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14. ABSTRACT: This research was conducted to understand whether complex information processing affects team performance. Specifically, information monitoring complexity was analyzed. The study used both subjective and objective measures. The subjective measures assess team effects in terms of team situation awareness (SA) and team informity (information sharing). The objective measures were signal sensitivity (d'), time and accuracy, and detection time-- were used to analyze effects of task performance on the signal detection. There was no difference between the teams used in the study with respect to how they reported seeing the same thing (team SA) and team informity. For the team with 3 members, the distributions of the mean percentages of team SA tend to follow exponentially decreasing function (negative slopes) as the number of signal presented increases. The team with 5 members reported more team SA. It is not clear from these results whether teams with more members tend to identify more signals than teams with less number of members. It is possible that signal complexity and signal timing control may interact to affect signal monitoring performance—which in turn affects the way people report what they see under stress. The mean detection accuracy was more pronounced at signal timing control of 10-15 sec. Generally, the results show that signal complexity and signal timing control have effect on the dependent measures. The teams did not show any indication of differences in signal detection time.

15. SUBJECT TERMS
Collaborative team decision; Complex information processing; Detection sensitivity; Situation Awareness; Team informity

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EXECUTIVE SUMMARY

This research was conducted to understand whether complex information processing affects team performance. Specifically, information display monitoring was analyzed. The study used both subjective and objective measures. The subjective measures were used to assess team effect in terms of team situation awareness (SA) and team information sharing. The objective measures—signal sensitivity (d'), time and accuracy were used to analyze effects of task performance, specifically, signal monitoring. There was no difference between the teams used in the study with respect to how they reported seeing the same thing (team SA) and exchanging information (team informity). For the team with 3 members, the distributions of the mean percentages of team SA tend to follow exponentially decreasing function (negative slopes) as the number of signal presented increases. The team with 5 members reported more team SA. It is not clear from these results whether teams with more members tend to identify more signals than teams with less number of members (G3). It is possible that signal complexity and signal timing control may interact to affect signal monitoring performance—which in turn affects the way people report what they see under stress. This was indicated by the interactions between signal complexity and signal timing control. The distributions of mean team informity show increasing positive slopes under different signal timing controls. Team G3 shows the least report on information exchange among members at signal control time of 0-5 sec, but scored high when the signal timing was random. Team G5 exhibited more information sharing among its members at signal time control of 10-15 sec. Signal detection sensitivity was calculated across all experimental blocks. In team G3, single or multiple signals presented randomly (random time control) tend to reduce the operator detection sensitivity. It is not clear why three signals with timing control levels of 5-10 sec and 10-15 sec induce poor sensitivity. The best d' for G3 team occurs when monitoring 4 signals at 10-15 sec time control (d' = 5.15) and also when 2 signals are presented at the same time control. With G5 team, a higher d' occurs at a timing control of 5-10sec for a single signal monitoring task (d' = 2.96); the worst d' occurs when 2 signals are monitored under random time control. In this study, interactions for mean detection accuracy are more pronounced at signal timing control of 10-15 sec. G5 team shows two possible interactions at random signal timing for signal complexities 1 and 2, respectively. In terms of detection (response) time, both teams tend to perform almost without statistically mean difference.

CHAPTER 1
STUDY RATIONALE

The primary cause in many accidents is the Captain's failure to control, and the Co-pilot's failure to monitor. Crew members are the final opportunity to stop errors, but the crew are also human (http://www.wcupa.edu/_ACADEMICS/sch_cas.psy/Career_Paths/Aviation/subfield2.htm)

1.1 Prolegomena

To better gain the thematic knowledge of this report, let us review some incidents that can be attributed to computer display and visualization information processing in teams or at individual levels.

(a)   On April 12, 1999, BBC World News reported that a train was destroyed as a result of a timing error. Russia and China lodged protests after Nato's raid on a railway bridge hit a passenger train, killing 10 and leaving 16 injured. The Belgrade-Salonika train had been crossing the bridge near Leskovac, southern Serbia as the air-launched missile released several miles away reached its target. Showing missile-cone video footage of the attack, Nato's commander of European forces Gen Wesley Clark said: ***"You can see if you were focusing right on your job as a pilot how suddenly that train appeared. It was really unfortunate."*** In monitoring large-scale information systems, these "pop ups" are considered surprises or threat incidents to be watched for.

(b)   On April 14, 1991, many refugees were bombed as a result of mistaken identity. After days of speculation, Nato leaders said the alliance was responsible for two attacks on Kosovo convoys, both of which might have included refugees fleeing western Kosovo. The alliance said that its pilots had been hunting Yugoslav units burning out villages in western Kosovo but Serb media said the attack left 70 dead. The picture was further muddied after it was revealed that a recorded debriefing of a Nato pilot, released to the media, was not the airman responsible for the strikes. ***"This is a very complicated scenario and we will never be able to establish all the exact details," said US General Daniel Leaf.***

(c)   At the end of the Persian Gulf War, two American A-10 Warthog pilots fired on what they thought was an Iraqi armored column that turned out to be a group of British fusiliers and nine were killed. A senior military spokesman noted that perhaps the ***"telemetry information" may have been confusing.***

(d)   On April 18 incident at Tarnak Farms, near Kandahar, two Air Force pilots saw muzzle flashes at an established firing range 20,000 feet below and ***mistook them for antiaircraft fire aimed at their F-16's.*** One pilot dropped a 500-pound bomb, killing four Canadian soldiers and wounding eight.

