well as man-to-man communication. The communication layers will be two or more in this instance. Figure 31 describes the complementarity of individual situation awareness and the cognitive cycle of a cognitive radio hand-held system.

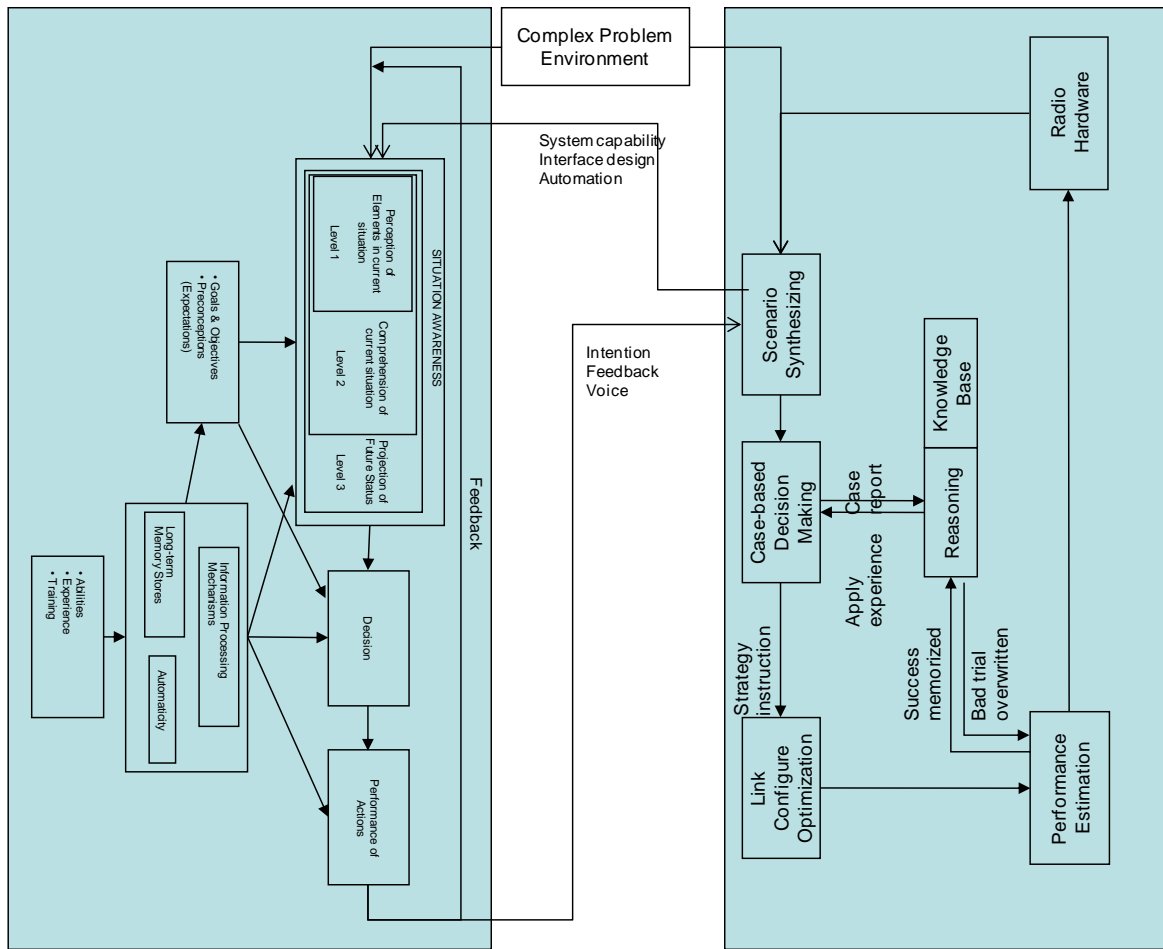


Figure 31. Individual Situation Awareness and Cognitive Cycle of Cognitive Radio (adapted from Endsley, 1995; Rondeau, 2007)

Obviously, the sensing and cognitive capabilities of man and machine are different. Thus, the concept of interoperability may be differently applied in humans and in machines. Nevertheless, each dimension of interoperability will guide those collaborations (man-machine, man-man, man with machine-man with machine, and simultaneous interactions that include multiple men and machines) in multiple layers.

8.2.2. *Understanding communication systems as joint cognitive systems*

The findings of this study suggest a valuable new perspective with which to understand intelligent interoperable communication systems as a joint cognitive system. Woods et al. (1990) used the concept of “joint cognitive systems” to stress the complex nature of problems that neither the system nor the user could solve alone. The need for communication arises due to the need for collaboration when individuals and organizations must work remotely to address a complex problem. Using the currently available communication technology, the Department of Homeland Security (DHS) has maximized operational performance by training public safety workers and redesigning incident command systems, including organizational structures and social organizations. However, as recent advances in cognitive radio technology have demonstrated, an opportunity to develop a machine that understands the needs of its users and adapts accordingly has arisen. As previously discussed, man-intelligent machine interaction or man-intelligent systems, such as a dispatcher center, can be considered as a joint cognitive system. The sharing of cognitive representations provides a capability not only to maximize operational performance but also to facilitate collaborations between different public safety organizations. Hence, the concept of interoperability may be an important perspective for those seeking to understand a joint cognitive system.

