ABSTRACT

THE VIABILITY OF IS ENHANCED KNOWLEDGE SHARING IN MISSION-CRITICAL COMMAND AND CONTROL CENTERS

by
Sameh A. Sabet

Engineering processes such as the maintenance of mission-critical infrastructures are highly unpredictable processes that are vital for everyday life, as well as for national security goals. These processes are categorized as Emergent Knowledge Processes (EKP), organizational processes that are characterized by a changing set of actors, distributed knowledge bases, and emergent knowledge sharing activities where the process itself has no predetermined structure. The research described here utilizes the telecommunications network fault diagnosis process as a specific example of an EKP. The field site chosen for this research is a global undersea telecommunication network where nodes are staffed by trained personnel responsible for maintaining local equipment using Network Management Systems. The overall network coordination responsibilities are handled by a centralized command and control center, or Network Management Center. A formal case study is performed in this global telecommunications network to evaluate the design of an Alarm Correlation Tool (ACT).

This work defines a design methodology for an Information System (IS) that can support complex engineering diagnosis processes. As such, a Decision Support System

design model is used to iterate through a number of design theories that guide design decisions. Utilizing the model iterations, it is found that IS design theories such as Decision Support Systems (DSS), Expert Systems (ES) and Knowledge Management Systems (KMS) design theories, do not produce systems appropriate for supporting complex engineering processes. A design theory for systems that support EKPs is substituted as the project's driving theory during the final iterations of the DSS Design Model. This design theory poses the use of naïve users to support the design process as one of its key principles. The EKP design theory principles are evaluated and addressed to provide feedback to this recently introduced Information System Design Theory. The research effort shows that use of the EKP design theory is also insufficient in designing complex engineering systems. As a result, the main contribution of this work is to augment design theory with a methodology that revolves around the analysis of the knowledge management and control environment as a driving force behind IS design.

Finally, the research results show that a model-based knowledge capturing algorithm provides an appropriate vehicle to capture and manipulate experiential engineering knowledge. In addition, it is found that the proposed DSS Design Model assists in the refinement of highly complex system designs. The results also show that the EKP design theory is not sufficient to address all the challenges posed by systems that must support mission-critical infrastructures.

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by
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THE VIABILITY OF IS ENHANCED KNOWLEDGE SHARING IN MISSION-CRITICAL COMMAND AND CONTROL CENTERS

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To my parents, whose love, affection and support have guided me through the years and allowed me to be everything I am today. I started and completed this work primarily to make them proud.

To my beloved wife, whose patience and love have supported me through this journey to completion. I realize it hasn't been easy and that much of it has been unfair to her. But she still stood by me and made it easier to complete my work. For this, as with all she has stood by me in, I am forever grateful.

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CHAPTER 1

INTRODUCTION

Traditional design methodologies have been utilized in a plethora of system environments. The shortcomings of these methodologies become more obvious when the design involves complex global information infrastructures with varying user characteristics and highly intensive knowledge management requirements. Traditional Information Systems (IS) design has long emphasized the need for valid requirements elicitation methods. This methodology has worked successfully for traditional systems where the problem being solved is bounded in nature and does not pose the constraints introduced by global systems that must traverse both geographical and cultural barriers. Furthermore, the organizational structure and knowledge sharing environment typical of systems that support global mission-critical infrastructures also present a number of roadblocks to applying traditional design methodologies. Those methodologies are ill-equipped to handle a "wicked problem", created by compounding of domain constraints and high-level requirements interacting in a complex manner (Rittel et al. 1973). Wicked problems do not have solutions, only best possible resolutions. "As we move into the Information Age, or perhaps the Knowledge Age," Decision Support System (DSS) designs must increasingly focus on finding possible solutions for these constraints (Courtney 2001). One such wicked problem is the management of mission-critical infrastructures using large integrated information and communications systems.

This research contributes to IS Design Science by proposing a design methodology to assist in the introduction of Information Systems in an environment with conflicting requirements related to organizational control, and as a result, the control of organizational memory (Ackerman et al. 2000) in the form of knowledge bases. Another significant contribution of this research is the validation of an empirically derived DSS design model within the context of an additional mission-critical infrastructure domain. Finally, a recently published IS Design Theory (Markus et al. 2002) that was used for the development of a system that supports emerging knowledge processes is incorporated in an innovative manner (Hevner et al. 2004) by combining the theory with this DSS design model. This synthesis and analysis is centered around an iterative evaluation of systems in a specific mission-critical domain (Klashner et al. 2004b).

The world's complex of interrelated mission-critical infrastructures relies heavily on tightly coupled Management Information Systems (MIS) to coordinate globally dispersed telecommunication resources. The emerging global marketplace has forced multinational telecommunications firms into a conundrum created by fraud (USSS 2002) and an increased awareness of terrorism. They must continue to aggressively compete while collaboratively providing network fault management to reduce the high cost of network unavailability, which could range from \$50,000 to \$1,000,000 per hour (Chao et al. 1999). Telecommunications companies have advertised high service availability, but actual Internet connectivity failures are still very common. Long periods of network unavailability account for a large portion of total failures (Dahlin et al. 2003). Interconnection failures between Internet nodes must be diagnosed immediately to reestablish "real" availability. A potential solution is to collaboratively diagnose network faults. Teams in the field from different multinational firms would collaborate using integrated Decision Support Systems (DSS) and Knowledge Management (KM) tools. These new Information Systems must be designed to protect knowledge capital because these networks are vital to national and global security. Therefore, the supporting DSS tools must be designed with socio-technical and geopolitical awareness by taking into account both the institutional and organizational environmental constraints. The introduction of a new class of DSS design leveraging KM techniques could theoretically increase network availability. A recurring problem in DSS design is the rapidly evolving network environment (Flynn et al. 2002). Flynn et al. also point out that one of the industry's major challenges has been the growth of networks and the increasing inability of traditional DSS to provide quick solutions.

A major stumbling block for traditional designs is the "emergent" nature of this environment and its KM requirements. Knowledge processes that "emerge" during organizational activities are characterized by:

- An evolutionary planning processes with no predefined optimal structure;
- Knowledge requirements that are complex, distributed, and evolving; and
- An unpredictable set of users (in roles, experience or prior knowledge).

When supporting these emergent knowledge processes in an organization, IS developers must take into account the fact that traditional system development techniques may not be sufficient to overcome these processes' inherent challenges, which include supporting unpredictable users and their unpredictable requirements. Although a design theory has been created to facilitate the development of systems that can support emergent knowledge processes, many questions still remain related to the design process of such systems (Markus et al. 2002). More generally, previous studies of IS implementation have yielded conflicting and confusing findings relative to the Information Systems' KM capabilities (Alavi et al. 1992; Shaw 2003). Thus, design theory verification is an important part of design science research, especially in situations involving emergent knowledge processes.

DSS, Expert Systems (ES) and Knowledge Management Systems (KMS) have been designed to help knowledge workers such as engineers, lawyers and managers, cope with complex situations. However, existing system design theories are unable to provide adequate support for emergent knowledge processes because these complex situations are further aggravated by introducing an unpredictable user population and an ever-changing process structure (Markus et al. 2002). Systems supporting the emergence of knowledge may be designed to include a combination of DSS, ES or KMS features. However, the main observation made by Markus et al. is that the IS design theories used to design current systems do not provide adequate support for processes that create emergent knowledge. Field surveys have shown that systems supporting the emergence of alarm correlation knowledge developed using traditional design guidelines have not provided sufficient support for the constantly changing telecommunications environment (Sabet et al. 2003b; Sabet et al. 2004).

Hevner et al. state that the objective of IS research is to gather knowledge and understanding that may support design of technology-based solutions for as yet unsolved important business problems (Hevner et al. 2004). Thus, supporting network fault diagnosis involving emergent knowledge processes ***is*** an important business problem requiring a unique system design. The complex types of knowledge and the novel knowledge requirements associated with such processes require new methods of capturing, codifying and distributing knowledge across an organization (Alavi 2000; Markus et al. 2002; Nemati et al. 2002). The research presented here examines current emergent knowledge process design approaches to determine their appropriateness for systems supporting mission-critical infrastructure. Specifically, this research applies aspects of IS design for emergent knowledge processes to a new real world global telecommunications problem within a general DSS design model (Klashner et al. 2004b). In addition, the resulting design artifact is evaluated, as per Hevner's research guidelines, in an engineering field environment. Whereas a notable prior emergent knowledge process design case study (Majchrzak et al. 2000a) was set in a manufacturing domain, the study discussed in this dissertation is conducted at command and control centers in the telecommunications industry.

Supporting today's mission-critical infrastructures is vital to national security as well as normal day-to-day lifestyles using internet-based services (Chao et al. 1999; Dahlin et al. 2003; Klashner et al. 2004a; NSTC 2002). Therefore, it is also critical to the public to verify that appropriate design theories, methodologies, and models exist for such mission-critical infrastructural systems. As part of this verification mechanism, the external validity of research questions is important. In keeping with those precepts, some of the research questions addressed in this work are directly related to prior questions posed by other design theory researchers (Majchrzak et al. 2000a). The "agenda for future research" resulting from their investigation of emergent knowledge processes (EKP) included:

- "Can other development teams follow the EKP design and development principles to produce successful systems?"
- "Are there alternative sets of requirements that also fit the kernel theory of EKPs?"
- "Are EKP support systems effective in all contexts?"

Data is collected during this study to evaluate specific aspects of the IS design theory for systems that support EKPs, as presented by Markus et al. In addition, the effectiveness of the resulting design while utilizing their design theory is evaluated. The data collected provides insight on how small research teams may follow the EKP IS design theory.

This research also builds upon Meira's alarm correlation research (1997). He evaluated appropriate techniques for capturing and maintaining the knowledge base for an IS designed to support emergent knowledge processes associated with alarm correlation in telecommunications (Meira 1997). Telecommunications networks produce large amounts of alarm information which must be analyzed and interpreted so that faults can be isolated and corrected. Alarm correlation is a central technique in the fault diagnosis process. While alarm correlation systems are becoming more widely used, the knowledge necessary for constructing an alarm correlation system for a network and its elements still remains lacking (Klemettinen 1999).

Finally, the DSS Design Model introduced by Klashner and Sabet (Klashner et al. 2004b) is very similar to one originally derived from mission-critical electric power domain data [Klashner, 2002]. Since the version of the model presented here is also utilizing field data from the global telecommunications domain, this research addresses future research questions posed by Klashner with respect to the model only being applicable to the electric power domain. Thus, another contribution of this global telecommunications domain research is to further verify and test the original model's generalizability.

The contributions from this research reemphasize the importance of organizational consideration in the design process — a recurring lesson over the past several decades. The organizational structure and relationships greatly affect the use of Information Systems (Markus 1983; Orlikowski 1992). Conway's law, a well known software engineering principle, states that "organizations which design systems (in the broad sense used here) are constrained to produce designs which are copies of the communication structures of these organizations" (Conway 1968). Curtis et al. also argue that organizational boundaries to communications affect and sometimes inhibit IS implementation (Curtis et al. 1988).

Detailed analysis of the target domain's organizational relationships can provide a better framework for a successful system design (Kling 1993). The organization's structure has a direct influence on the relationships between distributed teams of users. These relationships tend to form knowledge sharing patterns that are unique to the inter- and intra- teams' interactions. Finally, these relationships and the organization's structure serve to mold the Information Systems utilized in the day to day activities of the business. A successful design must support these day to day activities and integrate with the non-computerized part of the entire system [i.e., people, process and organization] (Turoff et al. 2004a; Turoff et al. 2004b).

1.1 Problem Formulation

Complex, global engineering diagnosis processes require highly sophisticated IS to support the communications and knowledge sharing requirements imposed by geographically and culturally dispersed engineering teams collaborating synchronously and asynchronously to effectively arrive at an efficient solution. Global telecommunications systems require extensive knowledge to diagnose network faults. The plethora of equipment and constantly varying configurations impose even greater constraints on the design of Information Systems – whether they be DSS, ES, KMS, or EKP systems – to support this area. In addition, due to the varying levels of experience and knowledge of the network operations staff, there is no predetermined set of user characteristics (in terms of expertise, education etc.) for such a mission-critical support system.

This mission-critical environment closely resembles a High Reliability Organization (HRO) in that a successful management strategy should include:

- an environment involving continuous learning and knowledge sharing
- an environment where efficiency and reliability are emphasized and rewarded appropriately
- an organizational vision that is clearly communicated to all employees ensuring their understanding of the organization's overall goals and purposes (Roberts et al. 2001)

It would certainly have been desirable to conduct this research and the design of the resultant system under an HRO framework. However, this proved impractical, since the field site organization itself did not view itself, and had not been structured as, and HRO.

The constraints presented by the mission-critical environment serve to confound the IS design process for systems that can support network fault diagnosis (referred to in the literature as Alarm Correlation systems). The traditional design methodologies, used to design the average accounting system for example, are clearly not equipped to deal with these constraints. Emergent Knowledge Processes design theories are a promising alternative. However, it is unclear whether they may be able to deal with the organizational knowledge control restrictions posed by rigid hierarchies and sociopolitical borders that are prevalent in global mission-critical infrastructure.

The intent of this research is to determine the appropriate design theory and methodology for introducing a Knowledge Driven DSS (KD-DSS) to support global mission-critical infrastructures. As part of this research intent, the EKP Design Theory and a DSS design model are utilized and evaluated. Finally, the appropriate knowledge capturing algorithm for this KD-DSS is also determined.

The key functional area investigated during this research is the fault diagnosis process in a global mission-critical environment. In this environment the major problem facing engineers is the information complexity presented to users when fault locating network failures. Furthermore, interpretation of the complex information presented to engineers during a network fault is highly dependent on individual knowledge and experience. This indicates that a knowledge driven system (in the form of a Knowledge Driven DSS) is needed to support this functional area. To understand the requirements for this system, designers must first understand existing system characteristics (for DSS, ES, KMS) to be able to synthesize features from each of these into the design that can effectively support the diagnosis effort and deal with the knowledge control constraints posed in this environment. The design of this system is greatly affected (hindered or supported) by the organizational norms and control structures exhibited in the field sites. An explicit IS Design Theory is required to guide the design process in this area, focusing design efforts in dealing with and understanding the knowledge sharing environment and the knowledge control structure in effect in the organization.

The research described in this dissertation evaluates such a design theory and contributes to Design Science by augmenting the existing design theory to specifically tackle the above mentioned constraints.

1.2 Research Approach

The research steps taken in this dissertation included:

- A preliminary survey was performed to measure and justify the importance of the fault correlation process and its supporting IS in the field organization.
- A recently proposed DSS Design Model was utilized to iterate through design iterations, evaluating the design theories and methodologies used to arrive at these resultant designs. This theory-driven model relied heavily on simulation techniques as well as domain feedback to guide design decisions.
- Once an appropriate theory was found (EKP design theory), a more comprehensive survey was performed to arrive at a baseline of the field organization's effectiveness and to understand the organization's pre-existing knowledge management environment.
- The final design was deployed in a real operational network management environment, in multiple field site nodes. A case study was performed to evaluate the design and to discern the organizational characteristics that determined the success or failure of the system design. The results of the case study were then used to augment the original design theory with specific guidelines that would allow it to support the design process for systems that entail managing global mission-critical infrastructures.

Following the above research track allowed for the gathering of a large set of rich empirical data in a realistic mission-critical environment. The resultant findings give rise to an important set of research contributions, explained in the next section.

1.3 Research Contributions

The results of the research discussed in this document are divided into 3 singular contributions and a single major contribution. The singular contributions are synthesized and built upon to arrive at the major contribution.

The first singular contribution involves arriving at an effective knowledge capturing technique for systems that support sharing of experiential engineering knowledge. The design utilized in this research shows that a model-based knowledge capturing algorithm provides an effective avenue for capturing, sharing and managing this knowledge type.

The second singular contribution of this work entails the validation of the DSS Design Model used to frame the design process of the IS used in this research. The model's generalizability is further tested in a new domain.

The third singular contribution of this work is the utilizing of recently published IS design theory for systems that support Emergent Knowledge Processes. During the research process, the IS design theory principles are addressed and feedback is provided to augment the theory based on the knowledge gained from this research's results.

The main contribution of this research is the proposal of a new design methodology to guide future designers of mission-critical infrastructure support systems. The singular contributions described earlier are combined to show that Information Systems that must support global mission-critical infrastructures, where a Knowledge Management approach is required, must be designed with an intimate understanding of the knowledge control structure already existing in the organization. The organizational power structure must be used as an indication of the knowledge sharing environment and can then be used to establish the framework for the design process itself as well as the effective resultant design.

These research results and the details of the research methodology and findings are discussed in further detail in the following chapters. The next chapter outlines related research relevant to this work. The theoretical background for the research is presented in Chapter 3. Chapter 4 explains the research methodologies adopted. Chapter 5 details the specific problem being addressed and the field site domain. Chapter 6 lays out a discussion of the research results. In the final chapter, the research results, contributions and future work are put forth in detail. Finally, the appendices present the survey questionnaire and Case Study protocol used as well as the detailed results of the case study and questionnaire themselves. The final appendix outlines the design and architecture of the Alarm Correlation Tool created during this research.

CHAPTER 2

RELATED RESEARCH

There has been extensive research in the area of IS design. Specifically, a number of studies have been performed to the design of Decision Support Systems, Expert Systems and Knowledge Management Systems. Knowledge taxonomies and capturing algorithms have also been researched in a number of academic papers and dissertations. This chapter outlines the previous research performed in these areas and defines the fundamental research concepts utilized in the remainder of the dissertation.

2.1 Case Work

The term case has been somewhat over-used in the literature. In this document, "case" is used to refer to four distinct, yet overlapping areas (Figure 2.1). The distinction between the various uses of "case" is put forth in this section to clarify further discussions throughout the document.

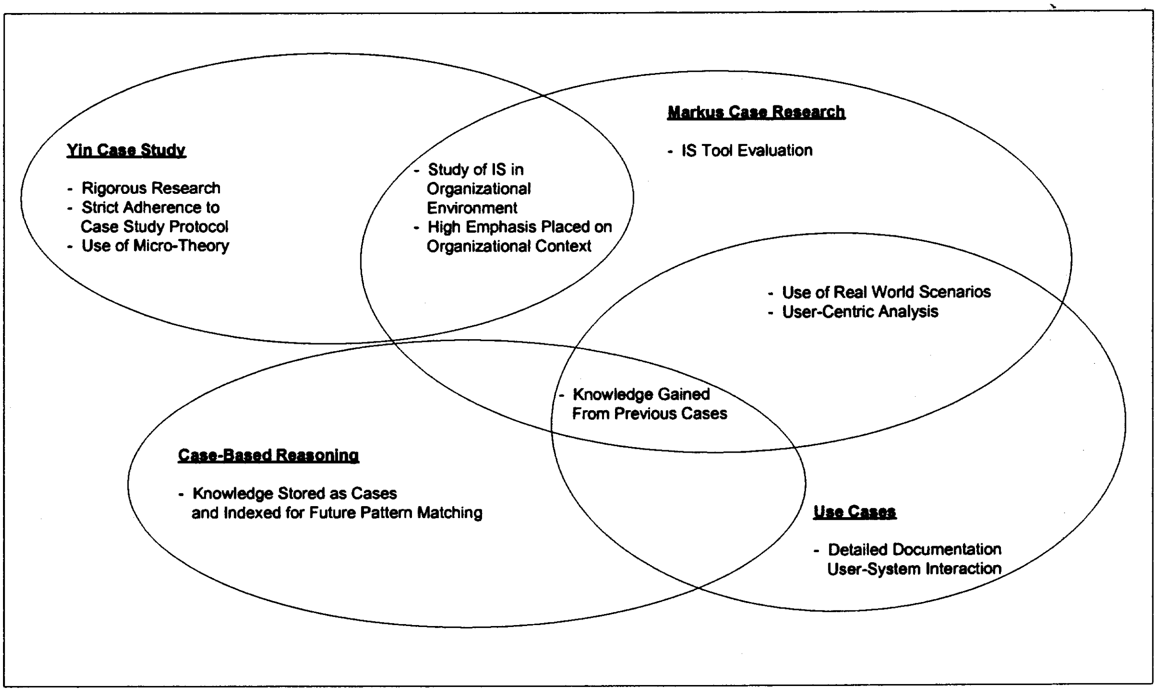


Figure 2.1 The term case is used to refer to four distinct, yet overlapping areas.

2.1.1 Yin Case Studies

The case study methodology is a social science research methodology (Yin 2003). The case study methodology is a positivistic approach utilized in programs where a complex phenomenon requires in depth, holistic investigation (Dubé et al. 2003). The theoretical aspects of case studies, as viewed by Yin, are discussed in more details in Chapter 4.

2.1.2 Markus Case Research

Markus has been one of the leading researchers in the IS community to popularize this form of research. Among the most famous *case* studies in IS research is the organizational study performed by Markus to determine user resistance to MIS implementations (Markus 1983). In this case study Markus gathers data that clearly indicates the importance of organizational context in IS implementation. The case study is an ideal example of in depth organizational inquiry. Markus et al. use the term case in their research related to Emergent Knowledge Processes (EKP) design theory (which will be discussed in detail in Chapter 3) to imply a field study research process where a specific Information System is deployed in a real-life environment and evaluated using "real" cases of IS usage (Markus et al. 2002). On the surface, their approach would appear to be similar to case studies as defined by Yin (Yin 2003). However, the Markus case research is philosophically significantly different and does not involve the positivistic research design imposed by Yin's case study protocol with the express use of micro-theories.

2.1.3 Use Cases

Use *cases* are an important aspect of user-centered analysis, where capturing requirements is performed from the user's point of view. A use case in analysis and design details the possible sequence of interactions between an actor and the IS (Rumbaugh 1994). "A use case is a sequence of transactions in a system whose task is to yield a measurable value to an individual actor of the system" (Jacobson et al. 1992). A scenario is an instance of a use case, and represents a single path through the use case using explicit values for user input in the interactions. Originally designed as an informal strategy to assist in Object Oriented Design, it eventually expanded to become a method for capturing system *functional* requirements.

2.1.4 Case-Based Reasoning

Case-based reasoning (described in further detail later in this Chapter) involves a set of past "patterns" that form a complete case. The patterns are stored as cases in a database for comparison with the incoming information in order to arrive at a predetermined result based on previous knowledge (Meira 1997).

These distinct concepts will be utilized in greater detail throughout this work. The essence of a case is often tightly coupled with the collection, storage, and dissemination of knowledge.

2.2 Knowledge

There are varying definitions of knowledge, ranging from the purely hierarchical view to the philosophical (Alavi et al. 2001). In the hierarchical view, data is defined as an aggregation of raw facts, information is processed data, and knowledge is authenticated information; whereas the philosophical view defines knowledge as being a true belief or universal truth (Alavi et al. 2001). In this research, the view that knowledge is defined as a "justified belief" including subjective expertise, mental models, insights and intuition that increases a person or organization's ability to act effectively has been adopted (Alavi 2000; Alavi et al. 2001; Nemati et al. 2002). Knowledge can simply be contextualized information used to guide execution of a task. However, knowledge is not simply data or information, but it is information leading to a specific, appropriate action; i.e., actionable information (Tiwana et al. 2001).

Ackoff discusses the fact that most systems are designed on the incorrect assumption that users suffer from a lack of relevant information. The reality is that there is an over-abundance of information presented to users. The two most important functions of an Information System is then the idea of “filtration” and “condensation” (Ackoff 1967). Knowledge is required to make sense of the vast amounts of information presented to users in an emergent type of IS design process. Therefore, knowledge in a system is applied utilizing the correct filter on a large quantity of accumulated data. This knowledge process enhances user understanding of their environment and effectively guides their decision-making. For example, in the case of alarm correlation, knowledge regarding alarm importance relative to the current state of the telecommunications network may be stored in specialized IS to enable accurate filtration of unimportant alarms so that those remaining can be condensed to show root causes of network faults (Sabet et al. 2003a).

The importance of knowledge in mission-critical IS development cannot be emphasized enough. Understanding the correct knowledge type being captured and leveraged in a system should directly influence the design of the system. There are a number of taxonomies of knowledge in the current knowledge management literature such as shown in Table 2.1 (Alavi et al. 2001). However, many researchers simply choose to have two broad classifications; i.e., explicit and tacit. Explicit knowledge may be formalized and expressed in various machine-readable forms. Thus, it is more easily placed into code than is tacit knowledge. As an example, some specialized DSS express explicit knowledge via the use of rules. These rules are easily programmed in the IS. Conversely, tacit knowledge resides in an individuals mind. It is difficult to formalize and communicate. This obviously means that it is difficult to code such knowledge. This type of knowledge may be transferred between individuals through a social process, such as training.

Table 2.1 Knowledge Taxonomies

Knowledge Types	Definition
Tacit Cognitive tacit: Technical tacit:	Knowledge is rooted in actions, experience, and involvement in specific context Mental models Know-how applicable to specific work
Explicit	Articulated, generalized knowledge
Individual	Created by and inherent in the individual
Social	Created by and inherent in collective actions of a group
Declarative	Know-about
Procedural	Know-how
Conditional	Know-when
Relational	Know-with
Pragmatic	Useful knowledge for an organization

Source: Alavi, M. and D. E. Leidner (2001). "Review: Knowledge Management and Knowledge Management Systems: Conceptual Foundations and Research Issues." MIS Quarterly 25(1): 107-136

Decision Support Systems are Information Systems intended to help *knowledge* workers in the decision-making process with less structured problems (Gorry et al. 1971; Power 2002; Sprague 1980). The next section discusses Decision Support Systems in further detail. It also outlines the latest developments in DSS related research.

2.3 Decision Support Systems

The main goal of Decision Support Systems (DSS) is to provide analytical tools to decision-makers for modeling decision scenarios and current domain indicators so their decision-making and understanding of the environmental constraints grows at a pace roughly equivalent to decision complexity. These systems are not intended to provide final solutions. DSS can, nevertheless, aid workers by helping them manipulate data in various forms to create models or futuristic "what-if" scenarios that provide insight into their current situation (Sprague 1980).

DSS have traditionally been aimed at solving less structured, under-specified problems (Holsapple 1995; Sprague 1980). They combine both analytical and model-like techniques with data access and retrieval functions to provide solutions to such problems. A main characteristic of a well-designed DSS is its degree of flexibility and adaptability in order to accommodate variety in the environment, the data, or the user's decision-making process. Many researchers believe that DSS must also provide support for the individual's decision-making style (Turban et al. 1998). Silver discusses the merits of consciously attempting to direct the way this change occurs rather than simply allowing it to happen as a side effect of introducing the new system (Silver 1990). A system may be designed to improve these biases and shape the way the decision maker assesses situations. On the other hand, the system may be designed to simply improve data manipulation without forcing a process change. This allows for unplanned changes in the decision making process to occur, thus leaving it up to the user to define the "content" of the changes occurring, allowing the DSS designer to simply facilitate user-directed change (Silver 1990).

As was mentioned earlier, a DSS may be used to offset inherent biases present in the human decision-making process. A system may be designed to substantially negate these biases and shape the way the decision-maker assesses situations. On the other hand, the system may be designed to simply improve data manipulation without forcing a process change which allows for unplanned changes in the decision-making process to occur. The former approach is called "directed change" whereas the latter is "nondirected change" (Silver 1990).

DSS are designed to augment human decision-making capabilities. To accomplish this objective, the designer must understand the human decision-making process. Psychologists know of a number of decision-making biases (Kleindorfer et al. 1993; Zhang et al. 2003), some of which are listed here.

- Anchoring: Humans give more unfounded weight to the first information received.
- Sunk-Cost: Humans tend to carry on past mistakes in an attempt to justify past decisions.
- Confirming Evidence: Humans tend to seek information that confirms their current biases, but discount new information refuting their biases.
- Overconfidence: Humans tend to over-estimate the accuracy of their own predictions.
- Prudence: Humans tend to be over-cautious when higher issues are at stake.
- Recallability: Humans remember recent events better and give then undue weight.

These biases may be alleviated via the use of a reliable DSS (Zhang et al. 2003).

Sprague further defines a DSS by specifying a framework for its design. He divides the framework into three areas. First, a specific DSS accomplishes the actual work or task required. Second, a DSS generator is a package used to easily and quickly create a specific DSS. Finally, DSS tools are the "most fundamental level of technology" that can be used in the development, such as programming languages or storage devices and software (Sprague 1980). Bhargava and Power describe a number of common DSS tasks including data analysis, visualization, query, and retrieval (Bhargava et al. 2001).

Future DSS work should utilize advancing software tools to improve productivity and allow for more efficient use of decision-making time (Shim et al. 2002). There are a number of DSS design challenges in rapidly changing industries, such as the telecommunications industry. One of the major challenges for DSS design in this industry is the growth of networks (Flynn et al. 2002). DSS is intended to assist a network operator must provide solutions on short notice. Therefore, not only does a telecommunications DSS have to support the capabilities mentioned earlier, but it must also be adaptable, capable of coping with changing configurations, and large amounts of raw data (Flynn et al. 2002). Power defines a DSS framework (Table 2.2), into which various specific DSS may be classified:

Table 2.2 DSS Types

DSS Type	Type	Explanation
Communication-Driven and Group DSS	Emphasizes communications and shared decision-making	To aid groups in making better decisions information is shared among the group members
Data-Driven DSS	Emphasizes access to, manipulation of, and analysis of data	Improving decision quality (e.g., OLAP, On-Line Analytical Processing)
Document-Driven DSS	Deals with manipulating and retrieving data in the form of documents	Documents may include oral, video and written documents)
Knowledge-Driven DSS	Stores knowledge	To suggest solutions to the decision-maker
Model-Driven DSS	Emphasizes the use and manipulation of a model for analyzing data	Models used to analyze and manipulate data
Spreadsheet-Based DSS	Based on the use of spreadsheets	Spreadsheet holds data and presents decision aids
Web-Based DSS	Provides decision aids through a web-based interface	Web applications implement on-line decision aids

Source: Power, D. (2000). Building Knowledge-Driven DSS and Mining Data (Power 2000a) - Decision Support Systems, HyperBook

A typical DSS design is intended to assist all knowledge workers in their decision-making processes. Unlike Executive Information Systems, DSS are not designed to solely support upper-level management needs. They are rather "dedicated to improving the performance of knowledge workers in organizations through the application of information technology" (Sprague 1980). A number of DSS variations include the ability to conduct group efforts using group decision support systems (GDSS), computer-mediated communications (CMC), and others (Turoff et al. 1993).

IS have also evolved to support the acquisition and dissemination of expert knowledge to assist users in solving various problems. This trend gave rise to a new type of IS, which is discussed in the next section.

2.4 Expert Systems

Expert Systems are used in many organizational areas including both managerial and non-managerial tasks, such as equipment fault diagnostics, medical diagnosis etc. (Blanning 1987). A large number of expert systems are standalone IS with a narrow specialization intended for solving specific problems.

There are three different methods for expert systems design. The first methodology involves the direct programming of all the knowledge via a computer language; i.e., hard-coding the expertise into the system. The second methodology involves the creation of logical and physical models via the use of Artificial Intelligence approaches. These expert systems can use their models to address different problems across multiple domains (similar to Model-Driven DSS). The third methodology, which is a compromise of the earlier two, is to store most of the knowledge as a separate model or rule database, but still use some explicit programming language to speed up the inference process (Bobrow et al. 1986). In following the latter approach, ES design begins to resemble emergent knowledge process support systems with respect to creating a component-based architecture for the knowledge base.

It is possible to integrate expert systems with GDSS or group support systems (GSS) (Aiken et al. 1991; Fjermestad et al. 2000). Group Support Systems are systems that combine "communication, computer, and decision technologies to support problem formulation and solution in group meetings" (DeSanctis et al. 1987). In combining expert systems and GDSS, one may use the GDSS model base and its communication tools while still relying on the integrated ES for providing solutions. That is, the ES may be considered a consultant to the GDSS (Aiken et al. 1991). Expert knowledge is gained in an incremental process through experience. As such, it is important to continuously update an expert system's knowledge base as such knowledge is acquired (Bobrow et al. 1986). This continuous updating of knowledge bases gives rise to the concept of systems that can support sharing and distributing knowledge, which is discussed next.

2.5 Knowledge Management Systems

A further evolution of IS to provide more sophisticated dissemination, capturing, and sharing of knowledge resulted in the design of Knowledge Management Systems (KMS). The classification "Knowledge Management Systems" is often used interchangeably with Expert Systems, but that usage is not consistent with the research in both communities. Although ES *have* helped the knowledge worker (e.g., by aiding in decision-making, automating tasks, etc.), knowledge itself is one of the most vital resources for the survival of any organization. A primary goal of using IS is the efficient use of an organization's knowledge resources.

Alavi and Leidner have also broadly categorized knowledge using the explicit and tacit descriptions (Alavi et al. 2001) in contrast with the finer-grained knowledge classifications defined in Table 2.1. Tacit knowledge must first be articulated in a manner that facilitates its conversion into explicit knowledge in an IS. There are a number of sociological and requirements engineering methods that have been developed for this purpose (Goguen et al. 1993). One method used to convert tacit knowledge into machine readable code is through "externalization". The externalization process formalizes expert knowledge that is written, and orally communicated through techniques such as protocol analysis, ethnomethodology, or ethnography. (Choo 1996; Mahapatra et al. 2000). In addition, formalizing tacit knowledge for use with IS also allows knowledge dissemination across the entire organization.

The formalization of learned knowledge into Information System's programs is called the "codification approach" (Hahn et al. 2000). The codification approach uses artifacts such as knowledge bases as the medium for knowledge sharing. In contrast to the codification approach, the "personalization approach" assumes that knowledge is mainly shared through individual interaction and interpersonal communication (Hahn et al. 2000). The personalization approach may also produce benefits in engineering processes such as diagnosis. For example, a collaborative system, such as an online discussion group, can be considered a personalization approach that can assist engineers in diagnosing faults.

While the creation and acquisition of knowledge is vital, its distribution and sharing are even more critical. Information Systems prove to be extremely valuable in this respect. Explicit knowledge may be disseminated across the organization once the knowledge is coded into an IS. Various functions such as search and retrieval, data mining, and database storage functions in general, facilitate the use of knowledge across an organization. Distributed workers are better able to find the answers they seek when attacking a specific problem if knowledge is disseminated. Hahn and Subramani point out the importance of handling fluid data in a KMS (Hahn et al. 2000). Fluid data is a direct consequence of the fact that experience and learning, in addition to processes and organizational environments, are constantly changing the basis upon which decisions are made through a complex adaptive evolutionary process.

2.6 Emergent Knowledge Process

A key area where knowledge management is acutely needed is during organizational adaptation to its domain. A case in point arises from environments that focus on knowledge processes wherein the knowledge is emerging as the overall process goes forward. These situations perhaps have the most taxing requirements on knowledge management. An instance of this type of adaptive behavior is specified by Markus et al as an Emergent Knowledge Process (EKP). They define an evolving organizational process, established by a changing set of actors who have not adopted a set structure for their knowledge sharing activities, that must be supported by some *nonexistent* IS (Markus et al. 2002). Information Systems designed to support such a process need to combine a number of characteristics from DSS, ES and KMS.

Table 2.3 DSS, ES, KMS and EKP Support Systems

Characteristics	DSS	ES	KMS	EKP Support Systems
Definition	Systems that aid users in the decision-making process.	Systems that store expert knowledge in a particular domain and attempt to solve problems in that domain.	Systems that contain a separate body of knowledge in a particular domain and provide the flexibility of use of that knowledge for various purposes.	Systems that support organizational processes exhibiting evolving requirements, distributed knowledge, and it cannot be predicted who will form the set of actors
Store Knowledge	Not Necessarily	Yes	Yes	Yes Requires support for dynamic knowledge accumulation
Aid Decisions	Yes	Yes	Yes	Yes Requires support for collaborating teams
Provide Explicit Solutions	No	Yes	Not Necessarily	Not Necessarily
Allow for Flexible Manipulation of data	Yes	Not Necessarily	Yes	Yes
Based on the use of Artificial Intelligence	Not Necessarily	Yes	Yes	Not Necessarily
Restricted to a Domain	No	Yes	Not Necessarily	Not Necessarily
User base	Unpredictable, but assumed to be knowledgeable	Predictable, assumed to have little knowledge	Unpredictable, but assumed to be knowledgeable	Unpredictable, not assumed to have any common characteristics

It is apparent from Table 2.3 that DSS, ES and KMS over-lap. In fact, there is an increasing push to combine the abilities of KMS in DSS design. Holsapple explains that decision-making must be guided by a knowledge store or a knowledge-oriented approach to decision-making (Holsapple 1995). Research into DSS design has increasingly investigated KM techniques because it advances the capabilities of these systems (Holsapple 2001). Power also emphasizes knowledge utilization when he introduced the concept of Knowledge-Driven DSS (KD-DSS) designs, which store knowledge as rules, facts, or algorithms (Power 2000a). These systems also combine many ES, DSS, and KMS features. Examples of KD-DSS include tax-advising systems for lawyers (TAXADVISOR), or expert configurors for VAX systems (Xcon) (Power 2000b). However, depending on the problem being solved, one of several combinations of these systems' attributes may be appropriate.

Information Systems that are intended to support Emergent Knowledge Processes require many of the characteristics of ES, DSS, and KMS as well.

> "Knowledge-intensive emergent processes have challenging information requirements. They require knowledge and expertise in applying the knowledge. They require tacit and explicit knowledge, general and contextual knowledge. Because knowledge is distributed, they require knowledge sharing" (Markus et al. 2002).

Developers will hypothetically be better prepared to fulfill these requirements by combining DSS, ES, and KMS features. If Information Systems are expected to support EKPs, they must be designed not only using traditional IS design approaches (e.g., from DSS, ES, or KMS), but with further concentration on knowledge capturing and unpredictable user support scenarios. The added characteristics needed for systems that support EKPs is detailed in Table 2.4.

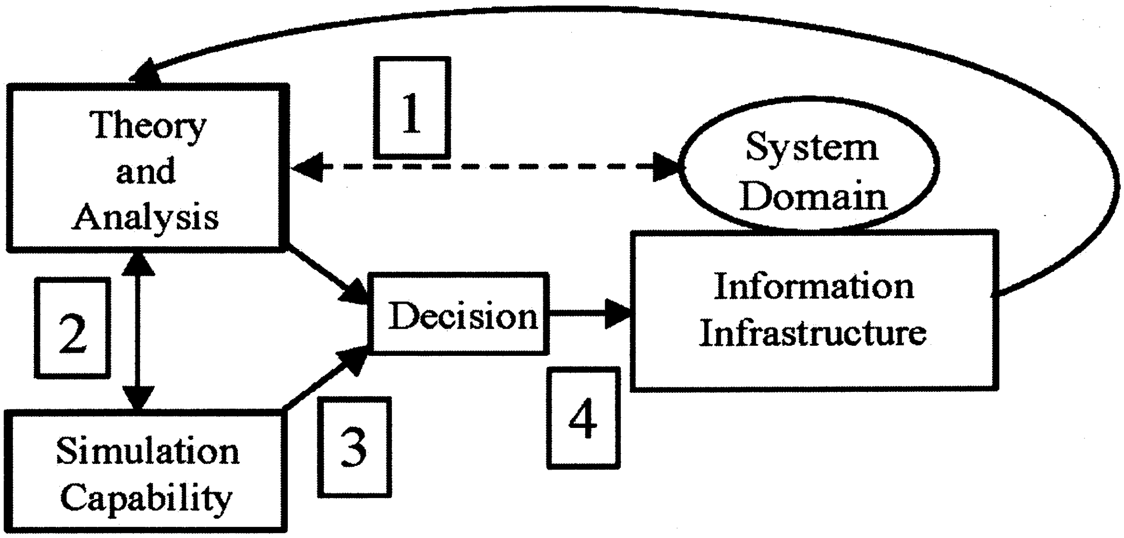
Table 2.4 KD-DSS and EKP Supporting Systems

Category	KD-DSS	System that support EKP
Definition	Systems that aid users in the decision-making process exploiting the knowledge base stored in the system and leveraging KMS methodologies	Systems that support organizational processes exhibiting evolving requirements, distributed knowledge and an unpredictable set of actors
Store Knowledge	Yes. Handle Fluid Data	Yes, further emphasizes componentization of the system including the knowledge base for increased flexibility
Ease Of Use	Emphasizes Ease of Use	Advocates Ease of Use Requires designers to seek out users who are ignorant ("naïve") of IS under development Allow the system to be "self-deploying" through users
Capture and Present Knowledge	Allows for expert knowledge capture and retrieval	Allows for expert knowledge availability to non-expert users and emphasizes contextualization of the knowledge.

These layers of additional design features, approaches, and constraints create a much more complex design process than that found in traditional IS development. To address the combinatorial and stylistic complexity introduced above, this research presents a design model in the next section that may be adapted to facilitate the design of any of the aforementioned combinations including EKP supporting systems.

2.7 DSS Design Model

"The DSS Design Model presented here seeks to reduce the theory-design mismatch by tightly coupling the theoretical aspects of DSS design into the [System Development Life Cycle (SDLC)] and implemented process" (Klashner et al. 2004b). The DSS design model (Figure 2.2) proposed by Klashner and Sabet describes an iterative process in which the DSS is incrementally evolved. The process is based on adaptively applying simulation, theory, and system domain feedback, as well as infrastructure interactions (Klashner et al. 2004b). Utilizing this development model, one can iterate through the design of a system and evaluate as well as refine the design using computer simulation methods that mimic the DSS's real domain states and inputs.



"This visual representation infers both iteration and incremental activities..."

Figure 2.2 DSS design model.
Source: Klashner, R. and S. Sabet (2004). "A DSS Design Model for Complex Problems: Lessons from Mission-Critical Infrastructure." To Appear in Decision Support Systems.

The numbering used in the model shown in Figure 2.2 is intended to facilitate an understanding of areas of the figure. Note that the numbered boxes are **not** intended to show temporal precedence since the model can represent parallel or serial temporal activities. The events, causal relationships, and temporal relationships are generally spatially represented by boxes labeled numbers 1 through 4. The roughly bounded areas of the figure that are demarcated by the boxes are meant to draw attention to general associations numbered as follows for:

Box #1. The DSS target domain data (dashed arrow) or the data from the Information Infrastructure supporting the domain (long curved solid arrow) can influence the choice of a theory or refine the theory once it is chosen for the current system design iteration. This same connection (i.e., the dashed arrow) is bi-directional, depicting the fact that the theory itself can also influence domain applications and knowledge through a (sometimes instantaneous) feedback loop.

Box #2. The use of simulations in the model is constrained by theoretical considerations, but the simulation can influence the theoretical adaptations by simultaneously producing feedback for interpretation by the chosen theory.

Box #3. Results generated from data analysis linked to the currently chosen (or previously utilized) theory or theories can continuously influence the actual design decisions. In addition, the results of simulations during the ongoing adaptive process are fed forward into the design decision process.

Box #4. The design decisions impact the domain's deployed Information Infrastructure; basically as an intervening variable or causal stimulus to be measured and validated. One must also note how a symbiotic relationship exists between the system domain component and the Information Infrastructure component such that the introduction of information technology or organizational change to the Information Infrastructure as a result of design decisions has an immediate and systemic affect on the target domain it supports.

> "The research model has three primary interactions with auxiliary feedback loops that are necessary based on the underlying [Complex Adaptive Systems (CAS)] theoretical framework. The applied theoretical constructs (e.g., descriptive approaches such as ethnography or Grounded theory) determine initial incremental steps through the model, but later increments are guided by the inherent feedback loops. The incremental relationships in the model components allow testing of theoretical conjectures without jeopardizing the actual operation of the infrastructure, thus satisfying a fundamental constraint from the domain. Also, the increments create temporal milestones. This process necessitates the utilization of a nondeterministic and descriptive SDLC. The combination of these conceptual constructs provides a great deal of intellectual leverage over the process, but also greatly increases the complexity of the seemingly simple DSS Design Model. The remainder of the model consists of the following components: theory and analysis, simulation, decision/design. Two headed arrows between model components indicate an interaction leading to information exchange in both directions. The dotted line indicates an interaction that can be a real-time synchronous exchange of information...

The research is driven by the available data. Qualitative techniques (e.g., ethnographic methods) were used because of the lack of experience of the researcher and the deep domain knowledge of the informants. This dichotomy facilitates good data collection using ethnographic methods. Based on field data in the electric power industry, it became obvious that a conceptual framework (with the associated technical mechanisms) was needed to utilize numerous theoretical constructs due to the variety of data in the domain. Also, many qualitative methods (e.g., ethnomethodology []) do not scale well, so there must be an underlying theoretical motivation for different data collection and analysis approaches during subsequent iterations through the model...

The relation between the theory component and domain [] is maintained to continuously integrate emerging data and update the theory (e.g., if a Grounded Theoretic approach is utilized []). The real-time synchronous exchange of information (represented by the dotted line and Box #1) can result in an immediate evolution of ideas, concepts, and viewpoints is possible; e.g., analysts/theoreticians or practitioners meeting with domain experts to exchange ideas. Two other data feeds influence the choice of theory.

A direct feedback arrow (curved arrow on top of [the figure]) from the information infrastructure indicates a purely technical data feed from the specific DSS or general IS (e.g., integration testing). Based on the CAS theoretical framework, we assert SDLC activities that are normally after design (e.g., testing, deployment, maintenance) are not independent, but a natural morphogenic outcome of the design activity. Thus, the single feedback arrow from the information architecture component captures the necessary data for design from these concurrent or later SDLC activities. More recent agile SDLC configurations (e.g., eXtreme Programming []) have radically rearranged the order of activities such that testing is before design, which means the testing becomes an aspect of the theoretical analysis from a software engineering perspective (e.g., software engineering) and the simulation of component-based techniques are applied. The second data feed into the theory and analysis is from the simulation component...