The above scenarios capture some stories relevant to information processing—either in teams or individuals. In all cases, there are some elements attributable to complexity---such as "complicated scenario", "unexpected train appearance", "confusing", and "mistaken identity."

Decision making in time-critical, dynamic, and complex environments involves many complex processes that include, for example, the use of information display and visualization and teams of decision makers such as the military pilot and co-pilots. The information streams are a mixture of human and technology driven sensors. Singh, Tu, Allanach, Areta, Willett, and Pattipati (2006) observed note that *"Not only are the sources of information diverse, distributed, and possibly conflicting, but also the acquired information is very likely noisy, dynamic, incomplete, and uncertain.....The key issues involve not only identifying valuable information in a timely fashion, sharing this information across agencies in an efficient manner, but also integrating volumes of disparate information to support strategic decision making (pp.9)"*.

Decision making is the cognitive process of deciding upon a particular course of action based on available data. Cognitive Science has been able to create a substantial body of data on the decision process (Brehmer, 1984; Ho, 1980). Today, most of the decision making processes and the decision makers are supported in some way, by the use of computer information display and visualization models. This requires cognitive and neurophysical resources of the decision maker.

It is not clear how information display for teams involved in dynamic and collaborative decision making improves performance and mitigates occurrences of mishaps. Instances of information visualization currently range over many domains of human knowledge. For example, military and civilian command and control (C2) centers depend on information visualization to monitor, diagnose, and take actions during emergency conditions. In fact, in most cases, the information to be visualized is not static—as it changes according to real-time environment dynamics. More so, the displayed information is used by an individual or a team of decision makers for enacting the necessary system-level actions. Whether the information is presented for an individual or a team of decision makers, the density and volume of information presented to the human can be so overwhelming that it generates stressful conditions that may likely result in overburdened mental workload (Wickens, & Kessel, 1981), resulting in errors and costly accidents. The sample scenarios above illustrate these facts.

Having the right information at the right time is certainly helpful—often vital—for any decision making process. However, we recognize that too much information, or information that is presented in a way that overwhelms the human sensory or cognitive system can also fail to inform, impairing a decision making process.

1.2 Project Scope

The effect of complexity in information processing is addressed in this study because it provides a compelling view of the existing information-centric work domains. The scope of this project is limited to evaluating the performance of a team of decision makers (DMs) processing complex information during a crisis situation. The complexity is introduced by uncertainty of where the next crisis will occur, when it will occur, and

modalities of information communication between team members. Team characteristics such as differences in command and control policies and procedures, shared mental models, and shared situation awareness are used as important variables. Specifically, this research will emphasize the understanding of team characteristics as predictors of team performance in a complex information environment. The domain of signal monitoring that mimics an emergency situation is used to validate the hypotheses.

1.3 System Monitoring as the Major Task

Complex systems, such as urban traffic flow, air traffic control, or nuclear power plants are usually monitored by observing computer displayed information recorded by sensors placed at various locations in the system. Data from these systems must be monitored and crucial life and death decisions made by personnel within a short period of time. Exhibits 1-3 show examples of these kinds of systems.
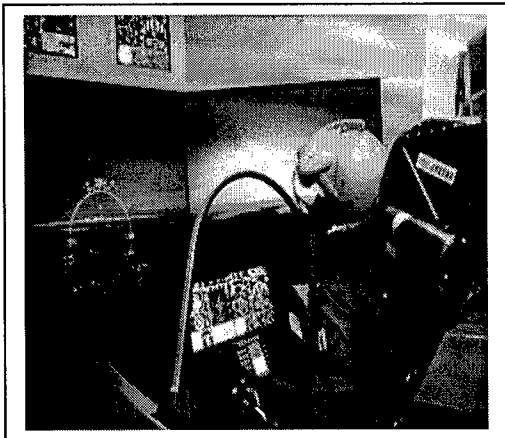
Exhibit 1: Cockpit Display
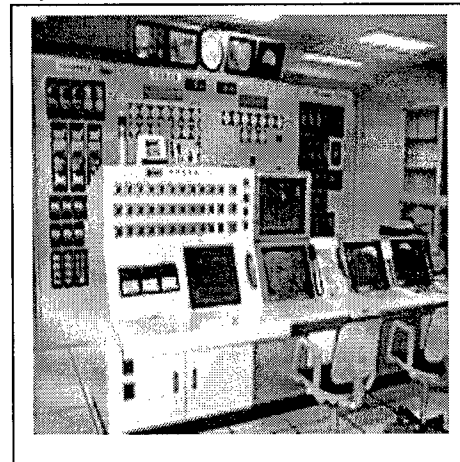
Exhibit 2. Nuclear Power Plant Display (Yokogawa, 2006)
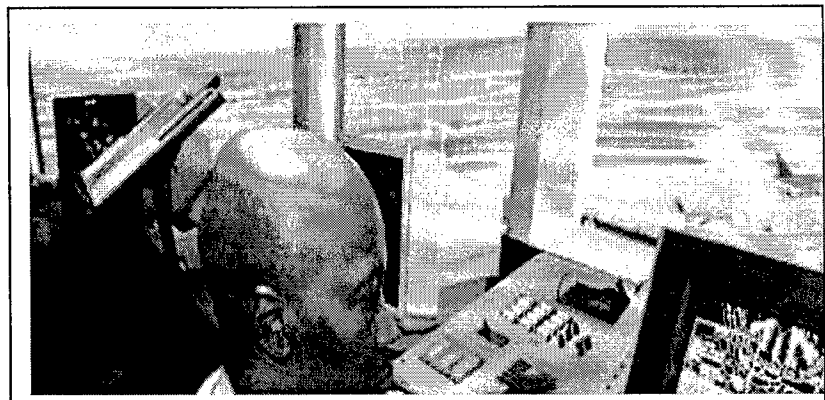
Exhibit 3. Air Traffic Controllers Monitor radar Screens to Help Aircraft Reach Their Intended Destinations Safely (http://www.bookrags.com/sciences/computerscience/aircraft-traffic-management-csci-03.html