8.2.3. *A Value-Sensitive Design Framework*

Value remains a controversial issue in systems design because it frequently conflicts with economic goals and is very difficult to identify (Friedeman et.al, 1996). Many researchers have addressed value-sensitive design over the last two decades (Agre & Harbs, 1994; Borning, 2005; Friedeman, et al., 1996; Friedeman, et al., 2006). However, there are still few examples that reflect how human or social values can be applied to systems design. This study has provided a unique way to decompose social values/properties to systems functions using the Abstraction Hierarchy (AH). When Rasmussen (1986) first proposed the concept of AH, the second layer between functional purpose and generalized functions was simply an abstract function related to the causal structure of a socio-technical system, such as mass, energy, and information flows. Later, Vicente (1999) and Naikar et al., (2005) enhanced the concept of AH and applied it to

social systems. This study has extended the concept further still by applying it to the identification of a social value, in this case interoperability, and decomposing it to reveal the essential functions of interoperable communication systems. Finally, the research applied this means-ends relationship to the Public Safety Cognitive Radio (PSCR) interface design level. There may in fact be no way to identify how many values should be considered in systems design (Friedeman, et al, 1996). However, in spite of this limitation, the critical values identified using this approach should be at the center of the design strategy. Safety critical systems, in particular, need to consider human/organization oriented values as the essential focus of systems design. This value-sensitive approach is very flexible in its application to other human-oriented systems designs. This study used an indirect method to prove the effectiveness of a design framework by using a focus group. With respect to future studies, comparing this framework with other frameworks quantitatively should prove to be very valuable. In addition, identifying concrete examples where it is particularly effective may help elucidate how best to apply this framework to different technical/social systems designs.

As this study has shown, communication among different organizations operating in stressful environments is a critical function in public safety operations. Understanding new concepts of interoperability as a social value has guided all of the design processes, while understanding how social values can be applied to the design of technical systems as well as to the development of new training procedures or organizational structures may also lead to new technical-social innovations.

8.3. Limitations

Despite all the methodological care taken in this study, several factors limit its applicability. First of all, there may be some sampling bias. Even though the researcher tried to contact a wide range of the available public safety organizations in the United States, most of the participants in this study belonged to local jurisdictions or EMS units. Thus, it is possible that there were some unknown patterns of behavior peculiar to this geographical area that skewed the responses. To

minimize the bias and maximize the variability, the participants' various experiences in public safety operations were confirmed. In addition, this study targeted a very special population. Because the nature of their work is frequently critical, many security and legal issues had to be dealt with. For example, the participants often hesitated to describe sensitive issues during the interviews even though the confidentiality of the contents of the interview, survey, and focus group was repeatedly emphasized.

Given the use of self-reporting scales to measure interoperability, task routineness and information processing, the reliability and construct validity need to be ensured again at different domain levels. In particular, in the structural equation model the values of the aggregating items diluted the variability of the measurement error. Thus, the relationship among the concepts of interoperability, task routineness, and information processing may not in fact be statistically significant. However, this study did identify a relationship among some dimensions of interoperability and task routineness. A larger data set would be helpful to verify the theory, including all dimensions without the aggregation of item values.

Many previous studies (e.g., Rasmussen et al., 1994, Naikar et al., 2005; Vicente, 1999) have promoted the Abstraction Hierarchy as one of the best ways to describe the field of systems and to ensure the completeness and appropriateness of an investigation. In this study, AH was the primary framework used to represent the knowledge structure of interoperable communication systems. However, due to economic constraints, just a few iterations were performed for this study. Most design frameworks are intended to be implemented iteratively. Hence, a direct comparison of the results of this study with the outcomes from other design frameworks may not be appropriate.

Finally, during the focus group session, questions were asked concerning the perceived completeness and appropriateness of the proposed model and prototype compared to the current communication system. The 5-point Likert scales used in this study may not accurately reflect the perceived quality. However, to support the results, this study also utilized qualitative data from the focus group.

8.4. Conclusion

This research has presented a method with which to develop a better understanding of the concept of interoperability and model interoperability with organizational variables in the public safety domain. This method can also be used in other similar areas such as military communication systems or complex socio-technical systems requiring timely decisions and close coordination. Understanding interoperability in terms of the properties of sense-making has provided a sound theoretical basis from which the concept of interoperability will serve as a core concept for resolving complex communication tasks. Weick et al. (2005) emphasized how important communication is in the organizational decision making process. As this study showed, the concept of interoperability is essentially a property of inter- and intra-organizational communication. Consequently, this may be an important variable explaining how such organizational sensemaking can be achieved. Considered alongside Klein's macro-cognitive model (Klein, 2005a) as an understanding of sensemaking, the concept of interoperability can be used as a mechanism to explain the macro-perspective of the group decision making process.

This approach to modeling a framework for interoperability can be extended to include other organizational characteristics and cognitive characteristics based upon the results of the second study. Many researchers (Daft & Macintosh, 1981; Daft & Lengel, 1984; Robert & Dennis, 2005) have provided evidence of the effect of task routineness and information processing on organizational performance. In particular, Ahuja and Carley (1999) studied the effect of task characteristics on virtual organizations in terms of network structure and network performance. Taken together with Ahuja and Carley (1999)'s study, this study identified the relationship among task characteristics, information processing, and interoperability in the context of public safety that is loosely-coupled and self-organized. Hence, the results of this study may be applicable to other organizations that share the same goals but have different functions and structures.

The proposed models for interoperable communications systems can be applied to various communication systems that require communications among different types of devices and different types of organizations. Particularly, the abstract function layer of the proposed model of

interoperable communication systems could also describe the common values or properties of most communication systems such as dispatch centers, laptop-based systems, or even web-based networks. Work Domain Analysis (Vicente, 1999) is an enabling approach that facilitates the design of socio-technical systems for highly complex tasks conducted under conditions of uncertainty. Corresponding to this general approach, the suggested framework provides an example of a value-sensitive design approach that shows how the values can be decomposed to the application layer.

The prototype PSCR produced as a result of the application of this new model of an interoperable communication system offers an organized interface that supports interoperable communication tasks. This prototype is proof of the suggested concepts and can be utilized to identify unexpected problems through a formative evaluation.

In sum, interoperability has been the subject of a great deal of debate during the past decade due to its importance in communication systems. However, to date there has been little systematic research to identify the semantic concepts of interoperability in the public safety domain. This research has identified the concepts governing interoperability using a systematic approach and suggested a model of interoperability. Based on the model of interoperability presented here, interoperable communication systems were modeled and reviewed. The results of this research are applicable to similar application domains, including military communication systems, as well as complex control systems.