The integrated theories (i.e., in theory component) at any particular increment during an iteration of the DSS Design Model dictates many aspects of the overall model execution. Obviously, the choice of theories should be predicated on the research goals, existence of prior collected data, and results from previous theoretical analysis, all of which may or may not be consistent with the current theoretical component. Since the type of data collection and analysis techniques are mandated by the theory, it is only logical these same constraints will guide the simulation design. The basic CAS tenets of integration and morphogenesis through interpretation of domain variety captured in feedback mechanisms factor heavily into the DSS Design Model capability to oscillate somewhere between the conceptual opposites of organized complexity and chaotic complexity; e.g., to a lesser degree, but somewhat analogous to prescriptive and descriptive SDLC…

Simulation is still used for information infrastructure modeling, but with a more expanded role than typically ascribed to it. The simulation referred to in this case can be of the traditional type [] or a type modified to hide simulation complexity from a particular stakeholder group [], wherein the simulation output is analyzed…The simulation and theoretical components leverage the flexibility provided by modern software engineering and software architectures techniques to integrate theoretically grounded assertions with the data feed. Emerging technologies are used to dynamically replace, and integrate computational components within systems. Thus, from a fundamental inception of the DSS, the design incrementally becomes more like the real-world artifact…

The cumulative effect of the theoretical analysis and/or simulation can combine to dynamically influence the design decision-making process []. Decision-makers such as IS analysts, software engineers, project managers, and other primary stakeholders interpret these inputs based on their 'shared understanding' [] of the relevant domain resource constraints. Thus, the combination of theory and simulation will inevitably impact the decisions, but only to the degree that it does not violate the decision-makers' shared understanding of the design goals.

These decisions may be made in real-time as the various stakeholders observe the prototype as it is time-spliced into the working infrastructure...By choosing different time increments, their subjective impression of the design will be altered in a nondeterministic manner because the data is live and random…this systemic behavior is the nature of real-world design and, more generally, of wicked problems. The design decisions impact the built information infrastructure (i.e., [] box #4) that needs to be factored into a systemic model.

Newly integrated design decisions immediately impact the symbiotic relation between the information infrastructure and the domain thereby completing the first full iteration since the general iterative flow of data shown in [Figure 2.2] is counterclockwise. Note, however, depending on the data, the theory or theories utilized, and the type(s) of simulation/prototypes developed there may an undetermined number of incremental steps in any particular iteration through the entire DSS Design Model" (Klashner et al. 2004b).

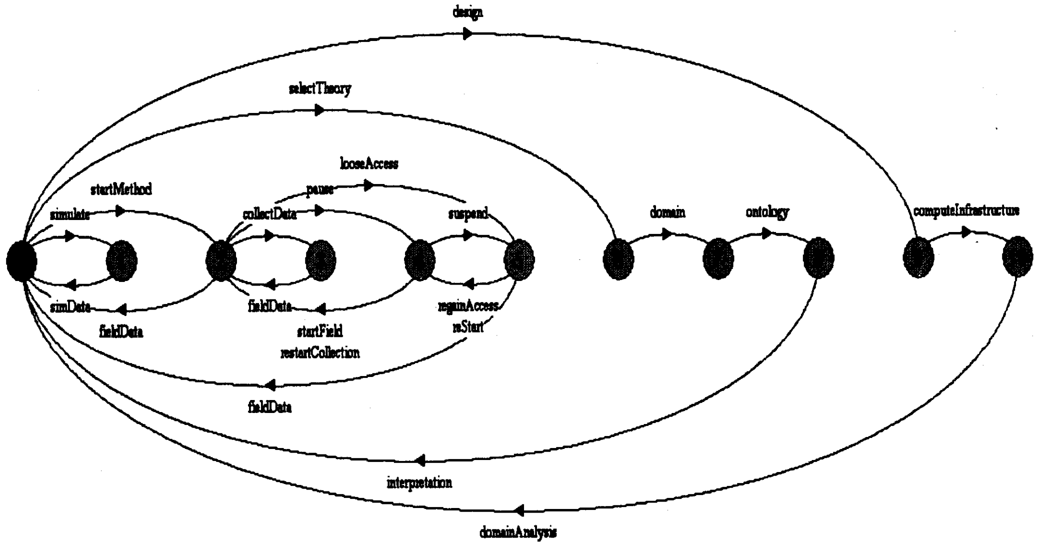


Figure 2.3 LTSA output of DSS design model.

A more formal approach of viewing the DSS Design Model is through the use of a finite (transition) state machine or a Labeled Transition System (Figure 2.3 utilizes a popular tool, LTSA, to create an LTS of the DSS Design Model). The model is designed to integrate the following process as shown in the Labeled Transition System (LTS) as represented by (Magee et al. 1999). The states and transitions in the LTS analyzer output in Figure 2.3 are intended to illustrate more clearly the overall ***concurrent activities*** necessary to carry out this research within the DSS Design Model framework.

- The possible states of the model:
  0. state(0) := [existence of some theory relevant to domain]
  1. state(1) := [existence of a simulation that has the capability to create data]
  2. state(2) := [existence of a the field site]
  3. state(3) := [existence of data collected]
  4. state(4) := [existence of paused data collection activity]
  5. state(5) := [suspended data collection activity]
  6. state(6) := [existence of a theoretical framework capable of modeling the accessed domain]
  7. state(7) := [existence of a domain model of the accessed domain]

8. state(8) := [existence of an ontology for this domain resulting from using the theoretical framework and domain model]
9. state(9) := [existence of a new design for this domain]
10. state(10) := [existence of an incremental or punctuated evolutionary change resulting in the current evolved, and adapted domain]

- *Creating a simulation* of the design based on theory causes a transition from state(0) to state(1), a simulation capable of creating simulation data (simData)]
    - At any time when the process is at state(0) a simulation activity can be started
- Using a theory-based data collection method (startMethod) transitions from state(0) to the field site at state(2), where a number of activities can take place
    - Data collection (collectData); i.e., the transition from state(2) to state(3), with a corresponding fieldData transition back to a collection state(2)
    - Negative transitions such as a pause or the loss of field site access (looseAccess) slow (state (4)) or stop (state (5)) the process
    - In any case, however, once the field site—state(2)—is reached, some data will be absorbed from the field and transferred back (fieldData) to inform the existing theory, which may cause the evolution of the theoretical perspective explained below.
- Based on the field data collected, any sequence of actions can take place among states (1), (2)-(5), but will generally reflect and impact the current set of theoretical premises in place at state(0).
- Based on the field data, the researcher(s) in state(0) will determine if the theory needs to be augmented or replaced through the following process:
    - Selected theoretical premises (selectTheory) will transition the process from a theory in state(0) to a theoretical framework capable of modeling the domain
    - The domain transition of analysis with the selected theory representation in state(6) results in a domain model
    - The model in state(7) becomes an ontological reflection of the domain via the transition to state(8)
    - The ontological representation is interpreted through transition interpretation resulting in an change to state(0); i.e., the researchers reorient themselves with the theory based on the domain model.
- The process is also <u>*concurrently*</u> using theory informed design to reach a new design state(9) while the other research activities are underway
- The transition from the design state(9) to a new domain state(10) is accomplished through the computational infrastructure modification (computeInfrastructure).
- The current domain state(10) is analyzed to inform the theoretical foundation through transition domain analysis.

The transformation of domain data into design relationships should utilize Software Engineering (SE) methods to maintain control over the process. The LTS reflects how software tool components designed using this framework must be integrated in such a way to transform unconventional inputs such as policy constraints into useful SE outputs.

This iterative, concurrent and incremental process may be combined with an extensive analysis phase utilizing methods such as explicit scenarios and use cases (Rumbaugh 1994). According to Klashner and Sabet, this process of iterative analysis using current theory and domain feedback should result in an optimized design.

Finally, as with any implementation, the resultant design must undergo testing and qualification before release to the end users. This testing may include the actual or derived scenarios that were utilized in the analysis phase (e.g., use case scenarios). This testing or verification of the system is also considered part of the evaluation of the resultant design. Wallace et al. explain in detail a number of testing techniques that may include simulations, prototyping, functional testing, and a number of software engineering analysis methods such as event tree analysis, or dataflow analysis (Wallace et al. 2000). The Klashner and Sabet design model and these testing/evaluation strategies can be adopted in the design of an EKP support system as well.

2.8 Knowledge Capturing Algorithms

A short summary is provided in Table 2.5 describing a number of knowledge capturing and manipulation algorithms. These algorithms may be viewed as a subset of KMS, ES and DSS techniques (refer to DSS types explained above).

Table 2.5 Knowledge Capturing Algorithms

Knowledge Capturing Algorithms	Description
Rule-Based	Knowledge stored as user-programmed rules. All incoming data/information are compared to these Boolean rules.
Fuzzy Logic	Fuzzy sets are created. Alarms have a degree of membership in a set. Algebraic operations are used to determine if incoming data/information belong to a set.
Bayesian Networks	Direct acyclic graphs connecting various knowledge point and the associated conditional probabilities are created. Traversing the graph provides for appropriate results.
Model-Based Reasoning	Functional and structural models of the domain are programmed into the system. These are then used to represent the correct solution to a specific problem.
Intelligent Filtering	Filter incoming information/data from being displayed to the user, utilizing preprogrammed knowledge as filter criteria.
Case-Based Reasoning	Storing of complete "cases" to be adapted and used for comparison against environment input.
Coding	Matrix solution of input vs. solutions.
Proactive Correlation	Use of data mining to learn patterns that may assist in the discovery of future solutions.
Artificial Neural Networks	Knowledge points are nodes in a neural network causing excitation in neighboring neurons to arrive at an appropriate solution.

2.8.1 Rule-Based Algorithms

Rule-based algorithms involve saving knowledge in the form of a set of rules that may be stored in a database. A rule is a boolean expression in the form of an "if-then" statement with two components — a condition and an action. When the condition is true then the action describes a specific solution set. Rules may be applied sequentially or prescribed in a specific order based on the system's control strategy. The Information System is divided into three levels:

- An inference engine which manipulates the rules and incoming data
- A knowledge base that includes the rules and solutions
- A "working memory" that includes the current state of the domain or the set of inputs being examined.

Rule-based systems are the most widely used solutions available in the telecommunications industry today (Lo et al. 2000). They are also widely used in the medical field by medical DSS (Achour et al. 2001). However, a major drawback of rule-based algorithms, as with any ES is the reliance on human actors to populate the knowledge base with rules and update them as the domain changes. Lewis argues that such a system quickly becomes obsolete in a fast changing environment such as telecommunications industry (Lewis 1993).

2.8.2 Fuzzy Logic

Fuzzy logic involves the use of "fuzzy sets". In this instance, a "fuzzy" set membership is not simply true or false as with a rule-based approach, but is conceptualized in degrees of membership. Special algebra is used to perform a number of operations on these sets. As such, the IS may be viewed as algebraic operations on fuzzy sets to produce a given solution (i.e., set membership). Fuzzy logic IS are still considered a novel idea, even though Zadeh discussed fuzzy logic in 1965 (Zadeh 1965). It is currently still virtually impossible to prove mathematically that a fuzzy logic system works. One must rely on empirical data for such proofs.

> "The stability of fuzzy logic-controlled systems cannot be proved mathematically" (VerDuin 1995).
>
> "There still are not tools that allow to prove, a priori, that this system works" (Meira 1997).

Since fuzzy systems reason using fuzzy logic membership functions, an object may have a degree of membership in various sets. A knowledge base combined with a fuzzy query system may be used to form queries or analysis using incomplete data and utilizing terms common to the domain. "Fuzzy techniques result in knowledge bases that are flexible and semantically rich" (Sedbrook 1998).

2.8.3 Bayesian Networks

A Bayesian Network is a directed acyclic graph in which nodes represent random variables. Each variable is assigned conditional probability, given all the possible combinations of values of the variables represented by the directly preceding nodes. Traversal to an edge in the graph shows the existence of a direct causal influence between the variables corresponding to the interconnected nodes (Heckerman et al. 1995; Meira 1997). There are two major problems with Bayesian Networks. The first is the fact that the probabilities assigned to the occurrence of given events is based on the subjective expert judgment. The second problem is the amount of processing power required to calculate the probabilities associated with each node. Every time an event occurs, it is necessary to reevaluate the probabilities associated with every node in the network, which obviously involves Nth-order processing (Meira 1997).

2.8.4 Model-Based Reasoning

Model-based reasoning (a concept from Artificial Intelligence research) uses a structural and a functional model of the system. The structural model is the description of the physical environment. The functional model represents the behavioral aspects of the environment (Meira 1997). A major problem with this approach is the idea of programming the functional model. This functional model must also be a dynamic model since system domains or environments are constantly changing and this model outlines process-steps, process transitions, and behavioral characteristics that describe the environment (Schmidt 1989).

2.8.5 Filtering Algorithms

The following two algorithms both help resolve problems by blocking the presentation of confusing data to the user. However, neither of the two conceptual algorithms presumes to deliver an adequate root cause analysis (i.e., an actual solution). The simpler concept is the use of intelligent filtering algorithms that sort out predefined "important" data (i.e., based on user entered characteristics such as category, severity, location, etc.) from incoming data in order to display only relevant data to the user. Intelligent filtering involves dynamic, automatic filtering of data. This approach may also be considered as a form of information masking.

The other conceptual approach associated with intelligent filtering is "hysterisis" as defined in the electrical engineering domain. It is used there for electrical circuits as a de-bounce mechanism. Hysterisis in that situation is intended to combat bursts of unnecessary information. Basically, when input stimuli occur or are cleared in electrical engineering the changes are not reported until the readings are stable. Active states are immediately reported. However, the clearing of a stimulus state is not reported until a specified delta in time passes. If the stimulus reoccurs during this temporal delta, then it becomes unnecessary to report the clear activity at all. When a stimulus finally clears for the entire delta, it is reported to the user as having been cleared. Thus, this toggling stimuli (or noise) behavior is stabilized, which stifles a flood of events to the user. This method relies heavily on time synchronization across the system and correct time stamping of events. The approach can be improved upon by dynamically assigning the delta time-span based on specific domain activity.

2.8.6 Case-Based Reasoning Algorithm

Case-based reasoning is very similar to rule-based algorithms. However, instead of being based on specific rules, this approach uses a complete case in which past "patterns" are stored in a database and compared with the data (El-Sawy et al. 1997). Cases are stored and indexed so that they may be searched based on the current state of the system. Searching the cases and adapting solutions to specific states remains a challenge (Meira 1997). As new patterns occur, they are indexed and stored in a database for future searches. Thus, the system "discovers" new knowledge via the occurring patterns rather than human intervention. However, one of the shortfalls of this method, which is obvious from the description, is the use of historical data. In other words, any given pattern must occur at least once before the system discovers the solution to the problem presented by the unknown pattern.

2.8.7 Code-Book

A matrix of cells is maintained in the "codebook" approach. The columns represent coded input data and the rows are maintained as coded solutions. The cells are populated with the probability of a solution resulting from a combination of input data. By comparing the matrix with states, the system can search the matrix for the appropriate solution. This approach provides for efficient searching mechanisms, but it still requires subjective probabilities to be defined.

2.8.8 Proactive Correlation

Proactive correlation uses data mining and knowledge discovery techniques to analyze patterns that have already occurred. The analysis should then determine patterns that can be used to discover solutions of future problems. Furthermore, determining patterns from the mined preliminary data may allow for identifying future patterns before they occur. Proactive correlation is a very promising approach. Human involvement is not completely eliminated, but as the system "learns" patterns the human's input in the loop is diminished greatly. Another drawback of this system is the obvious fact that the data mine must be substantially populated before it can be utilized. However, combining this approach with certain seed data (based on one of the above approaches) may prove to be very effective.

2.8.9 Neural Networks

A computational neural network system attempts to mimic the neural network in the human brain. In this modeling approach, each neuron is a processing unit with its own memory and communication channels to other neurons. A neuron processes its input channels comparing them to stored thresholds, which will actuate a signal on the appropriate output channels if the threshold is exceeded. In this manner (as in the human brain), neighboring neurons are "excited" by outputs from other nearby neurons. Neural networks have great parallelism abilities and are very efficient, but further development of improved computer hardware is necessary to support the processing involved in neural network implementations. In addition, neural networks provide for "learning" capabilities (theoretically similar to the human brain). However, this field of research is still in its early stages and the technology is risky when considering mission-critical infrastructure.

Meira provides a very extensive review of these various knowledge capturing and manipulation algorithms as they pertain to the telecommunications domain (Meira 1997). Any combination of these algorithms may be utilized in a single design. The resulting designs may then be evaluated to gain more knowledge and insight into the design process.

2.9 Design Science

Design is itself both a process and an artifact. Design science seeks to improve the design process by evaluating the resultant artifact in an organizational environment thus adding to the IS community's body of knowledge related to the organization's management and use of information technology by collecting empirical and qualitative data. The newly acquired knowledge can then be used to guide further design of classes of systems (e.g., DSS, KMS) (Hevner et al. 2004). IS research must address these design tasks faced by practitioners in both business and government (March et al. 1995). March and Smith explain that the results of design science can be categorized as four types; *constructs, models, methods and instantiations* (March et al. 1995).

Constructs are concepts from the IS domain. They include the language and knowledge shared across experts in the domain. Therefore, constructs are the language in which the problems and solutions are defined. Models use constructs and the relationships among these constructs to represent real world situations. Methods are algorithms that are based on constructs and take sections of the models as input to perform specific tasks. Finally, instantiations are the actual IS implementation or tools created to assist in the design of the IS (March et al. 1995).

There are four main activities that are performed in design science research. These activities consist of *building, evaluating, theorizing, and justifying* (March et al. 1995). Once an artifact, such as a construct, model, method or instantiation, is built it must then be evaluated. Design science research utilizes the evaluation of the built artifact to theorize about its characteristics or performance. Finally, the researchers must justify the resultant theories (March et al. 1995). Hevner et al. outline a number of guidelines for design-science research in Table 2.6.

Table 2.6 Design Science Research Guidelines

Guideline	Description
1. Design as an Artifact	Design-science research must produce a viable artifact in the form of a construct, a model, a method, or an instantiation.
2. Problem Relevance	The objective of design-science research is to develop technology-based solutions to important and relevant business problems.
3. Design Evaluation	The utility, quality, and efficacy of a design artifact must be rigorously demonstrated via well-executed evaluation methods.
4. Research Contributions	Effective design-science research must provide clear and verifiable contributions in the areas of the design artifact, design foundations, and/or design methodologies.
5. Research Rigor	Design-science research relies upon the application of rigorous methods in both the construction and evaluation of the design artifact.
6. Design as a Search	The search for an effective artifact requires utilizing available process means to reach desired ends while satisfying laws in the problem environment.
7. Communication of Research	Design-science research must be presented effectively both to technology-oriented as well as management-oriented audiences.

Source: Hevner, A. R., S. T. March, et al. (2004). "Design Science in Information Systems Research." MIS Quarterly 27(4): 75-105.

Hevner et al. also outline possible evaluation methods for design-science research (Table 2.7).

Table 2.7 Design Evaluation Methods

Evaluation Method Types	Evaluation Methods
1. Observational	Case Study: Study artifact in depth in business environment Field Study: Monitor use of artifact in multiple projects
2. Analytical	Static Analysis: Examine structure of artifact for static qualities (e.g., complexity) Architecture Analysis: Study fit of artifact into technical IS architecture Optimization: Demonstrate inherent optimal properties of artifact or provide optimality bounds on artifact behavior Dynamic Analysis: Study artifact in use for dynamic qualities (e.g., performance)
3. Experimental	Controlled Experiment: Study artifact in controlled environment for qualities (e.g., usability) Simulation – Execute artifact with artificial data
4. Testing	Functional (Black Box) Testing: Execute artifact interfaces to discover failures and identify defects Structural (White Box) Testing: Perform coverage testing of some metric (e.g., execution paths) in the artifact implementation
5. Descriptive	Informed Argument: Use information from the knowledge base (e.g., relevant research) to build a convincing argument for the artifact's utility Scenarios: Construct detailed scenarios around the artifact to demonstrate its utility

Source: Hevner, A. R., S. T. March, et al. (2004). "Design Science in Information Systems Research." MIS Quarterly 27(4): 75-105.

These guidelines and evaluation methods assist researchers in performing design science research that contributes to the IS community. Since design science is fundamentally about evaluating the built IS artifact, a specific type of IS design that represents a research challenge needs to be designed and developed. The artifact utilized in this research is a global telecommunications alarm correlation IS.

2.10 Alarm Correlation

Alarm correlators are designed to improve a Network Management System's (NMS) fault management capabilities (Sabet et al. 2003a). The greatest problems in network management is not the lack of information, but rather an increase of data that has flooded network management centers (Nygate 1995) leading to information overload for operators. This influx of data is due to the increased complexity of network architectures. Alarm correlation techniques are an attempt to reduce this flood of information while still providing effective management capabilities. Having received this information, users still require an increasing amount of knowledge and experience to manipulate the raw data in order to perform a root cause analysis of the network faults.

Alarm correlation attempts to condense and filter incoming information to assist in the diagnosis process, utilizing one of the knowledge manipulation algorithms introduced earlier such as rule-based correlation or intelligent filtering of alarms. Current solutions have major drawbacks including the effort required to populate their knowledge base and the inability of the system to remain up to date with the dynamic nature of the networks. These disadvantages may be due to the fact that the designed capture methods are not an appropriate fit to the type of knowledge being captured, possibly because an appropriate design theory was not followed.

A number of researchers have investigated methodologies and tools to improve alarm correlation facilities in network management systems (Klemettinen 1999; Klemettinen et al. 1999; Meira 1997; Meira et al. 2000). In addition, a number of commercial telecommunications companies and telecommunications equipment suppliers have also developed systems and published information related to their findings (HP, Cisco, Nortel, Sycamore, TTI-Telecomm, Ciena, and Lucent etc.). However, most of this research centers around specific algorithms and techniques to improve accuracy of the alarm correlations system. Little or no importance is given to the design methodologies and practices required for these complex systems.

CHAPTER 3

THEORETICAL BACKGROUND

This chapter presents the specific theoretical foundations that were utilized to guide this research. Design theory is presented in a general context and the specific design theory, for systems that support Emergent Knowledge processes, utilized during the research process is discussed in detail. Finally, the theory , Complex Adaptive Systems theory, upon which the DSS design model that framed the research work is explained in the final section of this chapter.

3.1 IS Design Theory

Information Systems Design Theory as defined by Walls et al. is intended to be a guide for the development process of a specific type of system. Design theory includes a set of user requirements, a set of system features and a set of principles to guide the development process (Hall 2003; Markus et al. 2002; Richardson et al. 2004; Walls et al. 1992; Walls et al. 2004). This definition addresses both the design process and the resultant artifact consistent with Hevner's explanation of design science (Hevner et al. 2004).

A design theory is built on a basic concept referred to as a "kernel theory" (Walls et al 1992). "This can be either an academic and scholarly formulated set of concepts, statements, or practitioners' theory-in-use which is made explicit through hermeneutic process of codification. A kernel theory enables [the designer] to formulate testable predictions of a class of solutions and their behaviors, or the associated design process" (Hanseth et al. 2004).

Other authors such as Richardson and Courtney (Hall 2003; Kasper 1996; Richardson et al. 2004; Stein et al. 1995) use Walls' definition to postulate their own design theories for KMS and organizational learning systems. Markus et al also adopt Walls' definition to produce an IS Design theory for systems that support Emergent Knowledge Processes (EKPs) (Markus et al. 2002). In the following section we discuss the IS design theory introduced by Markus et al. that may provide a method to meet the challenges introduced by global mission-critical infrastructures.

3.2 EKP Design Theory

Emergent Knowledge Processes, as defined in the previous chapter, are organizational processes that are characterized by a changing set of actors, distributed knowledge bases, and emergent knowledge sharing activities where the process itself has no predetermined structure (Markus et al. 2002). Markus et al. introduce an IS design theory that is intended to guide the building of systems that can support EKPs. This design theory is consistent with, and based on, the Walls et al. definition of IS Design Theory.

Table 3.1 IS Design Theory For EKPs

Components	Approach
Kernel Theory	EKPs require an EKP support system developed via an emergent development methodology
Users and Their Work Context	System must be self-deploying; developers should conceptualize each user-system interaction as a customer engagement process and repeatedly seek out "naïve" users through a process of "onion-layering" the design team
Users' Information Requirements	System must translate expert knowledge into actionable knowledge for non-experts; developers should expect to need many functional prototypes, instead of a few nonfunctional prototypes System must induce users to take offline action; developers must observe and strive to change users' offline, as well as online, action System must integrate expert knowledge with local knowledge sharing; multiple needed functionalities must be integrated rather than added
The Process	System must implicitly, not explicitly, guide users' deliberations in desirable directions, without restricting them to a prescribed process; developers should use a dialectical development process instead of a consensus-seeking approach System must be extremely flexible; developers should componentize everything, including the knowledge-base

Source: Markus, M. L., A. Majchrzak, et al. (2002). "A Design Theory for Systems That Support Emergent Knowledge Processes." MIS Quarterly 26(3): 179-212

The design theory proposed by Markus et al. is premised on six main principles:

- Design for customer engagement by seeking out naïve users
- Design for knowledge translation through radical iteration with functional prototypes
- Design for offline action
- Integrate expert knowledge with local knowledge sharing
- Design for implicit guidance through a dialectical development process
- Convert everything into components including the knowledge base

They assert that the design theory described in Table 3.1 can assist developers in producing better systems to support EKP. They state that DSS, ES and KMS design guidelines are not sufficient for development of such systems (Markus et al. 2002). As organizations break geographical barriers and enter an era of a global economy, system users become more unpredictable. Hunter and Beck discuss a classic IS research hypothesis that suggests industrialized societies throughout the world *will converge* and become more similar to one another as a result of globalization. The predicted convergence is better achieved when new technology, better education, and consistent training is introduced universally. On the other hand, there is *a divergence hypothesis* suggesting that cultures tend to resist change and societies strive to retain their cultural distinctiveness (Hunter et al. 2000). Thus, it is still unclear what the characteristics of users for future global, "cross-cultural" systems will be. Widely accepted DSS design guidelines do not easily support development of a system that satisfy these cross-cultural, and geopolitical requirements because they generally assume a predetermined user base that may be consulted and whose requirements are predefined (Grudin 1991).

Markus' research team respond to this challenge in their IS design theory. They explain that these systems should not only be user-friendly, but that the development process should induce "naïve" users — i.e., novices or experts in organizational practices who are ignorant of the details regarding the current system under development and in question — to use the system and provide them with immediate benefits as an incentive for further use. Therefore, such systems have to be developed to provide immediate improvements in the naive users' work efficiency. In addition, they suggest that developers should design systems to guide how users perform their jobs on-line and off-line (Markus et al. 2002; Silver 1990). The system should translate expert knowledge for use by non-experts (Markus et al. 2002; Shirley et al. 1999). To do this correctly, Markus et al. introduce the notion of a radical iteration approach to show that functional prototypes should be used and iterated through many times to acquire user feedback. Finally, the authors explain how distributed knowledge must be shared and how the system should contain a knowledge-base that is a separate system component to facilitate flexible modifications of acquired knowledge (Markus et al. 2002). This implies knowledge may be acquired through multiple users, which are perhaps even geographically (spatially) separated. That knowledge may then be captured in the system and disseminated to all users. However, because this shared knowledge is constantly updated and renewed, a simple centralized, monolithic solution is not practical. Therefore, the authors advocate a component-based architecture, an approach to architecting software solutions from components. This approach produces applications that are very flexible because of their component "plug and play" nature (Shaw et al. 1995; Wang et al. 2004).

The system's design must allow for distributed knowledge to be contextualized and shared instead of simply capturing expert knowledge as is advocated in ES design (Aiken et al. 1991; Markus et al. 2002). The EKP system design and development principles refine the idea of supporting fluid, highly manipulated and easily accessible data by specifying that the system shall contain a knowledge base that is a separate component to allow for flexible evolution of the acquired knowledge (Markus et al. 2002).

Markus et al. developed the EKP system design theory as part of an ongoing IS development effort; i.e., the "Technology, Organization, and People" (TOP) Modeler Integration. This field site IS under development was intended to support organizational design in manufacturing organizations. As the TOP Modeler development progressed, Markus et al. recognized their initial assumptions were incorrect regarding the use of the traditional semi-structured decision process design theories. The established theories implied they needed to (1) design for a specific user group, and (2) capture expert knowledge via if-then rules in the IS. That approach did not provide a good "fit" for the process they were trying to support (Zmud 2002). This situation was similar to the one encountered by Klashner (2002). In the latter case, the electric power industry was undergoing a paradigm shift due to deregulation policies enacted at the State and Federal government levels. The shift caused IS design strategies, which had met their needs for decades, to be abandoned in light of new domain constraints associated with market forces. These empirical observations contributed to the decision to include multi-theoretical capabilities in the original design model behavior (Klashner 2002).

The Markus research team in the TOP project modified their design theory by adding the principles described earlier to accommodate emergent knowledge processes. One of the specific changes was repeated deployment of prototypes (over 70 in all) in a number of partner companies testing the teams' assumptions in order to refine the TOP design. Their research work was led by at least three senior researchers and was funded by a three (3) million dollar grant, while being actively backed by four (4) major corporations. The final result of the research was a number of principles that can guide the development process for systems that may support other emergent knowledge processes. The authors make the claim that the success of the system design supports the EKP design theory they developed. The success of the system was measured as validation of the following:

- Knowledge base
- Delivery of the system on time and within budget
- Multiple use of the system in various organizations
- Favorable user evaluation results.

By observing and evaluating the system in a number of firms, Markus et al. had refined their system design. Their EKP design theory integrates a number of research concepts and augments current IS design research with new principles. Nevertheless, the

EKP design theory has many characteristics of another system design and development paradigm described next.

3.3 Complex Adaptive Systems

The DSS Design Model utilized in this research was derived from several disciplines (Klashner 2002). It was largely based on a model developed within a "complex adaptive systems" (CAS) framework Since CAS was the foundation for the DSS Design Model utilized extensively in this work, concepts of CAS are discussed in this section.

Systems theorists from the 1950s and 1960s had tightly coupled the concepts of organization, information, control, and communication. A system's environment is composed of a set or ensemble of elements, states, or events that are distinguishable based on spatial relations, temporal relations, or properties (Buckley 1967). These differences provide a range of options or "variety". Buckley asserted that CAS elements were almost entirely linked by the intercommunication of information. All entities are in a state of "organized complexity" ("collection of entities interconnected by a complex net of relations") that lies between the two opposite extremes of "organized simplicity" and "chaotic complexity".

Organized simplicity "is a complex of relatively unchanging components linked by a strict sequential order or linear additivity, without closed loops in the causal chain." Chaotic complexity refers to "a vast number of components that do not have to be specifically identified and whose interactions can be described in terms of continuously distributed quantities or gradients, as in statistical mechanics." Buckley asserts that all definitions of organization fall between these two extremes. Varying degrees of "contingencies" determine an organization's position between the two extremes. Buckley defined relatively stable spatial, causal, and/or temporal relations between elements or events as "constraints". Chaotic complexity exhibits an ultimate lack of constraint and organized simplicity exhibits the presence of maximum constraint. The entire ensemble of elements interacts within these relationships to create a "tension" or elasticity. The tension created adds referential validity within the system as it converts environmental variety into an internal information structure.

The third concept, in addition to "contingency" and "constraint" used by Buckley to explain complex organizations is "degrees of freedom in the interrelation of parts" (p. 83). Freedom to seek goals of its own is critical to the nature of a CAS since it is inherently connected to the evolutionary mission of the system. No freedom of choice implies a state of maximal organization, while complete or absolute freedom of choice implies a state of systemic chaos. Constraint and degrees of freedom become dynamic constructs that describe a complex adaptive systems' relation to a changing set of contingencies (Klashner et al. 2004a). Buckley connects these organizational concepts to an information theory providing a "generalized logical framework for the discussion of symbolic intercommunication" (p. 84). The CAS framework provides the basis of the DSS Design Model that, in turn, provided the entire foundation for this research. CAS helps guide the choice of theories with respect to the domain data, resources, and system composition. The model utilizes the relationships, contingencies, and constraints outlined in the theory to organize the system design process for complex IS such as DSS.

CHAPTER 4

RESEARCH METHODOLOGY

This chapter outlines the methodology used to perform the current research. The research discussed in this dissertation is framed around iterations of the DSS Design Model, described in the next section. The Case Study methodology was utilized to collect and analyze empirical data to arrive at the specific contributions of this research. This is discussed in the final sections of this chapter.

4.1 Model Iterations

The entire design and research for the KD-DSS followed iterations of the DSS Design Model. The initial major iterations of the model were based on conventional design wisdom, which included iterative development and prototyping. In developing an alarm correlation tool, as with any Information System, the choice of proper software engineering approaches becomes crucial. In fact, the bulk of current IS literature suggests that IS problems can be greatly reduced by improving the IS development process (Lyytinen 1987). The Rational Unified Process (RUP) was chosen within the CAS framework because it can take a holistic system view and it was a good fit for the development of the system prototype for this project. RUP allowed easier management of the project even while constrained by time and the structure of the project team (i.e., NJIT students were used for part of the development process).

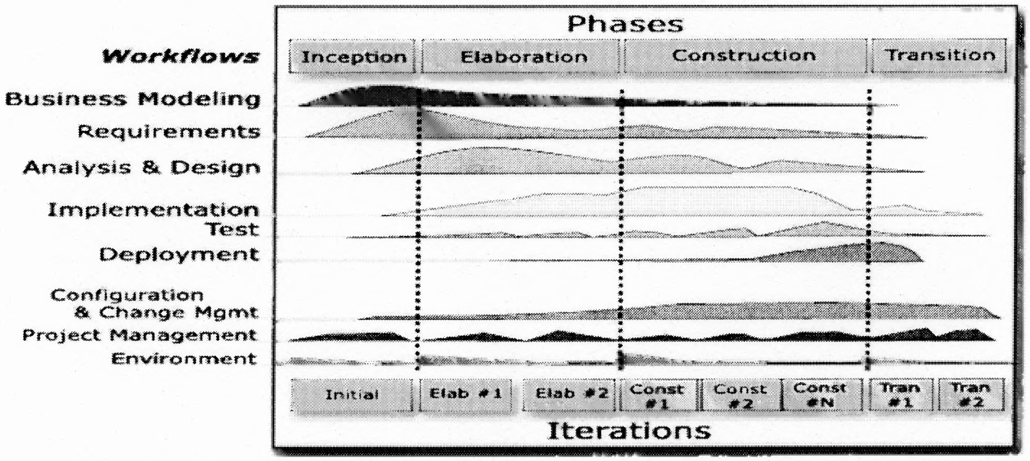


Figure 4.1 The Rational Unified Process.
Source: Unified Software Practices v2001.03.00 Copyright © 2000 Rational Software, all rights reserved

The RUP is a software engineering (SE) process used to guide the software development effort at an operational level. It is a positivistic and prescriptive SE methodology created within an Object Oriented paradigm by software engineers with a shared ontology embedded in a formalistic approach and notation (the Unified Modeling Language). Figure 4.1 shows the RUP high level representation as described by the Rational Corporation (IBM acquired Rational Corporation during this research effort). The horizontal axis represents a timeline and shows the software lifecycle of the process. The vertical axis shows the process areas that must be performed in logical groupings (workflows). The result of each workflow as time passes incrementally is an artifact (e.g., document) that is used as input for the next phase of the workflow. The process is intended to be an iterative approach (Kruchten 2003). The RUP best practices include:

- Focus on architecture
- Use case driven analysis and design
- Iterative and incremental software development
- Close attention to Requirements Management
- The use of component-based architecture
- Use of visual modeling of software
- Continuous quality verification
- Use of software change control

Many of these best practices were mapped into the various phases of the DSS design model. For example the use case analysis and the modeling of software comprised the theory and analysis phase of the model iteration. The component-based architecture practice and the incremental development approach influenced the design decisions phase in the model iteration. Finally the quality verification and utilization of prototypes provided the simulation phase of the model iteration.

The requirements elicitation phase was of particular importance to this project, throughout the DSS model iterations. Since users were geographically dispersed it was difficult to elicit requirements. The initial approaches used for the Alarm Correlation Tool (ACT) project were a combination of (Goguen et al. 1993):

- Field Surveys (Valenti et al. 1998).
- Developer as apprentice or participant observation in the field (Baskerville 1999).
- Literature reviews of existing products.
- Prototyping (Lowgren 1995).

These various techniques provided adequate insight into the users' requirements. In parallel with these requirements elicitation activities, the resultant tool was also extensively tested in simulations in a lab environment, since network faults are very costly to reproduce without the use of simulation tools. To accomplish this, over four (400) hundred field related trouble tickets representing transoceanic and transcontinental network faults were collected from the field site. This data was then analyzed by domain experts to determine the most common and most severely impacting fault. The trouble tickets representing these faults were then utilized as simulation scenarios as well as use case scenarios in the survey questionnaire. The simulations involved the use of multiple computers that ran processes programmed to emulate telecommunications network elements similar to the ones found in the field site network (equal to 2 network nodes with more than 256 network elements). These simulators were then "fed" the analyzed trouble ticket data to create realistic alarms mimicking the alarms generated during the network faults documented in the trouble tickets. The ACT was then run against the data provided by these simulators to examine the results of the various correlation algorithm designs when processing field-like network faults.

A number of the trouble tickets were chosen to simulate real-life scenarios as part of the DSS model simulation phases. These trouble tickets were chosen based on their complexity, frequency of occurrence and severity to network operations. The ideal tickets were ones that had a higher level of complexity based on the number of network elements and segments they affected, had a high frequency of occurrence (i.e., they fault type occurred multiple times), and that proved to be a real threat to transmission and customer services on the network. These simulations provided feedback for use in the analysis and theory selection phase of the DSS model. Through this process, the ACT design took shape based on a rule-based correlation algorithm (described in Chapter 2 of this document).

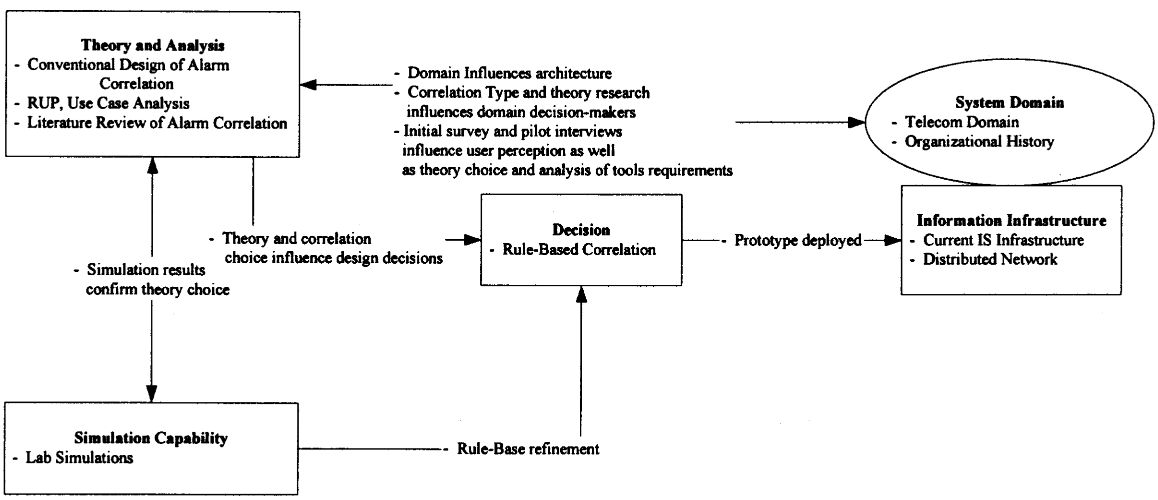


Figure 4.2 DSS Design Model first iteration.

Table 4.1 DSS Design Model First Iteration's Activities

Activity	Area of Model
Conventional Design of Alarm Correlation	Theory and analysis
RUP, Use Case Analysis	Theory and analysis
Literature Review of alarm correlation theory	Theory and analysis
Lab Simulations of analyzed field trouble tickets	Simulation Capability
Rule-Based Correlation	Decision
Current IS Infrastructure (ongoing through iterations of the model)	Information Infrastructure
Distributed Network	Information Infrastructure
Global Undersea Telecommunications Industry	System Domain

The first major DSS design model iteration, Figure 4.2 and Table 4.1, simply followed traditional software engineering practices. Requirements were gathered, the design phase approached and the system coded as per the RUP guidelines. The resultant design, however, proved to be incomplete. It became apparent that to define rules that would cover all possible network faults would be an all but impossible task. Furthermore, preliminary field surveys, in addition to showing the importance field personnel placed on alarm correlation tools, showed that alarm correlation systems developed using traditional design guidelines had not provided sufficient support for the constantly changing telecommunications environment (Sabet and Klashner 2004).

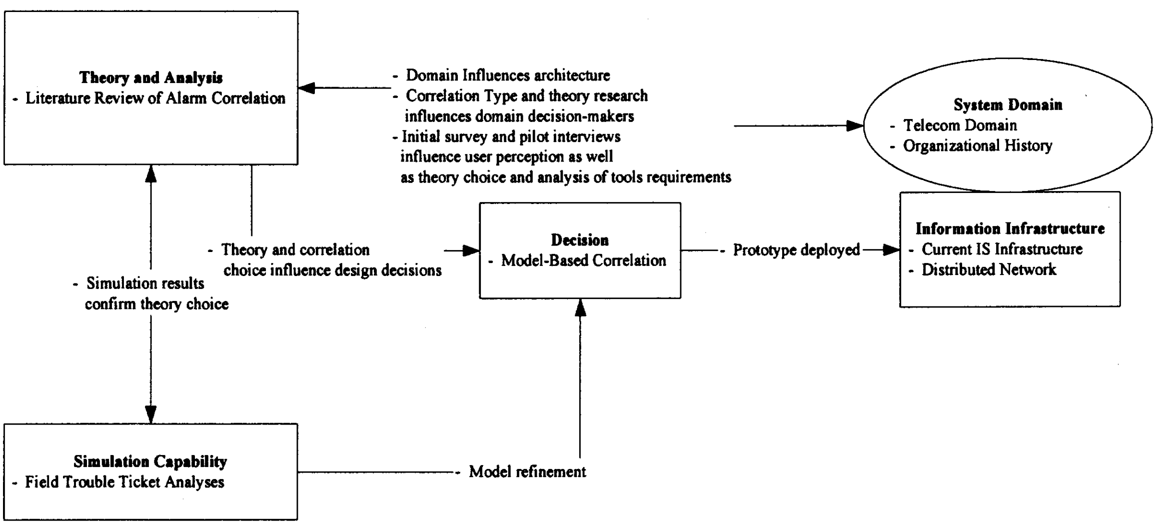


Figure 4.3 DSS Design Model second iteration.

Table 4.2 DSS Design Model Second Iteration's Activities

Activity	Area of Model
Literature Review of alarm correlation theory	Theory and analysis
Field Trouble Ticket Analysis	Simulation Capability
Model-Based Correlation (Meira 1997)	Decision
Current IS Infrastructure (ongoing through iterations of the model) – Included NMS, OSS, Deployed Hardware and Software Assets as well as Data Communications Network (DCN).	Information Infrastructure
Distributed Network	Information Infrastructure
Global Undersea Telecommunications Industry	System Domain

The shortcomings of the initial design stimulated a second major iteration of the model, Figure 4.2 and Table 4.3. Since the industry prevalent rule-based approaches seemed too cumbersome, a literature review of other available algorithms in the academic field was conducted. The literature review showed a number of more powerful algorithms available. However, when the domain constraints were considered and it became obvious that fault diagnosis knowledge was distributed across the entire network, a model-based approach was chosen. The resultant design was again tested using the laboratory simulation environment to reinforce the design decisions made. However, this design still proved inappropriate because it did not meet the distributed knowledge requirements posed by the domain.

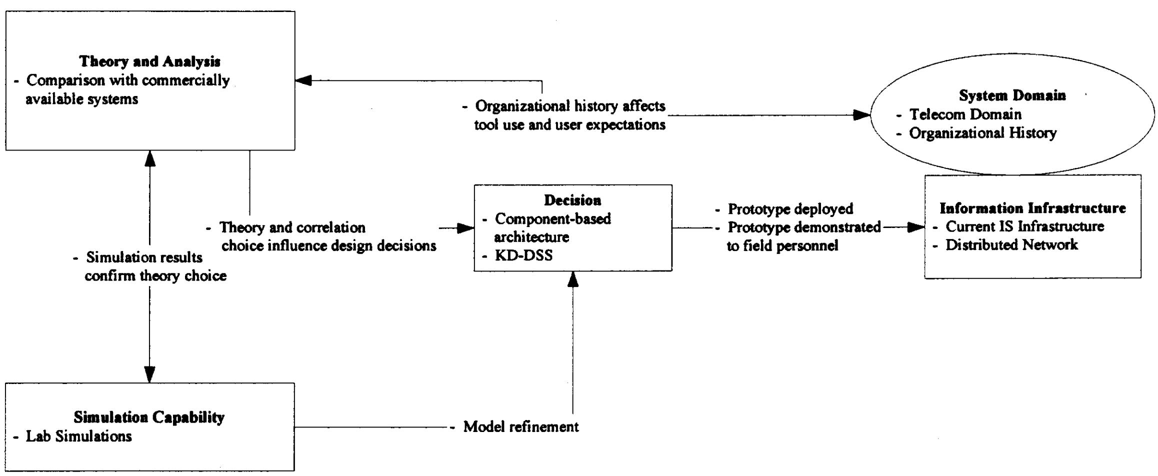


Figure 4.4 DSS Design Model third iteration.