Complex systems require increasingly sophisticated monitoring systems. Care must be taken to design secure systems that meet requirements and are perceived as accurate by the operators. Far too many accidents have taken place due to operators assuming that messages were false positives when, in fact, the alerts were accurate. A complex system has an area where there are constant false alarms coming from a monitoring system used to detect a security breach (Smith, 1995). Research in vigilance and automation monitoring provides the thematic understanding for experiments dealing with complex information processing of this report. The extent to which teams perform in making decisions using computer displays is assumed to be more realistic than studying single operator performance which is usually the norm in automation monitoring studies.

1.4 Consequences of Poor and Adequate Information Processing

Recent data has shown that human error is the leading cause of system unavailability in large-scale commercial data systems. The accident at Three Mile Island Nuclear plant is another example of a critically complex system where the monitoring process failed. Bignell and Fortune (1984) give a critical evaluation of the whole episode. Their conclusions show that the failure of one valve and the way the information was presented to the operators was the overwhelming cause of the disaster. The confusion in the data and the amount of signals to be monitored by the operators was too great for effective intervention.

There are three distinct problems associated with a human operator or a team of operators in a complex system of information processing and decision making. These are: visual search complexity, judgment errors, and poor prediction. When we are looking for objects in a visual scene, we often have to perform a time-consuming process called visual search, where we choose which objects to attend to and then perhaps perform additional mental processing on the attended items to find what we are looking for. Human Factors scientists have studied the mental processes that underlie visual search using a fairly standard paradigm, called a visual search task (Gai & Cury, 1976; Molloy & Parasuraman, 1996). In this task, a number of items are presented on a computer screen, and the subject searches for a known target item. Half of the trials contain a target item mixed in with distracter items, and half of the trials contain just distracter items. The subject in the experiment indicates on each trial whether the target is present or not, and the target-present and target-absent trials are presented in random order. Because this is usually a fairly easy task, the performance measure is how fast the subject responds with reaction time and number of errors committed (Eriksen, 1952; de Boer, 1966).

CHAPTER 2

COMPLEX INFORMATION PROCESSING ENVIRONMENT

2.1 Prolegomenon

C2 personnel working with dynamic and uncertain information face the challenge of continuing operations as well as surviving in a constantly changing environment. Complexity is an unavoidable part of modern work systems. Complexity theory attempts to tackle complex, interrelated systems by looking at the whole of the system, not just the component parts. Among these is how individuals or groups process complex and evolving information in a network of system of systems (Danielsson & Ohlsson, 1999)

Complexity is a relative term. Simon (1979) argues that information-processing psychology has been pursued at two levels: at the level of the "immediate processor" and at the level of "relatively complex human performances" (p. xi). Investigations of memory-scanning or sentence-picture verification (see, e.g., Clark and Chase, 1972) characterize the former approach, whereas the Simon and Kotovsky (1963) studies of letter series tasks are typical of the latter.

Difficulties relating to decision-making in complex problem solving domains can be exacerbated by uncertainty regarding available data and domain knowledge. A range of techniques exists to support decision-making processes, but a primary factor relates to information display.

The traditional definition of a complex system is that it involves a large number of dynamically interacting elements, leading to non-linear behaviors of the entire system or sub-systems (Cowan, Pines, & Meltzer, 1994). In today's information-centric society, complexity induces a network of interacting information in a dynamic environment—with evolving characteristics that involve uncertainties and equivocality.

2.2 Dimensions of Information Complexity

The state of the world can be predictable or unpredictable. Predictable states mean that the behavior of the system is deterministic—leading us to have some estimate of what the next system behavior will be. Unpredictable states of the world mean that we have no control of what will happen next. Dynamic complexity is a result of system whose state changes are either predictable or unpredictable with respect to time and changing patterns of information. Hill and Levenhagen (1995) note that unexpected cues within organizational information processing can lead to missed opportunities as a result of disoriented or misaligned mental models—leading to loss of meaning and construction of a mapping model that identifies with the situation. Table 1 illustrates these dimensions.