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APPENDIX A: INTERVIEW QUESTIONNAIRE

Scenario 1: Alcohol Poisoning Case

A male student around 20 years old has been drinking excessively all night on a college campus party and is suffering from alcohol poisoning. He is found unconscious in his dorm room by his RA who dials 911 to alert the emergency personnel.

Questions for the Police:

- 1: How and where is the call received? What problems have you experienced at this point?
- 2: What information is taken by the 911 call center?
- 3: What is this emergency classified as?
- 4: Which mode of communication is normally used?
- 5: Who is alerted by the call center once a call is received? Are there any specific problems with communication at this point?
- 6: How are these personnel alerted? What are the problems you encounter?
- 7: How much is the regular response time?
- 8: If the regular communications fail, what method is used to connect to the required personal?

Questions for EMS:

- 1: When a call is received from the dispatch center what information is generally collected?
- 2: How many personnel are sent to the required location? What problems do you encounter during communication?
- 3: What communications are made with the hospital about this case?
- 4: EMS Radio being on a different frequency, how are the police communicated with about the above case?
- 5: What is the most important thing lacking in communications with your agencies?
- 6: What is the method of communication if personnel encounter a blind spot on campus?
- 7: What location-based information would you like to know if it is possible to be integrated in the communications software?
- 8: What is the normal response time?

Scenario 2: Football Game Day Case

A big football game such as Virginia Tech vs. Miami is one of the most crowded events in Blacksburg. More than 60,000 people gather at the same place to watch the game and many restaurants are filled with football fans. To control this situation, many volunteers are involved in public safety agencies and other administrative regional agencies join in.

Questions for Police:

- 1: How are the police arranged?
- 2: In case of the incidence (depending on severity), how many personnel are notified?

- 3: If other agencies are helping how are they notified of this? How are messages conveyed to them once they are in different networks?
- 4: Since location is unknown, how does the search take place? How are communications made between the officers on foot, dispatch center and the police van?
- 5: Once location is established how do the different teams scan the area? Typically what messages are passed on and to whom?
- 6: As an officer on the scene what is the most critical need in terms of communications?
- 7: Would a visual display of the message be of any help?

Questions for the EMS:

- 1: Since there are patients, how do the EMS teams respond knowing the specific location and situation?
- 2: How does the EMS personal communicate at such a time with the police officers on scene but in different locations?
- 3: If more teams are to be alerted for standby what is the protocol?

Questions for Fire Marshal:

- 1: What part does role the fire marshal play in this case?
- 2: What information is conveyed to the fire dept?
- 3: How do the fire dept's vehicles communicate with each other? With other agencies?

Scenario 3: Fire on a Large Shopping Mall Case

A fire has broken out on a large shopping mall near the university campus. Most of the people in the building have been evacuated at the first alarm. However, the fire fighters still want to confirm that there are no people in the building and to extinguish the fire.

Questions for Police:

- 1: How are the police dispatched?
- 2: If other agencies are helping how are they notified of this? How are messages conveyed to them once they are in different networks?
- 3: As an officer on the scene what is the most critical need in terms of communications?

Questions for the Fire Marshal:

- 1: Being a very high risk operation who makes the calls and how? What problems do you encounter in situations like this that relate to communication?
- 2: How are outside agencies (building management organization or police) contacted?
- 3: If an EMS team is on scene, how do they communicate with the regular authorities? What are some of the communication problems you encounter?
- 4: If how many people are inside the building is not known, how are decisions made on the number of authorities dispatched?
- 5: What information is relayed by the first on-site fire fighters? What communication problems occur?
- 7: Is there a backup communications system?

8: What inter-operability system currently exists among the agencies? What new things would you like to see in a new one?

9: If personals from other agencies are present how is a plan of action coordinated with them?

Questions for the EMS:

1: What information is conveyed by the dispatch center to the EMS center and how?

2: How are the different teams deployed and what is the communication method between them, meaning the hospital and the center?

3: Once a patient is received, what information is passed on to the hospital and how? What problems are encountered at this point?

4: What changes would you like to see in the current operations method that relates to communication protocols with radio?

APPENDIX B: INTEROPERABILITY QUESTIONNAIRE

INTRODUCTION:

You have been selected to participate in a doctoral study to develop a model for interoperability and a model for an interoperable communication system for cooperating with other public safety agencies. Participation is voluntary, and your responses will be kept confidential. The data will be analyzed by a researcher in the Grado Department of Industrial and Systems Engineering at Virginia Tech and compiled in a dissertation.

DIRECTIONS:

- 1) This questionnaire should be completed by an individual who has work experience in public safety operation and communication.
- 2) Please read each question carefully.
- 3) Please answer where requested by marking 'X' in the appropriate square if there is not additional instruction.
- 4) If you wish to expand on the information you are providing, please feel free to make additional comments on the last section of the questionnaire.
- 5) Please return the completed questionnaire in the enclosed pre-addressed, stamped envelope.

If you need assistance or additional information, please call Gyu Hyun Kwon at 540-808-8638 or send an email to ghkwon@vt.edu

Thank you for your participation in this important study.

Return to:

Gyu Hyun Kwon
The Grado Department of Industrial and Systems Engineering,
250 Durham Hall (MC0118)
Virginia Tech
Blacksburg, VA, 24060

If you want to get the executive summary of this survey, please leave your physical address or email address here:

Definition of Types of Operation: Day-to-Day, Task-Force, and Mutual Aid (Adapted from Irving, 1996)

Day-to-Day (e.g. traffic accidents, other daily events)

- Usually involves single agency for an operation
- Most frequently encountered type of operation
- Operation within each regular organization or basic collaboration with other agencies

Task-Force (e.g. large planned events such as a foot ball game)

- Usually involves several layers of government (federal, state, and/or local)
- Typically, an opportunity for prior planning exists
- Usually involves use of portable and/or covert equipment.
- Often requires extensive close-range communications.
- Users may rove in and out of infrastructure coverage
-

Mutual Aid (e.g. Natural disasters or fire at a large shopping mall)

- Can involve multiple agencies with little opportunities for prior planning
- Often requires assignment of several to many small groups, each on their talk group or frequency
- Once on scene, typically involves the use of portable and mobile radios.