Table 4.3 DSS Design Model Third Iteration's Activities

Activity	Area of Model
Comparison with commercially available systems	Theory and analysis
Component Based Architecture	Decision
KD-DSS	Decision
Current IS Infrastructure (ongoing through iterations of the model) – Included NMS, OSS, Deployed Hardware and Software Assets as well as Data Communications Network (DCN).	Information Infrastructure
Distributed Network	Information Infrastructure
Prototype demonstrated to field personnel	Information Infrastructure
Telecom Domain	System Domain
Organizational history affects tool use and user expectation	System Domain

Further improvements of the design were accomplished in the third major iteration of the DSS model by performing a comparative analysis between the ACT design and other commercially available systems. These comparison systems included HP Openview's alarm correlation feature (Hewlett Packard), Nortel's Preside alarm correlation feature (Nortel Networks), and TTI Telecom's Alarm Correlation Module (TTI-Telecom). The improvements introduced in this iteration included inference engine algorithms as well as functional model modifications to better mimic the network element behavior exhibited by the domain equipment and discovered during the simulation sessions undertaken as part of the ongoing model flows.

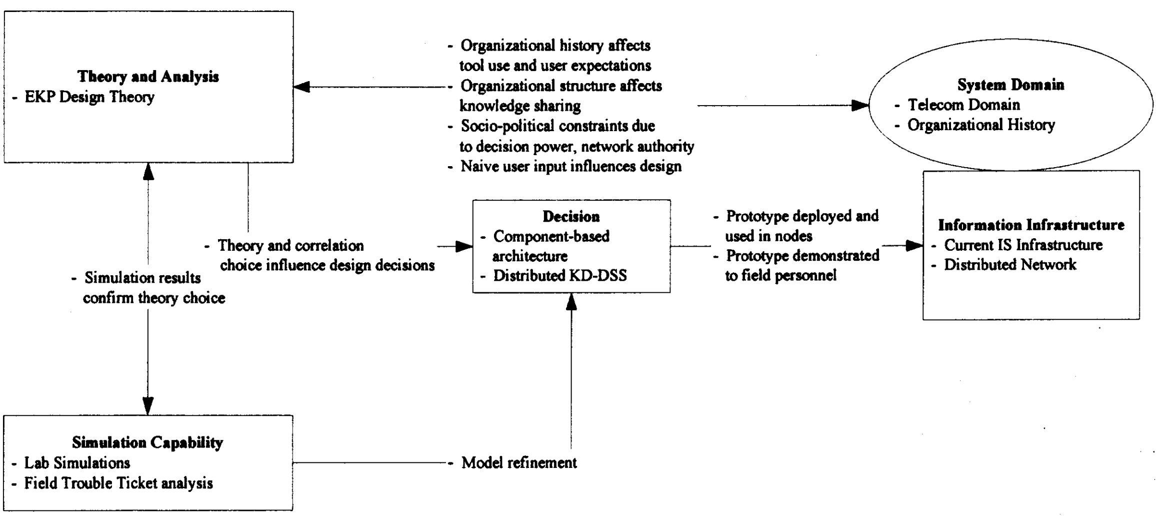


Figure 4.5 DSS Design Model fourth iteration.

Table 4.4 DSS Design Model Fourth Iteration's Activities

Activity	Area of Model
EKP Design Theory	Theory and analysis
Lab Simulations	Simulation Capability
Field Trouble Ticket Analysis	Simulation Capability
Distributed KD-DSS	Decision
Current IS Infrastructure (ongoing through iterations of the model) – Included NMS, OSS, Deployed Hardware and Software Assets as well as Data Communications Network (DCN).	Information Infrastructure
Distributed Network	Information Infrastructure
Prototype demonstrated to field personnel	Information Infrastructure
Tool deployed and used in nodes	Information Infrastructure
Telecom Domain	System Domain
Organizational history affects tool use and user expectation	System Domain
Organizational structure affects knowledge sharing	System Domain
Socio-political constraints due to decision power, network authority	System Domain
Naïve User Input influences design	System Domain

Domain feedback received after demonstrating the initial prototype of ACT to field personnel indicated that the knowledge required for fault diagnosis was not only distributed across the entire network, but was constantly changing. Furthermore, the diagnosis process itself was in a mode of constant adaptation to network and service changes. This feedback led to the determination that EKP design theory would be an appropriate fit for the ACT design. Therefore, the final iteration of the model utilized this design theory to influence design decisions. As with all previous iterations, simulations involving network element alarms and faults determined from field trouble ticket analysis were conducted in a laboratory environment. The results of these simulation sessions were very encouraging to the designers, showing over ninety percent (90%) accuracy in detecting root causes of network faults.

The research process and design work involved multiple iterations of the model. Although there were many minor iterations of the model, Tables 4.1 to 4.4, and Figures 4.2 to 4.5 describe the various major DSS Design model iterations performed during the research. In later iterations of the model, having received domain feedback, it became obvious that these traditional designs were insufficient for developing the tool. Further research in the IS literature revealed that KD-DSS may provide the answer needed for such a demanding system. The system was modified to conform to this approach, but when introduced into simulation environments and demonstrated to potential users, a number of shortcomings were discovered. At this stage, the final major iterations of the model, EKP design theory became the focus of the research team. As more information became available about the domain and the fault diagnosis process itself, it became obvious that traditional design methods were insufficient to support a design for this system. Once the researchers were able to classify the fault diagnosis process as an Emergent Knowledge Process, the EKP design theory became a natural choice as the design guideline for the ACT system.

The case study (Yin 2003) was performed during the fourth and final major iteration of the model. The main purpose of this case study was to collect evaluation data on the results of introducing ACT into the network and to gauge the success of using the EKP design theory during the this iteration. The next chapter outlines the field results gathered during this stage of the research.

4.2 Case Study

A significant portion of the methodology used in this research entailed the performance of a case study. The case study was performed near the end of the research timeframe and provided the bulk of field survey data for analysis.

Case studies have been accepted as an appropriate methodology for studying the implementation of Information Systems in an organization (Hevner et al. 2004; Majchrzak et al. 2000b; Yin 1981). Case studies observe the phenomenon in its real life environment. It is a way to observe Information Systems in the organizational setting. Interviews, questionnaires, and observation techniques (such as ethnography) may also be used in a field study (Baskerville 1999; Myers 1997). However, triangulating these qualitative methods with some quantitative methods to support the data retrieved from the field research is advisable (Majchrzak et al. 2000b; Myers 1997).

Case studies are "an essential form of social science inquiry" (Yin 2003). The case study methodology is a positivistic approach that has been utilized in many research programs where a complex phenomenon requires in-depth, holistic investigation (Dubé et al. 2003). There are three types of case studies:

- Exploratory case studies are used to define questions for further studies or establish the feasibility of some future research.
- Descriptive case studies are used to completely describe a phenomenon in its context.
- Explanatory case studies are used to discover causal relationships in a particular context.
- Any of the three types of case studies may be based on single or multiple-case studies.

The research described in this dissertation employed an explanatory, single case study methodology as part of the last iteration of the DSS design model. Theory in the case study was used to decide what was being explored and for generalizing its results (Yin 2003). During the research the following theories were developed.

4.2.1 Theory

The following micro-theory was introduced based on the DSS and KMS research (Chapter 2). The related research review showed that the introduction of knowledge management capabilities should facilitate the organization's effectiveness.

> "If we introduce/facilitate knowledge management capabilities into the system, we will evolve the troubleshooting process toward stability (organized simplicity) at the individual and group levels because the entire system has successfully mapped (through the KD-DSS) the domain variety into information and knowledge."

4.2.2 Rival Theory 1

The following micro-theory was introduced as an alternative explanation, should the primary theory prove wrong. Therefore, should the introduction of the KD-DSS into the organizational environment not improve the organization's effectiveness, then perhaps this is due to the fact that certain group relationships and behaviors are not changed when the system is introduced.

> "There are certain decision-making models that individuals and/or groups follow that will not be changed by the external stimulus; namely the introduction of Knowledge Drive Decision Support Systems (KD-DSS) group and individual normative behavior."

4.2.3 Rival Theory 2

A second alternative micro-theory was introduced as an explanation, should the primary theory and the first rival theory prove wrong. Therefore, should the introduction of the KD-DSS into the organizational environment not improve the organization's effectiveness and the first rival theory not offer the correct explanation, then perhaps this is due to the fact that the organizational structure imposes a decision making process that does not allow for the use of KD-DSS.

> "The information systems architecture, which is strongly correlated with the organizational structure, pre-determines the decision-making process in fault resolution. Knowledge management does not have to be a necessary component in this information systems architecture."

Using these (micro-)theories increases the external validity of the case study. Contemplating the rival theories guarantees internal validity to the research work. The case study researcher must triangulate multiple sources of data and evidence collected during the case study, guaranteeing construct validity to the research method (Yin 2003). During the case study research a large amount of data was collected (Appendix D) using interview, surveys, experiments/simulations, field site observation and document reviews. This data is collected in a case study database. Traceability across the theory, evidence and conclusions reinforces the reliability of the case study itself. Per Yin, a case study protocol (Appendix A) was developed to guide the researchers and increase the reliability of the case study. This protocol was shared with the field site upper management to document the activities the researchers would perform on site and to guarantee senior management support for the research.

Survey questionnaires were sent to all the field personnel directly involved in fault diagnosis of the network. Face-to-face interviews were conducted with a number of local field personnel. In addition, telephone conference call interviews were performed with remote field personnel. In total, three pilot interviews were performed and sixteen subsequent interviews were accomplished. The interviews were performed by an interviewer who was not involved in the domain itself to increase the reliability of the interviews and minimize any biases that may be introduced by the main researcher who was immersed in the domain being studied. Interview questions were designed based on the Critical Decision Method (Klein et al. 1989) – an interview methodology that requires probing questions, after the fact, to investigate the decision-making process during a critical incident. As decisions are made, one can utilize CAS (defined in Chapter 3) to view decisions as choices made when presented with variety in the domain (based on information presented and the possible choice alternatives) and contending with constraints that arise during the critical incident.

In addition, observational sessions were conducted in a telecommunications command and control center, or Network Management Center, to observe how operators attempted to solve network faults. Unfortunately, the researchers were not allowed to video tape these sessions. However, all activity of note that was observed, was documented and carefully analyzed at a later time. Finally, these observational sessions also provided the opportunity for informal discussions with network operations personnel during network "downtime".

CHAPTER 5

RESEARCH FIELD SITE

Chapter 5 presents the details of the field site for this research. The field site chosen was a global telecommunications network where the complex fault diagnosis process required to maintain the network had exhibited a large number of problems and users had expressed a great deal of dissatisfaction with supporting IS tools.

5.1 Global Telecommunications Domain

The field site consisted of several data collection locations including the only command and control center in a global network and many of the network's nodes. One organization operates the entire global undersea optical telecommunications network, which is the overall "field site". Nodes in this network are "cable stations" that house a plethora of network elements (NEs) traditionally managed by a DSS known as the Network Management System (NMS). The engineers/technicians staffing the cable stations are responsible for maintaining the local equipment in their node. They are also given access to the NMS screens pertaining to their "jurisdiction". The overall coordination of management of the network is performed by a centralized Network Management Center (NMC). The NMS has been developed to remotely manage this equipment in automated stations. In a typical global network, there may be dozens of cable stations across the globe operating in various countries.

One of the most important areas of network management in the telecommunications domain is fault management. Generally, engineering development and diagnosis is a very complicated process. In global telecommunications network, groups of field personnel including both expert engineers as well as less knowledgeable technicians collaborate remotely and often asynchronously to diagnose network faults and minimize downtime. As these networks explode in size and complexity the environment becomes more unpredictable. Furthermore, due to the distributed global nature of these systems, it is impossible to determine the current socio-political climate in the network at any particular time (Sabet et al. 2003a). These factors combine to characterize such network fault diagnosis as an Emergent Knowledge Process.

Current NMS approaches maintain a centralized decision process that often excludes expert knowledge distributed throughout the NMC's area of control. All transmission equipment report alarms and faults to the NMS. An equipment failure often causes alarms to occur in "downstream" equipment (Figure 5.1), possibly in another geopolitical jurisdiction. These undesired extra alarms cause confusion to users and hinder their ability to correct the root cause of the faults in a timely and cost effective manner. The extra alarms cause more events shifting the complex system closer towards a state of organized chaos, as per the CAS theory (defined in Chapter 3).

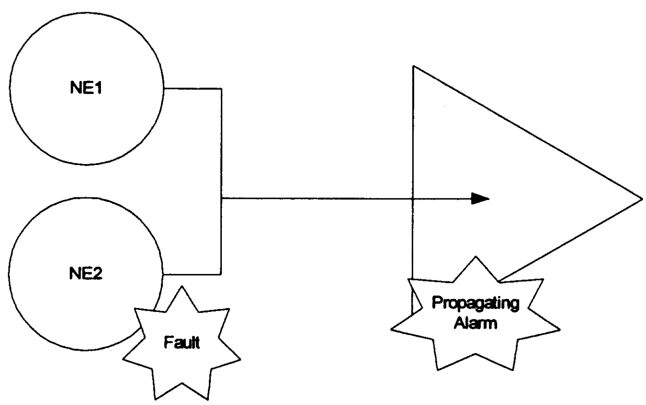


Figure 5.1 Alarms in one NE cause downstream faults.

The process of diagnosing network faults requires multiple groups of knowledge workers collaborating both synchronously and asynchronously to diagnose the faults. Furthermore, due to the geographical separation and sociopolitical differences, there is no way to guarantee the specific knowledge or experience of operations personnel working on the fault scenario; i.e., it is an unpredictable user base (Hunter et al. 2000). In addition, the hierarchical structure of the current NMC DSS does not always impose the "best" approach because it causes loss of efficiency due to the knowledge and experience of local personnel not being exploited to its fullest. Local knowledge is not distributed to the other nodes in the network and collaboration between nodes is hindered. Furthermore, the relationship between nodes is constantly changing due to the global political climate, the industrial or market turmoil currently being experienced in the telecommunications industry, and the constant network changes (Flynn et al. 2002). Daily events, ranging from corporate business choices to packet flow characteristics, all interact to impact future decisions regarding the telecommunications infrastructure. Business acquisitions, mergers, multi-firm collaboration and fierce competition all interact to cause constant change not only in service offerings, but also in the actual footprint of the network.

This research utilizes the deployment of the Alarm Correlation Tool (ACT) to investigate the design of a system that supports the described evolving (i.e., emergent and adaptive) knowledge process. The system's design is evaluated in a real field environment and the field personnel's usage and underlying motivations are investigated using a case study methodology. This investigation, in turn, allows the research to shed light on related IS design methodologies.

5.2 Field Site Organization and Information Infrastructure

The organization in question attempted to follow a standard operations process known as the Telecommunications Operations Map (TOM) around which all the Information Systems Infrastructure was built. The IS Infrastructure itself followed the telecommunications management network (TMN) standard, developed by the International Telecommunications Union (ITU) to allow interconnectivity and communication across heterogeneous operating systems and telecommunications networks. These operating systems include Network Management Systems (NMS) and transmission Element Management Systems (EMS) as well as Operations Support Systems (OSS). TMN was developed as a framework to support management and deployment of dynamic telecommunications services (Figure 5.2).

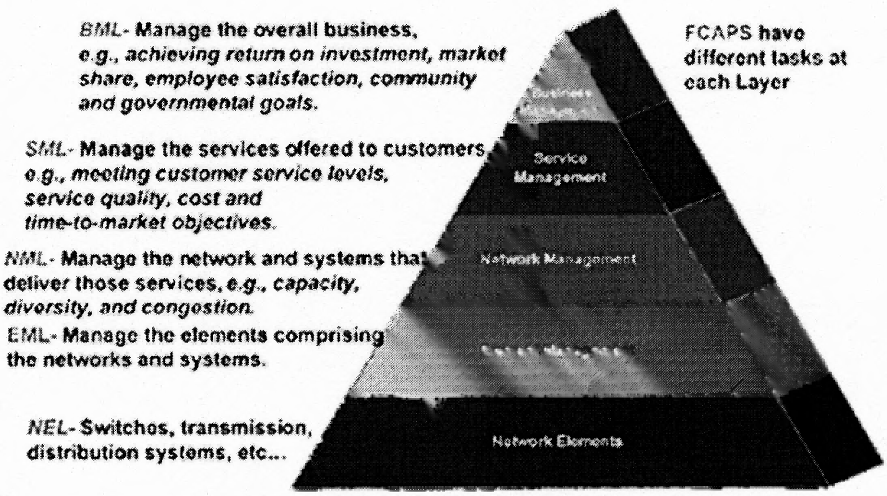


Figure 5.2 TMN Pyramid.
Source: ITU, 1985.

The International Organization for Standardization (ISO) network management model describes network management in terms of five functional areas (FCAPS).

- **Fault management** — Detect, isolate, notify, and correct faults encountered in the network.
- **Configuration management** — Aspects of network devices such as configuration file management, inventory management, and software management.
- **Accounting management** — Usage information of network resources.
- **Performance management** — Monitor and measure various aspects of performance so that overall performance can be maintained at an acceptable level.
- **Security management** — Provide access to network devices and corporate resources to authorized individuals.

Thus, a Network Management System is an Information System that provides complete monitoring and support for troubleshooting of a network. NMS are designed to provide a single, graphical, integrated view of the network topology, which supports seamless operations of the network and allows the operator the ability to "drill-down" into the different components of the network for management purposes. These systems are typically used in Network Management Centers. "Management purposes" include both fault diagnosis and routine maintenance or monitoring. Due to their importance and the vast networks they monitor, these systems must support high availability (redundancy, recovery etc.), and multi-user environments.

An OSS is generally seen as the system in the next stage of management hierarchy above the NMS. It is a system that is designed to coordinate and control the telecommunications functions. The term operations support system (OSS) generally refers to the system (or systems) that perform management, inventory, engineering, planning, and repair functions for communications service providers and their networks. The OSS encompasses all the high level functions shown in Figure 5.2.

5.2.1 Fault Management

Network Elements on the network are time synchronized via a GPS satellite signal. Alarms on a failed piece of equipment or network element, are reported to the NMS along with a timestamp indicating the alarm occurrence time. This data is stored in the NMS database and displayed to the user on demand. Alarm correlation tools may retrieve the alarm information from the database and utilize the time stamps to determine occurrence orders for root cause analysis scenarios.

5.2.2 Configuration Management

The network configuration and topology is stored in the NMS database. This data can be displayed to the user and retrieved by alarm correlation tools to facilitate the root cause analysis process. Inventory information is also stored by the NMS. Finally, version numbers for installed software and firmware may be retrieved and archived by the NMS.

5.2.3 Performance Management

The NMS retrieves periodic information from network elements on the quality of the transmission lines. This performance data aids in characterizing the behavior of the transmission network in order to detect impairments before they cause customer affecting service degradation. Its primary goal is to provide data used for proactive maintenance and network capacity planning. Furthermore, most NMS allow users to define thresholds for various performance parameters that if exceeded will raise alarms that can be viewed by users (i.e., performance is on the verge of violating QOS agreements). Such alarms may also be used to facilitate alarm correlation based on performance degradation.

5.2.4 Security Management

The NMS allows control and configuration of network elements. Visibility and control of this equipment must be protected against unauthorized access. This feature, which includes User Management and Network Partitioning, ensures that accidental or aggressive access is prevented, as well as supporting normal operations such as logins/passwords associated with specific user feature capabilities.

5.3 Network Maintenance Process

The network operations staff also attempted to model the TeleManagement Forum's (TMF) network maintenance process a part of the TOM process adopted by the field organization. This process encompasses the collection of network usage data, as well as network and Information Systems events and data for the purpose of network performance and traffic analysis. In addition, any faults are diagnosed, corrected and traffic restored as quickly as possible to maintain customer service level agreements. Figure 5.3 documents this process in more detail.

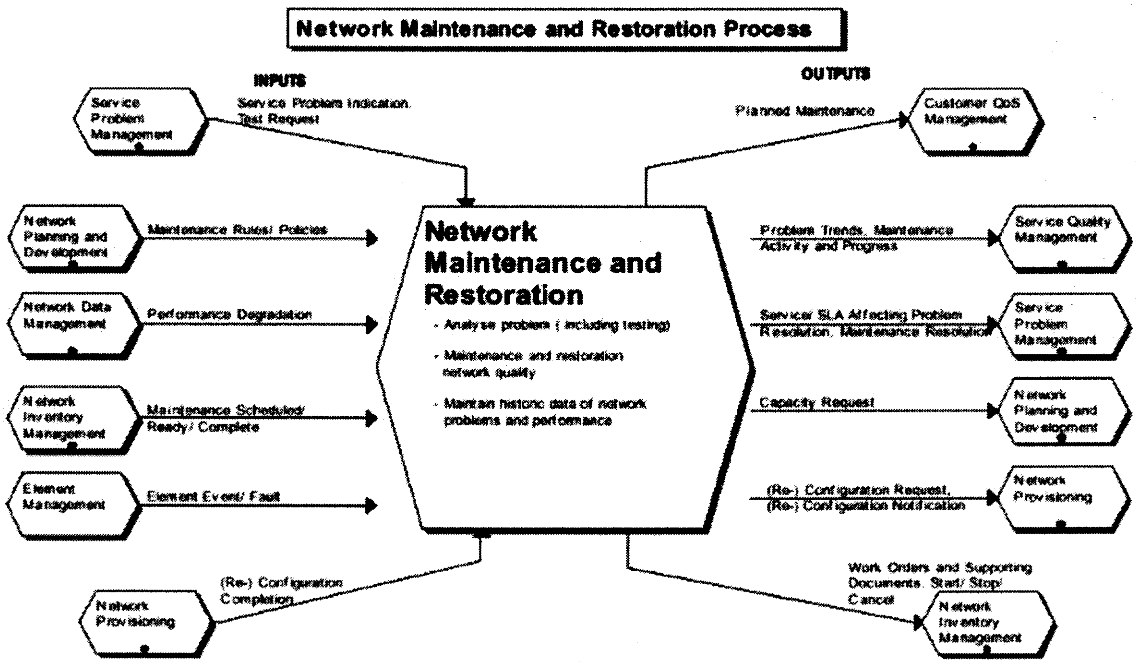


Figure 5.3 Network maintenance and restoration.
Source: TeleManagement Forum (www.tmforum.org), 2000.

5.4 Design Attempts History

Original IS designs at the field site followed a haphazard process attempting to integrate multiple systems together under a standardized infrastructure (as per case study interviews with field site IS design manager). However, this failed due to partner relationships, resource constraints and informal design processes. Alarm correlation itself was originally introduced without following any formal elicitation or analysis methodology.

The first alarm correlation system was assumed to be a Commercial Off The Shelf (COTS) solution that would require minimal customization. Vendors delivered a rule-based DSS that would simply require updates to the rules database in order to adapt the

COTS to the field site's specific environment. Unfortunately, the field design engineers fast discovered the COTS solution did not take into account:

- The decision-making process of users
- The knowledge management requirements/environment of the organization
- The inherent relationships in the network.

Other attempts at manually modeling a fault diagnosis process also failed and were abandoned. These attempts had no formal process and proved to be too complicated to complete.

CHAPTER 6

DISCUSSION

This chapter discussed the results and findings of the research. The actual design process is explained in the first section followed by a discussion of emergent phenomenon found at the field site. The next sections summarize the questionnaire and case study results. The final section discusses feedback to the EKP Design theory as it is supported by the case study findings.

6.1 ACT Design Process

ACT itself followed multiple design iterations which were partially successful, but were hindered because the design methodologies used became inadequate. ACT was originally thought to be a simple DSS that would be designed using traditional IS Design theory. An iterative DSS Design Model was adopted to encompass and bind the work. In the initial iterations through this model, RUP was utilized as a convenient approach to achieving a quick implementation and to handle resource constraints. The resultant system was insufficient because it did not take into account conflicting actor needs and the killer requirements placed on the system by organizational structure, as well as geographical and cultural dispersion of the users. Furthermore, the system did not take into account the knowledge and experience variations between all users.

The type of knowledge targeted by the system was defined to be engineering, experiential knowledge. To acquire this knowledge, engineers required a great deal of training and immersion in the field environment. In addition, it involved tacit knowledge, described by the users as "gut feel" decisions. The system design proposed was built on the hypothesis that ***such knowledge is best captured and utilized in a model based system to match the engineers' mental model of the physical infrastructure being managed.*** The deployed ACT design provided a convenient avenue for capturing this knowledge. When changes were required by the users, the model-based approach was easily modified and molded to meet these evolving changes. In addition, during interviews, expert users supported the design assumption that engineers viewed the network through a mental model based on multiple components and relationships (both spatial and temporal in nature).

The ACT mimicked this mental model by defining the entire network utilizing a relational approach to network connectivity and equipment. Causal relationships between various network elements (NEs) are specified as part of building the ACT topology base. Furthermore, each type of network equipment is also modeled individually by defining the possible alarms each type can support and specifying a causal relationship within the network element itself (using both priority definitions and cause/effect indicators for each alarm). As such, the ACT model mimicked the idea that engineers continuously alluded to by describing "upstream" and "downstream" effects. The spatial and temporal relationships in the network were defined through a set of causal descriptors related to all possible alarms an NE could generate. New knowledge could be entered into the system in as differing causal effects (by changing either the causal descriptors of alarms) or by changing the relative priority of specific alarms. In addition, each root cause of a network fault included an associated corrective action. This corrective action could be modified as new knowledge is acquired and engineers learn through experience more effective methods of quickly correcting an existing fault.

Subsequent model iterations showed that it was necessary to tackle the users' knowledge and experience requirements. As such, ACT was conceived to be a Knowledge-Driven Decision Support System that would utilize knowledge bases defined by experienced users to assist novice users in the fault diagnosis process. However, such a system proved too complicated to be handled simply utilizing conventional design methodology. The introduction of distributed knowledge bases and varying user expectations, knowledge and experience placed too much strain on the conventional requirements analysis and design process. Through the feedback avenues of the DSS Design Model, a more appropriate framework was perceived to be required. Information Systems Design Theory provided a complete framework for guiding complex designs. A specific Information Systems Design Theory, the design theory for systems that support Emergent Knowledge Processes, was researched for this complex problem. At this point EKP Design Theory was found to be a good fit for designing such a system. All the characteristics that worked to strain the conventional methodologies appeared to be the exact environment for which EKP was tailored (unpredictable users, distributed knowledge, emergent/unstructured processes).

The ACT design proved to be a technically viable solution. It handled all the proposed requirements collected while targeting naïve users as per the EKP design principles. In addition, as of the writing of this work, the organization had been awarded a patent for the ACT algorithms in Europe (and awaiting a decision from the US patent office) and had made a decision to merge ACT into its standard product line. However, when the system was deployed in this particular field site, it failed to achieve the expected results. Few users utilized it, and those who did were not comfortable sharing their knowledge and capturing such knowledge in the system. As such, it was viewed that the theory utilized for this purpose required augmentation to handle the complex user relationships and collaboration environment presented by mission-critical infrastructures.

6.2 Emerging Phenomenon at the Field Site

Engineering development and diagnosis in general is a very complicated process. The engineering diagnosis process in telecommunications networks, in particular, is also an emergent knowledge process. In a global optical telecommunications network, groups of field personnel including both expert engineers as well as less knowledgeable technicians collaborate remotely and often asynchronously to diagnose network faults and minimize downtime. As these networks explode in size and complexity the environment becomes more unpredictable. Due to the distributed global nature of these systems, it is impossible to determine the current socio-political climate in the network at any particular time (Sabet et al. 2003a). These factors combine to characterize such network fault diagnosis processes as an EKP.

This research utilizes the deployment of the Alarm Correlation Tool (ACT) to investigate the design of a system that supports the described EKP. The investigation, in turn, allows the research to shed light on related IS design methodologies.

6.3 Questionnaire Results Summary

Although questionnaires are not well suited for answering **explanatory** research questions, nevertheless this research utilized survey questionnaires to understand ***what*** the organization's knowledge sharing environment included before performing the case study interviews and deploying the KD-DSS. This tool was used as the smallest of a number of data gathering techniques which included documents, archival records, interviews, direct observations, participant-observation, and physical artifacts.

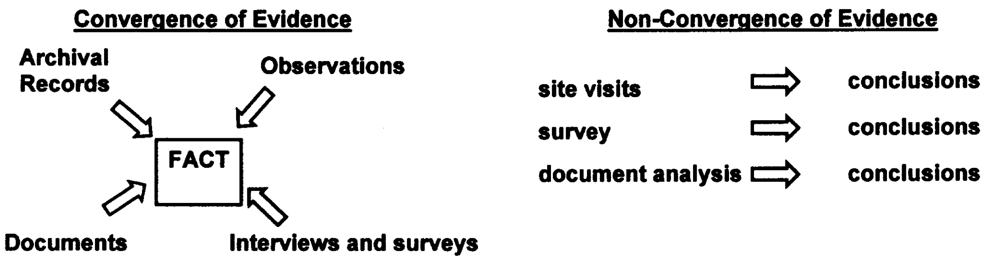


Figure 6.1 Convergence and convergence of multiple sources of evidence. Triangulation of data addresses *construct validity.* Case studies using multiple sources often are considered to have higher overall quality.
Source: COSMOS Corporation (Yin 2003 p 100).

> "...a survey can be readily designed to enumerate the 'what', whereas a case study would not be an advantageous strategy in this situation...In contrast, 'how' and 'why' questions are more explanatory and likely to lead to the use of case studies..." (Yin 2003)

> "...'analytic generalization'...has been contrasted with another way of generalizing results, known as 'statistical generalization'. Understanding the distinction between these two types of generalization may be your most important challenge in doing case studies. Let us first take the more commonly recognized way of generalizing – 'statistical generalization' – although it is the ***less*** relevant one for doing case studies...this is the most common way of generalizing when doing surveys...A ***fatal flaw*** in doing case studies is to conceive of statistical generalization as the method of generalizing the results of the case study...under these circumstances, the mode of generalization is 'analytic generalization,' in which a previously developed theory is used as a template with which to compare the empirical results of the case study." (Yin 2003).

> "One of the most important sources of case study information is the interview. Such an observation may be surprising because of the usual association between interviews and the survey method. However, interviews also are essential sources of case study information. The interviews will appear to be guided conversations rather than structured queries. In other words, although you will be pursuing a consistent line of inquiry, your actual stream of questions in a case study interview is likely to be fluid rather than rigid...most commonly, case stud interviews are of an open-ended nature, in which you ask key respondents about the facts of a matter as well as their opinions about events...A second type of interview is a focused interview, in which a respondent is interviewed for a short period of time – an hour, for example. In such cases, the interviews may still remain open-ended and assume a conversational manner, but you are more likely to be following a certain set of questions derived from the case study protocol...***Yet a third type*** of interviews entails more structured questions along the lines of a formal survey." (Yin 2003) (pp. 89-91).

Although statistical analysis and survey questionnaires are not the focus of this empirical research, the researcher outlined a survey questionnaire that was sent to field personnel working in the case study organization. Fifty three (53) field and NMC personnel were surveyed and asked to fill an online questionnaire. Thirty seven (37) of these successfully completed the questionnaire, of which 10 were managers, 10 were engineers and 17 were technicians (Table 6.1).

Table 6.1 Respondent Demographics

Position	Experts (Greater than 5 Years of Experience	Novices (5 Years or Less of Experience)	Total
Managers	5	5	10
Engineers	4	6	10
Technicians	6	11	17
Total	15	22	37

The results showed that the organization did not put high value in knowledge sharing. It also became clear when analyzing the results that the organization's knowledge sharing environment was not at its full capacity. Little or no knowledge in the organization was acquired directly from co-workers. Utilizing Gold's measurement of organizational effectiveness, the results showed that due to this lack of knowledge sharing, the organization's effectiveness was greatly hindered (Gold et al. 2001). On the whole, the users were neutral to the organization's efforts at adapting to changes (Table 6.2).

Table 6.2 Summary of Questionnaire Results

Category	Result (50% is neutral)	Comment
Training	56.45%	There is very little training occurring and most of it is self taught
Satisfaction with current tools	62.28%	There is little satisfaction with current tools and all users view the addition of alarm correlation as a valuable feature.
Organizational effectiveness	65.12%	Respondents perceive their organization as not very effective.
Knowledge acquired from co-workers	78.63%	Communications with coworkers is high and most knowledge acquired is by such communications with immediate group members.
Diagnosis		On average personnel spend 2.27 hours in fixing a fault. On average personnel believe an alarm correlation tool would eliminate 52.54% of this time. However, it is viewed that little customization would be needed for the KD-DSS (70.98%).
Communications	64.57%	Communications is limited across the network.
KM environment	61.26%	Knowledge in this organization is shared in a limited fashion and not managed well.
Organizational facilitation	56.85%	The organization does not facilitate knowledge exchange well.

The survey questions were measured eight specific categories related to the organizational environment. The above table presents percentages of answers (for each of these categories) based on a normalized 7-point likert scale where 1 means extremely dissatisfied or strongly disagree and 7 means extremely satisfied or strongly agree. The average of all the responses is then divided by 7 (and multiplied by 100) to arrive at a percentage. 100% implies complete satisfaction or agreement that the organization performs well in the areas described, whereas as 10% would indicate complete dissatisfaction or disagreement related to performance in these areas.

Very little training was provided to the personnel, most of which was self achieved or through college training (Figure 6.2).

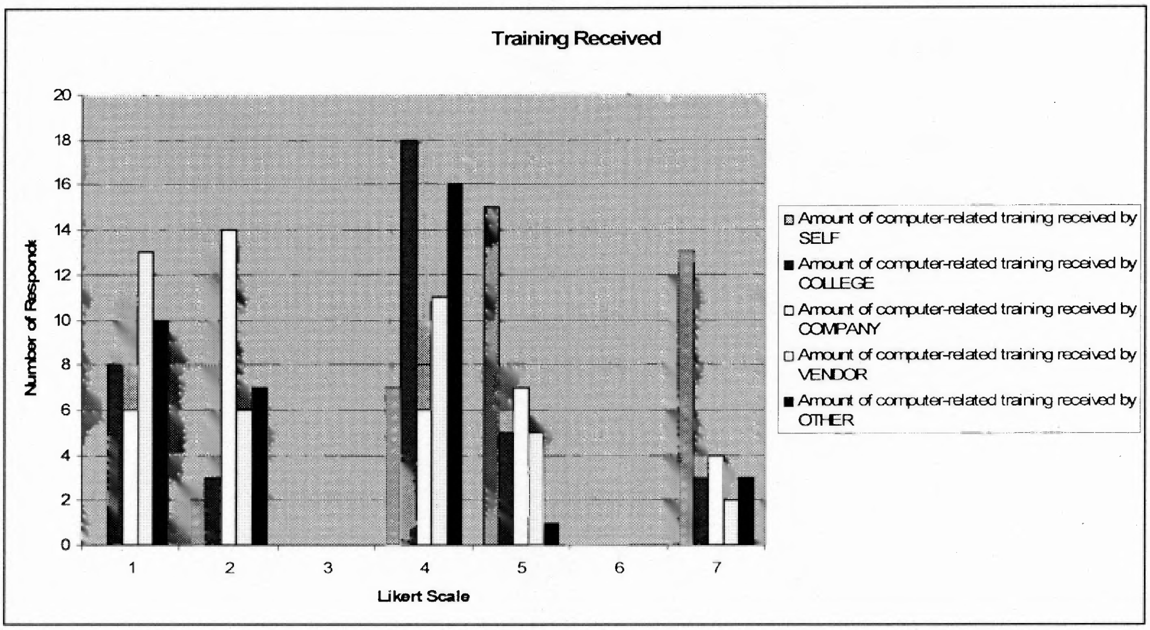


Figure 6.2 Amount of training received.

The questionnaire also presented users with field trouble ticket scenarios in which respondents where asked to pinpoint which elements were Data, which elements were Information and which elements were Knowledge. The result of the Data vs. Information vs. Knowledge question was quite surprising. It would appear that personnel confused data and information frequently. Of the people interviewed, sixty-eight percent (68%) could not properly identify instances of data. Thirty-two percent (32%) could not identify instances of information. However, more people were able to grasp the concept of knowledge, equating it to experience and instincts. Only nineteen (19%) had difficulties identifying specific instances of knowledge.

When asked how satisfied users were with streamlining of the fault diagnosis process in their organization, the results were visibly lower. This was another indication of their discontent with the fault diagnosis area in general (Figure 6.3).

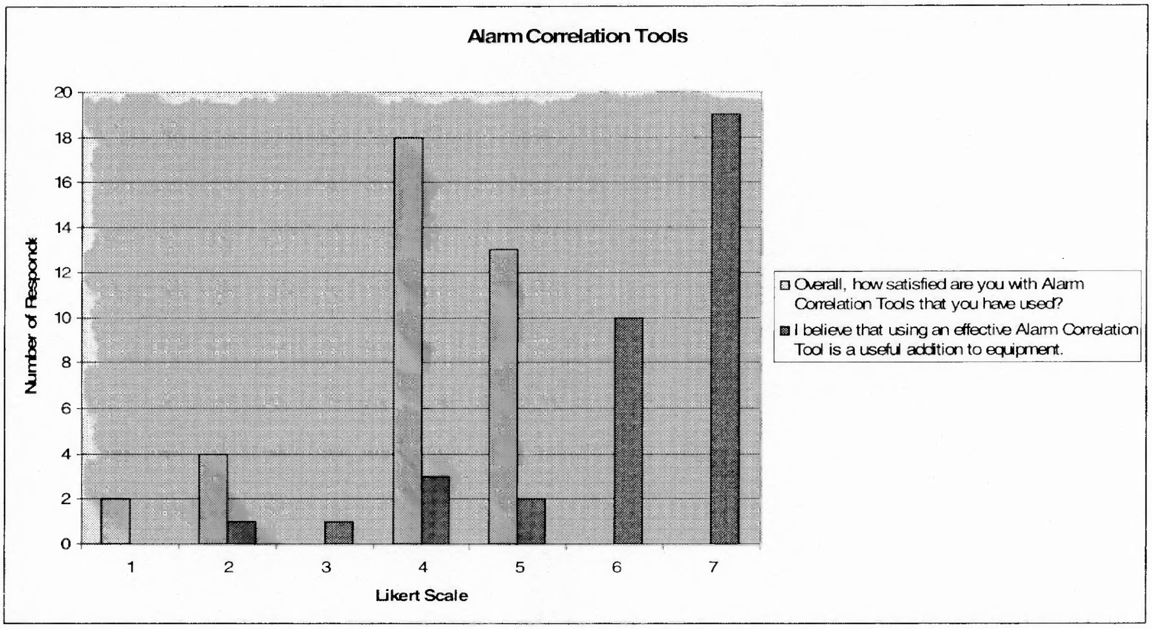


Figure 6.3 Satisfaction in current tools and value placed on new alarm correlation tools.

The following two questions measured formal knowledge sharing behavior between coworkers:

Formal1 - I often obtain useful knowledge by reading written materials authored by coworkers.
Formal2 - I read documents written by coworkers to increase my knowledge on a topic or issue.

A factor analysis of these two questions was performed to determine if they could be combined into an index measuring knowledge sharing (Babbie 1999). Table 6.3 represents the correlation values (Pearson's correlation coefficient, r) between the various measures using the samples from the survey questionnaire (N=37).

Table 6.3 Factor Analysis for Formal Knowledge Sharing

Variables	Formal1	Formal2
Formal1	1	0.435
Formal2	0.435	1

Cronbach's alpha: 0.606

The following four questions measured informal knowledge sharing behavior between coworkers:

Informal1 - I use targeted one-on-one conversations with other employees to acquire work-related knowledge.
Informal2 - When I need to access to knowledge, I frequently use personal communication with individual employees.
Informal3 - I frequently consult with groups of coworkers when I need to improve my knowledge on a topic or issue.
Informal4 - I use conversations with a group of coworkers as a way of acquiring knowledge.

A multivariate analysis of these four questions was performed to determine if they could be combined into an index measuring knowledge sharing (Babbie 1999). Table 6.4 represents the correlation values (Pearson's correlation coefficient, r) between the various measures using the samples from the survey questionnaire (N=37). Note that values in bold are statistically significant (a=0.05).

Table 6.4 Multivariate Analysis for Informal Knowledge Sharing

Variables	Informal1	Informal2	Informal3	Informal4
Informal1	**1**	**0.920**	**0.927**	**0.939**
Informal2	**0.920**	**1**	**0.921**	**0.823**
Informal3	**0.927**	**0.921**	**1**	**1**
Informal4	**0.939**	**0.823**	**0.828**	**1**

Values in bold are significantly different from 0 with a significance level alpha=0.05

Cronbach's alpha: 0.971

The respondents' answers implied that they tried to get more knowledge from coworkers through oral communications rather than utilizing written methods (Figure 6.4).

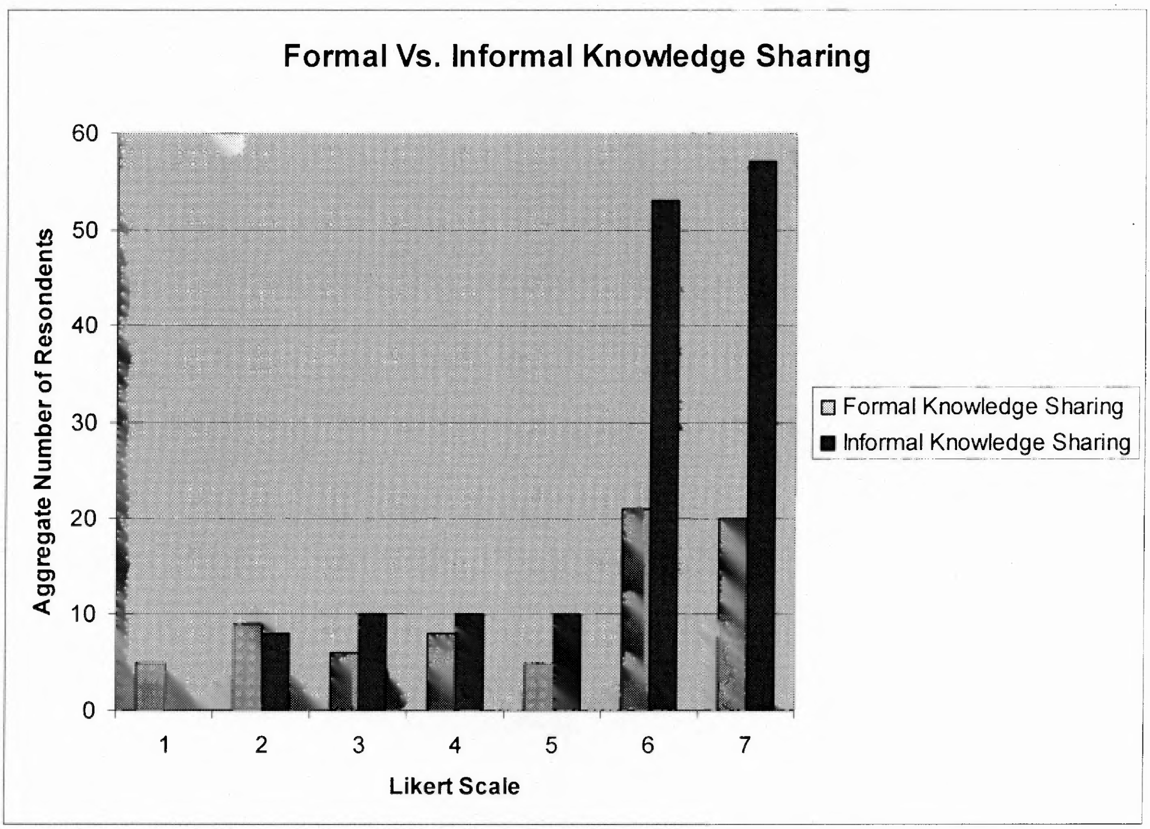


Figure 6.4 Informal versus formal written knowledge sharing; written methods are used less often than verbal communications methods.

Although, if this were true, it would have been expected that these respondents would also have indicated that they had a knowledge sharing culture. This did not appear to be the case since there was a noticeable spike to the lower scale when answering questions measuring the organization's knowledge sharing culture (Figure 6.5). Furthermore 31% of non-managerial respondents, ***not located in the NMC,*** agreed that there was a knowledge hoarding environment. When compared with only 12.5% of NMC located employees that indicated they thought of the organization as having a knowledge hoarding environment, this supports the case study findings that the NMC controlled most of the knowledge in the network.