Table 1. Simplified Taxonomy of Complex Information System
Information Characteristics

The World	Deterministic	Random
Predictable	Simple	Complex
Unpredictable	Complex	Wicked

Some of the characteristics of information complexity that may affect decision making by individuals or teams of decision makers are:

1. Information is often highly ambiguous—leading to possible erroneous and multiple interpretations or understanding.
2. Information may have multiple meanings in a context.
3. Information patterns are dynamic and change in space and time.
4. Information has multi-traits, multi-scales, and multi-attributes.
5. Information states are usually unstructured, leading to disorganized processing by the human—e.g., mapping the human mental model to the information space.
6. Information presentation by technology display mode may create many forms of uncertainty—leading to situations where cause and effect linkages are not inherently knowable; e.g., effect of display compatibility (Wickens, 1992) or mental model capture (Johnson-Laird, 1998).

2.3 Information Processing and Task Complexity

The complexity of search and monitoring tasks has been shown to be an important factor in searchers' ability to find relevant information. The literature suggests many task characteristics related to complex information environment: information density, search and confirmation strategies, number of goals and conflicting dependencies among them, uncertainties, presentation format and modalities, number of inputs, cognitive and skill requirements, as well as the time-varying conditions of task performance (Bystrom and Jarvelin, 1995; Campbell, 1988). In a study by Ntuen and Rodgers (2002), information selection was found to be a limiting factor in determining predictive accuracy of signals presented randomly, with information processing being a limiting factor for the groups with heavy workload (measured by information density).

2.5 Visualizing Uncertain and Poorly Constructed Patterns of Information

Visual search is the cognitive process of finding particular data within a visual field. In crisis management, visual search occurs when a user responds to a situation and requires additional information, thus requiring the user to search the crisis management interface for the relevant information. Gilmour and his colleagues at Boeing (Snyder, 1970) have shown that for nearly all air-to-ground search conditions, the observer wastes more than 40 percent of his time in useless search activity during the period after the target has become available. Several studies have reported that search times are related to

the density or complexity of the background (Bloomfield, 1984; Eriksen, 1952; Drury, Clement, & Clement, 1978).

There is more than one way to classify how uncertainty can be visualized. One is by how uncertainty itself is represented; another is by how uncertainty is encoded into visualization. For the latter, there are two general ways of combining uncertainty into visualization: (a) mapping uncertainty information as an additional piece of data, and (b) creating new visualization primitives and abstractions that incorporate uncertainty information.

Information uncertainty is ubiquitous in almost every decision-making and problem solving situation. It is a major source and characteristic of complexity. Information uncertainty can be induced by time, location, events, situations, and tasks. For example, the path trajectory of a car driving on the highway can induce path uncertainty with respect to position and angle, often caused by speed, vehicle control, other vehicles and external information on the highway.

CHAPTER 3
COLLABORATIVE TEAM DECISION

Modern organizations, including the military establishments, are designed around coalitions, where two or more organizations with mutual goals, collaborate to pursue common goals. Typically, collaboration involves a situation where the collaborating entities share the same information space; the same interests; share the same mutual and consensus strategies. Depending on the composition of the collaborating organizations, managing the evolving collaborative behaviors can be complex.

The resurgence of research effort in military team decision-making has reverberated across military and civilian organizations as emergency and preparedness models are sought to counter the dreadful expectations of terrorism, both at home and in U.S. interests abroad. Emergency management offers varied challenges to the many facets of information processing—spanning across different organizational hierarchies to first responders in the field. For example, complex and interrelated plans from different command and control (C2) agents must be developed and executed in real-time. Limited resources must be carefully managed and coordinated, and time-critical, high-stake decisions must be made. Generally, the use of information display that captures the realism of ecological niches through various sensor mechanisms is the key to detecting potential system anomalies, such as terrorist threats, component failures, and other unwanted events in a system operation. Detecting these anomalies through predictive simulated scenarios will help decision makers to prepare for "worst case" situations in real world situations—an example is the recent catastrophe from hurricane Katrina.

In many work domains, such as aviation, pilots keep track of a dizzying amount of visual information while operating commercial and military aircraft. Air traffic controllers on the ground must remember the contents of their radar displays while executing multiple peripheral tasks. Similarly, in surface transportation, automobile drivers must remember the positions of other cars on the road while planning their route and attending to road signs, traffic lights, and dashboard instruments; the subway train operators are equally tasked to monitor many levels of sensor information that track inbound and outbound buses. By monitoring computer displays, most tasks involve team work: (1) the pilot and co-pilot team members; (2) two or more people monitoring urban traffic; (3) a team of physicians viewing the same display while making surgery decisions.

A significant body of literature exists on team decision making and collaboration. Horvitz (1999) characterizes the types of collaboration as follows:

- *Mixed initiative.* The parties to collaboration have a mixed initiative relationship. Any of the collaborating parties can propose information, interpretations and solutions to the problem being addressed.
- *Shared purpose.* The collaborating parties have a shared sense of purpose. There may be other goals of the parties that are not shared, or even openly contested, but the parties agree on the purpose of their collaboration.
- *Shared situation.* The collaborating parties must interpret the conditions of the environment in the same way. If the assessment of the situation is not the same at the start of collaboration, the parties must resolve the relevant differences.