Please recollect the previous cases that you experienced. Each question needs to be answered based on above-mentioned type of operation.

Dimensions of Interoperability

Information Sharing (Asymmetry/Overload/Social awareness/Willingness/Readiness/Copresence)		Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Each team member easily identifies and understands what the operational goal is.	Day-to-Day					
	Task Force					
	Mutual-Aid					
What I know is the same as what the people in the group know.	Day-to-Day					
	Task Force					
	Mutual-Aid					
I know the person who has relevant information.	Day-to-Day					
	Task Force					
	Mutual-Aid					
I am willing to share the information in the network.	Day-to-Day					
	Task Force					
	Mutual-Aid					
I have experience to turn off radios due to information overload.	Day-to-Day					
	Task Force					
	Mutual-Aid					
I am ready to share the information that I have collected at the scene with other agency.	Day-to-Day					
	Task Force					
	Mutual-Aid					
Communication technology can easily support to collaborate with other agency.	Day-to-Day					
	Task Force					
	Mutual-Aid					
It is easy to work together with other people in a remote environment.	Day-to-Day					
	Task Force					
	Mutual-Aid					
Self-organization		Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I have many chances to work with other agencies without planning.	Day-to-Day					
	Task Force					
	Mutual-Aid					
I need to communicate within my organization as well as with other people from different organizations at the scene.	Day-to-Day					
	Task Force					
	Mutual-Aid					
The structure of incident organization frequently changes as time goes.	Day-to-Day					
	Task Force					
	Mutual-Aid					
Synchronicity of communication		Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I need to communicate with people in real-time.	Day-to-Day					
	Task Force					
	Mutual-Aid					
I need to save the communication history and to refer it whenever I need.	Day-to-Day					
	Task Force					
	Mutual-Aid					

Recognition of Communication Group (Dynamic Operational Boundaries)		Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I know the people who are currently involved in this operation.	Day-to-Day					
	Task Force					
	Mutual-Aid					
I can identify my current communication group.	Day-to-Day					
	Task Force					
	Mutual-Aid					
I know the people who should listen to my message.	Day-to-Day					
	Task Force					
	Mutual-Aid					
I know who is saying the current message.	Day-to-Day					
	Task Force					
	Mutual-Aid					
I know how many people are in the current tactical team.	Day-to-Day					
	Task Force					
	Mutual-Aid					
Decision Making- Distributed/ Duality of centralization		Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I can easily know who the decision makers are in this situation.	Day-to-Day					
	Task Force					
	Mutual-Aid					
I frequently need to make decisions myself.	Day-to-Day					
	Task Force					
	Mutual-Aid					
I can easily communicate with decision makers.	Day-to-Day					
	Task Force					
	Mutual-Aid					
Decision makers can easily communicate with their team members.	Day-to-Day					
	Task Force					
	Mutual-Aid					
Adaptability (technical and environmental)		Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I frequently use other devices such as a cell phone rather than the formal communication method (radio).	Day-to-Day					
	Task Force					
	Mutual-Aid					
Communication methods depend on the environmental constraints.	Day-to-Day					
	Task Force					
	Mutual-Aid					
Work Coupling (Functional and Procedural)		Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I can solve problems by myself.	Day-to-Day					
	Task Force					
	Mutual-Aid					
My tasks are functionally related to other people's tasks.	Day-to-Day					
	Task Force					
	Mutual-Aid					
My tasks are sequentially related to other people's tasks.	Day-to-Day					
	Task Force					
	Mutual-Aid					

Task Routineness

Analyzability		Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I know a lot of procedures and standard practices needed to do the communication task well.	Day-to-Day					
	Task Force					
	Mutual-Aid					
I can easily understand the sequence of steps that can be followed in carrying out the communication work.	Day-to-Day					
	Task Force					
	Mutual-Aid					
I actually rely on established procedures and practices.	Day-to-Day					
	Task Force					
	Mutual-Aid					
Established materials (manuals, standards, directives, statutes, technical and professional books, and the like) can effectively support the communication work.	Day-to-Day					
	Task Force					
	Mutual-Aid					
Variety		Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
The communication work can be described as routine.	Day-to-Day					
	Task Force					
	Mutual-Aid					
Work decisions are similar from one operation to the next.	Day-to-Day					
	Task Force					
	Mutual-Aid					
It takes a lot of experience and training to know what to do and when a problem arises.	Day-to-Day					
	Task Force					
	Mutual-Aid					
I need to do an extensive and demanding search for a solution.	Day-to-Day					
	Task Force					
	Mutual-Aid					

Work Unit Information Processing

Amount		Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I need to wait until all relevant information is examined before deciding something.	Day-to-Day					
	Task Force					
	Mutual-Aid					
I usually keep gathering information until an excellent solution emerges.	Day-to-Day					
	Task Force					
	Mutual-Aid					
I usually acquire all possible information before making a final decision.	Day-to-Day					
	Task Force					
	Mutual-Aid					
I usually go over available information until an excellent solution appears.	Day-to-Day					
	Task Force					
	Mutual-Aid					
Equivocality		Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Information can be interpreted in several ways and can lead to different but acceptable solutions.	Day-to-Day					
	Task Force					
	Mutual-Aid					
Information used in making decision means different things to different people.	Day-to-Day					
	Task Force					
	Mutual-Aid					
There is more than one satisfactory solution for problems faced.	Day-to-Day					
	Task Force					
	Mutual-Aid					