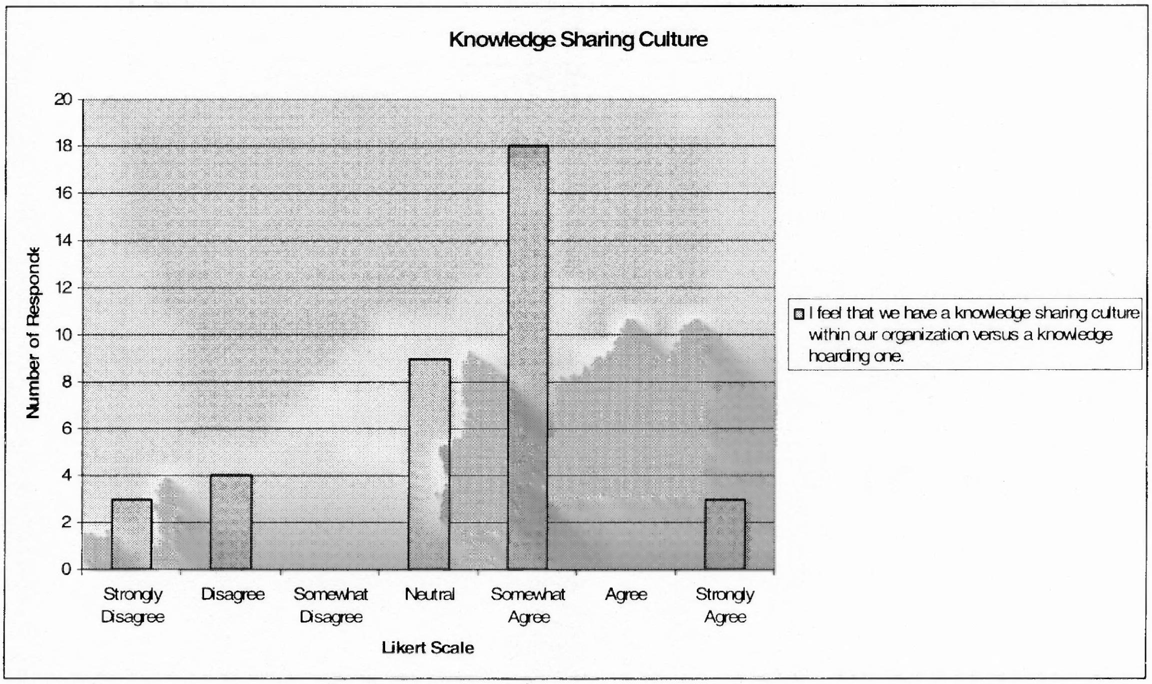


Figure 6.5 A knowledge sharing culture.

The following five questions measured the organization's knowledge capturing:

Capture1 -	Key expertise is often captured in an online way in my organization.
Capture2 -	I get appropriate lessons learned sent to me in areas where I can benefit.
Capture3 -	I usually have time to chat informally with my colleagues.
Capture4 -	Individualized learning is usually transformed into organizational learning through documenting this knowledge into our organization's knowledge repository.
Capture5 -	There are lessons learned and best practices repositories within my organization

A multivariate analysis of these five questions was performed to determine if they could be combined into an index measuring knowledge sharing (Babbie 1999). Table 6.5 represents the correlation values (Pearson's correlation coefficient, r) between the various measures using the samples from the survey questionnaire (N=37). Note that values in bold are statistically significant (a=0.05).

Table 6.5 Multivariate Analysis for Published Organizational Information

Variables	Capture2	Capture2	Capture3	Capture4	Capture5
Capture1	1	**0. 825**	**0. 949**	**0. 960**	**0. 972**
Capture2	**0. 825**	1	**0. 834**	**0. 944**	**0. 932**
Capture3	**0. 949**	**0. 834**	1	**0.934**	**996**
Capture4	**0. 960**	**0. 944**	**0.934**	1	**0.828**
Capture5	**0. 972**	**0. 932**	**0.932**	**0.996**	1

Values in bold are significantly different from 0 with a significance level alpha=0.05

Cronbach's alpha: 0.985

Very little information seemed to be published in terms of lessons learned or best practices (Figure 6.6). The results also showed that field personnel preferred informal communications for acquiring knowledge as opposed to reviewing published data.

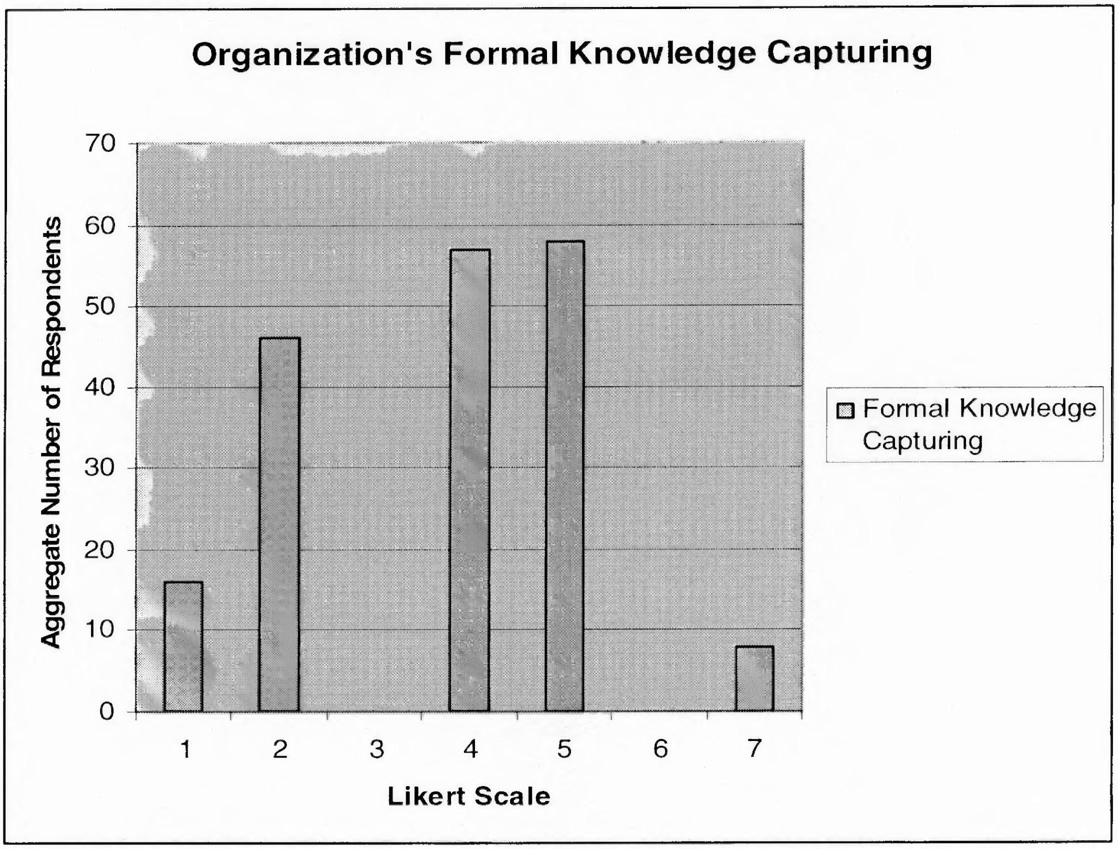


Figure 6.6 Knowledge is not captured well across the organization.

The following seven questions measured knowledge sharing behavior between coworkers:

F1 - I often obtain useful knowledge by reading written materials authored by coworkers.

F2 - I read documents written by coworkers to increase my knowledge on a topic or issue.

F3 - I use targeted one-on-one conversations with other employees to acquire work-related knowledge.

F4 - When I need to access to knowledge, I frequently use personal communication with individual employees.

F5 - I frequently consult with groups of coworkers when I need to improve my knowledge on a topic or issue.

F6 - I use conversations with a group of coworkers as a way of acquiring knowledge.

F7 - I feel that we have a knowledge sharing culture within our organization versus a knowledge hoarding one.

A multivariate analysis of the responses to these seven variables was performed to determine if they could be combined into an index measuring knowledge sharing (Babbie 1999). Table 6.6 represents the correlation values (Pearson's correlation coefficient, r) between the various measures using the samples from the survey questionnaire (N=37). Note that values in bold are statistically significant (a=0.05). F1 and F2 are measures of written or formal knowledge sharing, while F3 to F6 are measures of informal knowledge sharing activities. Finally F7 measures the overall perception of the organization's knowledge sharing environment.

Table 6.6 Multivariate Analysis of Knowledge Sharing Indicators

Variables	F1	F2	F3	F4	F5	F6	F7
F1	1	**0.573**	0.109	-0.016	0.134	0.176	**0.382**
F2	**0.573**	1	0.176	0.049	0.221	**0.389**	0.200
F3	0.109	0.176	1	**0.456**	**0.372**	**0.514**	0.180
F4	-0.016	0.049	**0.456**	1	**0.675**	**0.553**	0.101
F5	0.134	0.221	**0.372**	**0.675**	1	**0.820**	0.059
F6	0.176	**0.389**	**0.514**	**0.553**	**0.820**	1	-0.048
F7	**0.382**	0.200	0.180	0.101	0.059	-0.048	1

Cronbach's alpha: 0.74

Since F3, F4, F5 and F6 exhibit strong correlation relationships, the average of the responses of these four factors are used as an index of knowledge sharing between coworkers (the shaded area in Table 6.6). One can then investigate the relationship between the level of experience of respondents and the amount of knowledge sharing in the organization. The more experienced workers tended to communicate with coworkers less to share knowledge, whereas the less experienced (measured in this case by years employed in the organization) personnel tended to communicate more frequently with other coworkers as a means of learning.

- **Co-variance knowledge sharing (F3-F6) Vs. Years of Employment in the network equal to -0.25 (for all N=37).**

Table 6.7 shows that the respondents' answers to question F3-F6 was significantly different based on their position in the organization. Managers responded that they shared more knowledge (100% of them agreeing to all four questions), while only 70% of engineers agreed to some degree that they shared knowledge with co-workers. More than 85% of technicians also agreed to some degree that they share knowledge. In this respect, if engineers are the most technically knowledgeable in fault location, this data supports the finding that more knowledgeable employees tended to share knowledge less.

Table 6.7 Respondents By Position Composite Scores For F3-F6

	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Some what Agree	Agree	Strongly Agree	Total
Managers	0	0	0	0	3	8	29	40
Engineers	0	4	3	5	4	10	14	40
Technician	0	4	3	3	2	34	22	68
Total	0	8	6	8	9	52	65	148

P=0.004955, df=12

Analysis of the use of alarm correlation tools revealed that more experienced users tended to use them less (Table 6.8).

Table 6.8 Use Of Alarm Correlation Tools

Position	# of Novices	# of Hours By Novices (5 Years of Experience or Less)	# of Experts	# of Hours By Experts (More than 5 Years of Experience)	Total # of Hours
Engineers	6 22.2%	27	4 14.8%	5	32 51.2%
Techinicians	11 40.7%	23	6 22.2%	7.5	30.5 48.8%
Total	17 62.97%	50 80%	12 37.03%	12.5 20%	62.5 100%

The sum of average hours of alarm correlation tools use indicated by non-managerial respondents was 62.5 hours. Of these, 20% were indicated by field personnel with more than five years of experience, even though 37% of respondents fell into this category of users (greater than 5 years of experience). This further supports the hypothesis that experienced engineers utilize mental models of the network based on their experience rather than falling back on explicit written or system provided directions.

The node locations of respondents were numbered 10 through 70. Where 10 signified the NMC and 70 signified the farthest node (geographically, culturally and organizationally in terms of jurisdiction) from the NMC.

- East Coast USA=10
- West Coast USA=20
- UK=30
- Spain=40
- Portugal=50
- Holland=60
- Japan=70

When analyzing responses to questions F3 through F6 it was obvious that the further away respondents were located from the NMC, the higher their knowledge sharing activities. Each location's answers to F3 through F6 were averaged as an index measuring their knowledge sharing activities.

- **The correlation factor between location and the knowledge sharing activities index was r=0.229 and a covariance=3.388.**

This implied that NMC personnel did not support knowledge sharing and exerted this influence on close locations.

Other interesting findings included the fact that a number of people responded that they typically worked in groups, and yet most of the case study interviews indicated a contrary finding. When more probing questions during the interviews were used, it became clear that clusters of groups in different nodes worked together, but the overall organization did not support a group working effort. It was also found that little online group sharing occurred as part of daily work activities.

These results are indicative of an organization that does not encourage knowledge sharing, supporting the case study's second rival theory, namely that the organization structure in place would not allow the realization of benefits introduced by the KD-DSS.

6.4 Network Maintenance Official Process

Network operations personnel have the sole responsibility for maintaining the network and assuring continued acceptable levels of traffic quality that are intended to meet customer service level agreements. To assist personnel in doing this, the field site management specified an official process description of responsibilities and functions of the network operations department.

> "This process encompasses maintaining the operational quality of the network, in accordance with required network performance goals. Network performance goals are set to support the service levels of the services provided by the network infrastructure. Network maintenance activities can be preventive (scheduled or routine maintenance) or corrective. Corrective maintenance can be in response to faults or indications that problems may be developing (proactive or potential service affecting)" (field site's official process document)

What was interesting about the official, published network maintenance process description was that the cable stations or remote nodes were conspicuously missing from the documentation. The process assumed that the NMC would control the activities and decide on corrective actions for any network maintenance, only utilizing the cable station to implement the solutions. Furthermore, when analyzing the troubleshooting flow chart which the NMC attempted to use to document the fault diagnosis process, it was found that the cable station field locations were simply not taken into account in the process at all.

6.5 Case Study Summary

The case study methodology emphasizes the triangulation of multiple sources of data to increase the validity of the research results.

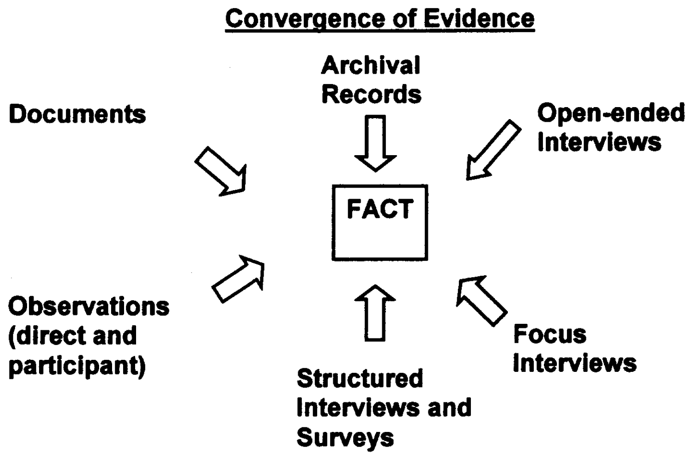


Figure 6.7 Case Study activities.
Source: COSMOS Corporation (Yin 2003 p 100).

In this research all the above activities were performed. Table 6.9 documents the various activities performed and provided details on the efforts involved in these activities. The activities are in the table are arranged in chronological order (refer to Appendix A, the Case Study Protocol, for exact time lines of data collection activities).

Table 6.9 Case Study Activities

Activity	Description
Documents	The Network Official Process Document, TOM, and the network maintenance process documentation were reviewed in detail to obtain a clearer understanding of what "should" happen.
Archival Records	Field Trouble Tickets were analyzed to determine the process involved in fault diagnosis performed by the engineers and to provide simulation and use case scenario guidance
Structured Interviews and Surveys	A field survey questionnaire was sent out to 53 field and NMC personnel were surveyed and asked to fill an online questionnaire. 37 of these successfully completed the questionnaire: • 10 Managers • 10 Engineers • 17 Technicians
Observations (direct and participant)	Both researchers involved in this work observed NMC personnel at work for a number of hours. In addition the principal researcher assisted in the NMC as a participant observer.
Open-ended Interviews	Open ended interviews were carried out with: • 4 Managers
Focus Interviews	Focused interviews using the Critical Decision Method performed with • 3 Engineers • 6 field technicians • 2 Managers • 1 engineer who had participated as a Engineer, a Engineer and an R&D engineer.

The above activities converged to reveal the findings discussed in this section. Knowledge was not shared among the field personnel. This was apparent from both the interviews and the questionnaire results. The organizational structure had been setup such that all knowledge flowed from the NMC and was not shared or disseminated to the field personnel. This may have been due to the fact that the NMC had been setup as the center of control of the network (very early on in the network conception the 2nd, backup, NMC was cancelled due to resource constraints). This organizational structure would appear to discourage the use of KD-DSS. The official view from management was that the NMC coordinated the network and field personnel activities. However, the reality appeared to be that the NMC viewed the field sites as simply an extension of their jurisdiction. Any system that would allow these sites to gain more knowledge, and consequently more autonomy was viewed as unnecessary and perhaps even resisted.

The history of the organization itself indicated its immaturity in relation to the utilization of IS tools. Information Systems were not extensively used to manage network equipment till 1996. When complicated systems became required, the company contracted with a number of external suppliers to assist in the development of these systems. However, the relationship with these external suppliers quickly deteriorated, due to the collapse of the telecommunications market, and the resultant products became too difficult to maintain. As a result the organization was in the process of redesigning many of its systems and later on, during the writing of this dissertation, abandoned a number of these systems completely. The obvious outcome of this was that users became dissatisfied with the current systems and were not very receptive to the use of new ones. Users were unlikely to invest their time and energy into improving the systems (e.g., capturing knowledge) because they mistrusted them and felt that it was not their job to do improve deployed systems, having become accustomed to rigid relationships with external vendors. The organizational structure enforced an Information Systems structure that also created a number of difficulties when integrating a KD-DSS into the existing infrastructure.

Additional findings included the fact that it appears that novice users do not use a relationship analysis scheme to fault diagnose, but rather look towards written material for explicit instructions on troubleshooting – two of the subjects interviewed described themselves as non-experts and explained that they preferred to refer to user manuals for instructions on how to fault locate network problems. The more experienced personnel utilize their past knowledge and a mental model of the network to analyze a fault, using temporal and spatial relationships. The decision-making process for fault diagnosis itself varied based on levels of experience. However, one common factor appeared to be that a form of "process of elimination" was used to find root causes and over time personnel recognized patterns in these faults (e.g., faulty packs, more frequent failures in certain segments etc.). The detailed findings from the case study interviews are shown in Tables 6.11 through 6.20 below. Qualitative analysis of the interviews was performed to arrive at interview patterns that indicated a support for one of the case study theories and/or the mental model hypothesis. The summary of each set of interview patterns is presented in summary tables before the detailed analysis is presented. It should be noted that the sample size for these interviews is much too small for any statistical analysis of significance to be performed on the results. Samples of the detailed subject interviews are presented in Appendix B. Sixteen field personnel were interviewed of which 6 were managers, 6 were technicians and 4 were field engineers (Table 6.10).

Table 6.10 Interviewee Demographics

Interviewee	# Of Experienced (Greater than 5 Years of Experience)	# Of Novices (5 Years of Experience or Less)	Total
Manager	5	1	6
Engineer	2	2	4
Technician	2	4	6
Total	9	7	16

Table 6.11 Summary of Main Theory Support

Interviewee	# Of Experienced (Greater than 5 Years of Experience)	# Of Novices (5 Years of Experience or Less)	Total
Manager	1	0	1
Engineer	1	0	1
Technician	0	2	2
Total	2	2	4

Table 6.12 Interview Patterns Supporting Main Theory

Pattern	Indicated Interview	Specific Interview Quotes
Experience, Knowledge is combined with information from EMS A and what's explained by the people who report faults are used to pinpoint the problem Information and data feeds come from many different directions	Subject E Pg2 Ln19 (Engineer 7 Years Experience)	Q: OK, so you take these two forms of information. What they saw, and what you see yourself, and as you said, you open up the other end if you have to. And if you don't see what the problem is right there you do a physical inspection, you don't see anything wrong with that, what's the next step? A: Umm, I just sit back and think about it a little bit. Take a step back if it's not obvious what it is, then based on previous experience, just think about it and say, well this happened before and we know what we did before. Because we've problems that are not explainable. If we've dealt with them before we know what we did before so start with that.
	Subject I Pg3 Ln27 (Technician 5 Years Experience)	Q: So, the fact that the voltage change with umm, the time that it was changing was the key piece of information that helped you make the decision on which alarm was the cause of the problem? A: Yes, that piece of information directly split the NE into 3 parts for me and the fact that it occurred in one converter...there are 3 major components in each converter.
	Subject K Pg5 Ln11 (Technician 4 Years Experience)	A: It's an experience thing, you know. Part of it comes down to experience. You say a less experienced operator, but one of the things that we have here is that we had this cable station from new and we had a lot of faults on it, so we saw a lot of different faults from the start. Where at the moment there's not a lot here, there's not so many faults happening so you don't get too much chance to learn about them.
	Subject P Pg3 Ln27 (Manager 8 Years Experience)	Q: Umm, when you were, when you're doing your analysis, you were looking at the various alarms and, to determine umm, what was going on, what really gave you the insight to understand exactly what was going on? What was the root cause? A: Well, the experience with working with the network for the past you know 4 years, really. We rely on a level of previous history and experience that you see those alarms and while each of the equipment sends...a lot of it comes down to experience.

Table 6.13 Summary of Rival Theory 1 Support

Interviewee	# Of Experienced (Greater than 5 Years of Experience)	# Of Novices (5 Years of Experience or Less)	Total
Manager	2	1	3
Engineer	1	0	1
Technician	0	2	2
Total	3	3	6

Table 6.14 Interview Patterns Supporting Rival Theory 1

Pattern	Indicated Interview	Specific Interview Quotes
A perception that KD-DSS tools should not require any effort from the user to customize, capture data and/or extra training	Subject A Pg14 Ln39 (Manager 8 Years Experience)	A: Just to compare it to other intelligent systems we have, we don't have to do that. We don't have to actually train it. These systems that's already trained in there. You know, I'm sure probably the vendor changes some of the stuff that comes in it as later releases of software come out, but... Q: But then, knowing that you find the problems, you don't think it would be beneficial for the operators to be able to on the fly fix those? Interviewee: No. Definitely not. I have hundreds of nodes, hundreds of pieces of equipment all over the place. And if you had different people putting different sets of rules in each one...I don't know. I mean someone would have to manage that activity, that effort.
	Subject G Pg1 Ln16 (Manager 20 Years Experience)	A:...because the stuff you find in the lab, the stuff you can up with in the lab has it's own merit and you'll implement a whole bunch of rules based on that and you know, we have some of the...basically best labs available. I mean, we have one of the best labs available in the world because we can actually mimic the undersea, the ocean, I mean distance. From a distance perspective not from a environmental perspective. I mean there are other environmental labs here, but umm, but in order to look at the operational aspect of things day to day, you have component there that's usually not in the lab and it's only in operation. And short of taking somebody like Sam or like myself who is very much a candidate for a Ph.D. and plant them at the NMC as part of operation and making them go through that drudgery for a year, you're not going to get that type of, you know, perspective. Umm, but there's always that you know, the ops versus engineering. The friction that's always there.
	Subject B Pg12 Ln22 (Manager 4 Years Experience)	Q: The people, yourself as well as the people you work with, do you feel that to be easy it's graphical or is it logical, is it well written text or did... A: Graphical is very beneficial. Most of you applications, computer users, PCs, they're all used to graphical interfaces, and I think that would have to be a key factor in any tool or design. A: That's where I'm trying to...It would have to be easy, you know, I don't think it's something that you'd want to have to sit down and write a paragraph or two about, you know, because nobody is going to do it.

Table 6.14 Interview Patterns Supporting Rival Theory 1 (Continued)

Pattern	Indicated Interview	Specific Interview Quotes
Novices would follow rules and simple instructions on just scanning for alarms from a NMS, not using their own knowledge but falling back on written instructions. They are less likely to look for patterns or relationships, but rather expect a hard set of possibilities to be provided to them.	Subject F Pg1 Ln18 (Technician less than 5 Years of Experience)	Q: So what do you do when you're troubleshooting? How do you go about your troubleshooting? A: Well, it depends on the nature of the alarm. You know, a lot of times the NMC now they're up to par, they can direct you to a specific card or site where to go to and tell you take it from there. We have manuals, troubleshoot manuals downstairs too that are written. Help us find faults. Q: So how are those manuals written in. Are they like if then statements, or what... A: No they'll tell you, you know, if you receive, you know...you know the manuals what are they called, the umm, the SIMs...the...shop instructions...the troubleshooting Q: You got to look for patterns? A: Yes, well, it's not really...I don't think there's any pattern, like I don't think there's any patterns because that would be a flaw, you know, an engineering flaw, so I don't know if there's any patterns. I think you just look for consistency, you know, you have an overflow, and 90% of the time maybe it's this, you know, something like that. First go to this, if you have this and that, then go to this, you know, because that rules one out or something like that.
	Subject N Pg3 Ln35 (Technician 4 Years Experience)	Q: And when you address these tickets, do you umm, find yourself needing some sort of information or advice that you would just rather have right there at your desk? Rather than having to call somebody or go talk to somebody? A: Everything else...as far as the...say certain NE alarms, I might not understand what does this alarm actually mean. Umm, I think that's experience, to see more, I'd ask more, unless if I did have like a book, this is how it works. This alarm means this or can mean this. But I don't know if it's that solid black and white, this alarm means this. I don't know that for sure at this point.
	Subject O Pg3 Ln39 (Engineer 6 Years Experience)	Q: Great, now when you think about alarm correlation, what umm, I mean, you just told me a functional definition. Now if you had to give me a description of it, how it works, like umm, what you just said sounded a lot like filtering. A: Right. Q: Alright, I mean are there any other descriptions that come to mind, if you're trying to explain it somebody that has never seen the NOC or anything like that? You know simple terms like filter, everybody understands what a filter is. A: Right, filter, maybe a logic diagram, you know if you had A and B then C occurs then...nothing too hard, its basic math if, then, and, or.

Table 6.15 Summary of Rival Theory 2 Support

Interviewee	# Of Experienced (Greater than 5 Years of Experience)	# Of Novices (5 Years of Experience or Less)	Total
Manager	5	1	6
Engineer	2	2	4
Technician	1	3	4
Total	8	6	14

Table 6.16 Interview Patterns Supporting Rival Theory 2

Pattern	Indicated Interview	Specific Interview Quotes
Communications is rarely Face-to-Face (locally) and mostly over the telephone and via e-mail. This coupled with time differences and cultural differences makes knowledge sharing and diagnosis more difficult.	Subject A Pg2 Ln17 (Manager 8 Years of Experience)	Q: But, they…how much communication during the day between the cable station and the NOC? A: Quite a bit. Q: Is it face to face ever, or is it all through… A: In this building it's face to face. Otherwise it's over the telephone.
	Subject B Pg2 Ln27 (Manager 4 Years of Experience)	Q: Do they call you up on the phone, or send you e-mail or how do they contact you? A: Both. They send e-mails and call me on the phone, pretty much non-stop.
	Subject K Pg5 Ln37 (Technician 4 Years Experience)	Q: OK, when starting your shift, or coming in on…if umm, you know, coming in a situation like when you're on call like this…the same situation…what summary information would help you in solving this type of fault? So when you walk in the door… A: When the NMC called me about this fault I asked them to e-mail me every bit of information they had about the fault while I was on my way in so that it sat here on my terminal when I got here.
	Subject O Pg5 Ln5 (Engineer 6 Years Experience)	Q: So it's generally all oral? A: Oral and visual, come here and take a look. And e-mail, you know, I might send an e-mail on something if it's something that's really unusual, you might get an e-mail out of it.

Table 6.16 Interview Patterns Supporting Rival Theory 2 (Continued)

Pattern	Indicated Interview	Specific Interview Quotes
	Subject A Pg13 Ln19 (Manager 8 Years of Experience)	Q: Could you name the, lets call these degrees knowledge bases. That's what they are, they're transferring the knowledge from the school to the individual. What are like the top 3 or 4 degrees or knowledge bases that you would consider most beneficial to your backbone people. A: Well, aside from degrees, actually experience. It really comes down to experience. People that have been out there building systems. In most cases, in the NOC, you normally don't get to go and play around with the equipment because it's live. But the people that had the opportunity to go and build a system from scratch, put something together, build it piece by piece, definitely come along a lot quicker. When I first started here, I actually put together this network. The Atlantic cable. I actually transitioned here very easily because I had extensive knowledge of this system as well as other systems. A few of the other people we have out there, they also came over from a background where they were building systems. They were able to pick it up you know in a couple of weeks. It was just a matter of learning processes. The other folks, when I first came in the first thing I did, I had to train this whole team of people to manage the network and to learn to troubleshoot and operate it. It took them 1 to 2 years to become experts.
	Subject D Pg2 Ln4 (Manager More than 5 Years of Experience)	Q: Or do you just have intuition about it? A: Well somewhat intuition, but I mean, from experience and then, you know, you just...really it's what I outlined before, is you...the direction umm, then interpreting SDH and the other information, you can isolate usually isolate what interface or what element is causing the alarms. And then from that...you know it's pretty simple steps. Q: Or do you just have intuition about it? A: Well somewhat intuition, but I mean, from experience and then, you know, you just...really it's what I outlined before, is you...the direction umm, then interpreting SDH and the other information, you can isolate usually isolate what interface or what element is causing the alarms. And then from that...you know it's pretty simple steps.
	Subject J Pg6 Ln26 (Technician 7 Years Experience)	Q: So the novice, they wouldn't probably figure it for a long time or at all. A:... or it's you know I think, that's what I call gut instinct, which as you said is experience, you know, does help, you know.
	Subject P Pg5 Ln1 (Manager 8 Years of Experience)	Q: OK great. Now that's the questions that we would like to ask the other cable station personnel in this first go around and once again it's just to understand how each person thinks about solving faults. A: Sure, OK. Well I hope that all my staff think of things in a fairly similar fashion. I would think that you could look at the type of person that is good at fault finding, I believe thinks in a certain way. Has a logical process they follow in analyzing the failures that's in front of them. Well I hope so anyway.

Table 6.16 Interview Patterns Supporting Rival Theory 2 (Continued)

Pattern	Indicated Interview	Specific Interview Quotes
Organizational structure and diagnosis structure is rigid enough to not allow the local personnel enough freedom to make decisions and/or have access to required knowledge. All decisions and requests must be cleared with the NMC first.	Subject B Pg2 Ln46 (Manager 4 Years of Experience)	A: It really depends on the condition, ummm, all the managers have a receive in the right scenario they receive a flash on their cell phone or text message, usually in indicating the fault and depending on the type of fault. Depending on the type of fault whether it requires escalation, which generally if there's an outage or customers that are experiencing hard outages, that's generally when I get a call. Or...
	Subject F Pg7 Ln34 (Technician Less than 5 Years of Experience)	A: You don't want us to start changing all kinds of power levels and doing things like that. That's not really you know in our scope without the guidance of the engineers.
	Subject I Pg 5 Ln5 (Technician 5 Years Experience)	Q: OK, suppose the answer to this problem wasn't at your cable station what would you have done differently? A: If I'd still seen the alarm at Highbridge and I was troubleshooting from the Highbridge side and didn't see any problems with the converters, that stage would have been to...I mean, having already talked to the NMC, I would then talk to the staff in Lisbon who are responsible for the far end of the cable. Umm, and have them...they would have to drive down to their cable landing station which is remote from their site and start troubleshooting it from there. So I would have informed the NMC, which is the Network Management Center, and I would have informed the cable station in question who are on the other end of the cable.
	Subject K Pg4 Ln1 (Technician 4 Years Experience)	A: Yes, there wasn't really another solution, the NMC already made that decision. It was basically roll over traffic to get the customer on the protection, get them back up and then they can get on with getting the fault rectified with the people in Spain.
What's reported by personnel in the field and the NOC is different from reality. This leads to not trusting what the other personnel report.	Subject B Pg7 Ln31 (Manager 4 Years Experience)	Q: The reality varies a lot from what they're reporting? A: Sometimes, yes.
	Subject K Pg5 Ln37 (Technician 4 Years Experience)	A: When the NMC called me about this fault I asked them to e-mail me every bit of information they had about the fault while I was on my way in so that it sat here on my terminal when I got here.

Table 6.16 Interview Patterns Supporting Rival Theory 2 (Continued)

Pattern	Indicated Interview	Specific Interview Quotes
	Subject O Pg5 Ln9 (Engineer 6 Years Experience)	Q: Ok, now umm, going back to what you were saying before about small hardware level knowledge that you might gleam, is there things that you could get from the cable stations that would help you do a better job with alarm correlation? Is there some form of knowledge that you feel you're lacking that the people that are really familiar with the equipment out there might be able to give you? A: I wouldn't say cable stations, I would say more labs. If there was someone at a design level that they had the information that would make my job easier. You know, not to speak down on anybody, but the cable stations guys are really just our puppets, you know, we decide what needs to be changed, we decide what the problem is, we tell them ok change this card. You know, so they're really just remote hands for us. I think so.
You need verification of local personnel to trust the information provided by the various Network Management Systems because the system can sometimes lie or have ghost alarms.	Subject B Pg8 Ln23 (Manager 4 Years Experience)	Q: So you have these fuzzy kind of problems, how do you parse out the various possible solution sets. I mean, when you have a lot of things that are overlapping how do you begin to make sense of it? A: Ummm, well I would say you definitely need the assistance of the sites to start taking measurements and confirming what you're looking at, you know, and then that's the lot of the first suspicion, is what I'm looking at real? And then they start taking measurements if it's something in an optical span. This is already if you're acting upon a situation that's very severely degraded, you know, and that's what you're looking for. You would start sending technicians out, taking measurements and testing fibers and the routes to see if there is...if you confirm what the system is reporting.
	Subject J Pg7 Ln9 (Technician 7 Years Experience)	Q: Right, so you'd basically do it in a tenth of the time that it could take, based on your knowledge? A: Yes, I mean I think that applies for everyone here. Do you see the alarm? Yes, but that's just NMS lying to us, we know what the proper alarm is don't we?
	Subject M Pg5 Ln1 (Less Than 5 Years of Experience)	Q: And that's one of the things we're trying to address. Umm, getting back to something you just said that's very interesting. How often do you think NMS gives a false alarm? A: Ohh it happens quite a lot. Ghost alarms, you know, you go in there, you look at an alarm that popped up. You go over to the EMS you think and it's not there.

Table 6.16 Interview Patterns Supporting Rival Theory 2 (Continued)

Pattern	Indicated Interview	Specific Interview Quotes
Field Personnel follow a tried and true process for fault management, by looking at the data available from the IS's, tracing the transmission path, using process of elimination at each possible point in the set	Subject B Pg17 Ln19 (Manager 4 Years of Experience)	Q: Umm, now would you consider it like a puzzle. You know, some people solve puzzles, either crossword puzzles or physical puzzles, and you know they leave them sitting over in the corner for, you know, maybe a month or two and then they'll sit down, they'll work on it for a while and they'll get frustrated and walk away. A: It's possible, you can't spend any more than a few hours on a situation that's not immediately affecting the network, because that's really what you want to protect. That comes top priority, you know. If there's a problem you're going to work feverishly to correct it. But if it's one of those things that you know, it's a bug it's not right, you just can't...leave it in the corner, we didn't get the right piece today, but we're not going to leave it alone. We'll try again, and in a sense it's like you say that it's a puzzle.
	Subject E Pg2 Ln35 (Engineer 7 Years Experience)	Q: So then what do you do to fix that? A: I mean, before we just went through all like 4 packs, receiver, transmitter, receiver and transmitter on the other end. So we'll start with one because we're not really sure what's causing it. You know, we've even looked at the optical spectrum, looked to see what that looks like, and it looks ok. So then it's kind of a guessing game. Because you're not really sure...because you have 4 packs and one of them is bad, you know, but you don't know which one. So you start with one, change one you wait a few hours and see if the problem comes back. You change another pack, the receiver and transmitter, if it's not the receiver you change the transmitter. If it's not the transmitter, then you don't really know what it is. You know, but I've never had any problem like that.
	Subject M Pg8 Ln34 (Technician Less Than 5 Years of Experience)	A: Well, what would I do differently, well umm, first off the alarm, lets say on the Lucent gear would give us an incoming LOS. Alright, that tells you something right there. If I take that, if we loop back our own equipment and the alarms clear, well that's an indication probably there's nothing wrong with the gear itself. Maybe a cable or a fiber issue, the fiber going towards the customer or vice versa, depends where you want to start first. Umm, they don't see the light, we have to sort of work back to the farthest point we have access to. We have the next tech see if they see, you know, if they see the same thing. See if they see light going to our gear and light going to the customer, you know, see which side has the problem, you know. You know, process of elimination.

Table 6.16 Interview Patterns Supporting Rival Theory 2 (Continued)

Pattern	Indicated Interview	Specific Interview Quotes
Only NMC personnel get to see the big picture to correlate throughout the network, field personnel do not have that information handy and therefore do not have access to the overall context (spatial and temporal relationships) of faults, so they make due with the IS at their disposal. They are not always informed of what the "real" problem is once its fixed, so they form their own theory on what the problems could be (they acquire "experience")	Subject C Pg3 Ln17 (Manager More Than 5 Years Experience)	Q: So if we're thinking about these as relationships, this is very spatially related, right. Really looking at the topology of the network and left to right. A: You got to look at the big picture.
	Subject E Pg8 Ln44 (Engineer 7 Years Experience)	Q: Now what kind of knowledge could they share with you that would help. I mean, not...I don't mean the, like, calling you up and telling you stuff, but I mean, what kind of knowledge would you like to look at, that you know they have that would help you? A: You know, problems they see more problems on a daily basis than we do, you know, from other stations. Put that in something like a database or a place that we could access it, you know. Go in type in the problem that we have and it would show up, we've dealt with this problem somewhere in the past, the cause of the problem, so we wouldn't have to waste hours trying to troubleshoot the problem. Q: Well do you ever actually find out what the problem is, is it a firmware problem is it a physical problem? A: I have my own, you know, ideas what the problem is, but the designers don't really want to share that information with you, you know. We just tell them what we found, and we never get the feedback form them.

Table 6.16 Interview Patterns Supporting Rival Theory 2 (Continued)

Pattern	Indicated Interview	Specific Interview Quotes
Stations do not talk to each other, only if they are immediate neighbors, otherwise they go through the NMC, through a centralized management center. This hierarchical policy as well as language and time barriers could discourage knowledge sharing.	Subject E Pg4 Ln12 (Engineer 7 Years Experience) Subject F Pg7 Ln8 (Technician Unknown Years of Experience)	A: We go back to the NMC, the network management people, tell them, can they…because we could ask, but it's like we only work with the NMC, we don't want to call…so we work with the NMC and the immediate station. If we wanted help from other stations, we usually talk to like Managers and they can, you know, either they know already with their experience with other stations, or if they don't know, they probably would ask, you know, stations in the Pacific or Europe. Q: So, from a learning perspective do you want to share what you find out, let's say when you find something that's new that you didn't run into before? Do…if there's a mechanism for you to share that, would you share it? A: We always do, amongst ourselves. We always do. Q: Here at the cable station? A: Yes. Yes we always do. Q: But like sharing with other cable stations? You know, beyond your contact with neighboring cable station. Ae: I don't know, I mean, in the operations, that's what we are the operations, we have like guys that are strong parts and weak, like you know, I'm more of a, I keep the lights on type of guy, you know, plumbing electrical HVAC. And then we have subject E and we have another guy that's here that do real good with the transmission. And I think the neighboring cable station has their key guys, you know, I think everybody has their key guys. I don't think any site would have a problem at our level, what management expects us to be able to perform. I don't think any of us would…I think we could all handle what we had to handle at any given time.
Information and knowledge isn't easily shared (maybe for job security etc.)	Subject E Pg6 Ln28 (Engineer 7 Years Experience) Subject G Pg1 Ln35 (Manager 20 Years of Experience)	Q: Like the cable stations that you don't talk to now, or… A: When I used to do like commissioning, we used to find that people wouldn't like really share the information you had. You had to find the problem on your own, then you'd come back to tell somebody and you'd say I found this, but they're like, ohh we already know about this problem, you know. You might have spent 7 or 10 days trying to find the problem, then somebody tell they already know the problem. A: The NOC protects its information from the cable stations. They view a more efficient process as meaning less people in their group.

Table 6.16 Interview Patterns Supporting Rival Theory 2 (Continued)

Pattern	Indicated Interview	Specific Interview Quotes
Knowledge was shared with the NMC over time to "bring them up to speed", but now that they are up to date the knowledge does not flow in the opposite direction.	Subject E Pg7 Ln15 (Engineer 7 Years Experience)	Q: Now, umm, what's the relationship between the NMC and the cable stations, how do things…I mean, we've gone through a problem, but what's kind of like the general relationship? A: As far as when they first came in, they usually told us like…the knowledge that the guys from the NMC had was…they were like a little behind, because the guys at the cable stations came from like I did, from, you know, from commissioning, from the labs, they had more information, more knowledge. So they were kind asking us questions, what would you do because there's a problem. But now, that over time they've evolved, so they, what they do is most of the work and just call us and tell us. Most of the time, they kind of narrow it down before they call us. They used to call us and say there's a problem, but I don't this equipment. They didn't even narrow it down to a station, the problem could be coming from like two stations away. But now it's like, communication is much better, you know. Information sharing and the knowledge these guys have is much better.
	Subject F Pg1 Ln42 (Technician Less Than 5 Years of Experience)	A: It took them a while to learn the network and learn how to fault locate. You know, if you get an alarm here, they would say it was here, but a lot of times it was a bad card in cable station A, you know. Q: So, before they got up to speed, how would you have to figure that out? A: We would work, we would both come into the site. You know if it was off hours, I would come in and they would come in and we'd troubleshoot it, you know, together.

Table 6.16 Interview Patterns Supporting Rival Theory 2 (Continued)

Pattern	Indicated Interview	Specific Interview Quotes
NMC sees more examples of faults and gain more experience/knowledge, while the field personnel are not exposed to these scenarios or given the knowledge. The NMC is also the one with access to past history of incidents. Another example of not shared knowledge is distribution of customers across the network so that field personnel can quickly tell if some alarms are customer affecting or not.	Subject E Pg8 Ln3 (Engineer 7 Years Experience)	A: You know, problems they see more problems on a daily basis than we do, you know, from other stations. Put that in something like a database or a place that we could access it, you know. Go in type in the problem that we have and it would show up, we've dealt with this problem somewhere in the past, the cause of the problem, so we wouldn't have to waste hours trying to troubleshoot the problem.
	Subject F Pg2 Ln27 (Technician Unknown Years of Experience)	Q: So you wouldn't care about what went on the previous few weeks? A: No. It's all managed in the NMC. Like I don't really get in it, like if I come up to a specific frequency, and there's an alarm on it, I would go downstairs and ask if there's any history on that. Then they would look at the NMS or wherever they go into, Trouble Ticket System, see if there's any open tickets. See if that frequency had work. You know, because the guy yesterday had worked on it. So they'll tell me yes we changed this card, we changed that card, Cable Station A did this, Cable Station B did this blah blah blah. So then I'll say OK well that's been done ladidadi you know then I'll just go forward with assumptions of the problem.
	Subject J Pg4 Ln21 (Technician 7 Years Experience)	Q: Yes it does. How much time did it take to solve the problem? A: Umm, with calling back to the NMC, and then saying look this has appeared, is there any traffic on there? And then 9 times out of 10, they will phone you back, if they know there's no traffic on there, you could troubleshoot that, you know, channel. Or yes there was traffic on there, you know, but that was on ring 10 and it switched or whatever, you know, I'd say all in all you're looking at 20 to 25 minutes.
	Subject P Pg3 Ln3 (Manager 8 Years of Experience)	Q: Umm, what was your most important concern at the time? A: Whether or not it was customer affecting.

Table 6.17 Summary of KD-DSS Introduction Support

Interviewee	# Of Experienced (Greater than 5 Years of Experience)	# Of Novices (5 Years of Experience or Less)	Total
Manager	2	0	2
Engineer	1	0	1
Technician	1	0	1
Total	4	0	4

Table 6.18 Interview Patterns Supporting Introduction of a KD-DSS

Pattern	Indicated Interview	Specific Interview Quotes
Knowledge is a large factor of how you interpret the information provided by the various NMS. Simple flowcharts of a process are not enough and are too difficult to define. Patterns are seen in certain defective components or modules	Subject B Pg8 Ln19 (Manager 4 Years Experience)	Q: So you have these fuzzy kind of problems, how do you parse out the various possible solution sets. I mean, when you have a lot of things that are overlapping how do you begin to make sense of it? A: Ummm, well I would say you definitely need the assistance of the sites to start taking measurements and confirming what you're looking at, you know, and then that's the lot of the first suspicion, is what I'm looking at real? And then they start taking measurements if it's something in an optical span. This is already if you're acting upon a situation that's very severely degraded, you know, and that's what you're looking for. You would start sending technicians out, taking measurements and testing fibers and the routes to see if there is...if you confirm what the system is reporting.
	Subject C Pg4 Ln1 (Manager More Than 5 Years Experience)	Q: Great. Now when you're solving these problems, can you think of any information or knowledge that would help you that you don't have right now? A: We don't really have, you know, there's not one...one-stop shopping as a resource. I mean, it's really just based on...I mean, we have, you know, we have information we have things that we've tried to compile here and there as we've gone along based on past experiences. Experiences are so varied it's been very difficult but we spent some time early on trying to come up with our own flow chart to some...if you see this... Q: Do you still have a copy of it? A: You know what, it never really got off the ground, once we really started to try to think this through, it just became so all encompassing...multiple different directions...
	Subject J Pg6 Ln1 (Technician 7 Years Experience)	A:...but you know 9 times out 0f 10, has been the problem is the Receiver pack, you know. It's...it just seems a bit...that's the pack that's causing the problem, but no alarms come up from it. Q: So in a lot of ways, it's how the various pieces of equipment, the network elements and so on and so forth, interact. That creates a behavior that you recognize. A: Yes, if you know that side of the NE, the working part or that side, obviously you get the Receiver, on to the Decoder, then the Transmitter and the you know on to the SDH. Then the one that is causing the problem, is the only one that hasn't got an alarm on it. It just seems a bit, a bit whacked out a little.
	Subject O Pg4 Ln37 (Engineer 6 Years Experience)	A: We, my job personally, I don't have anything formal that's done, you know, I don't write anything up, but what I would do is I'd just show either my field or network ops specialists, you know, take a look at this, show something what happened, so you don't get tripped up next time and I'd show my manager. And then where it goes from there...