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- *Shared planning.* The collaborating parties have a common set of expectations about the availability and applicability of methods to resolve the problem. A resolution to the problem requires consensus of the collaborating parties.
- *Communications.* A communications mechanism must exist to enable the collaborating parties to exchange information about the exercise of initiative ("rules of order"), joint purpose, situation and candidate problem resolutions.

Studies in team collaborative decision making have been conducted from different disciplinary viewpoints: social and cognitive psychologists (Burke, 2000), systems engineers (Handley and Levis, 2001), and organization theorists (Marks, Zaccaro, and Mathieu, 2000). The transition from traditional hierarchical team problems to distributive team decision-making has taken many modeling ideologies: from mathematical optimization (Miao, Luh, and Kleinman, 1992), normative-descriptive (Adelman, Zirk, Lehner, Moffett, and Hall, 1986) to cultural cognition studies (Klein, 2000).

A team interaction mental model and situation awareness (SA) have also been investigated, and results show that both hold information concerning the roles, responsibilities, communication patterns, and interactions among team members (Converse, Cannon-Boers, and Salas, 1991; Endsley and Pearce, 2001). Testimonies to their effectiveness reflect on many axiomatic definitions.

Wellens (1989, 1993) and Endley (2000) have distinguished between individual and team SA, with team SA referring to the sharing of an SA regarding system events (current and future status). Group SA can be defined as "the sharing of a common perspective between two or more individuals regarding current environmental events, their meaning and projected future status" (Wellens, 1989, p. 6). Group SA and sharing of information has been shown to be a critical factor in the performance of airline crews (e.g., Foushee & Helmreich, 1988). The accuracy of group SA depends not only on the shared information, but also on the shared "mental model" (Rouse, Cannon-Bowers, and Salas, 1992). According to Wellens (1993), the shared mental model includes: 1) a shared idea of how the group operates the system, and 2) a shared understanding of the system problem the group encounters.

CHAPTER 4
SOME RELEVANT HUMAN FACTORS ISSUES

4.1 Background

The study of collaborative team decision making and complex information processing constitutes a domain of inquiry for human factors engineers and scientists. The complex nature of the tasks—including task difficulties, task performance under stress, latent issues of personality and the nuances of collaboration—such as conflict management, pose specific challenges that must be resolved during the design evaluation and prior to fielding work design plans that involve human and automation. Many human opportunities in the context of this study include, but are not limited to: issues in working memory (WM), attention and WM capacity, controlled versus automatic processing, change blindness, shared situation awareness (SSA), and team mental models. For this study, we will measure SSA and to some extent, use signal detection theory (SDT) to capture some aspects of team vigilance. A review of some of these human factors concerns are summarized below.

4.2 Memory Systems

The psychological mechanisms that store information relevant to the task at hand are referred to as working memory (WM). The standard theory of WM includes separate stores for verbal information and visual information (Baddeley, 1986). The earliest information-processing models posited one or more sensory buffers, a limited-capacity short-term memory, and an unlimited long-term memory. However, the old notion of a relatively passive, limited-capacity short-term memory has been replaced by a more active working-memory system that not only holds and manipulates information (Daneman & Carpenter, 1980), but also attends selectively to one stimulus while inhibiting another, coordinates performance on tasks, and switches strategies (Baddeley, 1986). Oberauer et al. (1996) summarize these processes as (1) simultaneous storage and processing, (2) supervision or monitoring, and (3) coordination.

Fockert, Ress, Frith, & Lavie (2001) tested the hypothesis that working memory is crucial for reducing distraction by maintaining the prioritization of relevant information. The test used neuroimaging and psychological experiments with humans. Participants performed a selective attention task that required them to ignore distracter faces while holding in working memory a sequence of digits that were in the same order (low memory load) or a different order (high memory load) on every trial. Higher memory load, associated with increased prefrontal activity, resulted in greater interference effects on behavioral performance from the distracter faces, plus increased face-related activity in the visual cortex. These findings confirm a major role for working memory in the control of visual selective attention.

4.3 Attention and Working-Memory Capacity

Visual attention is particularly important to assess in monitoring tasks. In general, information monitoring consumes between 20 percent and 50 percent of visual attention,

(Hughes and Cole, 1986). In complex task processing, it will be of interest to understand the human ability to process information in parallel or in a time-sharing manner.

4.4 Controlled and Automatic Processing

The controlled versus automatic processing distinction refers to the degree to which a knowledgeable or skillful performance requires conscious attentional resources for successful operation. Automatization occurs when cognitive tasks are consistent in their information-processing demands such that a transition from controlled to automatic processing can occur with practice. Controlled processes are voluntary, require attention, and are relatively slow, whereas automatic processes are fast and do not require attention for their execution. Performance of novel tasks is typically thought to rely on controlled processing; however, with extensive practice, performance of some tasks can become automatic (Posner & Snyder, 1975; Schneider & Shiffrin). Information processing enabled by display automation in complex work systems remains a fertile ground to validate the performance of single versus team operator performance.

4.5 Change Blindness and Detection

In the change-detection procedure, people have to remember a briefly presented visual display in order to compare it to a second display and detect any differences between the two. Change blindness is the induced failure to detect changes in a display (Rensink, O'Reagan, and Clark, 1997). This blindness to change is due to the failure to notice unattended objects in the direct line of sight. Change blindness typically occurs when the visual scene is changed and the eyes are in motion.