Incident Command System

Size		Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
There are many people in an incident command system.	Day-to-Day					
	Task Force					
	Mutual-Aid					
Complexity (Differentiation and Integration)		Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
There are many levels of organizational hierarchy involved in an incident command system.	Day-to-Day					
	Task Force					
	Mutual-Aid					
There are many different teams in an incident command system. (e.g. Operation section 1, section 2, etc.)	Day-to-Day					
	Task Force					
	Mutual-Aid					
There are many different organizations in an incident organization. (e.g. VT police, VT EMS, Bburg Fire, etc.)	Day-to-Day					
	Task Force					
	Mutual-Aid					
I can easily see and reach all operational area.	Day-to-Day					
	Task Force					
	Mutual-Aid					
I need to communicate and coordinate with others using many devices and procedures.	Day-to-Day					
	Task Force					
	Mutual-Aid					
Centralization		Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
An individual at the scene makes decisions.	Day-to-Day					
	Task Force					
	Mutual-Aid					
An incident commander usually makes decisions.	Day-to-Day					
	Task Force					
	Mutual-Aid					
Formalization		Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Standardized procedures are well established at an incident organization.	Day-to-Day					
	Task Force					
	Mutual-Aid					
I always follow existing procedures for communication tasks.	Day-to-Day					
	Task Force					
	Mutual-Aid					
I am sometimes forced to modify standard procedures to get the work done.	Day-to-Day					
	Task Force					
	Mutual-Aid					

Demographic/Communication Technology Information

Regular Organization							
Which organization do you belong to?	Police	EMS	Fire	Others			
How many people are in your organization?	Please write down an estimated number						
What is your job duty?	Police officer	EMS provider	Fireman	Security Guard	Dispatcher	Others	
Your organization mainly covers	Univ.	Town	City	County	State	Nation	
Your organization is located in	Rural		Suburban		Urban		
Gender							
What is your gender?	Male			Female			
Number of Communication Channels			Please write down estimated number				
How many channels of communication are used in the following operations?	Day-to-Day						
	Task Force						
	Mutual-Aid						
Experience			Very rarely	Rarely	Neutral	high	Very high
I am very frequently getting involved in the operation.	Day-to-Day						
	Task Force						
	Mutual-Aid						
How much do you have experience as public safety personnel?	_____ years as a police officer _____ years as an EMS provider _____ years as a fire man _____ years as other public safety personnel						

Comments

* Your comments are very important to us. Please provide any additional information you think is important about interoperability or communications in general.

Thank you very much for your answers.

APPENDIX C: FOCUS GROUP SCRIPT

Investigating ecological validity of the model of interoperable communication systems

Objectives of Focus Group Interview

The main objective of this focus group is to investigate that the proposed prototype and specification of interoperable communication systems is usable in real world context. By the end of this focus group, I hope we will have done the following:

1. Review appropriateness of the proposed set of requirements (model of interoperable communication systems);
2. Review completeness of the proposed set of requirements;
3. Review systems usability for a prototype (early design) based on the proposed set of requirements.

Script:

Introductions:

Good morning/afternoon, I am Gyu Hyun Kwon. I am a researcher at Virginia Tech. I will be moderating this discussion. To help record and take notes on the discussion, our Undergraduate Research Assistant, Eric King, will be joining us today. (All participants will introduce themselves by name.)

Directions for Participants:

Thank you for agreeing to help us with this project. We appreciate your willingness to share your time and expertise. We, in collaboration with the National Institute of Justice, are working on a project to develop a Public Safety Cognitive Radio (PSCR). Since you are the experts on this topic, the information you give us will help us develop/improve a new communication system to help other emergency personnel or first responders.

What you say here is confidential and your name will not be included in any reports. We are interested in hearing about your experiences. If you have any questions about this interview or the project after we leave, you can call us at this number, or you can talk to Dr. Tonya Smith-Jackson here, who can get in touch with us.

This is an informed consent form. Please read carefully and if you agree with participating this study, please sign at the participant sign area. You can withdraw from the focus group at anytime during the session if you wish to.

I want you all to communicate with to each other rather than to me. I will start the

conversation out with a question, please give any opinions you have. Feel free to disagree with what others have said or give another opinion: the more different ideas we hear, the more information we will have to work with. During the discussions, I will just jump in to get us back on track if we have gotten off the topic, or to bring up something we are interested in that you have not covered. Again, we are interested in hearing your experiences and opinions about public safety communication practice, so please tell us what's on your mind.

This session will take about an hour and a half. I will let you know when we are near the end of our time. If you have to go to the bathroom, just slip out quietly and come back as quickly as you can. Are there any questions before we begin?

Introduction of the objectives:

As you are already aware of this project, we aim to develop new communication systems for public safety agents. We developed a set of functional requirements of new interoperable communication systems. It is supposed to effectively support your communication task. Even though this set of requirements was developed based on the input from several public safety organizations, I want to review and validate this model in a real world situation. Thus, your feedback is very important to finalize the model and develop a new communication system to effectively support your important tasks. To make clear in terminology, I will provide each communication situation example.

(Provide day-to-day example: Alcohol poisoning case)

(Provide task-force example: VT football game control)

(Provide mutual-aid example: fire at shopping mall)

(Provide exit-questionnaires)

Starting Focus Group Interview:

Now, we will start the discussion. Feel free to say anything you want to discuss. Your input is very important.

(Provide a set of functional requirements (a model of interoperable communication systems) using both paper version and screen projection)

This set of requirements shows what kinds of functions communication system should have in the emergency operation. The previous version of your communication system was actually developed more than 50 years ago and has evolved to fit the communication environment. This set of requirements describes how communication will be performed in real world situation. It will provide some flexibility and constraints to the system design.

For example, in a disaster situation, which needs the collaboration with other agencies, communication readiness is relatively different than the day-to-day operation within single agency.

(Show a prototype picture)

This is an example of the system for a mutual-aid situation. You can select a communication group or people directly through the screen. This function provides more flexible and effective communication in emergency situations.

Thus, here, we will review that this communication system works well in three real-world situations.

<DAY-to-DAY>

(Review appropriateness)

Let's think about your day-to-day operation such as traffic accident or alcohol poisoning.

Do you think this model is appropriate for your day-to-day communication activities?

If there is any additional functionality needed, feel free to tell us. What I mean by functionality is the types of things the phone needs to be able to do.