Table 6.19 Summary of Mental Model Hypothesis Support

Interviewee	# Of Experienced (Greater than 5 Years of Experience)	# Of Novices (5 Years of Experience or Less)	Total
Manager	3	1	4
Engineer	0	0	0
Technician	1	1	2
Total	4	2	6

Table 6.20 Interview Patterns Supporting Mental Model Hypothesis

Pattern	Indicated Interview	Specific Interview Quotes
The network is viewed to have temporal and spatial relationships (like plumbing, like a living thing etc., bi-directional vs. uni-directional issues, topology, what happened first). Issues and faults occur in various areas causing effects to occur later in both time and spatial distances.	Subject A Pg 5 Ln5 (Manager 8 Years of Experience) Subject B Pg4 Ln39 (Manager 4 Years of Experience)	Q: How do you do that isolation process? A: You know, it's really, you know, network problems…it's a stream you have to determine if it's up the stream, down the stream, where the problem is. You normally keep looking up the stream until you don't see any more problems. Q: So there are a lot of temporal relationships that…with the rotation of the Earth and the social relationships as far as going to work, going home, network traffic all this kind of stuff which really factors in to the organization's decisions on when you do something when you don't do something? A: Absolutely. A: We ran some calculation loss, and we were able to verify that based off of the transmitting values and the receiving values, and what our documents on turn up were recorded at. We could confirm that there's a loss in both directions from the original values. Ummm, and being that it was bi-directional really didn't raise much of a question from that point that there's something going on in the span itself of the fibers. It's not, it's very rare that you would have a bi-directional issue with the amplifiers and it's equipment failing. Unless there was like a power level, not actually a power level, I can't really say, like, DC supply or something. Each site's it's own transmitter, each site's diverse from it's own… Q: Now you've mentioned the suspicion several times when we've been talking and I get the general feeling that you view the network as having behavior that you get a feeling about. A: It does. Definitely a living things. It's an animal. Q: And so, the level that you operate at and the gurus on the floor operate at is really the level of behavioral analysis rather than analytical analysis. A: Definitely, without a question you know how it behaves, you know what to expect and you know how it reacts on a daily basis, and when you see something that, alright here you go, hmm what's this? You sit back and even if you're talking to someone and they know how it behaves and how it reacts, they'll say the same thing, this is not normal, you know.

Table 6.20 Interview Patterns Supporting Mental Model Hypothesis (Continued)

Pattern	Indicated Interview	Specific Interview Quotes
	Subject C Pg3 Ln17 (Manager More Than 5 Years Experience)	Q: So if we're thinking about these as relationships, this is very spatially related, right. Really looking at the topology of the network and left to right. A: You got to look at the big picture. Q: What happened first, like temporal relationships? A: Well, timing obviously, yes, I mean, you know, what times the alarm came in is critical. Sometimes that will run itself to try to map the sequence of events, you know, there's obviously, very often a cause and effect. Something happens here will signal a whole bunch of alarms downstream because they...you don't want to be chasing all those, you know, you want to...so you got to see what came in first.
	Subject D Pg2 Ln4 (Manager More Than 5 Years Experience)	Q: If, as you train these people, and you're training them to look for different types of knowledge, information you know. Look for anything that'll help them. Where do you, you know, give them hints at where to look? Or what to look for? In...not in specific terms, but more general terms. As I said, if you just started to train people umm, are you telling them to look for particular patterns? Or...behaviors? A: I think mostly...well yes behaviors, but most of it is really the optical path. You track the optical path and you know, just sequentially can end up isolating it. So if you know sort of, just I don't know, common sense, there are some specific failures that we see more often than others.
	Subject H Pg2 Ln6 (Cable Station Tech 17 Years Experience)	Q: What was your most important concern at the time? A: Umm, localizing, clearing the fault. Proving that the fault is out here or it's in a different end.
	Subject N Pg1 Ln22 (Technician 4 Years Experience)	Q: Now, umm, when you say health, umm, what would you compare the network to, is it like a factory or is it like a automobile or is it like person? A: Like all, it's something that runs, it's a system with many different parts, members and everything has a function and it either works or it doesn't work. Q: Would some sort of a additional visual aid help? A: Yes, sometimes I try to visualize, you know, a schematic of let's say the cable, the info, the data. Signal running through it, try to visualize where does it stop or why did they get input in the first place.

Note: subject names have been removed and replaces with letters for confidentiality.

Operations management made a conscious decision to control field personnel's activities as much as possible because of a number of errors that occurred during the initial few months of service of the network. This, however, propagated to all field personnel, even when more experienced engineers were hired for field sites. Having created this center of control, the NMC began to grow its jurisdiction and overall responsibilities, resulting in the field sites slowly losing most of their autonomy and their access to any information or knowledge that would facilitate this autonomy. Introducing a KD-DSS into this environment was not a welcome addition.

The management structure attempted to enforce a highly formalized bureaucracy as often seen in a number of High Reliability Organizations such as nuclear power plants, emergency services, and air traffic control applications. However, management failed to institute a "learning organization" environment that would allow this rigid hierarchy to continue to be viable and even allow for future innovations (Van Den Eede et al. 2004). In addition, field personnel were not given empowerment to act during network failures, another advantage prevalent in HROs (Roberts et al. 2001). It may still be possible for such an organization to maintain hierarchical structure, which in theory ma serve to increase its reliability, while still expanding its knowledge management environment to allow for improved learning and knowledge acquisition across the organization, thus also improving its flexibility (Van Den Eede et al. 2005). However, the purpose of this research was to contribute to IS Design Science research by arriving at an appropriate design methodology and design theory that would guide the design of Information

Systems in general, and specifically KD-DSS, while coping with the organizational constraints posed by the ***current*** organizational environment.

The design artifact and design process themselves are the subject of this study. Reports of people who used the design artifact, the Alarm Correlation Tool, showed that it was accurate in its findings and that the tool agreed with experts' independent findings when real network faults occurred. Unfortunately, this technical viability was not sufficient for the tool to be successful. The organizational structure and the power structure at play in this environment inhibited the successful use of the tool. Furthermore, field personnel at the NMC actively resisted research attempts to gain further insight aimed at improving knowledge distribution.

The results of the case study show that elements of Rival Theory 1 – cultural, group and organizational norms overshadowed the use of the KD-DSS – and Rival Theory 2 – the organizational structure was not designed to support knowledge management tools, and therefore the utility of a KD-DSS being integrated into the Information Systems Infrastructure is greatly diminished. However, Rival Theory 2 is the dominant explanation for the inherent resistance to the use of the KD-DSS. It is the organization structure in effect, and as a result the Information Systems Infrastructure built to support the organizational power structure, that determined the lack of use and adaptation of the KD-DSS design. In the next chapter a methodology to deal with these organizational constraints is presented as part of the main contribution or this research.

6.6 Feedback on EKP Design Theory

The EKP Design Theory used in this research specified 6 main principles related to designing an Information System that would support Emergent Knowledge Processes. During the case study and model iterations performed throughout this research, the principles were used, evaluated and augmented when necessary. Table 6.21 presents the principles, the research feedback and the supporting evidence for this feedback derived from the case study and model iterations.

Table 6.21 Feedback on EKP Design Theory Principles

EKP Design Principle	Feedback
Design for customer engagement by seeking out naïve users	Seeking out naïve users provided valuable input into the technical design of the tool, but did not assist researchers in determining the organizational power structure since naïve users were not forth-coming with such information.
Design for knowledge translation through radical iteration with functional prototypes	Prototyping and radical iterations provided a means for quick feedback on the system design.
Design for offline action	Introducing a model-based approach allowed users to formalize their mental models and thought process which had been previously subconsciously used in the fault diagnosis process. This did improve users understanding and use of the system.
Integrate expert knowledge with local knowledge sharing	Knowledge sharing was technically facilitated by allowing expert users to the ability to capture and disseminate knowledge. However, due to knowledge hoarding practices this was seldom utilized.
Design for implicit guidance through a dialectical development process	Through continuous analysis and dialogues with the users, the ACT design morphed to include their traditional expectations of a rule-based system while encompassing the model-based approach which closer mimicked the decision process followed by expert users. In doing so a more efficient design was created.
Componentize everything, including the knowledge base	Component-based architectures were utilized under the RUP framework and provided for an efficient design methodology and eased the iterative design process.

6.6.1 EKP Design Principle 1

Design for customer engagement by seeking out naïve users. In the survey responses it was confirmed that users understood the concept of knowledge management. They also responded that they would like to share knowledge and that they believed the environment was a knowledge sharing one. However, during the case study interviews and the evaluation of the design, it became obvious that knowledge was not to be shared amongst field personnel. Naïve users helped with the system requirements, providing valuable insight into what type of network elements must be handled and the various technical aspects of fault correlation the system had to deal with. However, naïve users did not explain the organizational environment and were not forthcoming with details about the knowledge control structure prevalent in the organization. This severely hindered the success of the system's design. This principle would be substantially more effective if augmented with the use of organizational analysis methods to understand the organizational and knowledge control structure at play.

6.6.2 EKP Design Principle 2

Design for knowledge translation through radical iteration with functional prototypes. The radical iterations synthesized well with the DSS Design Model. Multiple DSS Design Model Iterations involved prototyping and simulation of the system, further guiding design decisions. Augmenting this design principle with the use of simulation feedback proved to be a valuable input into the system design.

6.6.3 EKP Design Principle 3

Design for offline action. The case study interviews indicated that more experienced users utilized a mental model of the network for fault diagnosis. The system design took this into account to allow less experienced/novice users the ability to start viewing the network in the same fashion. This did contribute towards a better design, and therefore the research results appeared to support this design principle.

6.6.4 EKP Design Principle 4

Integrate expert knowledge with local knowledge sharing. The case study results showed that it is global knowledge sharing that hindered the success of the system. The organization knowledge control characteristics did not facilitate this knowledge sharing scheme. Therefore, in addition to integrating expert knowledge with local knowledge sharing, for the EKP Design Theory to truly support a global mission-critical infrastructure, this design principle must also address global knowledge sharing and the associated geographical and cultural barriers.

6.6.5 EKP Design Principle 5

Design for implicit guidance through a dialectical development process. The resultant system evaluation during the case study, including field use and simulations, showed the design to be 90% accurate and more efficient in finding faults as compared to the operators' manual process. This was a direct result of on-going expert user involvement in the design of the correlation algorithms. As such, the research results support the accuracy this design principle.

6.6.6 EKP Design Principle 6

Componentize everything, including the knowledge base. The componentization of the knowledge base and system architecture facilitated the DSS Design Model iterations. The case study observation sessions (using the system) showed that this allowed for faster responses to user initiated changes. Component-based architectures and modularization of systems has long been a standing best practice of software engineering. The results of this research serve to further support this concept.

The feedback and evidence discussed in this section gives rise to one of the singular contributions of this work. The case study results, supporting the rival theory that the organizational structure plays a much larger role in the use of knowledge driven system, as well as the EKP design theory feedback identified during the research combine to provide a strong argument towards understanding the knowledge sharing environment prevalent in the organization before endeavoring to design a system to support Emergent Knowledge Processes. In the next chapter the remaining research contributions are presented along with an agenda for future work.

CHAPTER 7

CONCLUSIONS

In this chapter the research contributions, both singular and major, are described. The singular contributions are synthesized and built upon to arrive at the major contribution of this work. As such, the singular contributions are explained first followed by the work's major research contribution. Finally, suggestions for future work are posed in the last section of this chapter.

7.1 Contributions

The intent of this research was to investigate design methodologies for creating systems that would support engineers in managing and maintaining mission-critical infrastructures. Such systems require tight control of knowledge management in conjunction with extensive knowledge sharing and collaboration techniques. The results of this investigation, in expanding the community's understanding of design methodologies, are a valuable incremental knowledge addition to Design Science and Information System Design Theory.

A specific mission-critical infrastructure, a global telecommunications network, was chosen as an appropriate field site for the research. A case study of the design of an Alarm Correlation Tool for fault diagnosis of the network was performed. The research investigated both the organizational structure and the actors' knowledge management practices and decision-making processes to influence the design of the system. The resultant design was evaluated in the field environment to shed light on the design process and methodology required to successfully create these vital systems.

7.1.1 Singular Contributions

The research results have provided a number of incremental knowledge additions to design science. Apart from the main, major contribution of this research, three singular contributions have also resulted from this work. Whereas each of these is of lesser importance than the main contribution, in their own turn, they provide additional insight to the IS community in the area of DSS design and serve to support and augment the main research contribution.

7.1.1.1 Alarm Correlation Algorithm. One of the first major questions facing designers of engineering, mission-critical infrastructure management systems is the adequacy of knowledge capturing techniques used in the design. In fault diagnosis systems, this problem presents itself in the form of what alarm correlation technique is an appropriate fit with the engineers' decision-making, mental model. Domain experts indicated during informal conversations that operators used mental models to fault diagnose the network. Existing alarm correlation systems unsuccessfully attempted to assist in fault diagnosis by utilizing a rule-based approach to capture knowledge. Since the rule-based solutions were inappropriate for capturing mental models, engineers tried to codify knowledge using diagrams and flowcharts.

The appropriate correlation technique was integrated as part of the ACT design's knowledge management capabilities. It was determined that the original hypothesis was indeed correct; *engineers fault diagnose systems by creating a mental model of the* *network that they then use to manipulate the information provided to them by Network Management Systems to arrive at the appropriate root cause.* Engineers interviewed stated that they conceptualized the network as a series of relationships, "a living beast", or a constantly changing "thing". Model-based alarm correlation (Meira 1997) supported this mental model formulation and facilitated capturing and manipulation of the engineering knowledge targeted, in direct contrast to the currently, commercially available solutions, that rely heavily on rule-based correlation algorithms.

7.1.1.2 The Validation of Existing DSS Design Model. The DSS Design Model provided the framework for the entire design process. The design process benefited from the iterative nature of the model and its focus on theory, simulation and domain feedback. As aspects of a particular theory were found to be inappropriate for the specific context, new theories were utilized and "plugged into" the model. For example, when utilizing traditional IS design methodologies such as RUP proved inappropriate, the domain feedback describing the alarm correlation process indicated that EKP design theory may be a more appropriate fit. EKP design theory was easily plugged into the DSS Design Model to influence future design decisions.

Iterations of the DSS Design Model were utilized to correct these decisions and arrive at an appropriate final design as simulations and domain feedback shed light on deficiencies in the original design decisions. The resultant designs in turn modified the domain and its associated deployed Information Infrastructure, providing further feedback to improve the system's design. The DSS Design Model proved to be invaluable in guiding the design process through a myriad of theories, design decisions, domain relationships and their interactions.

7.1.1.3 Determining the Usability of EKP Design Theory. The original authors of the EKP design theory specifically posed questions about the theory's generalizability and the degree to which it could be successfully utilized by other teams. Can EKP Design Theory be used by smaller teams that are not led by senior IS researchers? If so, does utilizing the theory ensure successful design of a system? The ACT design utilized this theory and provided feedback and augmentation to tailor it towards use in a mission-critical engineering environment.

The EKP Design Theory research was led by at least three (3) senior researchers. The research project was funded by a three (3) million dollar grant and involved four (4) Fortune 500 corporations. Conversely, the team involved in the ACT design case study was much smaller, with an almost non-existent budget and less experienced researchers than the original authors of the EKP Design Theory. Due to the fact that utilizing the theory itself was successful in that the correct processes were followed and naïve user feedback sought out, the research team was misled into assuming that the design itself would be successful. However, through the case study data collection, it became clear that unless the system became a derivative of the existing IS infrastructure and management systems in place, the success of the project would be drastically constrained. Therefore, the theory should be augmented with additional guidelines to analyze organizational relationships and the organizational power structure during the design phase.

7.1.2 Main Contribution

The singular contributions mentioned above, namely the synthesis of the correlation techniques, the DSS design model feedback, and the augmented methodology with IS Design Theory are interrelated with, and serve to support, the main contribution of this work. The ACT design itself was technologically sound. The system achieved the appropriate goals required to perform successful fault diagnosis. However, the use of the system was limited due to various relationships that were discovered during the case study. These relationships showed that the global undersea telecommunication network's command and control center (i.e., NMC) actively limited the access network nodes (i.e., cable station) personnel had to operational information, and ultimately knowledge. Their access was limited not only to preserve the NMC's power, but also because remote nodes were seen to be manned by people that lacked experience and expertise to adequately utilize these resources. In some cases this view did reflect reality, but there were many instances where the cable station personnel were actually much more experienced and knowledgeable than the NMC personnel. Regardless of the circumstances, an organizational structure and processes were put into place to centralize information resources, knowledge and control to the Command and Control Center or NMC.

The results of this research show that for systems supporting management of mission-critical infrastructures, where a Knowledge Management approach is appropriate, an intimate understanding of the knowledge sharing relationships and the organization's power structure is essential to establish the framework for a successful system design. The power structure surrounding the organization's knowledge includes who controls knowledge, who is allowed access to it and to whom is it disseminated.

These aspects of knowledge control must be thoroughly understood before any design decisions can be made, and in fact before a decision is made as to whether a KM design is at all required or appropriate. Once this decision is made, then the appropriate theoretical repositioning should, and can, occur as part of the design process.

Control of knowledge sharing is viewed as a strong indicator of the actual organizational power. Whereas data, and to a lesser extent information, may be freely disseminated to all members of the organization (e.g., all field personnel in the case study had access to raw alarm data from network faults, but less people could access information such as customer traffic routes), knowledge items are considered a more valuable asset and are more actively controlled (e.g., lessons learned were less frequently sent to field personnel). Ideally, a useful way of quickly determining the knowledge control relationships within an organization would be to search an existing knowledge base that had been populated through previous historical designs and implementations. If previous attempts at designing Information Systems in the organization were documented in a repository (or knowledge base), then the organization's interactions, power structure and constraints would be apparent by reviewing these results. Therefore, to improve the systems analysis and design process in a knowledge management environment, organizations must endeavor to build this repository of past design efforts. In the absence of such a knowledge base, the DSS Design Model, utilizing a case study methodology and KM design guidelines provides an appropriate medium for gaining this understanding.

Traditional IS design and Software Engineering principles have long emphasized the need for effective user requirements elicitation methods. Those methodologies have worked successfully for traditional systems where the problem being solved is bounded in nature and does not pose the constraints introduced with global systems that must traverse geographical, cultural, organizational and institutional barriers. Furthermore, the organizational structure and knowledge sharing environment typical of systems that support global mission-critical systems also present a number of roadblocks in applying the traditional methodologies. The organization's structure has a direct influence on the relationships between the distributed teams of users. The relationships tend to form knowledge sharing patterns that are unique to the inter- and intra- teams' work relationship. These relationships and structure affect the use and design of Information Systems (Markus 1983; Orlikowski 1992). Organizations tend to design systems that mimic their communications relationships (Conway 1968). Organizational boundaries to communications may also inhibit IS implementation (Curtis et al. 1988)

These relationships and the organization's structure serve to mold the Information Systems utilized in the daily business activities. A successful design must support these day to day activities and integrate with the non-computerized part of the system [i.e., people, process and organization] (Turoff et al. 2004a; Turoff et al. 2004b). This integration would be greatly facilitated by analyzing a pre-existing design knowledge base.

7.2 Future Work

Traditional design methodologies have been utilized in a plethora of system environments. However, they still display many shortcomings. These shortcomings become more obvious when the design involves complex global information infrastructures with varying user characteristics and highly intensive knowledge management requirements.

Future work for this research should focus on further iterating through the DSS Design Model to test the specific application of the proposed analysis and design methodology. Once a detailed analysis of various organizational relationships is performed, is the resultant system design better utilized in the field site? This analysis should investigate:

- Organizational structure.
- Is the organization a centralized or decentralized organization?
- Should knowledge bases be distributed or localized at a central command and control center?
- Users' relationships.
- Do users trust each other's expert opinions?
- Does a specific set of characteristics (e.g., years of experience, type of experience), when published to other users, increase this trust?
- Physical relationships encompassed in the organization's Information Systems Infrastructure.
- Is access to specific information, or other IS resources, required by the system restricted to certain geographical nodes or to the command and control center only?
- Teams/business units' knowledge sharing and political relationships.
- Are there specific turf battles that will prohibit knowledge sharing and distributed knowledge bases?
- Are there certain political and process restrictions that will actively limit the information sharing required by the system?

These relationships and their various aspects may be documented in an IS design knowledge base and/or compared to historical documentation of previous designs to characterize the organization's knowledge management environment and power structure. It may then be possible to investigate whether future system designs are indeed improved through the use of this knowledge base.

Additional avenues for future work should attempt to add more validation to the hypothesis that model-based correlation algorithms are the correct knowledge capturing techniques for engineering systems. A direct comparison between this algorithm and other popular algorithms, as described in the related research section of this work, would be valuable in validating this assertion.

A longer term focus for future work would entail expanding this research to other mission-critical environments. For example, for disaster recovery systems, or homeland security and emergency response systems, can the methodology proposed by this work assist in producing a more successful system design?

Perhaps the design process followed in this research may have been different had the organization been viewed and structured as a High Reliability Organization (HRO) (Roberts et al. 2001; Van Den Eede et al. 2004; Van Den Eede et al. 2005). In this particular instance that was not feasible or practical given the organizational history of the field site. Future work building upon this research may also branch into the investigation of using this methodology within an HRO framework.

The analysis methodology proposed here is consistent with Information Systems philosophy in stating that the organization and individual use of the system are strong contributors to the success of a system. This methodology may be used to verify the applicability of specific system types within an organizational environment.

APPENDIX A

CASE STUDY PROTOCOL

This appendix shows the case study protocol used in this research.

CASE STUDY PROTOCOL

INVESTIGATING THE USE OF KNOWLEDGE MANAGEMENT IN A GLOBAL TELECOMMUNICATIONS NETWORK

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Overview

The following case study protocol documents the plan for the case study. It explains the intent of the study, describes the data to be collected and the methods used to do so. The case study protocol also defines a timeline for the study and finally describes how the results of the study shall be documented.

Background

The field site organization decided in 2000 that it should be in the service provider market as well as the supply market. They built the Global Network (NETWORK A) and spun it off subsidiary as an independent company (IPO). In 2003, with the decline of the telecommunications market, the organization re-acquired its previously spun-off subsidiary as a fully owned subsidiary. Today, the organization has sold off the NETWORK A unit, but remains committed to maintaining the supply part of the telecommunications business.

Between 1998 and 2005, the telecom organization has developed a number of software systems to support the management of their undersea networks. These software tools have included both the Element Management Systems (EMS A) and a Network Management Systems (NMS A). They also collaborated with a number of outside suppliers in these development efforts. NMS A has included a traditional rule-based alarm correlation feature. The current development project is focused on internally developing and designing a new network management system (EMS/NMS). The new tool will support a model-based alarm correlation feature that is intended to improve the management and fault correlation processes.

The Alarm Correlation Tool (ACT) project is an integral part of this new EMS/NMS development effort. The new design is aimed at improving the deficiencies and limitations presented by the original systems. The organization is determined to improve the product by introducing a state of the art integrated network fault diagnosis system.

Statement of Intended Research

Engineering processes such as the maintenance of mission-critical infrastructures are highly unpredictable processes that are vital for everyday life as well as national security (Dahlin 2003, Chao 1999, National Science and Technology Council 2002). Decision Support Systems (DSS) are information systems (IS) developed to aid users in making informed decisions. However, one of the problems that operators in telecommunications networks face is that they are presented with an overabundance of information and stimuli during a network fault. They require assistance in filtering and processing this information and deciding what the correct action should be to solve the network fault. These decisions require not only an informed user, but one who has the knowledge to discern the important aspects of the fault scenario and determine the best corrective action. This knowledge can be captured and shared across the network using a Knowledge Driven Decision Support System (KD-DSS).

The current NMS is a DSS that is designed using extensive simulation techniques for verification, since actual network faults are expensive, if not impossible to test. Field engineers acquire local equipment knowledge and use it to intuitively filter out any unimportant events related to network faults while still utilizing the information presented by the NMS. However, this localized acquired knowledge has not been leveraged across the entire network. The engineering teams at various nodes collaborate using traditional methods to correct faults that occur across the network. These teams are made up of users with varying degrees of experience, knowledge, cultural, and educational characteristics. The decision-making process at the field sites is currently very hierarchical and controlled by the command and control center (i.e., the NMC). However, there also exists strong coupling at the interpersonal, intra-group, and inter-group levels of analysis.

R&D and NETWORK A operations management have placed a strong emphasis on improving the network management products by including improved alarm correlation features in their new offerings. The results of this case study will improve the design of alarm correlation tools that will be deployed in the future to assist operations personnel in maintaining the network. The case study itself will be performed by Dr. Robb Klashner (NJIT) and Sam Sabet (NJIT) as part of a rigorous study in the design of systems that support mission-critical infrastructures.

Rationale for site selection

NETWORK A provides a unique opportunity for investigating the fault diagnosis process as it is a truly global network where teams and individuals collaborate in solving problems. Network faults provide complex decision-making situations that require pre-acquired knowledge to correct. This knowledge must be shared among the various collaborating group members to facilitate quick resolution of network faults. The US and UK cable stations have allowed us access to install a prototype of an Alarm Correlation Tool that would allow us (along with this case study) the opportunity to analyze the decision-making model required to troubleshoot complex engineering problems. Since it is our conjecture that individuals solve these problems differently when in groups, it is an obvious conclusion that we must analyze the mental models of both the individuals and the group as a whole. The resultant findings should help guide the design of any systems (and in particular alarm correlation systems) that can support the maintenance of complex infrastructures such as global undersea networks.

Hypotheses

This research investigates the ability of end-users to own the maintenance of the knowledge base within an emergent knowledge process support system (Markus et al. 2002). The tool's effectiveness and success will be evaluated in the global telecommunications network that includes multiple geographically dispersed and fully staffed field sites where teams of personnel collaborate to diagnose network faults. The results of the evaluation will serve to augment current design theory with specific guidelines for designing mission-critical engineering diagnosis systems. The algorithms used by personnel for diagnosing network faults will be documented to verify that a better design for systems that support this process cannot simply follow a rigid rule-based algorithm, but must conform to the model-based approaches engineers use for their mental models.

It is our conjecture that when operators work in groups (inter- and intra-node) the diagnosis process is performed differently and knowledge is shared differently among the groups than between intra-group members. Therefore, we will investigate if changing software tool designs will facilitate knowledge capture and sharing that will make the fault diagnosis process more efficient.

Relevant Theoretical Considerations

This research will investigate the mental algorithms used by field personnel (both as individuals and in groups) to trouble shoot network faults. We will investigate how the introduction of knowledge management (KM) software tools will change the fault diagnosis troubleshooting process in a global telecommunications network. It is our conjecture that the behavior of NETWORK A personnel will be modified by evolving their fault diagnosis processes. Concepts from General Systems Theory have been adopted in order to establish a foundation to modify the entire complex adaptive system that forms the NETWORK A. A significant aspect of this approach is the general classification model for all organized systems. We contend this theoretical perspective can be leveraged to understand key aspects of this mission-critical infrastructure. Assuming the general systems perspective, we view a KD-DSS to be part of the larger domain such that it is actually part of the overall system or organization.

The overall system is conceptualized as a *set* or *ensemble* of *elements*, *states*, or *events* that are modeled using *causal relationships*, *spatial relationships* and *temporal relationships*, or *properties*. The *variety* in these relationships and/or properties results in information and is also used to determine the level of organization. That is to say, no variety exists (and no new information is gleaned) if all components are required in an organized ensemble. But, with some *degree of freedom* to organize *component* sets, the concepts of *constraint* and *contingency* become important. Relatively stable spatial, causal, and/or temporal relations between elements, states, and/or events are considered to constrain the organizational form. Contingent elements, states, or events are also necessary for variety to truly be present; i.e., if there are no contingencies, then the organization is deterministic in nature. Therefore, these concepts interact in a variable manner leading to information. This information is used in a communicative fashion to evolve current constraint and control mechanisms within the system, which permeates the KD-DSS boundary and has an impact on the systemic evolution of the network and tool.

Another major factor in the evolution of a methodology is the current state of the overall system's organizational state. From General Systems Theory, we use the concepts of *organized simplicity* and *organized chaos* to set endpoints of a continuum wherein all organized systems will fall. Firms demonstrating a high degree of organized simplicity have a great number of causal relationships and therefore constrain the degree of freedom for which information can flow in and through them. On the other hand, firms exhibiting organized chaos are consistently introducing variety into the organization allowing for greater information flows, but are more unstable due to weaker relationships and consistent properties. The usage of these General Systems Theory concepts facilitates the development of specific theories and guides the analytical research investigation.

Observations and Insights

The observations and insights underlying this case study are that introducing the management of knowledge to the network fault diagnosis process will improve the operators' ability to solve problems. The purpose of this case study is to explore that perspective.

Theories

Theory:

If we introduce/facilitate knowledge management capabilities into the system, we will evolve the troubleshooting process toward stability (organized simplicity) at the individual and group levels because the entire system has successfully mapped (through the KD-DSS) the domain variety into information and knowledge.

Rival Theory 1:

There are certain decision-making models that individuals and/or groups follow that will not be changed by the external stimulus; namely the introduction of Knowledge Drive Decision Support Systems (KD-DSS) group and individual normative behavior.

Rival Theory 2:

The information systems architecture, which is strongly correlated with the organizational structure, pre-determines the decision-making process in fault resolution. Knowledge management does not have to be a necessary component in this information systems architecture.

Field procedures

Access to sites and personnel

NETWORK A operations has been gracious enough to allow us to install a prototype of the Alarm Correlation Tool in the US and the UK. In addition, the US site is logistically convenient for the investigators. We have also requested and received NETWORK A's permission to interview the personnel in the Network Operations Center (NOC) and the cable station, which are collocated at the same campus, but separated organizationally and physically.

Case study field resources

While in the US building (both at the NOC and the cable station), SUBJECT A will be our main contact. We will not perform any activities without first informing him and obtaining his permission. Also, we are endeavoring to secure access to a conference room in the facility for the purpose of interviewing personnel and writing up the resultant data.

Finally, we are planning for the contingency wherein an opportunity arises to conduct phone interviews with remote personnel in cable station nodes located elsewhere in the NETWORK A. The rationale for these specific but opportunistic interviews with node operators is associated with possible fault diagnosis activities. We will seek out the operators who have recently diagnosed a problem in order to perform an audio conference call interview with them.

Assistance procedures

The investigators understand that should issues arise that require more in-depth investigation they may require the assistance of other colleagues. Should any particular part of the research require us to research new methodologies and/or procedures, we may contact a number of academic experts at NJIT (New Jersey Institute of Technology). However, these colleagues will not be given access to private NETWORK A or the organization's data that has been gathered in the course of this research.

Schedule of data collection

Multiple cable station nodes in the global network (NETWORK A) will be data collection sites. Within the overall research design, several activities will be concurrently ongoing. The case study is fully integrated inside our overall design model that introduces various complex relationships. Thus, the research activities are nested and interrelated although we are presenting them in a linear manner in this protocol. So, in actuality, the following action items will have a dynamic behavior rather than following a static model. The following data collection will be performed:

- A survey questionnaire shall be initially e-mailed out to system test personnel at the organization's R&D labs as part of a pre-case study research process.
- The survey will be e-mailed to all the NETWORK A cable stations, NOC personnel, the members of the technical support center (TSC), and commissioning and acceptance (C&A) team, after the pre-case test is successfully completed. These groups have a wide range of experience.
- A prototype alarm correlation tool shall be installed in the USA and UK cable stations.
- Structured, semi-structured, and unstructured interviews shall be held with members of the system test team as part of the pre-case study to determine how they would solve network faults in the US
- Semi-structured case study interviews shall be held with members of the TSC to determine how they troubleshoot trouble tickets in the US.

- Semi-structured case study interviews shall be held with the members of the commissioning and acceptance (C&A) team to determine how they solve network faults.
- Semi-structured case study interviews shall be held to determine how network personnel solve network faults with
- The cable station and NOC personnel in the US.
- Members of R&D in the, US.
- We would like to monitor alarms on the NETWORK A network (by asking the NOC to inform us when a network fault has occurred) and, once we find a "suitable" alarm scenario that has occurred, we would like to interview the personnel involved in solving the fault via an audio conference call.

Timeline for Data Collection

Table A.1 Data Collection Timeline

Data Collection Activity	Time Frame
Pilot survey	05-17-05
Pilot case study responses Interview System Test personnel	05-18-05
Send out survey to cable station and NOC Personnel	05-18-05
Dynamically interview via phone any node groups involved in interesting faults during study	05-20-05 – when matrix of all faults are completed
Collect as many historic documents as are relevant to faults	05-17-05 – end of study
Receive results of survey	05-20-05
Observations at NOC and node	05-20-05 – 06-01-05
Interview NOC and node personnel—both individual and group	05-20-05 – 05-25-05
Introduce Alarm Correlation Tool into NOC and node	05-23-05
Interview network members based on alarm occurrence	05-20-05 – 06-01-05
Interview TSC members	06-01-05 – 06-10-05
Interview commissioning and acceptance (C&A) team	06-10-05 – 06-10-05
Send out follow-up survey	Dependent on access

Unanticipated events

Should we be able to continue the case study past 06/01/05 and this does not present any conflict with NETWORK A's operations, we may request additional site visits and/or follow-up interviews. If for any reason scheduling conflicts occur and we are not able to carry out the pre-planned interviews during the case study, we may follow a number of contingency plans which include interviewing TSC personnel individually and/or as a group to understand their troubleshooting process.

Questions of Interest

General questions we are interested in answering:

- Why does the current industry design available commercially not work?
- How can operators author and utilize indicators for fault diagnosis?
- How are these indicators stored in an element management system?
- How to create or process information using their experience and knowledge?
- How do we choose knowledge worth capturing and/or sharing?
- How to determine the correct course of action based on emerging knowledge?

Specifically, this case study is being performed to answer the following questions:

- How do we design a Decision Support System to facilitate knowledge sharing and management?
- How do operators use current software tools to share knowledge amongst themselves at different hierarchical levels in the telecommunications network? Specifically,
- How and why do Network Operations Center personnel share data, information, and knowledge now?
- How and why do NETWORK A node personnel share data, information, and knowledge now internally with each other?
- How and why do cable stations share data, information, and knowledge now?
- How are the interpersonal, inter-NOC, and inter-nodal relationships changed by the introduction of Knowledge Driven DSS (KD-DSS) tools?

Case Study Questions

Semi-structured case study interviews

The interviews are intended to investigate the process of telecommunications fault diagnosis by individuals, small groups, and between groups. The focus of initial analysis will be to discover the algorithms used in the separate situations. Therefore, the interview process will consist of:

- Interviewing individuals separately by providing them with generic fault scenarios representing communication and transmission type faults.
- Interviewing individuals separately by providing them with a specific fault scenario that required a relatively large period of time to solve in the network.
- Interviewing a group (i.e., compiled from the personnel from the same shift) by providing them with generic fault scenarios representing communication and transmission type faults.
- Interviewing a group (i.e., compiled from the personnel from the same shift) by providing them with a specific fault scenario that required a relatively large period of time to solve in the network.

With each interview, the interviewee's will be asked probing questions to understand what their mental model and thought process was during the fault scenarios. The interviewers will try to define the step by step process followed to discover what the root cause of the problem is and how a decision to perform a specific action that could solve the problem was taken.

Finally, by comparing the interviews done with groups as opposed to individuals, the interviewers will try to understand how the process changes when a group is involved in the troubleshooting process. Particular attention will be paid to what served as the basis for the decisions (i.e., what knowledge) and how this was acquired. Questions will be asked to determine how this knowledge was built and whether or not it is shared and used with other individuals.

Questions to guide the interviewer

The following are questions that will guide the interviewer in the case study semi-structured interviews. They are not intended to be questions that are directly asked of the subjects, but rather a guideline to the entire interview.

- How did they solve the problem?
- How could the individuals have utilized more knowledge in their process?
- How did the groups solve problems? Did they share knowledge among themselves?
- If the process involved discovering new knowledge, would they be willing to share this knowledge with other nodes/individuals/groups?
- If they were willing to share this knowledge with other nodes/individuals/groups would the receiving personnel be willing to accept this knowledge?
- Would the new knowledge have helped the receiving personnel in their fault diagnosis process?

Network Fault Categories

Network faults can be classified into the following broad categories:

- Equipment Failures – These are circuit pack failures and bad hardware type faults.
- Transmission Failures – These may be faults caused by wrongly optimized parameters, failing hardware that has not completely reported a hardware failure alarm yet, upstream failed equipment etc.
- Configuration Failures – These network faults introduced by improper user control.

Outline for interview to establish the general aim for fault diagnosis

- We are making a study of fault diagnosis. We believe you are especially well qualified to tell us about fault diagnosis.

- What would you say is the primary purpose of fault diagnosis?
- In a few words, how would you summarize the general aim of fault diagnosis?

Fault type descriptions

- What are the characteristics of the most common type of fault?
- What are the characteristics of the rarest type of fault?
- What other fault types are there?
- Why do you characterize faults this way?

Critical Decision Method Questions

State the primary purpose of fault diagnosis.

- Think of the last major fault alarm that directly affected your node. (Pause until they have an incident in mind.) What type of fault was it? (If they do not have an opinion, describe our fault types.)
- Did your node solve the fault? (If not, basic TT information.)
- What were the general circumstances leading up to this incident?
- What first gave you the indication that there was a network fault?
- How did you know it was a serious problem?
- Was this fault similar to other faults you have seen in the past?
- What was your most important concern at the time?
- What were the various solutions or root causes that you considered at the time?
- How did you decide between the various solutions? (Get specific steps.)
- (lastly) So, ____(restate)__ was a key piece of information that helped you make the decision on which alarm was the root cause of the problem?
- What other information did you have at your disposal that you did not use?
- How much time did it take to solve the problem?
- What key piece of knowledge would have made the solution to this fault obvious and much faster to solve?
- How much time pressure did you feel you were under while trying to solve the problem?
- When starting your shift, what summary information would help you in solving this type of fault?
- Suppose the answer to this problem was not in your cable station. What would you have done differently?

Guide for Case Study Report

The result of the case study shall be documented in report that shall be delivered to NETWORK A and organization for review to provide additional validity. The report should explain how the current fault diagnosis process works, how operators utilize and share their experience and knowledge, and finally how the process may be improved using new alarm correlation tools.

The report shall follow the outline below:

I- Introduction and purpose of the case study

II- Documentation of the fault diagnosis process
   a. How do operators currently solve faults?
   b. How do operators work as a group to solve faults?

III- Use of Knowledge in the fault diagnosis process
   a. How is knowledge utilized in the fault diagnosis process?
   b. How do the groups share experiences and knowledge about faults?

IV- Outcome of introducing knowledge management to fault diagnosis process
   a. What impact can a KD-DSS have on the diagnosis process?
   b. What knowledge can be captured and shared between network nodes?
   c. What is the right design of a system that would facilitate such knowledge sharing?

V- Attachments (if any)
   a. Summary of results of questionnaires.
   b. Summary of interview results.

References

- Chao, C. S., Yang, D. L., and Liu, A. C. "An Automated Fault Diagnosis System Using Hierarchical Reasoning and Alarm Correlation," IEEE Workshop on Internet Applications, July 1999.
- Dahlin, Michael, Chandra, Bharat Baddepudi V., Gao, Li and Nayate, Amol. "End-To-End WAN Service Availability," IEEE/ACM Transactions on Networking (11:2), 2003, pp 300-313.
- Markus, M. Lynne, Majchrzak, Ann and Gasser, Les, "A Design Theory for Systems That Support Emergent Knowledge Processes," MIS Quarterly (26:3), September 2002, pp 179-212.
- National Science and Technology Council, "Networking and Information Technology Research and Development; Supplement to the President's FY 2003 Budget," 2002.
- Sabet, S., "Methodology for Design of an Emergent Knowledge Process Support System", Dissertation Proposal, IS Department, NJIT, 2004.
- NETWORK A – Operations Process Document
- EMS-NMS Requirements Document

APPENDIX B

QUESTIONNAIRE

CONSENT TO PARTICIPATE IN A RESEARCH STUDY

TITLE OF STUDY: Methodology for Design of an Emergent Knowledge Process Support System

RESEARCH STUDY:

I, ______________________, have been asked to participate in a research study under the direction of Sameh Sabet.

PURPOSE:

This questionnaire is intended to help in the assessment and design of an alarm correlation tool. An alarm correlation tool is a software tool that would be incorporated with the Network Management System to help filter alarms and identify root causes as of network faults. In addition, it would provide helpful information on how to correct certain alarms when they are found to be the root cause of a network fault.

The intent is to measure how useful these tools are to network node personnel. Also, we would like to determine the best design for the tool. Please feel free to comment on any issues related to alarm correlation.
There are several purposes of this questionnaire. First, we are gathering information about how you perceive alarm correlation tools. Are these tools currently being exploited in the network? How could these tools be used differently?

DURATION:

My participation in this study will last for 1 month.

PROCEDURES:

I have been told that, during the course of this study, the following will occur:

I will be asked to fill out a questionnaire. I may also be asked to evaluate a proto-type of the Alarm Correlation System.

PARTICIPANTS:

I will be one of about 80 participants to participate in this trial.

RISKS/DISCOMFORTS:

I have been told that the study described above may involve the following risks and/or discomforts:

No known risk; confidentiality of the data will be fully protected.

There also may be risks and discomforts that are not yet known.

I fully recognize that there are risks that I may be exposed to by volunteering in this study which are inherent in participating in any study; I understand that I am not covered by NJIT's insurance policy for any injury or loss I might sustain in the course of participating in the study.

BENEFITS:

I understand that participating in this study will allow me to learn more about Alarm Correlation Tools and their effectiveness when used in a global network.

CONFIDENTIALITY:

I understand confidential is not the same as anonymous. Confidential means that my name will not be disclosed if there exists a documented linkage between my identity and my responses as recorded in the research records. Every effort will be made to maintain the confidentiality of my study records. If the findings from the study are published, I will not be identified by name. My identity will remain confidential unless disclosure is required by law.

RIGHT TO REFUSE OR WITHDRAW:

I understand that my participation is voluntary and I may refuse to participate, or may discontinue my participation at any time with no adverse consequence. I also understand that the investigator has the right to withdraw me from the study at any time.

INDIVIDUAL TO CONTACT:

If I have any questions about my treatment or research procedures, I understand that I should contact the principal investigator at:

sas7455@njit.edu

If I have any addition questions about my rights as a research subject, I may contact:

Dawn Hall Apgar, PhD, IRB Chair
New Jersey Institute of Technology
323 Martin Luther King Boulevard
Newark, NJ 07102
(973) 642-7616
dawn.apgar@njit.edu

SIGNATURE OF PARTICIPANT FOR WEB-BASED SURVEY

By submitting my e-mail address in the questionnaire website I understand that this action certifies that:

I have read this entire form, or it has been read to me, and I understand it completely. All of my questions regarding this form or this study have been answered to my complete satisfaction. I agree to participate in this research study.

Enter your e-mail address in the box below and click submit.

[ ] Submit | Reset

QUESTIONNAIRE SECTION 1

Background:

The questionnaire is divided into three sections. It should not take more than approximately 45 minutes.
Also, please remember the following:

1. All the information you give will be kept entirely confidential.

2. We need answers to all questions. Please don't skip any.

3. Your input is important. We would like your personal opinion. Please do not talk to others about the questions.

4. Move rapidly through the questionnaire. We are interested in your first impressions, so please do not spend an excessive amount of time on each question.

Personal Background Questions:

We would like to ask a few questions about yourself. Could you please answer the following:

1- I have been employed by the company for a period of years.

2- My position in the company is .

3- I have years experience in network operations.

4- I have received training in the company's Network Management System.

-

5- I consider myself an expert in the following area (e.g. NMS, Transmission, Facilities, Undersea, Terrestrial etc.):

6- My highest level of education: -

7- My native (first) language is:

8- My work location (city and country) in the network is:

Background Knowledge Definition Questions:

A scenario from a telecommunications network is presented below. Please read the scenario before answering the questions. Answer the questions below based on your personal understanding and interpretation of the scenario.
A cleaning crew working in a cable station accidentally trip over a fiber carrying a signal to a network element (NE). The network element detects a signal failure. The NE then sends a bit encoded status message to the network management system (NMS) indicating the alarm(s). The NMS displays the following message on the alarm summary window "NE1 - Incoming Signal Loss". When the cable station personnel see this alarm, they attempt to troubleshoot the problem. Jim is one of the cable station personnel. He is an experienced operator and immediately realizes that the problem must be upstream of the NE. Jim also thinks the problem must either be the connection into the NE or in the equipment feeding NE1. Jim immediately heads to NE1 to trace the line back to the upstream equipment.
Answer the following 3 questions based on your understanding of what happened in this scenario. You can type as much as you feel is necessary in the space below each question, respectively.

9- If you consider something to be data, list those thing(s).

10- If you consider something to be information, list those thing(s).

11- If you consider something to be knowledge, list those thing(s).