Regardless of the type of environment, it has been shown that humans have difficulty in detecting changes in scenes (Rensink, et al., 1997). An object often changes position within a display or disappears completely and the observer's eyes come to rest without noticing the change in magnitude or position. O'Regan (2000) provides an overview of the findings applied to the way humans build internal representations with an emphasis on the criticality of attention in detecting changes.

Vogel et al. (2001) presented more evidence for a longer-duration visual store. They used a change-detection task with displays consisting of colored squares, as illustrated in Figure 1.In a trial in their experiments, a display was presented for about 100 ms, next the screen remained blank for 900 ms, and then a second display appeared that was either identical to the first or differed in the color of one square (e.g., in Figure 1, the stimulus on the lower right has changed color). Participants determined whether or not the displays were identical. Vogel et al. showed that response accuracy declined as the number of squares in each display increased, suggesting that there was some limited capacity system for retaining the squares from the first display. Further analysis suggested that participants retained approximately four items' worth of information from the first display. Requiring participants to remember two digits while performing the change-detection task had no effect on performance, suggesting that storage was not verbal. Thus, there is some evidence that unsupported visual representations can be retained, and that retention is in the form of a visual code—such retention would be mediated by visual working memory.
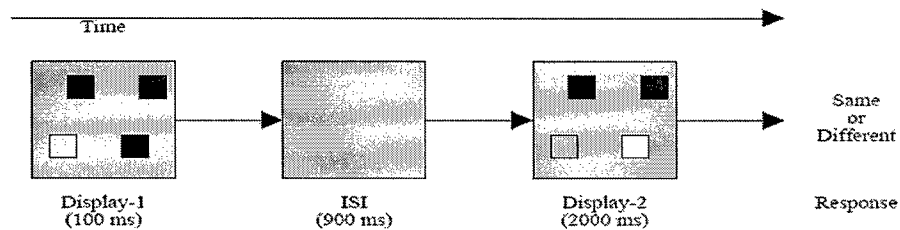
Figure 1:   Illustration of the Visual Change-Detection Task used by Several
             Researchers (e.g., Vogel, Woodman, & Luck, 2001). *Note: Stimuli
             are not drawn to scale.*

4.6 Shared Situation Awareness

Solving complex problems involves several cognitive tasks that are often studied separately. These include situation awareness (SA), decision making, and visual search. Situation awareness (Endsley, 1985) is the cognitive process of becoming aware of numerous pieces of data, relating them to each other and projecting their effect on future system states with respect to the user's goals. In crisis management, SA occurs when users notice and respond to events such as fires, emergencies, and road blockages (due to floods, lava flows, high winds, snow, etc.). Although neither the concept nor the measurement of SA has been fully developed, several reports have explored the potential and the problems of the situation awareness concept. According to Endsley (1985), SA is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future. This definition lends itself to defining specific levels of situation performance:

- *Level 1 Situation Awareness*: perception of the status, attributes, and dynamics of the individual task-relevant elements in the environment;
- *Level 2 Situation Awareness*: holistic comprehension of the current situation, based on a synthesis and understanding of these elements in light of one's goals; and
- *Level 3 Situation Awareness*: projection of the future actions of these elements in the environment, at least in the very near term.

The perception of elements within the environment (Level 1) is principally guided by the contents of working memory and long-term memory that direct attention, recognition, and categorization. Once perceived, the information is hypothesized to reside in working memory where it is combined with existing knowledge to develop a composite picture of the situation.

4.7 Team Mental Models

Mental models are representations of reality that people use to understand specific phenomena. Norman (in Gentner & Stevens, 1983) describes them as follows: "In interacting with the environment, with others, and with the artifacts of technology, people form internal, mental models of themselves and of the things with which they are

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interacting. These models provide predictive and explanatory power for understanding the interaction."

The existence of mental models is widely asserted in the literature. They are often used in a way that is synonymous with "knowledge" in general (Rouse Cannon-Bowers, Salas, 1992). However, according to Holyoak (1984, p. 193), a mental model is a "psychological representation of the environment and its expected behavior." By adopting a functional approach, Rouse and Morris (1986) state that the role of mental models is to provide a conceptual framework for describing, explaining, and predicting future system states.

4.8 Human Performance: Individuals versus Teams

Increasingly, organizational research is reflecting the fact that team strategic decisions are often made by groups instead of individuals acting alone (e.g., Axelrod, 1976; Orasanu & Salas, 1993). Thus, several constructs which have been traditionally considered at the individual-level of analysis are now being recognized as group-level phenomena. A recent review of group research described the development of "shared understanding" as an essential group process (Bettenhausen, 1991, p. 350).