(Based on their feedback, the coordinator explains the model and system functions)

(Review completeness)

Thus, do you think this model can fully support your day-to-day communication activities?

If there is any additional functionality needed, feel free to tell us.

(Based on their feedback, the coordinator explains the model and system functions)

[After participants have listed a number of suggested changes, move on to the next situation and repeat the question.]

<TASK-FORCE>

Let's move to another case.

You are involved in a VT football game. This is what we call as a task-force situation.

(Review appropriateness)

Do you think this model is appropriate for the task-force communication activities?

If there is any additional functionality needed, feel free to tell us.

(Based on their feedback, the coordinator explains the model and system functions)

(Review completeness)

Thus, do you think this model can fully support your task-force communication activities?

If there is any additional functionality needed, feel free to tell us.

(Based on their feedback, the coordinator explains the model and system functions)

[After participants have listed a number of suggested changes, move on to the next situation and repeat the question.]

<*MUTUAL_AID*>

(Review appropriateness)

Do you think this model is appropriate for the mutual-aid communication activities?
If there is any additional functionality needed, feel free to tell us.

(Based on their feedback, the coordinator explains the model and system functions)

(Review completeness)

Thus, do you think this model can fully support your task-force communication activities?
If there is any additional function you need, feel free to tell us.

(Based on their feedback, the coordinator explains the model and system functions)

Without any technical limitation, what kind of function will you need to include your systems?

Thank you for the discussion. It's almost over.

Can you fill this overall review forms?

When you fill this form, you can include your suggestion in this session.

(Provide set of questionnaires for appropriateness, completeness, and usability)

(Give 10 minute to complete the forms)

Closing comments:

Your feedback is really valuable in this research.

Thank you for your precious time and effort.

If you have any other opinion and questions, don't hesitate to contact me.

APPENDIX D: INFORMED CONSENT FORM (INTERVIEW)

Informed Consent Form for the Semi-Structured Interview

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

Informed Consent for Participants in Research Projects Involving Human Subjects

Title of Project (Continuation of) A Prototype Public Safety Cognitive Radio For Universal Interoperability

Investigator(s) 1. Dr. Tonya L. Smith-Jackson, Associate Professor, ISE
2. Gyu Hyun Kwon, Graduate Research Assistant, ISE

I. Purpose of this Research/Project

The purpose of this research is to capture user-centered requirements for the mobile Public Safety Cognitive Radio. The purpose of this study includes eliciting data on their needs, preferences, and contexts and environment of use. The result of this interview will be used to generate detailed scenarios which reflect the public safety environments and work contexts.

II. Procedures

The procedures for the experiment are as follows. First, you will be asked to read and sign the informed consent form for the experiment. Once the form is completed, you will be interviewed by the researcher about the radios that you use and communication procedures that you follow. You will also be provided three different scenarios and scenario-relevant questions which include a football game day, a case of fire on a large shopping mall, and a case of drunken student. The session will begin with a short introduction of the PSCR and its proposed uses. This will be followed with the questions for the scenarios. You will be asked to discuss what an “ideal” radio / device given the situation. You will also be asked to draw upon previous experiences which were related to information needs, operational issues, technological issues and organizational issues.

III. Risks

Participation involves being interviewed for a short period of time. The physical components of these tasks are not stressful. All light and sound intensities are well within normal ranges. However, it is possible that discussions of disasters such as 4/16 or natural disasters might lead to residual anxiety or psychological stress. We will concentrate on the communication tasks, technologies and their response procedures rather than focusing on the personalized aspects of the events. If at any time, you become uncomfortable, you will be allowed to leave with no

penalty.

IV. Benefits

Your participation in this research will be used to generate user requirements for a mobile Public Safety Cognitive Radio. The findings of this study will be used towards the creation of an interface that is usable and intuitive to officers in public safety.

No guarantee of benefits has been made to encourage you to participate by the researchers

V. Extent of Anonymity and Confidentiality:

The results of this study will be kept strictly confidential and anonymous. The information you provide will have your name removed and only a subject number will identify you during analyses and any written reports of the research. The audio from the session will not be recorded. We only take notes during the interview. All transcriptions will be done only by the researchers. Access to the written materials will be restricted to researchers directly involved in this study.

It is possible that the Institutional Review Board (IRB) may view this study's collected data for auditing purposes.

VI. Compensation: Your participation is voluntary and unpaid.

VII. Freedom to Withdraw

You are free to withdraw from this study at any time for any reason.

VIII. participant's Responsibilities

I voluntarily agree to participate in this study. I have the following responsibilities:
Answer each question as accurately as possible.

X. Subject's Permission

I have read the Consent Form and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent:

_____ Date _____
Subject signature

_____ Date _____
Witness (Optional except for certain classes of subjects)

Should I have any pertinent questions about this research or its conduct, and research subjects' rights, and whom to contact in the event of a research-related injury to the subject, I may contact:

Dr. Tonya L. Smith-Jackson, Associate Professor,
Industrial and Systems Engineering 540-231-4119/smithjack@vt.edu
Faculty Advisor Telephone/e-mail

Departmental Reviewer/Department Head Telephone/e-mail

David M. Moore 540-231-4991/moored@vt.edu
Chair, Virginia Tech Institutional Review Telephone/e-mail
Board for the Protection of Human Subjects
Office of Research Compliance
1880 Pratt Drive, Suite 2006 (0497)
Blacksburg, VA 24061

APPENDIX E: INFORMED CONSENT FORM (FOCUS GROUP)

Informed Consent Form for the Focus Group

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

Informed Consent for Participants in Research Projects Involving Human Subjects

Title of Project (Continuation of) A Prototype Public Safety Cognitive Radio For Universal Interoperability

Investigator(s) 1. Dr. Tonya L. Smith-Jackson, Associate Professor, ISE
2. Gyu Hyun Kwon, Graduate Research Assistant, ISE
3. Eric King, Undergraduate Research Assistant, ISE

I. Purpose of this Research/Project

The purpose of this study is to investigate ecological validity of a new prototype and model of public safety cognitive radio. The result of this interview will be used to evaluate the completeness and appropriateness of the proposed prototype as well as the overall usability of the proposed prototype.