Use of Alarm Correlation Tools Questions:

How would you describe the amount of computer-related training that YOU have received from each of the following sources?

Please answer the questions 12 through 16 by choosing a number from 1 to 5 where 1 means you had very little or no training and 5 means you had a great deal of extremely good training.

12- Self

○ 1 ○ 2 ○ 3 ○ 4 ○ 5

13- College

1 2 3 4 5

14- Company

1 2 3 4 5

15- Vendor

1 2 3 4 5

16- Other

1 2 3 4 5

Please answer the question #17 by choosing a number from 1 to 5 where 1 means you are extremely dissatisfied and 5 means you are extremely satisfied.

17- Overall, how satisfied are you with Alarm Correlation Tools that you have used? Please answer the following question by choosing a number from 1 to 5 where 1 means you extremely dissatisfied and 5 means extremely satisfied.

1 2 3 4 5

18- On the average day, how many hours do you spend using Alarm Correlation Tools to do your job? Hour(s)

Next Section | Reset Form

QUESTIONNAIRE SECTION 2

Background Information:

Definitions
Data: Raw unprocessed transmissions from network elements.

Information: Processed data that is considered to be of value to a user.

Knowledge: Information with added context, experience and expertise to come up with actions and solutions to solve problems.

For example, raw alarm messages sent to a Network Management System (NMS) from a Network Element (NE) is considered to be data. When the NMS processes this data and displays it to a user in a human-readable from we consider the data to have been processed into information. Finally when a user combines this NMS information with their training and expertise (or perhaps by using their memory of similar alarms having occurred in the past) to come up with an action that can solve the network fault that has occurred due to the alarm, they are utilizing knowledge to do so.

Based on these definitions, please answer the remaining questions in this survey.

Organizational Background Questions:

Questions 1-11 below are related to fault diagnosis of the telecommunications network.

Please answer the following questions by choosing a number from 1 to 7 where **1 means you strongly disagree** with the statement and 7 means you strongly agree.

I feel my organization has:

1- been able to identify new opportunities for maintenance:

○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7

2- not been able to coordinate the diagnosis efforts of different units in the field.

1 2 3 4 5 6 7

3- been able to rapidly deploy new solutions or corrective actions.

1 2 3 4 5 6 7

4- been able to adapt quickly to unanticipated changes.

1 2 3 4 5 6 7

5- been able to quickly adapt its procedures to network changes.

1 2 3 4 5 6 7

6- not been able to decrease response times.

1 2 3 4 5 6 7

7- been able to react to new information about the network and/or equipment.

1 2 3 4 5 6 7

8- been able to be responsive to new network operations demands.

1 2 3 4 5 6 7

9- not been able to avoid overlapping efforts between different units.

1 2 3 4 5 6 7

10- not been able to streamline the fault diagnosis processes.

1 2 3 4 5 6 7

11- been able to reduce redundancy of information and knowledge.

1 2 3 4 5 6 7

Knowledge Sharing Questions:

Please answer the following questions by choosing a number from 1 to 7 where **1 means you strongly disagree** with the statement and **7** means you strongly agree.

12- I often obtain useful knowledge by reading written materials authored by coworkers.

1 2 3 4 5 6 7

13- I rarely read documents written by coworkers to increase my knowledge on a topic or issue.

1 2 3 4 5 6 7

14- I rarely use targeted one-on-one conversations with other employees to acquire work-related knowledge.

1 2 3 4 5 6 7

15- When I need to access to knowledge, I frequently use personal communication with individual employees.

1 2 3 4 5 6 7

16- I frequently consult with groups of coworkers when I need to improve my knowledge on a topic or issue.

1 2 3 4 5 6 7

17- I rarely use conversations with a group of coworkers as a way of acquiring knowledge.

1 2 3 4 5 6 7

Alarm Correlation Tool Questions:

18- I believe it takes on average [ ] hours to diagnose and correct most faults (Listing a fractions of an hour is OK here).

19- I believe that using an effective Alarm Correlation Tool would decrease the diagnosis process by [ ] hours (0 is OK here).

Please Answer the following questions by choosing a number from 1 to 7 where **1 means you strongly disagree** with the statement and 7 means you strongly agree.

20- I believe that using an effective Alarm Correlation Tool is a useful addition equipment.

( ) 1 ( ) 2 ( ) 3 ( ) 4 ( ) 5 ( ) 6 ( ) 7

21- I believe that while using an effective Alarm Correlation Tool I would tend to customize the configuration files related to the tool:

( ) 1 ( ) 2 ( ) 3 ( ) 4 ( ) 5 ( ) 6 ( ) 7

Other Comment:

22- Please provide any other comments related to fault diagnosis of the network. Also any information you think may be helpful in assisting us in improving the fault diagnosis process so that it may become more effective would be greatly appreciated. All comments and information should be typed in the text box below:

[Next Section] [Reset Form]

QUESTIONNAIRE SECTION 3

Please answer the following questions based on your current understanding and feelings:

1- Key expertise is often captured in an online way in my organization.

○ Strongly Disagree ○ Disagree ○ Neutral ○ Agree ○ Strongly Agree

2- I get appropriate lessons learned sent to me in areas where I can benefit.

○ Strongly Disagree ○ Disagree ○ Neutral ○ Agree ○ Strongly Agree

3- I usually have time to chat informally with my colleagues.

○ Strongly Disagree ○ Disagree ○ Neutral ○ Agree ○ Strongly Agree

4- Individualized learning is usually transformed into organizational learning through documenting this knowledge into our organization's knowledge repository.

○ Strongly Disagree ○ Disagree ○ Neutral ○ Agree ○ Strongly Agree

5- There are many knowledge fairs/exchanges within my organization to spawn new colleague to colleague relationships.

○ Strongly Disagree ○ Disagree ○ Neutral ○ Agree ○ Strongly Agree

6- There are lessons learned and best practices repositories within my organization

○ Strongly Disagree ○ Disagree ○ Neutral ○ Agree ○ Strongly Agree

7- We have a mentoring program within my organization.

○ Strongly Disagree ○ Disagree ○ Neutral ○ Agree ○ Strongly Agree

8- We have Centers of Excellence in our organization whereby you can qualify to become a member/affiliate of the Center.

○ Strongly Disagree ○ Disagree ○ Neutral ○ Agree ○ Strongly Agree

9- We typically work in teams or groups.

○ Strongly Disagree ○ Disagree ○ Neutral ○ Agree ○ Strongly Agree

10- Our main product is our knowledge.

○ Strongly Disagree ○ Disagree ○ Neutral ○ Agree ○ Strongly Agree

11- I feel that we have a knowledge sharing culture within our organization versus a knowledge hoarding one.

○ Strongly Disagree ○ Disagree ○ Neutral ○ Agree ○ Strongly Agree

12- We have a high percentage of teams with shared incentives whereby the team members share common objectives and goals.

○ Strongly Disagree ○ Disagree ○ Neutral ○ Agree ○ Strongly Agree

13- There are online communities of practice in my organization where we can exchange views and ideas.

○ Strongly Disagree ○ Disagree ○ Neutral ○ Agree ○ Strongly Agree

14- I am promoted and rewarded based upon my ability to share my knowledge with others.

○ Strongly Disagree ○ Disagree ○ Neutral ○ Agree ○ Strongly Agree

15- There is an adequate budget for professional development and training in my organization.

○ Strongly Disagree ○ Disagree ○ Neutral ○ Agree ○ Strongly Agree

16- Success, failure, or war stories are systematically collected and used in my organization.

○ Strongly Disagree ○ Disagree ○ Neutral ○ Agree ○ Strongly Agree

17- The measurement system in my organization incorporates intellectual and customer capital, as well as the knowledge capital of our products or services.

Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree

18- We have the technological infrastructure to promote a knowledge sharing environment within our organization.

Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree

19- We typically have integrated assignments where the number of projects in which more than one department participates occurs.

Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree

20- We have internal surveys on teaming which surveys employees to see if the departments are supporting and creating opportunities for one another.

Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree

21- We track the degree to which the organization is entering team-based relationships with other business units, organizations, or customers.

Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree

22- The reuse rate of "frequently accessed/reused" knowledge in my organization is high.

Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree

23- The distribution of knowledge to appropriate individuals in my organization is done actively on a daily basis.

Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree

24- New ideas generating innovative products or services are a frequent occurrence in my organization.

Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree

Completed Survey | Reset Form

APPENDIX C

SAMPLE CASE STUDY INERVIEWS

Subject C Interview

Interviewer: Robb Klashner
Interviewer2: Sam Sabet
Interviewee: Subject C
Date: 05-24-05 – 11:00am

Interviewer: Lets start with your full name, and your job title and a short description of what you do.
Interviewee: Full name is Subject C. My job title, I guess it's, network operations manager. My focus has been on inventory, database work, also the transmission inventory. Kind of migrated more away from process stuff, communication to trouble ticketing all that type of deal. That's mostly where my focus it.

Interviewer: You work with your trouble tickets?
Interviewee: Yes.

Interviewer: What do you do with them
Interviewee: Primarily just reviewing reports, things like that. I mean, I don't actively open the tickets or take the notes, the guys out in the field do that. Just ensuring that we're trying to follow the process, opening the tickets when we're supposed to be, updates are getting made as they should and if there's any questions, what we should or shouldn't do. Sometimes, you know, I'll get someone will consult with me should I open a ticket now, should we close it, just things like that. Mostly administrative type functions.

Interviewer: What would you say is the criteria for opening a ticket?
Interviewee: Well we pretty much open a ticket for any alarm. Anything.

Interviewer: For nominal status?
Interviewee: Yes. As far as the network goes, the transmission goes, pretty much any alarm, regardless.

Interviewer: Any given week, what's the average number of tickets that you see?
Interviewee: 20 or so a day.

Interviewer: 20 or so a day?
Interviewee: Yes on average. I mean…

Interviewer: And these are trouble tickets?

Interviewee: These are trouble tickets. But there are tickets generated for building issues, HVAC alarm or things like, we open tickets. It's not necessarily transmission affecting, it's not a customer affecting event, but it's something that needs to be logged and tracked so we open a lot of tickets for that types of activity.

2:49
Interviewer: Alright, now do you now or have you in the past participated in the trouble shooting of the alarms?
Interviewee: Yes, that was part of my role initially. As we hired additional personnel you've already talked with Subject B. Subject B and Subject A are really the two goto guys on our team as far as you know, a lot of issues with...troubleshooting and again I've kind of migrated away from that and I've done all the other stuff. So to be honest I don't spend that much time with it any more. Subject B and Subject A are really the guys that are the front line as far as that goes.

Interviewer: Great. Now with respect to the alarm...are you familiar with alarm correlation.
Interviewee: Uhuh.

Interviewer: How do you conceptualize alarm correlation?
Interviewee: Well here we have, you know, we have numerous systems that we're working on and often we're in a position where we may have to look at a variety of EMS type systems that we can see an alarm in one place, is it also shown here, is it also shown here and try to put the pieces of the puzzle together. From that point of view. We have multiple sources of data, different thing flashing. Sometimes something may show up in one system but not the other. And then depending, you know, we really have to take the next step depending on what the alarm is.

Interviewer: With respect to data, do you recall our definitions in the survey?
Interviewee: Yes.

Interviewer: Ok, did you somewhat agree with them, completely or...
Interviewee: Yes, I mean, for the most part. I mean, you know, data and I guess it's a kind of a blurred line maybe between data and information, I guess, it depends on...I know, sometimes, they could be one and the same, it really just depends. Data, you know, the alarm itself obviously could be one of the data, something coming in. Information is getting whatever additional details on the alarm.

Interviewer: So with respect to the alarm correlation would you say that correlation is information or knowledge?
Interviewee: Correlation I would put more as knowledge, I think. I mean, you're going to get multiple alarms and maybe based one's experience, then determine how you tie them together. We really don't have anything here that would just kind of tie everything together. I mean, we will get the alarms but it's really up to each individual to try to make sense out of it and decide is this an upstream or downstream problem, or what have

you. There really isn't any one thing that points to the user to, does the correlation for you.

Interviewer: Right, now when they're making sense of that, umm, you know, when people try to make sense of a puzzle or make sense of a math problem, or make sense of a, you know, piece of string that's tied into a know, they usually try to break it into some component pieces or types, right. So for example with the puzzle they might put all the sky together, you know, or leave that the last if they then, you know, if it's just flat blue, or something like that. Now, with respect to alarms, are there certain types that you would tell a novice, you know, look for this type or look for that type or look for this other type when you first start to do this correlation?
Interviewee: Umm, it's so hard to say, because it's such a...hodgepodge, such a variety, different types of network elements umm...I mean obviously I would say you know, if someone is seeing an incoming loss of signal on a node, you have to go upstream from that to see, you know, what's feeding that and try to follow the path until you get something that's good and you know those types of things maybe you can...

Interviewer: Something we've struck up was here, downstream would be one type.
Interviewee: Right, something like that, I mean, basically if you see, you know, something incoming to a node, you might want to be looking at...the issue is not past the node in the other direction and I mean at least you have to get to that point. So see this, look to the left.

Interviewer: So if we're thinking about these as relationships, this is very spatially related, right. Really looking at the topology of the network and left to right.
Interviewee: You got to look at the big picture.

Interviewer: What other kind of relationships do you look at?
Interviewee: Umm..

Interviewer: What happened first, like temporal relationships?
Interviewee: Well, timing obviously, yes, I mean, you know, what times the alarm came in is critical. Sometimes that will run itself to try to map the sequence of events, you know, there's obviously, very often a cause and effect. Something happens here will signal a whole bunch of alarms downstream because they...you don't want to be chasing all those, you know, you want to...so you got to see what came in first.

Interviewer: Now are there certain kinds of alarms that have...you know that they're tied to a certain component because of the properties of the component?
Interviewee: Umm..

Interviewer: Like a service pack or a particular maybe a particular span that you had problems with before, something like that, that you know has a particular behavior? If there's not, I mean, don't reach for it.
Interviewee: Yes, there's nothing that...jumping at me, I mean, we have spans in the network that are exclusively like CoreStream equipment, Lucent equipment, and

obviously the undersea plant is all Company A equipment. There are certain alarms that are the same, but then there are…the terminology may be different an alarm on the Lucent they may call it different from what Ciena may refer to what's in essence the same alarm, differently. So you have to kind of understand a different language with each NE a little bit.

Interviewer: Great. Now when you're solving these problems, can you think of any information or knowledge that would help you that you don't have right now?
Interviewee: We don't really have, you know, there's not one…one-stop shopping as a resource. I mean, it's really just based on…I mean, we have, you know, we have information we have things that we've tried to compile here and there as we've gone along based on past experiences. Experiences are so varied it's been very difficult but we spent some time early on trying to come up with our own flow chart to some…if you see this…

Interviewer: Ohh really?
Interviewee: Yes…

Interviewer: Do you still have a copy of it?
Interviewee: You know what, it never really got off the ground, once we really started to try to think this through, it just became so all encompassing…multiple different directions…

Interviewer: Was it oral or did you actually write things down?
Interviewee: Trying to put some stuff down…I may actually I may have a very early version…started to come up with.

Interviewer: That would be great.
Interviewee: But we kind of just disbanded the effort relatively quickly because it just became too overwhelming, I mean, there's just so many unique situation, I mean, this isn't…it's not a nice, neat, cookie-cutter type environment…if you see this it's always going to be boom, boom, boom.

Interviewer: Right.
Interviewee: I mean everything…you know, that there's so many unique situations as we've found going through here, we're like putting out a new fire every time. You kind of have to assess it on the fly and there maybe core things that you kind of refer to or keep in mind, but then there's those variables, that there's just so many of them. We…it's hard to put that into a flowchart.

Interviewer: OK. So let's go back to the..the…your job function. You work with database. So obviously data is data. Umm, would database schematic, what would that be?
Interviewee: Umm, something just like umm…just a relationship?

Interviewer: Yes, when you're designing a database.

Interviewee: Yes, just umm…coming up with, trying to see what…we start with what we want out of the database, you know…when you're starting from scratch, you know, go to the user…what is it we're trying to capture, how would you like to see it, and then create, you know, try to create the appropriate forms, set up a table structure, relationships.

Interviewer: Alright, so if we were talking about specifically about the trouble tickets and umm, an example would be if you wanted to reconstitute in an auto accident. Let's say a car accident instead of trouble ticket. You'd have multiple witnesses, right, with multiple versions of how they saw it and umm, each one would have a context. Now they would say it was a sunny day, it was a slippery road, whatever, right. Umm, now when you put in the trouble tickets your people probably don't have time to write up a story about what the context was.
Interviewee: Right.

Interviewer: Alright, but would you consider that like knowledge that would help in solving future trouble tickets or somewhat similar?
Interviewee: Yes. And when we've tried to umm…we've tried to categorize tickets as best we can so you can try to keep common types of tickets together if it's possible. Umm, the challenge we've always had is that the real meat and potatoes of the issue are in the notes of the ticket and it's just, you know, just text field. So, it has been…in the past it was challenging to try to…you don't want to sit there and do word searches and stuff like that, it's going to drive you crazy. But we've gotten the tickets to the point where we can categorize them into pretty…we've adde3d a lot of fields where we categorize things by, you know, the vendor, the card type, the alarm itself that came in, you know, try to do things that we can…searchable fields that we can run quick reports on…how many times has this occurred in the last X number of months. But to get into the resolution, you're ultimately going to have to get into the notes. See what was actually done in each given case, and that is just...that's just an extremely time consuming endeavor, that it never really…we grouped the tickets together, now for somebody to really figure out…to come up with sort of a knowledge base to try to look at any…was there any common trouble shooting approach that worked, in the vast majority of this group of tickets, I mean, you have to sit there and read through every single ticket and try to find those common denominators.

Interviewer: And try to build the context in your mind?
Interviewee: And try to build it up.

Phone call…

15:26
Interviewee: Go down that path, there's just this huge amount of…we're not going to do anything else if we just go through…

Interviewer: Right.
Interviewee: I think I do have some early versions.

Interviewer2: If you can send me a copy.
Interviewer: Or if you have any drawing, you know, we'll make Xerox copies or whatever.
Interviewee: OK. I think I have it..powerpoint…slide show type of deal. We didn't get very far, but we did get started. Whatever may help.

Interviewer: Great.
Interviewer2: Thank a lot.

Subject O Interview

Interviewer: Robb Klashner
Interviewer2: Sam Sabet
Interviewee: Subject O
Date: 05-24-05 – 10:40am

Interviewer: Lets start with your name, your job title and your job function.
Interviewee: OK, my name's Subject O, I'm a network operations specialist. Basically what I do is I scan for alarms, if I see alarms or somebody calls in with a problem, I try to figure out what it is and fix is it as soon as possible.

Interviewer: When you say you scan for alarms, how do you scan?
Interviewee: I personally scan all the Lucent equipment, scan the Ciena CoreDirector equipment, CoreStream, Company A NEs and the Huawei DWDM stuff. Basically all the NMS systems.

Interviewer: Do you use information technology to scan or are you scanning manually?
Interviewee: Manually.

Interviewer: What is it exactly are you looking at?
Interviewee: I look at current alarms, if they're there. Any new of unacknowledged alarms that come in, current alarms and historical alarms. Every couple of hours or so I'll look through the historical alarms, see if there's stuff that came in that I didn't catch.

Interviewer: Sam, can you close the door, I got a feeling there's going to be a lot of background noise from the air condition or whatever that is out there.

Interviewee: I'm here 12 hours a day, so that's a lot of scanning. So if I had something that would make it easier, then I'm all for it.

Interviewer: Alright, so umm, when you have a problem what's the first thing that you do when you detect an alarm as you said, that you haven't seen before?
Interviewee: First thing I'd do is to find out if that particular alarm is going to be a traffic affecting or not traffic affecting. If it's going to be traffic affecting then it's obviously going to be a much higher priority.

Interviewer: How do you know if it's traffic affecting?
Interviewee: Depending on the alarm and the equipment that I saw if it's, for example NE, I'll find out if that NE channel is carrying traffic. If it is, then we have to you know go about it differently.

2:14

Interviewer: Would you say that umm, you don't have any sense of whether it's traffic affecting or not until you've investigated or do you have some sense as you first see the alarm?
Interviewee: Depending on the alarms you'll have a good idea if it's traffic affecting or not. For example if you saw something on the CoreDirector that were path level, AIS alarms, you would say that was probably a traffic affecting issue. So you do get an intuition as to whether or not it's going to be traffic affecting or not traffic affecting.

Interviewer: And that experience how do you, you, utilize that knowledge, I mean, is there different categories of experience or knowledge that you utilize or is it just a kind of a gut feelings?
Interviewee: Well I mean we go through it so much that, you know, you start to memorize channels ok error, 192.85 that's Qwest, OK. You know, so the more experience you get, just familiarity where everything is on the network so that it helps you find things faster.

Interviewer: Can you give me some sort of a metaphor or an analogy of what the...how do you view the network how do you conceptualize it, umm, you know, some people would think about it as a living thing, other people would think about it as something that's static that they've memorized, I mean, do you have a sense of what it is?
Interviewee: Metaphor, yes...

Interviewer: I mean, like Sam likes to think about it like plumbing.
Interviewee: Plumbing, that expression I've heard.

Interviewer: If you don't use one, then that's fine.
Interviewee: No nothing comes to mind.

04:17
Interviewer: OK. Now umm, what, how could you utilize more knowledge in solving these problems? I mean, you said that you've become familiar with this, well that's just memorization, right. You just memorize what paths links to who, and so what alarms are important and not important, umm, but if there was knowledge that was easily accessible by you that you hadn't memorized yet, or couldn't memorize because of the volume of it, or whatever. What...can you speculate what kind of knowledge that would help you? Speed up your job, make it more accurate it, simplify, you know, the complexity of the network?
Interviewee: Umm, well in terms of I would say, umm, for example SDH hierarchy, if you had greater knowledge in something like that umm, what the rules are, for example, a ring switch are, something like that that can help you out. Knowledge in terms of how the equipment acts, it works on a deeper level, I would say that would make your job easier.

Interviewer: By deeper do you mean closer to the hardware?
Interviewee: Closer to the hardware, umm, not just you know the traffic passing, but like the actual rules for why things happen. Why, umm, preemptable traffic is dropped first

and then a switch occurs, rules like that actually, I would consider knowledge, would make your job more efficient.

Interviewer: OK, now speaking of rules, umm, are you familiar with alarm correlation?
Interviewee: I am from the Ciena CoreStream, has a very good alarm correlation.

Interviewer: What is you conception with respect to alarm correlation?
Interviewee: Basically that in order to make my job easier to identify the problem, it's going to eliminate all the unnecessary information. Take a whole bunch of them off that I don't need and focus on the real problem.

Interviewer: Great, now when you think about alarm correlation, what umm, I mean, you just told me a functional definition. Now if you had to give me a description of it, how it works, like umm, what you just said sounded a lot like filtering.
Interviewee: Right.

Interviewer: Alright, I mean are there any other descriptions that come to mind, if you're trying to explain it somebody that has never seen the NOC or anything like that? You know simple terms like filter, everybody understands what a filter is.
Interviewee: Right, filter, maybe a logic diagram, you know if you had A and B then C occurs then...nothing too hard, its basic math if, then, and, or.

Interviewer: OK, now what...if they still don't get it what other pieces of knowledge could you bring in, so sort of visualization? I mean, do you draw them something that would help?
Interviewee: I suppose so.

Interviewer: What would you draw?
Interviewee: Umm, correlation I would think certain graphs A and B, A AND B, shading, things like that, text book math.

Interviewer: Right, alright. Umm, let's see, how much time do we have?
Interviewer2: 11:48, you've got about 7 minutes.

Interviewer: OK, if...first of all, Subject A and Subject B both mentioned that the shifts here operate differently based on who's sick, for example today he said you had somebody with strep throat, and last night somebody had called in sick as well, I don't if it's the same person, but umm, you have different numbers of people on the floor, at any time, night, days, weekends, umm...as well as vacation things like that. How do you do your job when you're alone and then I'd like you to tell me how you do your job differently when you're working in a group.
Interviewee: Personally I do it the same, it doesn't matter how many people are here. I have my routine that I need to do. Sometimes, if there's a group I can do other things because I don't have to rely on watching basically the big board, you know. Someone else can watch the big board and I can work on something else. So if there's other people

there, we can have more of someone else to rely on. You don't have to be the only one that's going to catch something.

Interviewer: OK, now when somebody else is watching the big board, umm, do you tack that activity to expert or a novice.
Interviewee: I would say a novice. There are things that personally I have experience with, having worked in the field, where the equipment that I know that someone else might not. So, I might work, if I have other people with me, I might work on that issue and then just let them watch the board, if I have someone to fall back on.

9:53
Interviewer: Alright, so that the novice becomes your eyes and ears, so you can concentrate on what you're doing.
Interviewee: Yes some particular problem that might be a little more in depth.

Interviewer: Alright, now I want you to think of the last really complicated alarm that you solved, OK. It might have been last week, last year, when you first got here maybe, OK. Do you have something in mind?
Interviewee: The most complicated things that we usually deal with are fiber breaks.

Interviewer: Ok.
Interviewee: In part because there is a lot of correlation. Alarm correlation, so if you have a fiber break in one direction and in response to that the lasers will go into an automatic shutdown, so when...our alarms will actually be loss of signals in both directions, so what we have to do is we have to filter what the real problem is. Is the loss of signal in both directions due to automatic shutdown or is it a fiber break in both directions. So a lot of times the alarm correlation makes our job tougher to figure out the root cause.

11:08
Interviewer: Great. Now, in that category, the fiber breaks, can you think of a particular incident that was exceptionally difficult to solve because of some extraneous activity, maybe than one alarm happened, or something that made it more difficult for you to tease it apart.
Interviewee: I'm sure I could, if I thought about, a case where we had two symptoms at the same time that kind of..

Interviewer: Just think about it, and then if...if you remember one, then maybe the next time we chat you can tell us about it.
Interviewee: I could probably come up with a problem, that because we had two incidents at the same time that masked each other or something like that.

Interviewer: That was just a for example, I know when you're building software, software engineer, that's one of the problems, when you have overlaying. Umm, if you had a particular solution that you had derived, let's say you said you were an expert in a particular equipment, if you did tease apart a problem, and you discovered some new

knowledge. Umm, what would you want to do with that, to make your life easier in the future, and make other people's job easier?
Interviewee: We, my job personally, I don't have anything formal that's done, you know, I don't write anything up, but what I would do is I'd just show either my field or network ops specialists, you know, take a look at this, show something what happened, so you don't get tripped up next time and I'd show my manager. And then where it goes from there…

Interviewer: So it's generally all oral?
Interviewee: Oral and visual, come here and take a look. And e-mail, you know, I might send an e-mail on something if it's something that's really unusual, you might get an e-mail out of it.

Interviewer: Ok, now umm, going back to what you were saying before about small hardware level knowledge that you might gleam, is there things that you could get from the cable stations that would help you do a better job with alarm correlation? Is there some form of knowledge that you feel you're lacking that the people that are really familiar with the equipment out there might be able to give you?
Interviewee: I wouldn't say cable stations, I would say more labs. If there was someone at a design level that they had the information that would make my job easier. You know, not to speak down on anybody, but the cable stations guys are really just our puppets, you know, we decide what needs to be changes, we decide what the problem is, we tell them ok change this card. You know, so they're really just remote hands for us. I think so.

Interviewer: Ok, now the labs, you're talking about vendor labs?
Interviewee: Yes.

13:58
Interviewer: Alright, how're we doing on time?
Interviewer2: 2 minutes.

Interviewer: Alright, lets briefly talk about data, information and knowledge. Do you see a difference in those 3?
Interviewee: Well I saw the example in the survey, I don't know if I got the exact answer, I consider data to be the actual alarm. And, umm, information to be the fact that the person is working, the cleaning crew was working in the area. I would consider that a piece of information, something that I know. And then knowledge is something that I've gained through my experience. I guess it's…it depends on how you define the 3 words.

Interviewer: Right, so more or less in the example in the survey, you were somewhat in agreement, or tightly in agreement…
Interviewee: I think we agreed on data, I think we agreed data was the same. I think we had a different definition on information.

Interviewer: Alright, last question, with respect to network faults, umm, can you give us any kind of category, let's say you were running a class and you wanted to start out by you know giving the novices kind of a general set of categories about faults. Which you're going to then drill into in subsequent classes, you know, you're going to...category 1 we're going to do next week, and then the following week we're going to do category 2 and so on and so forth, right. Umm, so you as a teacher, what kind of categories might you come up with? For network faults.
Interviewee: Probably I would have a category for every type of equipment that we have. An amplifier failure, would be one lesson. A fiber break would be one lesson. Dribbling SDH errors would be one lesson. Every circumstance that we've come across as far as being different. Different result.

Interviewer: And would certain categories have more umm, examples?
Interviewee: Well depending on how you define them, you know, there's a lot of failures could be classified as uni-directional failures, or bi-directional failures so...you would have more instances of uni-directional failures than bi-directional failures.

Interviewer: OK great, I really appreciate your time.

Subject T Interview

Interviewee: Subject T
Interviewer: Sam Sabet
Date: 11-21-2005 15:00

Interviewer: So let me give you a little background of why I asked you to come here and maybe you can help me. So, obviously you saw the alarm correlation tool in the field and I don't if you know it's related to 2 areas. One is EMS-NMS which we have now, right, but the other area that it's related to is my Ph.D. research. So I'm doing research about alarm correlation and how you do fault diagnosis in the network and not necessarily just for the tool, but at the bigger picture of how you manage mission-critical infrastructures. Umm, and this is part of a bigger project for NJIT, which is the university I go to, where they look at the whole process not just telecommunications, but power industry, anything that's mission-critical and has to be up all the time, 24x7 availability. And how you would manage that and how you could provide computer systems that help you do that, right. So…
Interviewee: But it it's based out of the EE faculty?

Interviewer: Right, well information systems, we're more concerned about how people deal with the equipment, more that what you have to do in the software itself. You know, it's how the software can help people do their job. So having said that, the first thing we did is, you know, we went out and surveyed THE NETWORK and you filled out the survey, right?
Interviewee: I believe I did.

Interviewer: Right, thank you. You're one of the few who did, but then we introduced the tool and we were watching the NOC and how they used it. So now after everything is done, I just wanted to get some feedback from you, since I can't get to the rest of THE NETWORK anymore, we're not part of that company. It was very lucky that you came back, so now I can ask you questions. Umm, so anyway, this is an official interview for the research, so if you don't mind can you state your name and your position and you know what you've done with Company A in the past few years.
Interviewee: Subject T. Now my position is, terminal engineer I think they call it.

Interviewer: Right, C&A.
Interviewee: Terminal Engineer, I was with Company A since 1998. Doing first installation then a little bit of commissioning , then moved to the operations group of the company, the network side. Was with the network side for about 3 years, two of those years overseas working in Spain and Japan.

Interviewer: I'm sorry you worked in Japan as well, in the cable station?
Interviewee: In the 3 places. In the cable stations and the tele-exchange.

Interviewer: Ahh, cool…ok.

Interviewee: Umm. Then I worked in Site A when I came back to the States. Spent a year and a half in Site A and after the year and a half, came to the NMC. Worked at the NMC for about 3 months or 4 months. And now I am back into the construction side...with Company A. Doing once again commissioning.

Interviewer: OK. So you're in a unique position because you've done both cable station and NMC, and you've been through a whole bunch of different cable stations.
Interviewee: I'm...in THE NETWORK I've been to Spain, been to Lisbon, which is both a cable station and a Tech. And the 2 cable stations in Japan plus the Tech in Tokyo. Then the cable station Site A plus the Tech in Portland.

Interviewer: Wow.
Interviewee: I wasn't officially over there, but we were doing jobs there.

Interviewer: You've been all over the place.
Interviewee: I've been lucky and had a lot of experience because I was doing installs and some C&A and then operations, although you don't learn that much in the operations on the technical side, it's still part of the...it gives a different perspective.

Interviewer: What do you mean you don't learn a lot?
Interviewee: No because, when you're out on the...I think we were talking about it the other day, when you're out in the cable stations, they clip your wings. The NMC clips their wings.

Interviewer: How so?
Interviewee: You don't get access as much as you wanted to...

Interviewer: To play?
Interviewee: To play with certain things because they don't quite allow it. That's what I mean you don't learn a lot because they clip your wings in that sense.

Interviewer: Whereas when you went into the NMC you had more...?
Interviewee: Yes you had more...still you know you can't really play that much because there's a lot of live traffic, but at least you have more access to things and to equipment and to procedures than when you were at the cable station. But I guess that's just the nature of the network...maybe more in the case of these guys.

Interviewer: Well actually you've been to some of the other networks, is that typical most networks?
Interviewee: But see the problem is in the other networks I actually haven't finished commissioning. I always left before that, and the other time I was doing installation so I had...I was during pretty much the construction side, site acceptance and beginning of commissioning and then had to relocate they needed me on another job, so I never really got to the point of signing off a whole commissioning segment or a segment of a ring and then...

Interviewer: Have you ever been involved in any upgrade, where the network was already up and running?
Interviewee: No not at all.

Interviewer: OK. Umm...
Interviewee: So the start form the beginning very much, it's just new constructions, new projects.

Interviewer: OK. So, why do you think THE NETWORK does that anyway? That they have the NOC you know...so if I understand what you're saying when you say clipping...the NOC has more access to the systems and the information and umm...actually let me digress for one quick second here... when you were doing the survey, you noticed that we had a definition for data, versus information versus knowledge, right?
Interviewee: I don't quite remember that because I was in Site A, that's quite...a good year and a half away.

Interviewer: Yes...it's about 6 months ago or so, you're right...time flies when you're having fun.
Interviewee: OK, for some reason I thought it was...

Interviewer: OK but we differentiate between what data is and information is and what knowledge is and...if you remember the definitions said some thing sort of: Data was bit encoded stuff that comes unprocessed from the network element, information is processed to be helpful to the user, and knowledge is experience or something gained...
Interviewee: Knowing what to do with that stuff you got...

Interviewer: Right. So and do you agree with those definitions?
Interviewee: Yes.

Interviewer: They make sense?
Interviewee: Yes.

Interviewer: So then I going to ask...so do you think that in the cable stations they're knowledge is limited, or they're not given to information or...
Interviewee: I think with THE NETWORK in particular is that I don't want to sound...how can I put this...

Interviewer: Don't worry this is confidential...so you can be politically incorrect...
Interviewee: Some people think, mistakenly, that some of the guys who are in the cable stations were pretty dumb...or we don't have an education. When the contrary some of us, I mean not that we have Ph.D.'s but you know...

Interviewer: You have a lot of experience.
Interviewee: No, No we have our degrees, I'm working on my Masters, there's people doing the same stuff, so I don't want to say that we are the know-it-all because that's not

the case, but also we are not just completely idiots. Like we don't know what the hell a spectrum is…But I think part of it is some people at the NMC may think that people out there are not knowledgeable enough to maybe understand what is going on or what's happening. And I can understand that because there are some people out there who really don't have any business in the industry, but that's another completely different issue. I think that's part of it and the other one is also the NMC, because there's people in the NMC that don't have the background…I don't know if you had the chance to talk to some of those guys, I mean I like all of them, I don't bad-mouth them, but some of those guys, yes they see a light on and they know it's an alarm, but they don't understand what a bit error, bit error rate is, they don't understand what Q is…they never went to school, they never studied, they…so, I mean when they see Q, they see Q as 10 dB, but they don't know what Q is, bit error rate and the integral of the Gaussian…whatever, whatever, whatever thing…and how to correlate that that is actually a bit error rate and stuff like that. For them it's jus OK…I gotta look at 12dB. And I can understand that, from one perspective yes they're doing the job, but they don't really have the knowledge or the background behind to understand the whole issue. And maybe that's one of the reasons why the policy was to not let people that much involved into things because maybe some of these people would not be aware of what they're actually touching or doing. And maybe they say well let us restrict people of here and keep them from using stuff…

Interviewer: OK.
Interviewee: That's my perspective…

Interviewer: So they're trying to be safe and…let people, even if you do have the knowledge, they don't let you handle the equipment.
Interviewee: So that's the thing, I don't know if they actually know that you have the knowledge. But even if you do, maybe they are trying to do it safely. Even if you do, they'd rather you say well we…maybe from a perspective of responsibility, it's more difficult to…although your login would tell you who did the change, but maybe just they'd rather just have us to be support be people and the NMC we have control and we know who is doing the change the right now. It's easier to track a problem.

Interviewer: So you think it's really a control issue? Them trying to keep most of the changes or the things that effect the network at the NMC level?
Interviewee: Yes I would say 90% that's the case.

Interviewer: So that doesn't explain though…I mean I understand the control, making changes, but it doesn't explain why you don't give access to the cable station to even view the information, right? So for example one of the things we noticed when we were doing all this is that, the only person who knows if there's customer traffic on a wavelength is the NMC.
Interviewee: That's correct.

Interviewer: So when we got his alarm from the cable station, if anything goes wrong the first thing they have to do is find out if it's customer-affecting, right, because that then

raises the priority. But they don't have a list that says that, they have to call the NMC to find out. Which would seem that you'd save so much more time and be able to react much faster if this information was available to the people in the field.
Interviewee: That's true, that's correct. But even until I moved to the NMC, then I found out how it worked, how awkward it was to get that info. Because they do have that list that was created by…I don't remember who created it. And I don't know if you had the chance to see that, I don't want to bad-mouth, because actually I had this conversation with Subject A and he agreed with me. He was the only…he had control of the document, but for instance you have these they call them rings but it's wrong because it should be an APS, not really a ring, but they call it rings…that's a bad name…but, then you have to go…if you had to go and…you know ring2742 and then go to the next page and look it up in a whole bunch of actually in a graph of the APS group instead of like for instance just go and have a link and click it right on the Excel spreadsheet and it takes it automatically to the other thing. I would have thought that…I'm not really…I'm a really bad programmer, that's not my issue. But I understand that you could probably pay somebody and there's a guy at the NMC that could probably do it, to say well you know as soon as I see something on Preside or on the EMS, we have the frequency, I could probably have a program that correlates that and says OK…reads my database and says it's AT&T stm 60-something is down. I don't think it would be, for somebody who is a really good programmer, I don't think that would be that much work.

Interviewer: No you're probably right.
Interviewee: I think it would have been super easier for everybody when you're working over there, just see an alarm, instead of all of a sudden go and dig who is over here, this and that, just automatically boom comes up on the screen and says AT&T STM46 LA-TOKYO down.

Interviewer: OK.
Interviewee: 192.something something, no traffic…Different approaches, I think it would be, having all the different network management systems already into one thing like Preside, I think it would just be another step, not that much difficult to create something in that sense, because I…we didn't believe it when we were in Site A, every time like you mentioned having to call the NMC and…192.4 something on G6 went down…OK let me get back to you…we were like what do you mean let me get back to you, don't you know. Well I gotta go and check…and we were kind of making fun, like what are these guys doing over there. But then when I came over here…I find out yes let me get back to you, because I got to go and open this stupid thing and start going over every single thing until I find the ring…so, I think it's just a very…maybe that's the way it has worked for them, but I don't think it's necessarily the optimum way to do business. Maybe it worked when they have few customers, but as they are expanding more and more and more, I think they're going to have to be a point where they say, they may have to come up with something a little bit better.

Interviewer: OK, but the fact this information is only available…I mean in today's age of networks, it could just as easily be a read-only file on a network share.
Interviewee: That's true…that's what everything we ask.

Interviewer: But you don't have any insight why you think that they…it is located in the NMC?
Interviewee: I would just think that maybe since even though…lets say they were going to put some government or homeland security agency traffic or some of the stuff like that…even though nothing is in the CoreDirector, nothing is going to say homeland security circuit #1…they're going to call it something else…I really don't see why, I don't understand why they don't put it out there. But maybe that was another perspective that maybe you know, maybe a disgruntled employee or somebody may mess it up.

Interviewer: They could secure it…
Interviewee: Maybe they have some…which I don't understand it, but maybe that has something to do with it…

Interviewer: So since you've been through all these different cable stations and including the NMC and you've even seen the Site B guys at work and stuff like that, have you noticed a difference between how people do their jobs in different areas. I mean, do the Japanese cable station really have the same procedures and process that the guys in Spain do? Do they follow different things…So go ahead.
Interviewee: Well we I think…ummm…Spain was similar to Japan, and that was something I created something myself just to help me out, in that when we found that it was…we found out then we were cross-connecting we created our own spreadsheet and not like the ones that they had…we kind of like did a flowchart in which it was you know you had a NE and then you know and arrow, then the first ODF, then second ODF arrow, something, CoreDirector, wavelength…something.

Interviewer: So you tried to build a model of what the network looks like for you?
Interviewee: Exactly. In my station, the rest of the stuff it was just way too big to handle, but at least in my stations…see how NEs were going, what were they connected, or my Lucent where it was connected. And I showed that to the guys in Japan, and the guys in Japan actually took it to the next level because they actually put in there a whole bunch of information on trace and cross-connection and stuff and they if you look at the stuff in Japan, they actually have like for…I think they went as far as having one per customer so they, they don't quite rely on the NMC as much as maybe some other stations, because they, every time they cross connected stuff they may not know maybe who the customer is, but at least they know there's some traffic and…

Interviewer: They made their own database.
Interviewee: Exactly, so they have done that in Japan and I think that's a difference. Site A we never got to do it because Site A was a mess. And we arrived over there, you didn't really know…every time you disconnected a fiber you were praying you were not going to be actually bringing down a customer. So they told us…I mean I wanted to do something like that, but first of all it has all the wavelengths all the fiber pairs connecting Japan and the Pacific, and LA and it was too much work to do it just like…well I guess this fiber, because I really wanted to do like ok this fiber if you disconnect it, this is really the fiber that is going over there…but there was so many fibers already connected.

Interviewer: You'd have to use trial and error?
Interviewee: And they wouldn't let me trial and error and by just assuming, the assumption would be certain percentage of fibers are already wrong, that I don't think that making the document would be worth it, because 80% of those fibers could not be physically umm, compared or proved that that was, the connection was actually physically done to where the document was. So I used...didn't think it was much of an issue. There wasn't that much of a positive thing for the station to create something that at the end 80% you don't know if this actually real or not. So that's why we...I never feel like that, but I think that there is definitely difference in different station on how they approach the documentation. Some people they just rely on what the NMC has and they just call them.

Interviewer: OK, so you think the guys in Japan are more self-sufficient, they work more in groups together or...
Interviewee: I think the way the Japanese way of doing things is very methodic. And maybe I'm going to sound very cultural in this sense, but I think it's just the culture that...that drives them to do things in certain ways, the way they're used to do things is with a lot of documentation with a lot of processes to be implemented while some other cultures are more like, well you know...we have an idea...

Interviewer: It'll work...
Interviewee: Exactly, there guys are more like yeah yeah...

Interviewer: OK.
Interviewee: I think it's part of that and my experience when I went to Japan since I had already been in Spain, I also mentioned that for the sake of their station I think they should keep what not me but some of the other guys that had worked with me, spend time in Japan, like Subject Q, I don't know if you had a chance to meet him at the NMC. He's done installation testing, he was over there and we kind of tell maybe you want to keep this on your own just because, maybe also that time the NMC wasn't that much of a mature entity. So I don't know because I wasn't here, but I think they also had their problems coming on line and maybe they didn't have their process completely set up at the beginning and that plus as I mentioned before the fact that some of the guys over there, it's not that they're not capable maybe, but they just don't have the knowledge or the experience it was more difficult at that time. Now they are more experienced, at least they know what to look for and stuff so it's different, but back some of those guys were completely maybe clueless as to what to look for or what was the nature of the job. So I have to give that to the NMC.

Interviewer: But umm, so...actually when you did join the NMC, did they give some sort of...this is our standard operating procedures, any documented this is how we do business?
Interviewee: Well they showed me all the information that they had on those drives which I wasn't aware they were there. Or at least I could see a whole bunch of stuff and...kind of you know this is you know you check the stuff, of course the hierarchical

process goes this way, you gotta call if you see this in this segment you gotta call whoever we are leasing this segment, Viatel or whoever. And then you call this guys, so in a sense they do have that process now implemented as to who to call and find who is the owner of certain fiber pairs or umm segments or stuff like that, and check for traffic, well check for whether the thing has traffic or not…the only problem that I saw and I don't know if this is umm because of politics is that they do have a divide between what is called the network side and the service side. So even when you find that there is a fault you kind like still gotta go through the service guy to make sure there is traffic and the service guy calls the customer…I can understand from a certain perspective because if you are troubleshooting something you don't want to be bothered to talk to the customer, but at the same time having such a big divide I don't think is good because I have always believed even in this company too, that the more that you know the better it is for the company. So if I can go and install or test or commission or do whatever, the better it is for me, but the better it is for everybody cause I can give you a hand if you need it. But if I'm not able to give you hand and we are somewhere 3000 miles from here then you're on your own or you have to call people over here to give you support. So that's a different perspective.

Interviewer: So, I mean, one thing that was my impressions and you can agree or set me straight is that the documented processes in the NOC…so they have a rigid ISO process that they follow, that they were supposed to follow and that was documented, right. And I got the impression that when you actually go look at what's happening in the NOC, it's more ad hoc than that, it's not exactly what's documented. Umm…
Interviewee: Somehow yes, I would say that's right.