It has often been thought that automation would reduce mental workload, but the work of Edwards (1976) and Weiner (1988) have shown this to be untrue. The work of Sheridan (1987) has shown that in some cases the workload with automation is greater than with manual control. Traditionally monitoring has been considered to be a low stimulus task leading to the problem of 'vigilance deficit' (Duffy 1957). Signals are usually clearly perceivable when observers are alerted to them but are not compelling changes in the observers' operating environment. In addition, the signals are usually embedded in a context of recurrent non-signal (neutral) events, which, unlike signals, require no overt response from observers. Idaszak and Hulin (1989) completed one set of experiments on the effects of monitoring automation with decision making tasks. They used subjects to simulate process control tasks, one set were active where the subjects were in control of the process and monitored it at the same time and the other where they were passive observers only. The active group was faster at detecting out-of-limit conditions and alarms than the passive monitors. In contrast Wickens and Kessel (1979) found that error detection was better in automated rather than manual assignment conditions. Hilburn, Jorna & Parasuraman (1995) examined Air Traffic Control simulation in Netherlands airspace and found benefit for automation on monitoring performance.

CHAPTER 5
DESIGN OF EXPERIMENT

5.1 General Note

The following experimental design components were consistent across all experiments

- Criteria used to screen participants.
- Apparatus used for the experiments.
- Design of the experimental scenarios.
- Procedures and protocols for administering experiments.
- Statistical Analysis Software (SA) was used to perform all analysis.[1]

5.2 Participants

Sixty students aged 18 – 26 years (mean age = 23.7; standard deviation = 3.45) participated fully in the study; 36 participants were males and 24 were females. The participants were undergraduates and graduate students from North Carolina A&T State University. To be eligible for participation, the subjects needed normal to corrected normal vision and possess normal color vision. All participants used in the study met the prescribed criterion after initial screening of a pool of volunteers. The 60 participants were randomized into two groups of three (G3) and five (G5) as follows: (1) The G3 group had 3 members in a team and participated in one experimental trials for a total of 10 experimental trials; (2) The G5 group had 5 members in a team and participated in one experimental trial for a total of 6 trials. The students either did so voluntarily or were compensated through a class grade through agreement with a class instructor.

The sixty students used in the experiment were determined by using statistical power of test analysis. The power of test is the probability or the ability of the test to detect an effect if it exists. The estimation approach in conjunction with assumed values for the expected standard deviation and margin of error was used to estimate the required sample size for a known power. The power is indicated by $(1-\beta)$, where β is the probability of Type II error (false hypothesis is accepted). The significance level $(1-\alpha)$ where α is the probability of Type I error (true hypothesis is rejected) typically varies from 0.90 to 0.99. In general power, the higher the alpha value, the lower the power.

5.3 Apparatus

A Gateway E-Machine Pentium IV computer with a 15-inch (viewable space) flat panel monitor was used to display the experimental scenarios. A computer program was developed to mimic emergency incidents with a decision support tool called

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[1] Dilorio, F.C. (1991). SAS: Applications Programming: A Gentle Introduction. Belmont, CA: Duxbury Press.

MERMAIDS-- *Medical Emergency Response* using *Military Asset in an Integrated Decision Support (MERMAIDS)*[2]. Figure 2 shows a screen capture of the MERMAIDS interface with possible location of incidents and the resources for emergency respond.
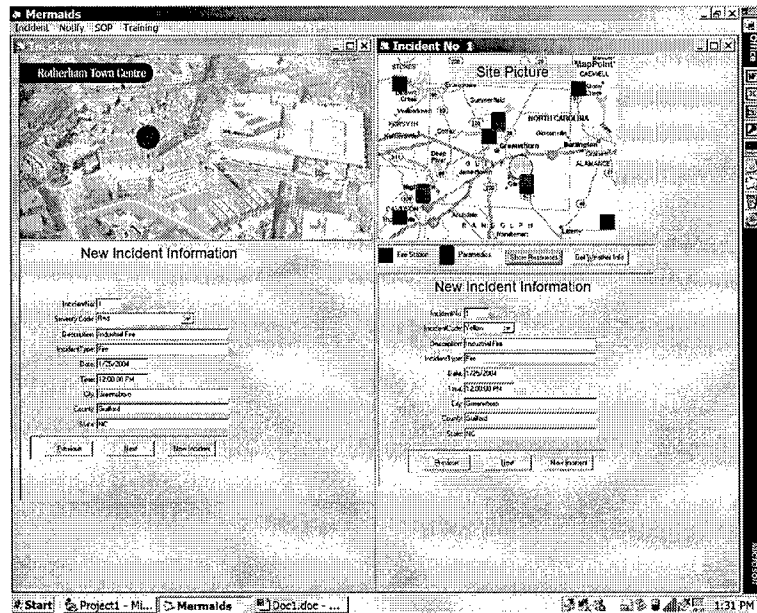

Figure 2.   Sample MERMAIDS Screen with Incident Map (right side) and Incident Aerial Photograph (left side). The red circle shows current point of incident.

5.4 Information Complexity Test and Scenario Design

Information complexity was mimicked with occurrences of emergency incidents by using computer display signals to indicate the points of incidents. The signal grouping varies from one to four—this is known as signal complexity (SC). To add complexity to the signals, timing was used to control the level of signal duration. The smaller the time duration, the more difficult it is to detect a signal (Sanders & McCormick, 1992). Four control timing durations were utilized: T1 (0-5) sec, T2 (5-10) sec., T3 (10-15) sec. and Random (0-15) sec. In the random signal timing, the time was generated using a uniform distribution with minimum value of 0 and maximum value of 15 seconds. A higher number of SC with shorter timing defines the most complex scenario. The scenarios illustrate samples of signal monitoring of customers in a security center in a large urban mall, such as the Mall of America in Minneapolis. Equivalently, it mimics the pilot who must decide whether to hit a hostile target or not—for example, Case 3 in Chapter 1 of this report in which two American A-10 Warthog pilots fired on what they thought was an Iraqi armored column that turned out to be a group of British fusiliers and nine were killed.