II. Procedures

The procedures for the experiment are as follows. First, you will be asked to read and sign the informed consent form for the experiment. Once the form is completed, you will be provided a current radio system, a prototype using a smart phone and a paper-based model. The session will begin with a short introduction of the PSCR and its proposed uses. You will also be provided three distinctive work situations. Based on the situation, you will evaluate and discuss for a proposed prototype and model will support your communication task. This will be followed with the questions for the appropriateness and completeness of a proposed prototype and model for the situation. You will be asked to rate the overall score of usability of a proposed prototype of cognitive radio.

III. Risks

Participation involves being interviewed for a short period of time. The physical components of these tasks are not stressful. All light and sound intensities are well within normal ranges. However, it is possible that discussions of disasters such as 4/16 or natural disasters might lead to residual anxiety or psychological stress. We will concentrate on the communication tasks, technologies and their response procedures rather than focusing on the personalized aspects of the events. If at any time, you become uncomfortable, you will be allowed to leave with no

penalty.

IV. Benefits

Your participation in this research will be used to generate user requirements for a mobile Public Safety Cognitive Radio. The findings of this study will be used towards the creation of an interface that is usable and intuitive to officers in public safety.

No guarantee of benefits has been made to encourage you to participate by the researchers

V. Extent of Anonymity and Confidentiality:

The results of this study will be kept strictly confidential and anonymous. The information you provide will have your name removed and only a subject number will identify you during analyses and any written reports of the research. The audio from the session will be recorded. All transcriptions will be done only by the researchers. Access to the written materials will be restricted to researchers directly involved in this study.

It is possible that the Institutional Review Board (IRB) may view this study's collected data for auditing purposes.

VI. Compensation: Your participation is \$20 per a session.

VII. Freedom to Withdraw

You are free to withdraw from this study at any time for any reason.

VIII. Subject's Responsibilities

I voluntarily agree to participate in this study. I have the following responsibilities:

Answer each question as accurately as possible.

X. Subject's Permission

I have read the Consent Form and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent:

_____ Date _____

Subject signature

_____ Date _____

Witness (Optional except for certain classes of subjects)

Should I have any pertinent questions about this research or its conduct, and research subjects' rights, and whom to contact in the event of a research-related injury to the subject,

I may contact:

Dr. Tonya L. Smith-Jackson, Associate Professor,
Industrial and Systems Engineering 540-231-4119/smithjack@vt.edu
Faculty Advisor Telephone/e-mail

Departmental Reviewer/Department Head Telephone/e-mail

David M. Moore 540-231-4991/moored@vt.edu
Chair, Virginia Tech Institutional Review Telephone/e-mail
Board for the Protection of Human Subjects
Office of Research Compliance
1880 Pratt Drive, Suite 2006 (0497)
Blacksburg, VA 24061

APENDIX F: EXIT QUESTIONNAIRES FOR THE FOCUS GROUP

Model Completeness/Appropriateness Scales

	Strongly Disagree				Strongly Agree
1. I think the purpose of Public Safety Communication Systems is well described					
	1	2	3	4	5
2. I think the overall value of this system is well represented					
	1	2	3	4	5
3. I think this system can provide support to directly and effectively communicate with incident commanders.					
	1	2	3	4	5
4. I think this system can provide support to directly and effectively communicate with partners during an operation.					
	1	2	3	4	5
5. I think this system can provide support to directly and effectively communicate with dispatchers.					
	1	2	3	4	5
6. I think this system has enough functionality to communicate with your partners within specific boundaries of operation.					
	1	2	3	4	5
7. I think this system has enough functionality to notice the emergency situation to your partners					
	1	2	3	4	5
8. I think this system can effectively support inter-organizational communication.					
	1	2	3	4	5
9. I think this system can support the communication among different teams in an organization					
	1	2	3	4	5
10. I think this system can support the communication among decision-makers					
	1	2	3	4	5
11. I think this system can support unit-to-unit communication					

12. I think this system has enough functionality to support the communication in day-to-day operations

1	2	3	4	5
1	2	3	4	5

13. I think this system has enough functionality to support the communication in mutual-aid operations

1	2	3	4	5
1	2	3	4	5

14. I think this system has enough functionality to support the communication in Task-force operations

1	2	3	4	5
1	2	3	4	5

System Usability Scale

© Digital Equipment Corporation, 1986.

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

APENDIX G: IRB APPROVAL FOR SEMI-STRUCTURED INTERVIEW




Office of Research Compliance
Institutional Review Board
2000 Kraft Drive, Suite 2000 (0497)
Blacksburg, Virginia 24061
540/231-4991 Fax 540/231-0959
e-mail moored@vt.edu
www.irb.vt.edu
FWA0000572 (expires 1/20/2010)
IRB # is IRB0000667

DATE: May 16, 2008

MEMORANDUM

TO: Tonya L. Smith-Jackson
Gyu Hyun Kwon
Michael Hupp-Polla

FROM: David M. Moore 

Approval date: 6/14/2008
Continuing Review Due Date: 5/30/2009
Expiration Date: 6/13/2009

SUBJECT: **IRB Amendment 1 Approval:** "User Centered Interface Design for the Prototype Public Safety Cognitive Radio for Universal Interoperability", IRB # 06-339

This memo is regarding the above referenced protocol which was previously granted approval by the IRB on June 14, 2008. You subsequently requested permission to amend your IRB application. Since the requested amendment is nonsubstantive in nature, I, as Chair of the Virginia Tech Institutional Review Board, have granted approval for requested protocol amendment, effective as of May 16, 2008. The anniversary date will remain the same as the original approval date.