Interviewer: And I was trying to understand how that came about. Did that evolve, did they find that it's better process what they're doing now, that's more efficient, or is it the fact that they don't think that they can trust the guys in the field…I don't know?
Interviewee: I think the ad hoc process more like people just doing it, but I don't think it's something that they actually want, they want to migrate more completely follow the process that's why they have all these tons of trouble tickets and NARs. Sometimes it's actually you know kind of like do you want me to solve the problem, or write the..send a flash. What is more important, for me to establish traffic or to send a flash so the big wigs over here find out that we lost traffic. So I think they want…from a certain perspective they want to just follow the thing, but people are people are kind of like, well before I open a trouble ticket which maybe is what I should be doing, or flashing stuff, let me see what the hell is wrong with his thing and trying to figure out and make some phone calls. So I think its mostly people just going the wrong ways, not necessarily the policy of the NMC, or was the policy of the NMC.

Interviewer: OK. So…The one thing that wanted to understand a little bit more is how the cable stations fit in with the NOC. Do the cable stations talk to each other at all, I mean, when people find out about problems…and they learn from experience, does this experience go across to other stations or do they only just tell the NOC?
Interviewee: I think…

Interviewer: You know what I mean, like you for example are one of the most experienced guys out in the field, right, because you've done C&A you've done all this different stuff. So you've got a lot of stuff that you've learned over the years that if you were in lets say Site A station for a long time, definitely other stations can benefit from this experience, right.
Interviewee: Yes but I think it only goes through…I think there's benefits, but only when the people…we always talk to each other, every day to the guys in Japan and LA, because we're connected to those guys. So yes between Japan and LA yes the information would be distributed, but unless the NMC would distribute the information to the European sites, I don't think it would get over there…well in my case maybe a little bit just because I know people in Europe, so I once in a while talk to the guys in London. Some guys who used to do C&A and I worked with them before, but that's more because of friendliness…because we're friends, not because the process. So it's ohh by the way, how u doing, what happened and some beers, ohh by the way this thing…you know something like that. But I don't that the NMC does it.

Interviewer: Well you were in the NMC, do they?
Interviewee: Ahh I don't think so, I think it just stays with the segment or ring. Part of the network, that thing will stay there. I mean the people at the NMC knows it and then when they see it they may relate to that and say ohh yeah I saw that happen in Germany, but I don't see people going and distribute that kind of information to the rest of the network. At least I didn't see it. But like I said, I don't know…we do it mostly on the basis of…since we know the people in Japan and we work with them or we…I think it's part the friendship thing, like boom boom boom, you know we're working with you, you get a copy of the e-mail, so I don't know if…it's not really that in Site A we had the policy, it just came across because you're talking to them.

Interviewer: Right it develops over time.
Interviewee: Exactly.

Interviewer: Umm…So I mean to…and the reason I ask all these question by the way is because any system that you put in to help fault diagnosis has to…you first have to understand how people do their job to be able to…it's not good enough…
Interviewee: To evaluate the network. It's not only use alarms comes in…

Interviewer: Right exactly you have to know how people think before you can help them. So…I mean do you think that the organization, would the network be set up in such a way that you really have to go back to the NOC to be able to solve a problem. If we were to for example give them a system that allowed the cable stations to talk to each other. Do you think they would actually talk to each other or they would still go to the NOC and the NOC would then…
Interviewee: That depends…I think that goes back to Site A for instance, because of the experience of the guys in Site A, Hoyt, myself and Subject Q was over there a while, but then Lay tem, used to do commissioning back in the days…there were a lot of times when the NMC actually would call us. So, you know, we have this thing and then we kind of…well do this, do that…but in some other stations in which the experience wasn't

there, they would just say well you are the NMC you tell me. I don't know...and for instance in the case of Japan, the Japanese guys have a lot of experience, but in certain times, certain ways, because of the hierarchical process they may go and say I know how to do it, but you are supposed to tell me. Because the hierarchical process say that you are the boss and the direction comes from you not from me, even though I know how to solve the problem, I kind of like I got to wait for you to tell me. Because...but that's just the way Japan works, you know, you got to follow the lead...it comes from here, until it comes from there then I go and do it, even though I already know what to do.

28:40
Interviewer: But the other sites are not like that?
Interviewee: I think a lot of the sites are not like, like I mentioned before, there are some people out there who don't have that much experience.

Interviewer: So actually, I mean, what you mentioned is pretty interesting. When you are in Site A, the NMC would call and would try to suck information or knowledge out of you, right? Basically try and learn from your experience.
Interviewee: Yes.

Interviewer: Did you notice that taper off as they gained more experience. They stopped calling you?
Interviewee: A little bit yeah, a little bit. But, certain things yes, but once again, if the situation changes and something that the guy at the NMC had never seen before, then once again they would make the phone call.

Interviewer: OK.
Interviewee: and also I think one of the issues too was that there was a big misunderstanding on how to troubleshoot because a lot of times, yes, people look at the segment, especially I guess on the preside, you see the big segment between Japan and the states all red, and people automatically ohh call Site A, since there's an alarm. But you go and say yes, but the alarm is coming from Santa Clara, they lost the SDH input and it just triggers over here, people didn't understood how to follow the downstream alarms and find out where the problem was coming from. It was automatically call Site A because the NEs are there and the segments we have yes will light up, but it's not us, it's coming from there. It took us a little bit and sometimes a couple of tough phone calls telling people it's not us why do you want me to put a stupid umm test set over here or what's it called...a loop-back if you're seeing that it's a loss of SDH, in Santa Clara and that's why we're losing SDH over here.

Interviewer: They basically didn't understand how the network works?
Interviewee: Some people did not, some people yes, but some people no.

Interviewer: Right...and umm...well actually that's another good segue, you're full of information...but no, I mean did you that maybe people...depending on their experience and stuff, they went about troubleshooting in different ways...like for example yourself when you think about troubleshooting do you think of the network as a bunch of

relationships, a bunch of connections, that you trace through, or do you think of it as a model, like some guys for example, personally I think of it as plumbing…if you follow the water, you'll find where the problem is, some people told use that they think of it as a living beast, it's like a human being or whatever, if you follow it to the heart or wherever to find out where the real problems are. Umm…but then some other people they don't do that. Did you feel that was the case or?
Interviewee: Well with some people yes because as I mentioned before some people will not understand what the difference between the line and the SDH is. So it's just because of that of course you're gonna have trouble understanding what is happening with the network, you see lights. So…umm…on the other hand you also have people with a lot of experience like I don't remember this one thing with the NEs, I don't recall right now but there is something which, for some reason I think it's happened a couple of time at the NMC, you don't get any alarms from the transmitter…there's no symptoms at all that the transmitter is failing, you get a whole bunch of different alarms at your receiver side and I remember that happened to me and Hoyt wasn't with me, he took the day off and we went over there and we said well according to everything, that looks like we're going to go and replace the receiver. First of all that's the way the troubleshooting is supposed to be done, second all the alarms, all the indications seemed to be this way. We changed it and nothing happened, then I remember he came in and just his experience and said ohh yeah I've seen that before commissioning whatever system, that's the transmitter. How do you know, there's no indication at all? Well you know because when this alarm comes in and this and that…and yes we changed the transmitter pack and it solved the problem. But that was only because he had seen the problem before and he had this experience. It happened to him, but for us it was like well we did what we were supposed to do according to our troubleshooting procedure of check this, check that X Y and Z and therefore do this, and he only knew this thing because experience gave you that, hed seen this before.

Interviewer: Right, so it would be valuable to try and capture that experience so if Hoyt had took a month off, you wouldn't be stuck with a dead…
Interviewee: Well I mean we eventually would have changed the transmitter pack too, when we see nothing's happening but…we wouldn't have to go and chase the receiver had we know automatically that that was the problem.

Interviewer: Right. Well hopefully there's a way to help people gain that experience without having to make as many mistakes, right. And that was the whole point of this alarm correlation tool. Umm, so remind me, did you say that you did work with the alarm correlation tool?
Interviewee: I did I did yes. But like I told you I actually didn't troubleshoot with it. I did my troubleshooting and after I finished, I ran that and I saw the results. Not that I didn't trust you work…

Interviewer: But you didn't trust the work…OK and the results confirmed your troubleshooting?
Interviewee: Yes.

Interviewer: They were the same results?
Interviewee: Yes.

Interviewer: Do you know by any chance how many times you ran it, just out of curiosity?
Interviewee: I probably did it between 5 to 10 times, no more than 10 for sure.

Interviewer: And all the times they were the way you would have expected it?
Interviewee: Yes.

Interviewer: So if there was any time that it didn't do what you wanted it to, lets say it came up with the wrong result, do you think that you would have gone in there and tried to make it work, for example, lets say this was a rule-based or model-based or whatever system that allowed you to input your knowledge in there…so like this transmitter problem for example, umm, obviously if you followed the letter of the law, a normal program would say replace the receiver, right because it goes to where the alarms are just like you would. But if you had experience and you know it's not the receiver, do you think that you would at any point try and change the tool so that it does that and so that the next guy who runs it now has the benefit of your experience?
Interviewee: Well I think I would communicate that, I don't think I would have gone and actually changed the thing, but I think I would communicate with the people who own the tool or the program or whatever.

Interviewer: OK, but you wouldn't…even if we gave you a way to do that, you wouldn't want to do it yourself, is that what you're saying?
Interviewee: No, but that's I think…you see I…all my programming I do it just because I have to, I really don't like it…

Interviewer: Oh no it wouldn't be programming, it would obviously be a nice user interface that you would go in, you wouldn't have to go in there and write C code…don't get me wrong.
Interviewee: Ohh OK OK…because I mean…that's another problem. I mean right now I am having nightmare because I got to do a thing for my class, and I'm suffering pain doing an actual wireless network simulation. So...

Interviewer: Where do you go to school by the way?
Interviewee: I'm doing the distance learning with Columbia university. I'm trying to get a Masters over there…telecomm…well I can do either wireless communication or telecommunication…I think I'm going to go with telecomm.

Interviewer: Right it fits your are…
Interviewee: It fits everything.

Interviewer: Right…so…
Interviewee: Yeah but I hate that's why I just mentioned because I hate C.

Interviewer: No by no means would we ask you to write programs, but I mean the idea is that as you learn you…
Interviewee: I mean if it's something easy, if it's something that you just go over there and boom boom boom, press a couple of thing, then yeah I would yeah.

36:30
Interviewer: Alright, you would try so that…I mean some people would say no we don't want to do that because your worried that you're making a mistake or you're worried that this is knowledge that I gained over time, why do I want to you know…why do I want to give someone an unfair advantage…
Interviewee: That a very narrow minded way…at least I don't…

Interviewer: OK, I never thought you would, you know like I said it's hard to find how people…what people would be willing to put in this tool, and what they wouldn't…otherwise a lot of people would say no, it's supposed to come from you working, I shouldn't have to do anything. If there's a problem with it, I'm going to write an MR, but I'm not going to put the data myself, it shouldn't be my job.
Interviewee: Well, you can look at it form the political point of view…that you are paying for that tool, then I can understand saying well…I'm letting you know that this is wrong, but since we're paying you for it…I mean from that political perspective I can understand doing it, because it's like well that's what why we pay X amount of money to actually come up with this thing, so I'm not going to go and fix it for you. I tell you what's wrong and you go and fix it. So from a political perspective I can understand that attitude. From that contractor political, you know, vendor thing. But I'm just looking at more into if we are working in the same company, what the hell…I mean…

Interviewer: Right, and…so, but I mean this goes back to the relationship between the NOC and cable stations. Now if this information were then to be allowed to be disseminated to the cable stations, for instance the tool was originally design so that as you gained more experience whether you were in cable station A or cable station B or in the NOC, everyone would gain this knowledge. So you enter it and then the next guy who has the problem can look it up and run it and he sees the answer that you said in Site A and he's in Japan or whatever…So, but I don't think…do you think that that's how if you were top allow that to happen in THE NETWORK, you think that they would actually go through that process of sharing that knowledge across the cable stations?
Interviewee: Yeah probably, but like I said the thing would be localized. The people in the Pacific sharing that knowledge in the Pacific and the people in England and Site B with their other things. That's my perspective. It would be just shared within these 4 node over here and these 4 nodes over here. Unless something more implemented from the NMC would somehow like completely disseminate information.

39:19
Interviewer: Right, so it really has to be the NMC that does the bridging across them.
Interviewee: Well I think…but what the thing is is that since you don't know that many…when you meet people it's easier to talk but since we never met the guys in Amsterdam, who knows who the hell they are, so to talk to them is kind of like, you

know and they don't know who the hell you are...so for you to come and say something, they may, who knows they may go and say yeah whatever you say.

Interviewer: Right, we don't trust you.
Interviewee: Exactly, we don't trust you whatever, so I think from that perspective, when you know people it's easier because then the other guy knows how you work or what you do and it's a different understanding between the cable stations and people. But when you don't know the guys it's difficult, you're nothing except for a voice coming out saying hey by the way I'm from Site A and this thing happened...well let me make a note, but...

Interviewer: So, I mean, in the end, and that's sort of the structure of the network. I mean it would be a different story, obviously the network is geographically dispersed, it's global so you're never going to have people in the same building all the time. But I also get the impression they don't try to facilitate people working together, getting to know each other, getting to talk or work in groups or whatever...it's more, I mean, as you said the guy in the UK never talks to the guy in Site A, never talks to the guy in Japan. Umm, which maybe because they don't need to because they never affect each other.
Interviewee: I think that's the case. Very very seldom do you have something that is going to be theoretically...

Interviewer: Going through the whole network?
Interviewee: Exactly.

Interviewer: And if there are anything that needs to be shared or if there is information that can help one site, as you said the NOC is the one that can you know...you send it to the NOC and then the NOC will...
Interviewee: will have to disseminate it...

Interviewer: If they want to. And that's the question, do they really ever want to?
Interviewee: I think the NOC also has the things...is shifting people, also that is a big problem because, some guys working the nights and by 7 in the morning, 8 in the morning the only thing you want to do is go home. So you kind of like, hey by the way 3 items and just let me go because I can't take it so...and the way the schedule works maybe if you're working one end of the week you don't see the people working on the other end of the week, so...

Interviewer: So you never actually get to...even inside the NOC.
Interviewee: Even inside the NOC exactly, and by the time you come back you have a list of like 400 e-mails, that may have a lot of information and is important, but out those 400 e-mails...I mean if you're going to read 400 e-mails it's going to take you hale a day to go over every single thing, so you maybe you go and say well you know that happened Friday, today is Tuesday, what the hell, from Friday to Sunday delete.

Interviewer: Wow.

Interviewee: I mean it could happen, I'm not saying that necessarily everybody does it, but it could happen. You know because you are more interested, especially if ohh we have a problem right now, here happening in this part, in France or something. Well I know there's 500 e-mails to read, but I have something to do over here so, whatever, maybe you leave 300 or 200 of them, and the next day you leave other ones, and next time you know, you say well it's been too late. Maybe there was something important in there, but…
43:00
Interviewer: So actually that's a good point. Did you get the impression that in the cable stations as opposed to the NOC and different cable stations that people work more in groups than they do in an individual basis? So like you said in the NOC, because of the way your shifts are you hardly work with anyone else, the next day or whatever. But in the cable stations you're usually all there at the same time, right. So does that tend to make them work better in groups than they do as…or does each one go do their own thing and then you know if they have problem they call someone else in, or..
Interviewee: Well I think it depends on how you're understanding like…I mean we all, like, when we were in Site A we kind of like did our own, but it was that we knew that for whatever reasons since I had more, for instance, I had more experience than anybody else over there in installation, if there was to be run a cable, I was running over the cable. Because I know how to stitch, and so it's like…so kind of like we still help each other, and hey I need some help with this and that…but we kind of like ohh let me…everybody would get a task and said let me just get this one on my own, and at least then you do that and yes if you get in trouble you can probably say, hey by the way I need some help or what happened over here. But it wasn't because we were not working as a team, it was just mostly like well you know you're good at this, or I want to do this..ok go and do that one.

Interviewer: You specialized in something?
Interviewee: Kind of, but else I mean we were actually as a team working, it's just that everybody was doing different tasks because when there was a problem everybody would get together..

Interviewer: So when there was a problem you'd get together and brainstorm or something?
Interviewee: Yeah exactly. You want to have somebody, or if I can from things of like founding out a problem with a NE to a drawing a cable, if I can't run the cable on my own, hey I need some help you guys gotta come and help. So it was a…

Interviewer: And that's the same across all the cable stations? Or did you find that some were more likely to…
Interviewee: Well my experience was the same for Japan and Site A. For Spain it was a little different just because the guys were brand new, so I don't they had that much experience. So maybe I was doing more of the transmission stuff and they were doing more of the environmental things. But that was maybe because of experience, maybe they just didn't want to get that involved into. Some people are different, some people want to jump in there and say well I don't know so let me just jump in there and ask

questions and see what I can learn. But some other people have a different approach, saying I'd better just, since I don't have the experience, let me stay away and later little by little or later I'll get into it.

Interviewer: So less experience, you say you found that in the areas where they were less experience they tended not to work together, you didn't tend to brainstorm as much or work as a group, they relied on the experienced person to do most of the work? The difficult stuff.
Interviewee: Yes. The non-experienced of some people.

Interviewer: OK, so when the tool was actually in the NMC, were you the only one who used it, or did you see the others trying to play with it?
Interviewee: Maybe Subject Q used it, I'm not sure if he did and I don't know who else to be honest with you, maybe Tom Smith might have. It wasn't broadcast, that it was there.

Interviewer: It wasn't broadcast that it was there, OK?
Interviewee: Not as far as I know, cause I found it was there because I was talking to Subject A and we were at EMS and I said what is this thing, ohh that's Sam Sabet's tool, this and that. And he's the one who showed me you gotta do this, and I said ahh OK cool. Yeah you know you can use it this and that, it's for his Ph.D. That's where I used it and I think I showed it, or somebody else, maybe Kevin asked me what is this thing? Ohh that's Sam Sabet's thing for his Ph.D. and stuff. So that's why maybe Kevin used it too. And as I said Tom Smith, is another sharp guy over there, he might have used. But the rest of the guys, I really have no idea. They used, or whether they even knew what the thing was. I never saw an e-mail myself, that doesn't mean that it wasn't sent out, maybe I just didn't get it, or I deleted it.

Interviewer: Friday to Sunday, delete?
Interviewee: I just don't remember myself it being broadcasted that the tool was available.

Interviewer: OK.
Interviewee: That doesn't mean that it wasn't.

Interviewer: Well no, I mean one of the things I am trying to understand is how much use it got and if it didn't what the reasons behind what were? You know, was it not user friendly enough, was it not the right idea, was it that people did not trust it or like you said, you know you went and did your troubleshooting and then just used to verify, just in case it was wrong you didn't want to rely on it. Which is OK, I mean, after all it's a prototype, right. But the more important reason is would it over time have grown and people started using it or is it something that you know, they'd much rather use their own experience or talk to someone instead of looking at.
Interviewee: I would think that some of the guys out there would. If by trial and error or by umm…by using it throughout a period time, would prove that X percentage of time is

good, I think people would definitely use it. That's my perspective, that people in the NMC would have gone and used it.

Interviewer: Ok, and in terms of, you think at any point they would have given it to the rest of the cable stations and used it to do this knowledge sharing at all?
Interviewee: That I don't know.

Interviewer: Well you were sure about the other one?
Interviewee: Because this one, I mean I can see some of the guys that still have problems figuring out certain things on transmission that would been very easy. If you know that that thing is 99% accurate, some of the guys that may have trouble as to what is what kind of stuff are we getting over here, well hmmm...ohh is...you gotta change this pack, instead of kind of like, do I need to change the FEC Decoder or you know...like they try to figure out but are still not sure, I think that that kind of people just to get the job the done it would help them definitely. As the cable station I'm not that sure if...what I meant is that I'm not sure that the NMC would disseminate that to the cable stations. Not that the people at the cable station would not would not use it. If the NMC would disseminate it I...

Interviewer: So you must have a reason why you think that they wouldn't disseminate it?
Interviewee: It's just because they're kind like keeping everything under control, just because of that. Just because of that history keeping everything in-house, just because of that.

Interviewer: Right, so even if it did prove to be working fine, there's a chance that they wouldn't have wanted to share that with the cable stations.
Interviewee: Well you know cause the perspective might be, well we have it at the NMC and it works right, so the guy at the NMC knows what the problem is and calls the people at the station and tells them what to do.

Interviewer: Right.
Interviewee: You know from that perspective they go and say there's no need for the people at the cable station to have it, because the guy's gonna call you and say you need to go and replace the laser or whatever.

Interviewer: Alright, great.
Interviewee: But that's just...

Interviewer: So I have another question just for my education here, and it's related to the NMC since you were there. I am finding the NMC, it's a very strange setup. I've been here since they started the network obviously when Subject D was in charge of the NMC and then Subject A took over and then Subject D moved on to Site B, which first of all I found interesting and I'm not sure what happened there, but anyway. But I guess Subject D was the one who originally set up the structure of the NMC and then Subject A took it over and grew it, right? Umm, but it's weird because the NOC belonged to Subject R, who's a director, then you had the director...Subject S for Pacific and the other guy for

Europe. But the real center of control is still the NOC, you know what I mean, so…it's sort of weird because you have 3 different ways to go up the ladder for management, but in terms of operations you only have one way up, so really Subject R is pretty much in charge of the network, is that…am I getting the right impression here?
Interviewee: Yes I think so, I think the other directors are mostly administration and maybe I don't know, the generator is defective, we need to open a PO so the signature power for fixing that generator in Japan belongs to the director for the Pacific area and I don't know the…the fuel tank has to be cleaned in England, therefore the signature has to come from the director in the UK or in Europe. But transmission wise, from that perspective yeah it would be one director, although personally also I think transmission wise the decisions are made form my perspective from Subject A.

Interviewer: So Subject A is the one who really pulls the strings?
Interviewee: I mean I think so. I mean Subject A is a sharp guy and he knows what he's doing and I think he's…I don't know I…from the transmission perspective point of view I don't think it would make a difference if you have a director or not. From the other political administration kind of thing, you may need that figure out there to deal with certain kinds of things and to do certain kinds of stuff. And maybe umm, what I'm saying also is a little bit blinded or narrow-minded in certain ways because I don't know what other abilities that position requires to deal with and cross. Because I was only at this level and I don't see what maybe this level is actually doing. And maybe what I'm saying is kind of rough, and I don't know. But from this perspective from the perspective of out here, I mean Subject A runs the thing and…

Interviewer: And that's it?
Interviewee: And that's it exactly.

Interviewer: OK, I mean because what I'm trying to understand is as you said you know if we were to…I mean it comes down to this, if we were to provide a tool that allowed people to share knowledge across the network and if we were to provided it but then the NOC says well no I'm going to keep it in-house and I won't disseminate it to the cable stations. First of all that defeats the purpose of knowledge sharing because that's just like have one central database for the NOC and none of the other cable stations get to use it. But more importantly, why doesn't that happen? You could say if I'm the big boss and I put my foot down and say I don't what you guys want in the NOC, the deal is it's going to go all the cable stations and that's how it's going to work. Well obviously the NOC now has to disseminate it, so what I'm trying to understand is what…who set up this process that says that the cable stations are not going to get this. Who says it's only the NOC that gets this stuff and decides what should or should not go to the cable stations?
Interviewee: I think that just developed over time. I don't think there's…because when you talk to umm, actually one of the things that changed is that umm, file with the frequencies and traffic now is finally in a share drive and you can get it from the stations.

Interviewer: So they finally shared it?
Interviewee: Exactly, now it's finally out there. I think it's just somehow this thing was developed in this way as time goes by and people are becoming more proficient in their

positions things are finally a little bit moving out. More than before. They still have the restrictions of not being able to shut down a laser from Site A for whatever the reasons they have. But I think at least the fact that they posted the thing on a share, where people in Japan or Site A can look at it, I think that's a start. But I don't know who set it up that way, I have no idea. But as I mentioned before I think it was mainly just because maybe some people committed some mistakes at the beginning of the network, made some mistakes and maybe from one perspective were really kind of like stupid mistakes from a sense of somebody looking at it with experience. But from a non-experienced people, well you know how do you know…it's an honest mistake, not…but maybe because of that kind of stuff, just at the beginning it was more like, well we want to avoid all these errors and mistakes, shortage or outages or…lets just keep it tight over here..

Interviewer: Right so they tried to keep the control?
Interviewee: I think maybe it was more that way and it just over time it kept going that and maybe changing a little bit and as time goes by maybe it's going to change but I think it just was something that just happened. Because like I said, I just cannot imagine how the thing was when they first started 5 years ago, 4 years ago and some of these guys, I mean you have people that came up from like mechanical shops, from like body shops, from out of high school, so it's not like you had 10 years or 5 years experience or 20 years experience. I'm not saying you have to have a degree, but some people that have a lot of experience just were wise and said I have 20 years doing telecom, yeah you don't need a degree you already know what it's all about and what you have done. But some fo the guys were really young and may not have that background, well you come out of there, and if you come out of high school you may not even know you know what is AC what is DC what is the return…and they tell you OK now you got go and troubleshoot this this thing, so it's kind of like well OK…what do I do?

Interviewer: But I got the impression that most of the cable station…or a lot of the cable station guys were actually a lot more experienced than the NMC. I mean, because a lot of them were C&A guys, Subject P in The UK, you have umm, you have a bunch of guys…in Site A there were a bunch of guys so I got the impression that…when I look at the guys in the NMC, there's maybe one or two who came out of the C&A world. So I got the impression that actually the cable station guys when things first started, they had a lot more knowledge.
Interviewee: Yes but some of these guys didn't come on till later on. Like we in the Pacific we didn't come till like the NMC was already set up and had traffic on the European side for 2 years or a year and a half at least. So we like I said, we didn't get to see what the NMC had to go through at the beginning, I don't know when Subject P and some of the people joined operation on the European side. But what I'm going to is at that moment, I don't know, especially England, when the thing first came to life, and maybe it goes the same way for the guys ate the NMC. They don't who, they don't know that the guy on the other end was Subject P who had 5 years of doing commissioning and experience in FLAG and all these other projects. For the guy at the NMC it's a guy…a brit called Subject P and well like, my ass is on the line and I gotta do this thing, you know what is the deal. Because they didn't know where we were coming from either,

they was…there was never a presentation, ohh by the way they guy who is in Spain he has you know…when you're talking to somebody over there a voice and you don't know.
Interviewer: You don't know what there experience is
Interviewee: Exactly…and if these were near you, I can understand that they were nervous, there's a lot of stuff I don't understand. Or what happened at that moment, I can just imagine that some of the reason they have this or things developed this way is because something happened at that time or…that created this kind of…policy or way of doing things or methodology for broaching things. It's just interesting, I don't know what would have happened…it's definitely I think…I think experience is definitely that makes a big difference when you talk to people and it shows especially when you're troubleshooting something that is live and you need to fix it quick. And I guess if it's tough for somebody who even has experience sometimes, for somebody who doesn't have it it's even more difficult because it like, you know, overwhelmed as to…

Interviewer: Right, and the idea is how do you help that guy without experience to get through the job or gain as much experience faster. I mean the intent of adding any of these tools it not to eliminate the human being, right, because you always need the smarts behind them, but the idea is…lets say it takes you two years to learn how to do things, maybe by adding tools to your work you can do it in 6 months or 5 months because you don't have to go through 20 different mistakes before you learn. You can only do the 1st mistake and then the tool helps you out a lot more.
Interviewee: Right and it saves the company money too because you are more in sync with what you're supposed to do in less time.

Interviewer: But it's hard to do that if the knowledge is not being shared. It's harder…you can't tell the cable stations guys you have to become experienced but we're not going to let you gain that experience. It's a double edged sword. So that was the whole point in this, is to see how willing people would be to share that knowledge…
Interviewee: I think it's…I don't know it's a weird thing because, like for instance they do want you to know and to be experienced. But for instance when they post the job, now they don't require a degree anymore, for my kind of position, they say you can pretty much just…so it's kind of like a double edged sword, you know, like they do look for somebody who may have experience or want something, but at the same time maybe for the economics times that we're living they may go and say well we're not going to pay this amount of mine, we get somebody at this level or this paycheck…I don't know.

Interviewer: I guess…correct me if I'm wrong, I think the philosophy behind that is if we keep 4 or gurus or 4 really really smart guys in the NOC, then in the cable stations and the rest of the NMC we can put low-level guys who don't have experience and they're just there to get the information and come back ask question form the 4 experts or whatever.
Interviewee: Could be that way yes. I mean from one perspective maybe is that exactly it's just that if you're at the cable stations, if you have all the knowledge at the NMC the only thing you need is somebody who is going to go and change the pack and make sure you clean the fibers properly. And that's it because with software you can initiate almost pretty much everything, in the majority of the systems except for a particular one you

may need a CIT to do something different that it does not allow you to do. But maybe that's what they're looking at it and saying in the long run it would save us money because if there's a turnaround you can get people who don't necessarily be that specialized in knowledge and therefore the money paid is less. I don't know, that might be one of the reasons, I don't if they are...if that would be something passing through their minds, I'm just saying.

Interviewer: Consciously or not
Interviewee: Exactly that that could be one of the things. Because from that perspective if the NMC takes everything you are only sitting over there and ok go and change the pack, which one, I change it clean it and it looks good. From that perspective it makes the job very boring that's what it's supposed to be.

63:03
Interviewer: Right, and basically at some point you're already dooming yourself, right. Because you're making sure that the job is boring enough that you're not going to get good enough people. Because a person who's good doesn't want to just be a circuit pack remover.
Interviewee: Exactly.

Interviewer: And the one who stays around just to remove circuit packs is just there for pay me my paycheck today.
Interviewee: Doesn't give you anything extra. But maybe at the same time maybe that's just the nature of the position, because from one perspective even if you put a lot of effort you know that unless the Manager retires or gets bumped out, you're not going anywhere unless you're working in a bug network, big enough that you could somehow make a lateral move or some other move to another department. But if it's not the case, you kind of like I got to go and look somewhere else.

Interviewer: That's interesting. So your only way up is actually to head towards the NMC, right? Do they consider moving from the cable station to the NMC a promotion? Or...
Interviewee: I don't think so.

APPENDIX D

INTERVIEW AND CASE STUDY RESULTS

Interview Results:

During the case study 17 network personnel were interviewed. Of these 17, 5 were UK cable station personnel, 3 were US cable station personnel, 1 was IS implementation and deployment, and 8 were Network Operations Center personnel.

When the KM tool was introduced in the form of the Alarm Correlation Tool (ACT), as part of the case study, the result unfortunately, was that it was hardly used. It is difficult blame that on ease of use of the tool, because from what was seen in the field site (via the tool's logs etc.) many of the operators never even clicked on the tool (to see if the interface was easy to use). The tool itself proved to work well. During its operation it was able to solve multiple network faults correctly. At one point the tool defined the root cause five minutes before the operators were able to independently verify the root cause manually. As a technical instrument the ACT proved to be an effective addition, however, users were reluctant to use it and enter their knowledge into it.

Also during the interviewing process some things that came to the surface were facts that implied that the organizational structure very much prohibited knowledge sharing, forcing the locus of control to be a central management center and explicitly ensuring that field personnel had little access to needed information and acquired knowledge.

Subject A states that the NOC personnel are overwhelmed and very busy, while Subject B states that there are many quiet times and that he has to work at distributing the work. This seems to be a contradiction and may point out the turf protection phenomenon that can be seen in many of the other findings.

It would appear that the NOC personnel don't trust what the field personnel say, but they also don't trust what the system says and require confirmation from the field personnel?

The NOC personnel believe that knowledge is needed to troubleshoot, but they are not willing to share it with the field personnel and consider them as just "eyes, and ears in the field" ("puppets").

It seems that a lot of the experience gained by field personnel in trouble shooting is based on trial and error and more folklore that justified data.

It seems that novices are less likely to utilize any type of relationship analysis and knowledge base. They expect explicit instructions to show them what to do.

One of the stumbling blocks of using such a system is that people might be scared that an ACT may end up removing a lot of their power (knowledge dissipation or ability to think on their own or even make their own decisions e.g., Subject P Pg5 Line13).

From many of the interviews if not all of them, the very first concern is whether or not the channel with a fault is carrying customer traffic. This would appear to be a very simple piece of information that should be made available to everyone in the network, however, the reality is that only the NMC has access to this information and it forces the field personnel to rely on the NMC as their locus of control. Perhaps this is intentional?

Questionnaire Results:

The additional tables below outline the detailed answers to each question.

Table D.1 Questionnaire Set 1

Questions	1	2	3	4	5	6	7
Amount of computer-related training received by SELF	0	2	7	15	13	0	0
Amount of computer-related training received by COLLEGE	8	3	18	5	3	0	0
Amount of computer-related training received by COMPANY	6	14	6	7	4	0	0
Amount of computer-related training received by VENDOR	13	6	11	5	2	0	0
Amount of computer-related training received by OTHER	10	7	16	1	3	0	0
Overall, how satisfied are you with Alarm Correlation Tools that you have used?	2	4	18	13	0	0	0
been able to identify new opportunities for maintenance	0	3	6	10	9	6	3
not been able to coordinate the diagnosis efforts of different units in the field	5	8	10	4	3	5	2
been able to rapidly deploy new solutions or corrective actions.	1	3	7	6	4	12	4
been able to adapt quickly to unanticipated changes	0	4	6	9	6	8	4
been able to quickly adapt its procedures to network changes.	1	3	5	7	7	11	3
not been able to decrease response times.	5	6	10	8	5	2	1
been able to react to new information about the network and/or equipment.	0	1	6	4	7	15	4
been able to be responsive to new network operations demands.	1	3	4	5	6	12	6
not been able to avoid overlapping efforts between different units.	5	3	7	9	5	5	3
not been able to streamline the fault diagnosis processes.	5	8	5	7	3	6	3
been able to reduce redundancy of information and knowledge.	3	5	10	10	4	5	0
I often obtain useful knowledge by reading written materials authored by coworkers.	4	4	4	5	1	13	6
I rarely read documents written by coworkers to increase my knowledge on a topic or issue.	14	8	4	3	2	5	1
I rarely use targeted one-on-one conversations with other employees to acquire work-related knowledge.	17	15	0	2	1	2	0
When I need to access to knowledge, I frequently use personal communication with individual employees.	0	1	2	5	4	14	11

Table D.1 Questionnaire Set 1 (Continued)

Questions	1	2	3	4	5	6	7
I frequently consult with groups of coworkers when I need to improve my knowledge on a topic or issue.	0	4	3	1	4	14	11
I rarely use conversations with a group of coworkers as a way of acquiring knowledge.	18	10	2	2	4	1	0
I believe that using an effective Alarm Correlation Tool is useful addition equipment.	0	1	0	3	2	11	18
I believe that while using an effective Alarm Correlation Tool I would tend to customize the configuration files related to the tool.	1	3	1	7	5	11	6
Key expertise is often captured in an online way in my organization.	3	8	14	10	2	0	0
I get appropriate lessons learned sent to me in areas where I can benefit.	4	12	8	13	0	0	0
I usually have time to chat informally with my colleagues.	0	2	5	24	6	0	0
Individualized learning is usually transformed into organizational learning through documenting this knowledge into our organization's knowledge repository.	3	6	12	13	3	0	0
There are many knowledge fairs/exchanges within my organization to spawn new colleague to colleague relationships.	6	10	14	4	3	0	0
There are lessons learned and best practices repositories within my organization.	3	10	11	11	2	0	0
We have a mentoring program within my organization.	5	15	13	2	2	0	0
We have Centers of Excellence in our organization whereby you can qualify to become a member/affiliate of the Center.	9	16	8	4	0	0	0
We typically work in teams or groups.	0	2	3	22	10	0	0
Our main product is our knowledge.	1	5	8	17	6	0	0
I feel that we have a knowledge sharing culture within our organization versus a knowledge hoarding one.	3	4	9	18	3	0	0
We have a high percentage of teams with shared incentives whereby the team members share common objectives and goals.	0	5	11	18	3	0	0
There are online communities of practice in my organization where we can exchange views and ideas.	4	18	10	4	1	0	0
I am promoted and rewarded based upon my ability to share my knowledge with others.	8	12	10	4	3	0	0
There is an adequate budget for professional development and training in my organization.	10	9	11	6	1	0	0
Success, failure, or war stories are systematically collected and used in my organization.	3	10	12	11	1	0	0

Table D.1 Questionnaire Set 1 (Continued)

Questions	1	2	3	4	5	6	7
The measurement system in my organization incorporates intellectual and customer capital, as well as the knowledge capital of our products or services.	1	7	24	5	0	0	0
We have the technological infrastructure to promote a knowledge sharing environment within our organization.	0	4	5	25	3	0	0
We typically have integrated assignments where the number of projects in which more than one department participates occurs.	0	5	18	11	3	0	0
We have internal surveys on teaming which surveys employees to see if the departments are supporting and creating opportunities for one another.	7	17	11	1	1	0	0
We track the degree to which the organization is entering team-based relationships with other business units, organizations, or customers.	6	13	16	1	1	0	0
The reuse rate of "frequently accessed/reused" knowledge in my organization is high.	1	10	17	7	2	0	0
The distribution of knowledge to appropriate individuals in my organization is done actively on a daily basis.	4	13	8	9	3	0	0
New ideas generating innovative products or services are a frequent occurrence in my organization.	2	9	18	7	1	0	0

Table D.2 Questionnaire Set 2

Question	Yes	No
TrainingInNMS	30	7

Table D.3 Questionnaire Set 3

Question	No High School	High School	Some College	Tech. School	Bach.	Master	PhD
Education	1	3	13	5	8	5	2

Table D.4 Questionnaire Set 4

Question	English	Spanish	Portuguese	Polish	Japanese	French
Native Language	23	5	2	1	5	1

Table D.5 Questionnaire Set 5

Question	UK	Spain	West Coast, USA	Portugal	East Coast, USA	Japan	Holland
Location	9	3	5	3	10	6	1

Table D.6 Questionnaire Set 6

Question	Averages	Std Dev	Max	Min	Median
YearsEmployed	3.8571429	1.784622	8	1	4
YearsOfExperience	5.8857143	3.521125	15	1	5
Average Hours of Using Alarm Correlation Tools per day	2	2.397916	12	0	1
Average Hours to Diagnose a problem	2.27	5.204667	30	0.15	1
Average Hours an alarm correlation tool would decrease the diagnosis effort	1.1928571	1.722308	7	0	0.5

Table D.7 Questionnaire Set 7

Years Employed in the Organization	Years of Experience	Trained in NMS	Education Received
4	13	Yes	Some College
2	2	Yes	Masters
7	3	Yes	Bachelors
5	15	Yes	Some College
4	4	No	Bachelors
8	4	Yes	Bachelors
7	13	Yes	Bachelors
4	2	Yes	Some College
2	5	Yes	Masters
2	9	Yes	Bachelors
2	2	Yes	Some College
4	8	No	Bachelors
4	8	Yes	Masters

Table D.7 Questionnaire Set 7 (Continued)

Years Employed in the Organization	Years of Experience	Trained in NMS	Education Received
1	1	Yes	Some College
2	4	Yes	Ph.D.
4	4	Yes	Some College
7	4	No	Ph.D.
2	8	No	No High School
4	4	Yes	Some College
4	7	No	Masters
1	6	No	Masters
4	6	Yes	High School
2	2	Yes	Some College
5	5	Yes	Technical School
2	5	Yes	Technical School
2	8	Yes	High School
5	5	Yes	Some College
4	7	Yes	High School
7	3	Yes	Bachelors
4	4	Yes	Some College
4	4	Yes	Some College
4	10	No	Technical School
4	4	Yes	Some College
4	4	Yes	Technical School
4	13	Yes	Technical School
4	30	Yes	Some College
5	1	Yes	Bachelors

A scenario from a telecommunications network is presented below. Please read the scenario before answering the questions. Answer the questions below based on your personal understanding and interpretation of the scenario. A cleaning crew working in a cable station accidentally trip over a fiber carrying a signal to a network element (NE). The network element detects a signal failure. The NE then sends a bit encoded status message to the network management system (NMS) indicating the alarm(s). The NMS displays the following message on the alarm summary window "NE1 - Incoming Signal Loss". When the cable station personnel see this alarm, they attempt to troubleshoot the problem. Jim is one of the cable station personnel. He is an experienced operator and immediately realizes that the problem must be upstream of the

NE. Jim also thinks the problem must either be the connection into the NE or in the equipment feeding NE1. Jim immediately heads to NE1 to trace the line back to the upstream equipment.

Answer the following 3 questions based on your understanding of what happened in this scenario. You can type as much as you feel is necessary in the space below each question, respectively.

Table D.8 Questionnaire Set 8

#	What is data? Answer
1.	Not sure on terminology here but I would class the bit encoded status message from the NE to NMS as data.
2.	The bit encoded status sent by NE to NMS.
3.	Data is the facts that are provided by the NMS
4.	Once the NE receives LOS an ISL alarm is reported to the NMS
5.	The encoded status message sent by NE to NMS
6.	The NMS displays the following message on the alarm summary window "NE1 – Incoming Signal Loss".
7.	Yes, I do consider some of the information to be data. These questions do not really make sense to me as they are all related in troubleshooting. The alarm data is critical in helping me to trace to the point of origin. Such things as the time stamps, etc on each alarm generated.
8.	NE detects signal failure
9.	Alarm list, History log, spare fiber list, spec of optical power level
10.	I require that the data offered directly from NE1 (Data based on CIT).
11.	To locate the point of problem, see the EMS A on display on each fibers on each related terminal station.
12.	Message from NE to NMS
13.	The bit encoded status message, this is just raw data.
14.	A cleaning crew working in a cable station
15.	Signal failure on NE, "NE1 – Incoming Signal Loss" alarm,
16.	PM
17.	Alarm messages
18.	Bit encoded status message
19.	ISL
20.	Bit encoded status message
21.	Alarm-NE1-Incoming Signal Loss;
22.	NE sends a bit encoded status message to the NMS indicating the alarm
23.	the encoded status message
24.	The bit encoded message sent to the NMS triggering the alarm, the actual "Incoming Signal Loss" alarm
25.	Do not understand the question
26.	"NE1 – Incoming Signal Loss".
27.	The bit-encoded status message
28.	Bit encoded status message.
29.	Bit encoded, Incoming Signal Loss

Table D.8 Questionnaire Set 8 (Continued)

#	What is data? Answer
30.	A cleaning crew working in a cable station accidentally trip over a fiber carrying a signal to a network element, The network element detects a signal failure
31.	Bit encoded message to NMS
32.	In this example Bit encoded messages between NE and NMS I consider as data, the signal/ traffic in the fiber will be carrying data
33.	A bit encoded status message to the network management system (NMS) indicating the alarm(s)
34.	The data is the bit encoded status message to the NMS indicting the alarm
35.	Bit encoded statues message between NE and NMS
36.	The NE then sends a bit encoded status message to the network management system (NMS) indicating the alarm(s)
37.	The bit encoded status message reported by the NE to the NMS.