As an investigator of human subjects, your responsibilities include the following:

1. Report promptly proposed changes in previously approved human subject research activities to the IRB, including changes to your study forms, procedures and investigators, regardless of how minor. The proposed changes must not be initiated without IRB review and approval, except where necessary to eliminate apparent immediate hazards to the subjects.
2. Report promptly to the IRB any injuries or other unanticipated or adverse events involving risks or harms to human research subjects or others.
3. Report promptly to the IRB of the study's closing (i.e., data collecting and data analysis complete at Virginia Tech). If the study is to continue past the expiration date (listed above), investigators must submit a request for continuing review prior to the continuing review due date (listed above). It is the researcher's responsibility to obtain re-approval from the IRB before the study's expiration date.
4. If re-approval is not obtained (unless the study has been reported to the IRB as closed) prior to the expiration date, all activities involving human subjects and data analysis must cease immediately, except where necessary to eliminate apparent immediate hazards to the subjects.

As indicated on the IRB application, this study is receiving federal funds. The approved IRB application has been compared to the OSP proposal listed above and found to be consistent. Funds involving procedures relating to human subjects may be released. Visit our website at www.irb.vt.edu for further information

cc: File

T. Coalson 0118

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APENDIX H: IRB APPROVAL FOR QUESTIONNAIRE STUDY



Office of Research Compliance
Institutional Review Board
2000 Kraft Drive, Suite 2000 (0497)
Blacksburg, Virginia 24061
540/231-4991 Fax 540/231-0959
e-mail moored@vt.edu
www.irb.vt.edu

FWA00000572(expires 1/20/2010)
IRB # is IRB00000667

DATE: September 29, 2009

MEMORANDUM

TO: Tonya L. Smith-Jackson
Gyu Hyun Kwon
Nigel Wray

FROM: David M. Moore 

Approval date: 6/14/2009
Continuing Review Due Date: 5/30/2010
Expiration Date: 6/13/2010

SUBJECT: **IRB Amendment 3 Approval:** "User Centered Interface Design for the Prototype Public Safety Cognitive Radio for Universal Interoperability", IRB # 06-339

This memo is regarding the above referenced protocol which was previously granted approval by the IRB on June 14, 2009. You subsequently requested permission to amend your IRB application. Since the requested amendment is nonsubstantive in nature, I, as Chair of the Virginia Tech Institutional Review Board, have granted approval for requested protocol amendment, effective as of September 29, 2009. The anniversary date will remain the same as the original approval date.

As an investigator of human subjects, your responsibilities include the following:

1. Report promptly proposed changes in previously approved human subject research activities to the IRB, including changes to your study forms, procedures and investigators, regardless of how minor. The proposed changes must not be initiated without IRB review and approval, except where necessary to eliminate apparent immediate hazards to the subjects.
2. Report promptly to the IRB any injuries or other unanticipated or adverse events involving risks or harms to human research subjects or others.
3. Report promptly to the IRB of the study's closing (i.e., data collecting and data analysis complete at Virginia Tech). If the study is to continue past the expiration date (listed above), investigators must submit a request for continuing review prior to the continuing review due date (listed above). It is the researcher's responsibility to obtain re-approval from the IRB before the study's expiration date.
4. If re-approval is not obtained (unless the study has been reported to the IRB as closed) prior to the expiration date, all activities involving human subjects and data analysis must cease immediately, except where necessary to eliminate apparent immediate hazards to the subjects.

As indicated on the IRB application, this study is receiving federal funds. The approved IRB application has been compared to the OSP proposal listed above and found to be consistent. Funds involving procedures relating to human subjects may be released. Visit our website at www.irb.vt.edu for further information

cc: File

T. Coalson 0118

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APENDIX I: IRB APPROVAL FOR FOCUS GROUP



VirginiaTech

Office of Research Compliance
Institutional Review Board
2000 Kraft Drive, Suite 2000 (0497)
Blacksburg, Virginia 24060
540/231-4606 Fax 540/231-0959
e-mail irb@vt.edu
Website: www.irb.vt.edu

MEMORANDUM

DATE: June 2, 2010

TO: Tonya L. Smith-Jackson, Gyu Hyun Kwon, Nigel Wray, Douglas Hogan, Yolian Amaro-Rivera, Eric King

FROM: Virginia Tech Institutional Review Board (FWA00000572, expires June 13, 2011)

PROTOCOL TITLE: User Centered Interface Design for the Prototype Public Safety Cognitive Radio for Universal Interoperability

IRB NUMBER: 06-339

Effective June 2, 2010, the Virginia Tech IRB Chair, Dr. David M. Moore, approved the amendment request for the above-mentioned research protocol.

This approval provides permission to begin the human subject activities outlined in the IRB-approved protocol and supporting documents.

Plans to deviate from the approved protocol and/or supporting documents must be submitted to the IRB as an amendment request and approved by the IRB prior to the implementation of any changes, regardless of how minor, except where necessary to eliminate apparent immediate hazards to the subjects. Report promptly to the IRB any injuries or other unanticipated or adverse events involving risks or harms to human research subjects or others.

All investigators (listed above) are required to comply with the researcher requirements outlined at <http://www.irb.vt.edu/pages/responsibilities.htm> (please review before the commencement of your research).

PROTOCOL INFORMATION:

Approved as: **Expedited, under 45 CFR 46.110 category(ies) 6, 7**

Protocol Approval Date: **6/14/2010** (protocol's initial approval date: **6/14/2006**)

Protocol Expiration Date: **6/13/2011**

Continuing Review Due Date*: **5/30/2011**

*Date a Continuing Review application is due to the IRB office if human subject activities covered under this protocol, including data analysis, are to continue beyond the Protocol Expiration Date.

FEDERALLY FUNDED RESEARCH REQUIREMENTS:

Per federal regulations, 45 CFR 46.103(f), the IRB is required to compare all federally funded grant proposals / work statements to the IRB protocol(s) which cover the human research activities included in the proposal / work statement before funds are released. Note that this requirement does not apply to Exempt and Interim IRB protocols, or grants for which VT is not the primary awardee.

The table on the following page indicates whether grant proposals are related to this IRB protocol, and which of the listed proposals, if any, have been compared to this IRB protocol, if required.

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