Wrong definitions: 15
Right definitions: 22

Table D.9 Questionnaire Set 9

#	What is Information? Answer
1.	Jim is working from the information provided by the NMS - "NE1 incoming signal loss"
2.	The msg "NE1 - Incoming Signal Loss" shown by NMS.
3.	I guess information and data will be correlated since they are both exported at the NMS
4.	This alarm information is available for Jim to investigate.
5.	The message display by the NMS "NE1 - Incoming Signal Loss"
6.	A cleaning crew working in a cable station accidentally trip over a fiber carrying a signal to a network element (NE).
7.	Information is everything surrounding the event in question. I see no significant difference between information and data. To me, they are both the same. However, if what you are asking for is information about a specific alarm, then this would be helpful. A database or click through for information and a definition of a specific alarm may be helpful in troubleshooting. I have found that the majority of techs I have working for me do not understand the SDH hierarchy and do not understand what specific alarms mean in reference to this hierarchy.
8.	NE1 incoming signal loss
9.	about cleaning crew (name, company), affected sites and customer, time, fiber type
10.	I require that the information of the NE1 ISL alarm circuit and upstream of the NE alarm information.
11.	Contact the related station closed to our site and exchange the information to narrow down the location and problem.
12.	ISL Alarm shown by NMS
13.	Message on the alarm summary window "NE1 - Incoming Signal Loss". This is the interpretation of the raw data.
14.	"NE1 - Incoming Signal Loss"
15.	An accident by a cleaning crew, NMS handling NE's bit encoded status,
16.	Alarms
17.	cleaning crew working around transmission equipment
18.	NE1 Incoming signal loss
19.	ISL
20.	signal failure; NE1 - Incoming signal loss
21.	Cleaning crew was working in the cable station;
22.	NE1 Incoming Signal Loss

Table D.9 Questionnaire Set 9 (Continued)

#	What is Information? Answer
23.	The alarm shown, the message that appear on a window saying "incoming signal loss"
24.	The cleaning crew tripping over the fiber
25.	do not understand the question
26.	The NE then sends a bit encoded status message to the network management system (NMS) indicating the alarm(s).
27.	"NE1 Incoming Signal Loss"
28.	Incoming signal loss
29.	Cleaning Crew trip over fiber carrying traffic, Problem must be upstream, Problem must either be connected to NE or in the equipment feeding NE
30.	The NE then sends a bit encoded status message to the network management system (NMS) indicating the alarm(s). The NMS displays the following message on the alarm summary window "NE1 - Incoming Signal Loss"
31.	NE1 ISL , Signal Fail
32.	From the example any message form the NMS e.g., indicating "Incoming Loss Of Signal" I deem as information.
33.	NE1 - Incoming Signal Loss
34.	Signal failure. 'NE1 Incoming Signal Loss' on the NMS
35.	Incoming signal loss
36.	The NMS displays the following message on the alarm summary window "NE1 - Incoming Signal Loss
37.	Message displayed on the alarm summary window "NE1-ISL"

Wrong definitions: 9
Right definitions: 28

Table D.10 Questionnaire Set 10

#	What is Knowledge? Answer
1.	Jim uses his knowledge to interpret the alarm. He knows the fault is likely to be upstream from NE1 (Fiber break / bend, Failed connector, Output failure from remote NE or control/NE Management pack erroneous alarm report)
2.	That the problem must be upstream of the NE and located in one of the connectors.
3.	Knowledge is the information that the operator has
4.	Jim understands that the problem is likely to be within that cable station.
5.	The problem must be in the NE's interface, in the equipment feeding NE1 or in the connections between the equipments. Jim forgot this last possibility.
6.	He is an experienced operator and immediately realizes that the problem must be upstream of the NE. Jim also thinks the problem must either be the connection into the NE or in the equipment feeding NE1.
7.	Knowledge is key to everything. I strongly believe that knowledge can only be gained through experience. The key to knowledge is in the first 2 answers; first you need data of the event, then you need to understand how to interpret that data. The only way to do this is through experience and experience gives one knowledge.
8.	Jim knows problem must be upstream of the NE or at the NE
9.	about the NE, handling optical power meter, fiber cleaning method
10.	I require that the knowledge of the functional NE1 and using test equipment.
11.	Location of the problem, status of the problem, Materialize the problem to inform to NMC. To inquire my action to restoration.
12.	Cleaning crew working in station, trip over fiber

Table D.10 Questionnaire Set 10 (Continued)

#	What is Knowledge? Answer
13.	Location of the problem. Either the connection into the NE or in the equipment feeding NE1. This is based on experience + training.
14.	problem must either be the connection into the NE or in the equipment feeding NE1
15.	Localizing the problem on the upstream, the connection in to the NE or the equipment feeding NE1
16.	Experience
17.	Known causes to Incoming Signal Loss
18.	problem must be upstream of the NE
19.	ILS
20.	knowing the problem being upstream of the NE, tracing the fault & connection to the or equipment feeding NE1 etc.
21.	Problem must be coming from the upstream equipment;
22.	Connection to NE or the equipment feeding NE1 is the possible cause of the problem
23.	Quickly realizing where the problem could be; the answer of the personnel
24.	Jim's thought that the problem is upstream of the NE and that the problem stems from either the connection into the NE or in the equipment feeding it.
25.	do not understand the question
26.	Jim also thinks the problem must either be the connection into the NE or in the equipment feeding NE1.
27.	Thinking the problem lies upstream if the NE, Thinking the problem is either connection to the NE or the equipment feeding it.
28.	Jimmy heading to NE1
29.	Problem in upstream equipment, cleaning crew tripped over fiber knocking out signal
30.	He is an experienced operator and immediately realizes that the problem must be upstream of the NE. Jim also thinks the problem must either be the connection into the NE or in the equipment feeding NE1
31.	He is an experienced operator and immediately realizes that the problem must be upstream of the NE. Jim also thinks the problem must either be the connection into the NE or in the equipment feeding NE1. Jim immediately heads to NE1 to trace the line back to the upstream equipment.
32.	In this example Jim automatically realizes the problem; this can only be because of the knowledge experience he has gained in his particular field
33.	An experienced operator and immediately realizes that the problem must be upstream of the NE. Jim also thinks the problem must either be the connection into the NE or in the equipment feeding NE1. Jim immediately heads to NE1 to trace the line back to the upstream equipment.
34.	Jim realizes problem must be upstream of the NE. Jim thinks the problem is the connection into the NE or the equipment feeding the NE1. Jim also probably knows there are cleaners working in the vicinity and a fiber trailing on the floor exposes the circuit as a point of failure.
35.	Jim's understanding of alarms and expertise
36.	Experience, knowledge the problem must either be the connection into the NE or in the equipment feeding NE1
37.	The station personnel's troubleshooting skills or approach to resolving problems based on collected data and available information.

Wrong definitions: 6
Right definitions: 31

Table D.11 Questionnaire Set 11

#	Other Information? Answer
1.	A complex network like NETWORK A utilizes several types of vendor equipment, various management platforms, terrestrial and submarine links and spans across continents. With multiple activities/events/incidents occurring at any one time an "effective" alarm correlation tool is essential to speed up fault diagnosis. However the experienced NMC/NOC operative will always add value to the process.
2.	We look forward to Demo-ing the tool on the NETWORK A network. Also - please tell Jim the technician that LOS can also be caused by a failed receiver.
3.	Fault diagnosis can only be as effective as the individual's ability to understand the meaning behind a fault. When I used to do system level testing in the labs, my technical manager always told me, "not only do I want you to test for alarm conditions, but I want you to understand why those alarms occur, and explain how to create those alarms." Fault diagnostic tools are wonderful and a good addition to our EMS and NMS. However, we still have a critical point a failure in our overall knowledge when the individuals that will use these tools do not have an understanding behind "why and what" alarms may mean. This may require some additional training.
4.	In my opinion, using the alarm correlation tools is effective to troubleshoot and decrease network interruption time.
5.	The alarm response of OLS SNMS is sometime not good.
6.	Recent email exchange has decreased the repeated redundant same question and answer during the diagnosis on alarm. I still would like to focus the human voice communication exchange will be much contributing to whole understanding the problem. I insist the mechanical diagnosis should include the supplement of human live exchange in text book e.z." ---- No.5 If the above process was completed, confirm the site personal by tele-exchanges"
7.	In the field Diagnose and correct I put 30 minutes to diagnose, to correct the fault it depends on type of fault, can vary a lot. Not the same to replace a circuit pack or to repair a fiber break in the high sea. Integration of different equipment information and data, in the whole network. Sometimes its confusing to interpret the alarm information, as the equipments do have different "response times". And the distribution of the network must also be considered.
8.	Indication, package fail or just signal loss?
9.	Any auto alarm correlation tool is beneficial
10.	For questions 18 & 19 I cannot put an answer. I put zero because it wanted a number. It depends on what equipment and what fault for how long. For example I have had a PFE problem for over six months that I am still working on. Paradoxically some HPOE faults take a few minutes to diagnose.
11.	It would be interesting to have a tool that filtered the alarm messages more efficiently, giving just a few message alarms in a first moment and more details if requested, so that the useful information would not be all mixed with non relevant data.
12.	I do not know how is the NMS itself and I could made a miss-judgment about the fault diagnosis actions/troubleshootings.
13.	If the HPOE could analyze incoming SDH to determine B1&B2 errors this would save significant time. If EMS A ran somewhat more quickly - rather than requiring mouse clicks of over a second to register the users intentions, and waits of 5-40 seconds for data retrieval.
14.	A fault diagnostic would be good but you cannot beat expertise and knowledge to correct faults.
15.	Over complication and too much information tends to cloud judgment and may increase the time taken for diagnosis.
16.	Alarms on the EMS A are sometimes misleading.
17.	90% of faults I have experienced have been diagnosed within 5 to 10 minutes, correcting the fault may take a lot longer, Q18/19 above did not take account of this. Any alarm/fault correlation system would still need human experience & knowledge to be effective.

APPENDIX E

ACT ARCHITECTURE AND DESIGN

The final deployed version of ACT will allow a number of key features (Figure E.1, Figure E.2, Figure E.3, Figure E.4, Figure E.5, Figure E.6) (Sabet et al. 2004):

- ACT provides a mechanism to leverage local field personnel's intimate knowledge of the specific node layout and equipment. This knowledge can then be used to diagnose higher-level problems at the network level.
- ACT facilitates distributed knowledge acquisition and sharing through a single tool interface.
- Learned scenarios become shared knowledge by dynamically distributing them to all cable stations and the NMC.
- An instance of the tool will function at both the local and at the network-level for correlation.

7.3 Design Approach

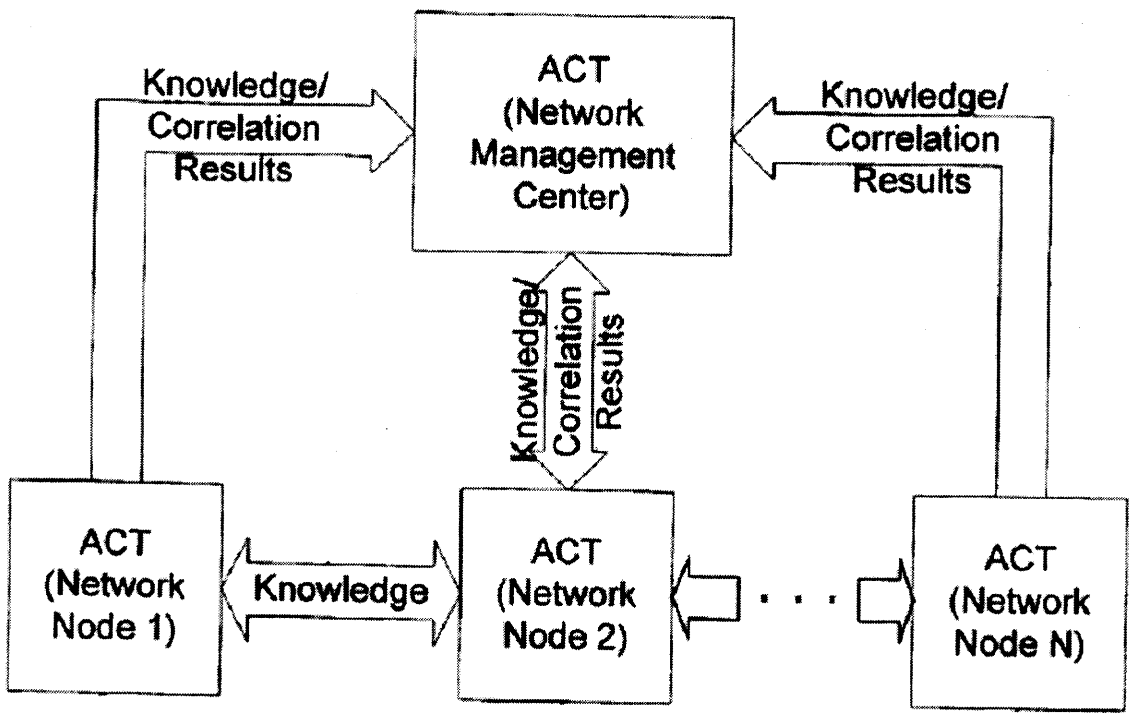


Figure E.1 ACT system deployment.

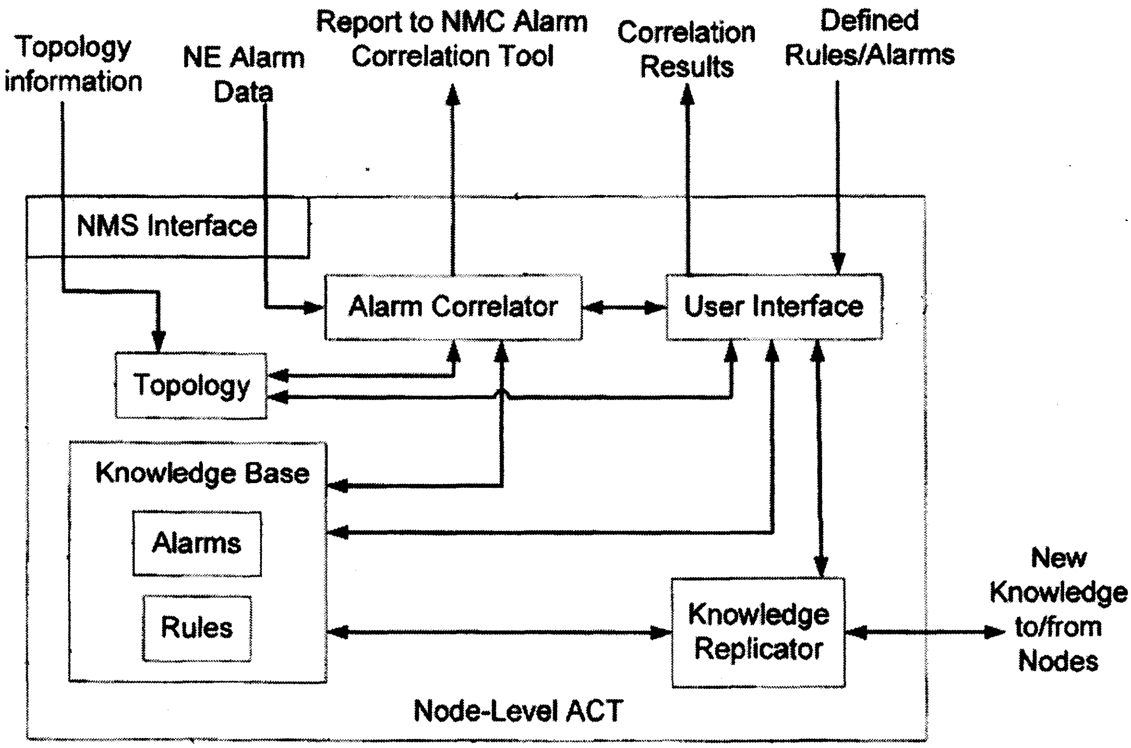


Figure E.2 ACT node level system.

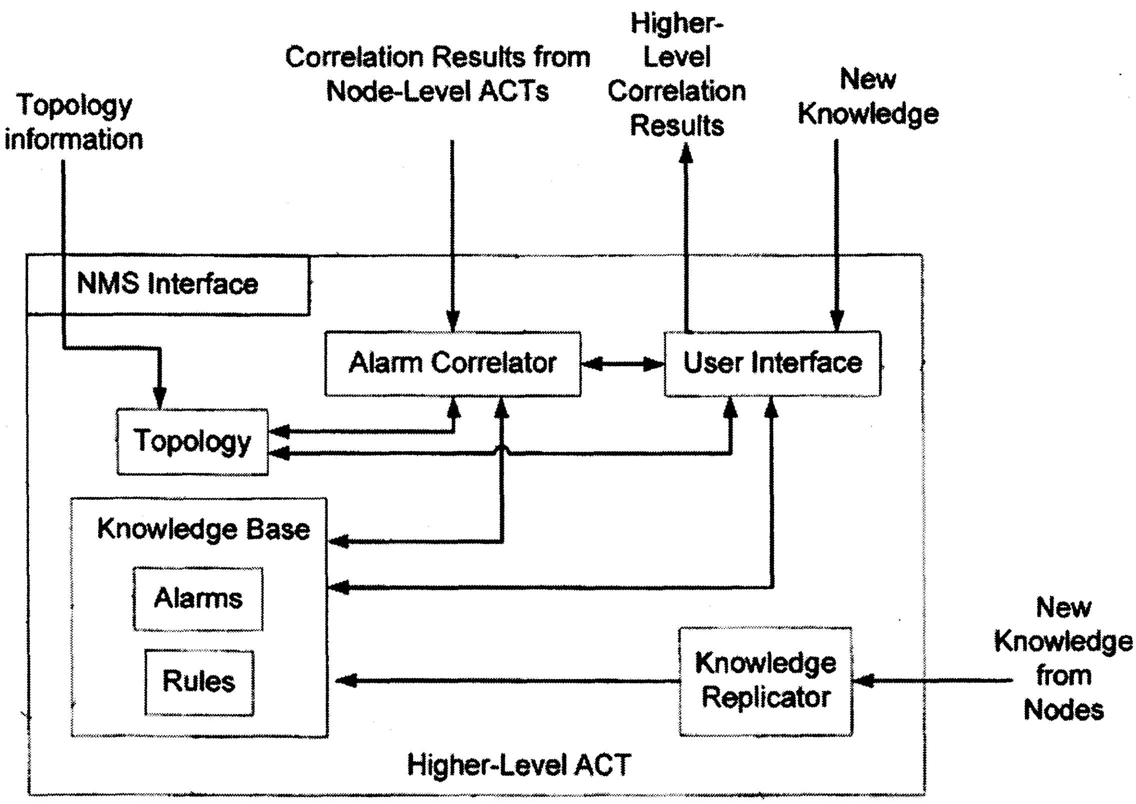


Figure E.3 ACT higher-level system.

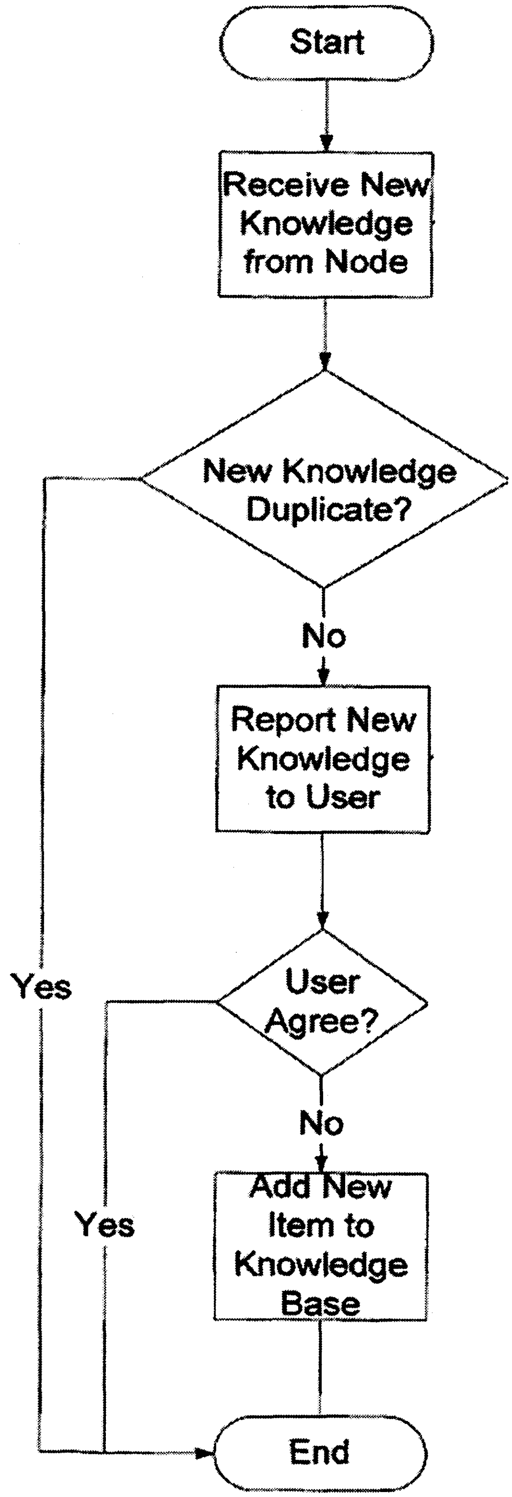


Figure E.4 ACT knowledge sharing algorithm.

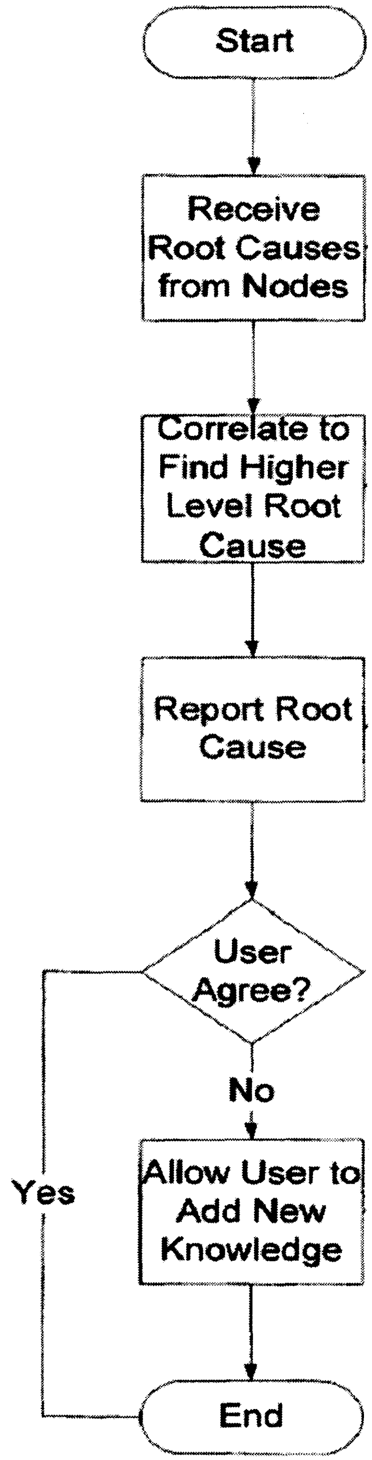


Figure E.5 ACT higher-level correlation algorithm.

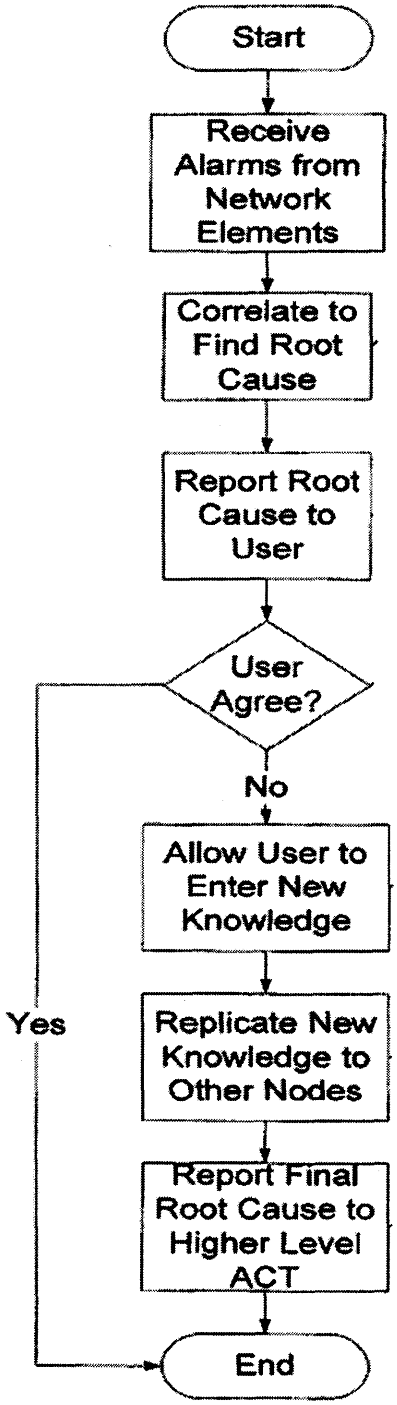
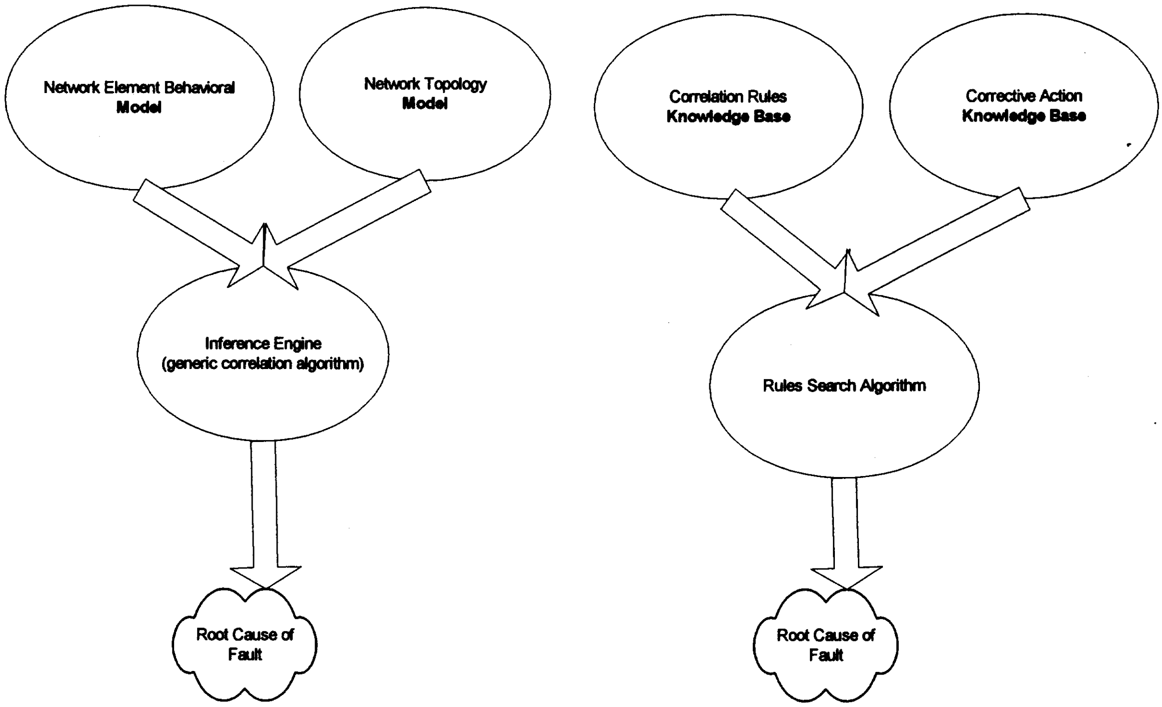


Figure E.6 ACT new knowledge creation algorithm.

Most IS designs are based on the incorrect assumption that users suffer from a lack of relevant information, but in reality an over-abundance of information is typically presented to users (Ackoff 1967; Nemati et al. 2002). Therefore, the two most important functions for an IS are filtration and condensation of information. Knowledge is required to make sense of the vast amounts of information presented to users in an EKP. The solution is to incorporate various KM/ES techniques into the design of the system, without compromising the EKP design principles.

The designs of DSS, ES and KMS overlap. However, depending on the problem being solved, one or more combinations of them may be appropriate. Systems that are intended to support EKPs require many of the characteristics of these three systems. However, EKP problems have different overall (process, user and knowledge) requirements from those supported by traditional IS systems (Markus et al. 2002). By combining the features presented by traditional system types as well as the principles introduced by the EKP system design theory, designers and developers are better prepared to fulfill these requirements.



Model Based Correlation
Section of ACT

Rule Based Correlation
Section of ACT

Figure E.7 ACT architecture.

The ACT is intended to be a hierarchical, distributed system that is used to fault diagnose network failures at individual network nodes (Figure E.1 and Figure E.3) as well as at the higher-level Network Management Center (Figure E.1 and Figure E.2). ACT is intended to be modifiable and allow integration with varying NMS. A major system requirement is that ACT allow for interface components that are easily modified to fit the deployed NMS. ACT utilizes a rules component as well as a modeling technique to capture engineering knowledge pertaining to network fault diagnosis (Figure E.7). The knowledge captured using these techniques may then be replicated to other network nodes to leverage locally acquired experiential knowledge (Figure E.4, Figure E.5, Figure E.6) (Sabet et al. 2004). In the first phase, the ACT will utilize a rules module and search algorithm to determine root causes of faults. In a second phase, the ACT design will utilize a network model (topology), a network element behavioral model (alarm definitions) in combination with a generic inference engine (alarm masking and correlation algorithm) to recommend generic solutions to fault diagnosis. The effectiveness of the two approaches will be compared so that the two evaluations should be able to shed light on the correct (KM) correlation technique for the system.

REFERENCES

1. Achour, S.L., Dojat, M., Rieux, C., Bierling, P., and Lepage, E. "A UMLS-based Knowledge Acquisition Tool for Rule-based Clinical Decision Support System Development," *Journal of the American Medical Informatics Association* (8:4) 2001, pp 351-360.

2. Ackerman, M.S., and Halverson, C.A. "Reexamining Organizational Memory," *Communications of the ACM* (43:1) 2000, pp 58-64.

3. Ackoff, R. "Management Misinformation Systems," *Management Science* (14:4), December 1967, pp B147-B156.

4. Aiken, M.W., Sheng, O.R.L., and Vogel, D.R. "Integrating Expert Systems with Group Decision Support Sys," *ACM Transactions on Information Systems* (9:1), January 1991, pp 75-95.

5. Alavi, M. "Managing Organizational Knowledge," *in Framing the Domain of IT Management: Projecting the Future Through the Past, R. W. Zmud (ed.), Pinnaflex Educational Resources*) 2000.

6. Alavi, M., and Joachimsthaler, E.A. "Revisiting DSS Implementation Research: A Meta-Analysis of the Literature and Suggestions for Researchers," *MIS Quarterly* (16:1) 1992, pp 95-117.

7. Alavi, M., and Leidner, D.E. "Review: Knowledge Management and Knowledge Management Systems: Conceptual Foundations and Research Issues," *MIS Quarterly* (25:1), March 2001, pp 107-136.

8. Babbie, E. *The Practice of Social Research*, (6th ed.) Wadsworth Publishing Company, Belmont, CA, 1999.

9. Baskerville, R.L. "Investigating Information Systems with Action Research," *Communications of AIS* (2:19) 1999, pp 1-31.

10. Bhargava, H., and Power, D.J. "Decision Support Systems and Web Technologies: A Status Report," Americas Conference on Information Systems, AIS, Boston, MA, 2001.

11. Blanning, R.W. "Expert Systems as an Organizational Paradigm," International Conference on Information Systems, AIS, Pittsburgh, PA, 1987, pp. 231-240.

12. Bobrow, D.G., Mittal, S., and Stefik, M. "Expert Systems: Perils and Promise," *Communications of the ACM* (29:9), September 1986, pp 880-894.

13. Buckley, W.F. *Sociology and modern systems theory* Prentice-Hall, Englewood Cliffs, N.J., 1967, p. 227.

14. Chao, C.S., Yang, D.L., and Liu, A.C. "An Automated Fault Diagnosis System Using Hierarchical Reasoning and Alarm Correlation," IEEE Workshop on Internet Applications, 1999.

15. Choo, C. "The Knowing Organization: How Organizations Use Information to Construct Meaning, Create Knowledge, and Make Decisions," *International Journal of Information Management* (16:5) 1996, pp 329-340.

16. Conway, M.E. "How Do Committees Invent," in: *Datamation Magazine*, 1968, pp. 28-31.

17. Courtney, J.F. "Decision Making and Knowledge Management In Inquiring Organizations: Toward A New Decision-Making Paradigm for DSS," *Decision Support Systems* (31) 2001, pp 17-38.

18. Curtis, B., Krasner, H., and Scoe, N. "A Field Study of the Software Design Process for Large Systems," *Communications of the ACM* (31:11) 1988, pp 1268-1287.

19. Dahlin, M., Chandra, B., Baddepudi, V., Gao, L., and Nayate, A. "End-To-End WAN Service Availability," *IEEE/ACM Transactions on Networking* (11:2) 2003, pp 300-313.

20. DeSanctis, G., and Gallupe, R.B. "A foundation for the study of group decision support systems," *Management Science* (33:5) 1987, pp 589-609.

21. Dubé, L., and Paré, G. "Rigor in Information Systems Positivistic Case Research: Current Practices, Trends, and Recommendations," *MIS Quarterly* (27:4), December 2003 2003, pp 597-635.

22. El-Sawy, O.A., and Bowles, G. "Customer Support Process for the Electronic Economy: Insights from Storage Dimensions," *MIS Quarterly* (21:4) 1997, pp 457-483.

23. Fjermestad, J., and Roxanne, H.S. "Case and Field Studies of Group Support Systems: An Empirical Assessment," 33rd Annual Hawaii International Conference on System Sciences, Hawaii, 2000.

24. Flynn, P., Curran, K., and Lunney, T. "A Decision Support System for Telecommunications," *International Journal of Network Management* (12) 2002, pp 69-80.

25. Goguen, J.A., and Charlotte, L. "Techniques for Requirements Elicitation," International Symposium on Requirements Engineering, 1993.

26. Gold, A.H., Malhotra, A., and Segars, A.H. "Knowledge Management: An Organizational Capabilities Perspective," *Journal of Management Information Systems* (18:1) 2001, pp 185-214.

27. Gorry, A.G., and Morton, M.S.S. "A Framework for Management Information Systems," *Sloan Management Review* (13:1) 1971.

28. Grudin, J. "Interactive Systems: Bridging the Gaps Between Developers and Users," *IEEE Computer* (24:4) 1991, pp 59-69.

29. Hahn, J., and Subramani, M.R. "A Framework of Knowledge Management Systems: Issues and Challenges for Theory and Practice," International Conference on Information Systems, Brisbane, Australia, 2000, pp. 304-312.

30. Hall, D. "Building a Theoretical Foundation for a Learning-Oriented Management System," *The Journal of Information Technology Theory and Application (JITTA)* (5:2), 2003 2003, pp 63-85.

31. Hanseth, O., and Lyytinen, K. "Theorizing about the Design of Information Infrastructures: Design Kernel Theories and Principles," *Sprouts: Working Papers on Information Enviroments, Systems and Organizations* (4:4) 2004, pp 207-241.

32. Heckerman, D., and Wellman, M.P. "Bayesian Networks," *Communications of the ACM* (38:3) 1995, pp 27-30.

33. Hevner, A.R., March, S.T., Park, J., and Ram, D. "Design Science in Information Systems Research," *MIS Quarterly* (27:4) 2004, pp 75-105.

34. Holsapple, C.W. "Knowledge Management In Decision Making and Decision Support," *Knowledge & Policy* (8:1) 1995, pp 5-22.

35. Holsapple, C.W. "Knowledge Management Support for Decision Making," *Decision Support Systems* (31) 2001, pp 1-3.

36. Hunter, G.M., and Beck, J.E. "Using Repertory Grids to Conduct Cross-Cultural Information Systems Research," *Information Systems Research* (11:9) 2000, pp 93-101.

37. Jacobson, I., Christerson, M., Jonsson, P., and Övergaard, G. *Object-Oriented Software Engineering: A Use Case Driven Approach* Addison-Wesley, Reading, Massachusetts, 1992.

38. Kasper, G.M. "A Theory of Decision Support System Design for User Calibration," *Information Systems Research* (7:2), June 1996 1996, pp 215-232.

39. Klashner, R. "Using Architecture Style to Design and Evolve Complex Integrated Information Infrastructure," in: *Information and Computer Science*, University of California Irvine, Irvine, California, 2002, p. 228.

40. Klashner, R., and Sabet, S. "Designing Malleable Cyberinfrastructure to Breach the Golden Barrier," *The Journal of Information Technology Theory and Application (JITTA)* (6:3), 2004 2004a, pp 59-84.

41. Klashner, R., and Sabet, S. "A DSS Design Model for Complex Problems: Lessons from Mission-Critical Infrastructure," *To Appear in Decision Support Systems*) 2004b.

42. Klein, G.A., Calderwood, R., and Macgregor, D. "Critical Decision Method for Elicting Knowledge," *IEEE Transactions on Systems, Man, and Cybernetics* (19:3), May/June 1989 1989, pp 462-472.

43. Kleindorfer, P.R., Kunreuther, H.G., and Schoemaker, P.J.H. *Decision Sciences: An Integrative Perspective* Cambridge University Press, New York, NY, 1993, p. 484.

44. Klemettinen, M. "A Knowledge Discovery Methodology for Telecommunication Network Alarm Databases," in: *Department of Computer Science*, University of Helsinki, Helsinki, Finland, 1999, p. 135.

45. Klemettinen, M., Mannila, H., and Toivonen, H. "Rule Discovery in Telecommunication Alarm Data," *Journal of Network and Systems Management* (7:4) 1999.

46. Kling, R. "Organizational Analysis in Computer Science," *The Information Society* (9:2) 1993, pp 71-87.

47. Kruchten, P. "What is the Rational Unified Process?" in: *The Rational Edge*, 2003.

48. Lewis, L. "A case-based reasoning approach to the resolution of faults in communications networks," IFIP International Symposium on Integrated Network Management, 1993, pp. 671-682.

49. Lo, C.-C., Chen, S.-H., and Lin, B.-Y. "Coding-based schemes for fault identification in communication networks," *International Journal of Network Management* (10:3), May-June 2000, pp 157-164.

50. Lowgren, J. "Applying Design Methodology to Software Development," Symposium on Designing Interactive Systems, ACM, Ann Arbor, Michigan, 1995, pp. 87-95.

51. Lyytinen, K. "Different Perspectives in Information Systems: Problems and Solutions," *ACM Computing Surveys* (19:1) 1987, pp 5-46.

52. Magee, J., and Kramer, J. "Concurrency: State Models & Java Programs," John Wiley & Sons Ltd., New York, 1999, p. 374.

53. Mahapatra, R., and Sarkar, S. "The Role of Information Technology in Knowledge Management," Americas Conference on Information Systems, AIS, Long Beach, California, 2000, pp. 1288-1290.

54. Majchrzak, A., Rice, R.E., Malhotra, A., King, N., and Ba, S. "Technology Adaptation: The Case of a Computer-Supported Inter-Organizational Virtual Team," *MIS Quarterly* (24:4) 2000a, pp 568-600.

55. Majchrzak, A., Rice, R.E., Malhotra, A., King, N., and Ba, S. "Technology Adaptation: The Case of a Computer-Supported Inter-Organizational Virtual Team," *MIS Quarterly* (24:4) 2000b, pp 568-600.

56. March, S.T., and Smith, G.F. "Design and Natural Science Research on Information Technology," *Decision Support Systems* (15:4), 1995 1995, pp 251-266.

57. Markus, M.L. "Power, politics, and MIS implementation," *Communications of the ACM* (26:6) 1983, pp 430-444.

58. Markus, M.L., Majchrzak, A., and Gasser, L. "A Design Theory for Systems That Support Emergent Knowledge Processes," *MIS Quarterly* (26:3) 2002, pp 179-212.

59. Meira, D.M. "A Model For Alarm Correlation in Telecommunications Networks," in: *Department of Computer Science*, Federal University of Minas Gerais, Minas Gerais, 1997.

60. Meira, D.M., and Nogueira, J.M.S. "A Recursive Approach for Alarm Correlation in Telecommunication Networks," IEEE/IFIP Network Operations and Management Symposium, 2000.

61. Myers, M.D. "Qualitative Research in Information Systems," *MIS Quarterly Discovery*) 1997.

62. Nemati, H.R., Steiger, D.M., Iyer, L.S., and Herschel, R.T. "Knowledge Warehouse: an architectural integration of knowledge management, decision support, artificial intelligence and data warehousing," *Decision Support Systems* (33) 2002, pp 143-161.

63. NSTC "Networking and Information Technology Research and Development; Supplement to the President's FY 2003 Budget," National Science and Technology Council.

64. Nygate, Y.A. "Event correlation using rule and object based techniques," IFIP/IEEE International Symposium on Integrated Network Management, 1995, pp. 278-289.

65. Orlikowski, W.J. "Learning from Notes: Organizational Issues in Groupware Implementation," *The Information Society* (9:3) 1992, pp 362-369.

66. Power, D. "Building Knowledge-Driven DSS and Mining Data - Decision Support Systems, HyperBook," 2000a.

67. Power, D.J. "Web-Based and Model-Driven Decision Support Systems: Concepts and Issues," Americas Conference on Information Systems, AIS, Long Beach, CA, 2000b.

68. Power, D.J. *Decision Support Systems: Concepts and Resources for Managers* Greenwood/Quorum Books, Westport, CT, 2002.

69. Richardson, S., and Courtney, J.F. "A Churchmanian Theory of Knowledge Management System Design," Proceedings of the 37th Hawaii International Conference on System Sciences, Hawaii, 2004.

70. Rittel, H.W.J., and Webber, M.M. "Dilemmas in a general theory of planning," *Policy Sciences* (4) 1973, pp 155-169.

71. Roberts, K.H., and Bea, R. "Must accidents happen? Lessons from high-reliability organizations," *Academy of Management Executive* (15:3) 2001, pp 70-78.

72. Rumbaugh, J. "Getting Started: Using use cases to capture requirements," *Journal of Object-Oriented Programming*) 1994, pp 8-23.

73. Sabet, S., and Klashner, R. "Evaluating Knowledge Management Techniques to Augment Network Fault Diagnosis," Americas Conference on Information Systems, AIS, New York, NY, 2003a.

74. Sabet, S., and Klashner, R. "Helping Network Managers Meet Service Demands Using DSS"," AIS SIGDSS 2003 Pre-ICIS Workshop, AIS, Seattle, Washington, 2003b.

75. Sabet, S., and Klashner, R. "Evaluating Knowledge Management Techniques to Augment Network Fault Diagnosis," The 2004 Americas Conference on Information Systems, AIS, New York, NY, 2004.

76. Schmidt, T.H. "Model-based fault diagnosis: knowledge acquisition and system design," Proceedings of the 2nd international conference on Industrial and engineering applications of artificial intelligence and expert systems, 1989, pp. 21-25.

77. Sedbrook, T. "A Collaborative Fuzzy Expert System for the Web," *The DATA BASE for Advances in Information Systems* (29:3) 1998, pp 19-30.

78. Shaw, M., Deline, R., Llein, D.V., Ross, D., Young, D.M., and Zelesnik, G. "Abstractions for Software Architecture and Tools to Support Them," *IEEE Transactions on Software Engineering* (21:4) 1995, pp 314-335.

79. Shaw, N.G. "Identifying Relationships Among Factors in IS Implementation," *Communications of AIS* (11:9) 2003, pp 155-165.

80. Shim, J.P., Warkentin, M., Courtney, J.F., Power, D.J., Sharda, R., and Carlsson, C. "Past, Present, and Future of Decision Support Technology," *Decision Support Systems* (33) 2002, pp 111-126.

81. Shirley, G., and Benbasat, I. "Explanations From Intelligent Systems: Theoretical Foundations and Implications for Practice [1]," *MIS Quarterly* (23:4) 1999, pp 497-530.

82. Silver, M. "Decision Support Systems: Directed and Nondirected Change," *Information Systems Research* (1:1) 1990, pp 47-70.

83. Sprague, R.H. "A Framework for the Development of Decision Support Systems," *MIS Quarterly* (4:4) 1980, pp 1-26.

84. Stein, E.W., and Zwass, V. "Actualizing Organizational Memory With Information Systems," *Information Systems Research* (6:2) 1995, pp 85-117.

85. Tiwana, A., and Ramesh, B. "A design knowledge management system to support collaborative information product evolution," *Decision Support Systems* (31) 2001, pp 241-262.

86. Turban, E., and Aronson, J.E. *Decision Support and Intelligent Systems*, (5 ed.) Prentice-Hall, Inc, Upper Saddle River, NJ, 1998.

87. Turoff, M., Chumer, M., Hiltz, S.R., Klashner, R., Alles, M., Vasarhelyi, M., and Kogan, A. "Assuring Homeland Security: Continuous Monitoring, Control & Assurance of Emergency Preparedness," *The Journal of Information Technology Theory and Application (JITTA)* (6:3), 2004 2004a, pp 1-24.

88. Turoff, M., Chumer, M., Walle, B.V.D., and Yao, X. "The Design of a Dynamic Emergency Response Management Information System (DERMIS)," *The Journal of Information Technology Theory and Application (JITTA)* (5:4), 2004 2004b, pp 1-35.

89. Turoff, M., Hiltz, S.R., Bahgat, A.N.F., and Rana, A.R. "Distributed Group Support Systems," *MIS Quarterly* (17:4), December 1993 1993, pp 399-417.

90. USSS "Telecommunications Fraud," United States Secret Service, 2002.

91. Valenti, S., Panti, M., and Cucchiarelli, A. "Overcoming communication obstacles in user-analyst interaction for functional requirements elicitation," *ACM SIGSOFT Software Engineering Notes* (23:1) 1998.

92. Van Den Eede, G., Kenis, D., and Van De Walle, B. "Combining Flexibility and Reliability for Mainstream Organisational Learning," ISCRAM, Paris, 2004, pp. 851 - 860.

93. Van Den Eede, G., and Van De Walle, B. "Operational Risk in Incident Management: a Cross-fertilisation between ISCRAM and IT Governance," ISCRAM, Brussels, Belgium, 2005, pp. 1-9.

94. VerDuin, W. "Knowledge-Based Systems for Manufacturing," *Intelligent Manufacturing* (1:2) 1995.

95. Wallace, D.R., and Ippolito, L.M. "Verifying and Validating Software Requirements Specifications," in: *Software Requirements Engineering*, IEEE Computer Society, 2000.

96. Walls, J.G., Widmeyer, G.R., and Sawy, O.A.E. "Building an Information System Design Theory for Vigilant EIS," *Information Systems Research* (3:1) 1992, pp 36-59.

97. Walls, J.G., Widmeyer, G.R., and Sawy, O.A.E. "Assessing Information System Design Theory in Perspective: How Useful was our 1992 Initial Rendition?" *The Journal of Information Technology Theory and Application (JITTA)* (6:2), 2004 2004, pp 43-58.

98. Wang, G., and Fung, C.K. "Architecture Paradigms and Their Influences and Impacts on Component-Based Software Systems," Proceedings of the 37th Hawaii International Conference on System Sciences, Hawaii, 2004, p. 90272.90271.

99. Yin, R.K. "The Case Study as a Serious Research Strategy," *Knowledge: Creation, Diffusion, Utilization* (3) 1981, pp 97-114.

100. Yin, R.K. *Case Study Research Design and Methods*, (Third Edition ed.) Sage Publications, Inc., Thousand Oaks, CA, 2003, p. 181.

101. Zadeh, L.A. "Fuzzy Sets," *Information and Control* (8) 1965, pp 338-353.

102. Zhang, Y., Thomas, D., Awazu, Y., and Desouza, K. "Human-Machine Strategies for Decision Support," Americas Conference on Information Systems, AIS, Tampa, Florida, 2003, pp. 2412-2416.

103. Zmud, R.W. "Executive Overview A Design Theory for Systems That Support Emergent Knowledge Processes," *MIS Quarterly* (26:3) 2002, p 179.