For a single signal presentation, it is assumed that the tasks involved almost completely a priori determinable. It is generally clear what information is required, how

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to find the information and how to assess relevance. However, when a "pop–up" anywhere concept is embedded with signal timing, the issue of spatio-temporality introduces a new level of complexity—making some parts of the search process or information needed difficult. In our experiments, signals are presented to balance search process against prediction process. Thus, it is assumed that it is unclear what information is being sought, how to obtain relevant information and how the searcher will know where to find relevant information. This is even problematic when people are searching for the same pattern of information in groups.

5.5 Methodology

5.5.1 Design of Experiment

The experiment was designed to gather information on (a) Effects of team on complex information processing and (b) Effects of information complexity on team detection sensitivity. Two groups of participants, G3 and G5 discussed above were used. Members were randomly assigned to a group with no homogeneity in a group—that is, a relative representation of genders as shown of 60% (male) to 40% (female). For the experiment, issues of personality psychology, expertise, and learning styles were not of interest. Each experiment starts with a random presentation of signals so that the complexity was balanced. Each signal was presented under four timing duration controls—T1, T2, T3, and Random. Again, the sequence of timing and signal complexity were random to counter any possibility of sequence memorization by any of the participants. Table 2 shows the skeleton layout of the experimental design. Statistically, the design is 2*4*4 between groups and within signal and timing design.

Table 2. Skeleton Layout of the Experiment Design

					Team Composition			
			G3			G5		
SC	T1	T2	T3	Random	T1	T2	T3	Random
1								
2								
3								
4								

5.5.2. Measurement
Dependent Variables: The dependent variables are:
  (a) Team SA (TSA): This is obtained by asking team members to describe, by pressing the dedicated computer key, what they see when a signal is presented. The data is summarized into percentage as a total count of report on "seeing the same thing."
  (b) Team Informity (TI): This is obtained by tallying the observations on how the team members communicate. Team informity is defined by Hang (2001) as "….. the degree to which the team members access all relevant data, particularly target

attributes---." TI values ranges from 0 (minimum) to 1(maximum).The data is summarized into percentage of report on "Telling others what you see."

    (c) Team Detection Sensitivity (TDS): This measures team detection sensitivity in processing the displayed information.

    (d) Team Detection Accuracy (TDA): This measures the team signal detection accuracy. Data is obtained on true detection rate (true positive detection).

Independent variables:

The independent variables consist of:

    (a) the two teams (G3, G5),

    (b) four levels of signal complexity (1,2,3,4; and

    (c) four levels of timing control (T1, T2, T3, and Random).

5.6 Experimental Procedures

Participants were greeted and thanked for their willingness to participate in the experiment. Participants were provided a short briefing about the experiment including requirements, experimental objectives, and time requirements. Those participants that did not meet the requirements or were not willing to participate were dismissed from the study after the color test and "20/20" eye test. Participants were then given a more comprehensive briefing of the experiment and experimental objectives. Participants were provided with the required Internal Review Board (IRB) content. Participants were asked to sign a consent form that indicated that they understood and voluntarily agreed to the conditions outlined in the experimental briefing. Agreed participants were told that they may withdraw from the study at any time.

Participants were told that they will work as a team by monitoring the MERMAIDS computer screen for incidents that will show up as a red circle. The incident resembles a traffic light and will follow a life cycle of "red-green-yellow-red". The participants are to press the signal number using the computer mouse when the signal turns red—indicating a possible time to respond. The color signals are randomly generated using a Poisson distribution with mean of 1200 msec. Pressing on a yellow signal indicates false alarm, and pressing on a green signal indicates a missed opportunity. After given general logistical instructions and time to adjust their workstation for comfort, participants were given specific task instructions. The participants were trained for 60 minutes with sample trial scenarios, and were instructed to come back after one day for the experiment sessions. All group members had to be present for the experiment to take place.

The experimenter was in control of presenting all scenarios by running different scenarios from the MERMAIDS software. Each experimental scenario took an average of 48.3 minutes for G3 group with three members and 55.1 minutes for G5 group with five members. Group G3 took a total of 7.4 hours to complete all scenarios (10 scenarios), spanning a schedule of three sessions offered in alternate days. Group G5 took a total of 8.3 hours to complete all scenarios (6 scenarios) spanning a schedule of four sessions offered in alternate days to G3 group. Three computer monitors were used to display information for the G3 group and four were used of the G5 group. A local area network

(LAN) protocol with common video display card was used to achieve these "common picture" scenarios. The set up duplicates a traffic monitoring center for a major urban city (See Exhibit 4 below). All group members have a workstation collocated to allow discussions and information sharing. As the signal is presented, the group members will discuss among themselves and press a dedicated "F3" key on the computer keyboard to indicate if they "see the same incident signal". The G5 group will use "F5" for the same purpose. A video camera was used to capture how the team members exchange information (latter used to define team informity).
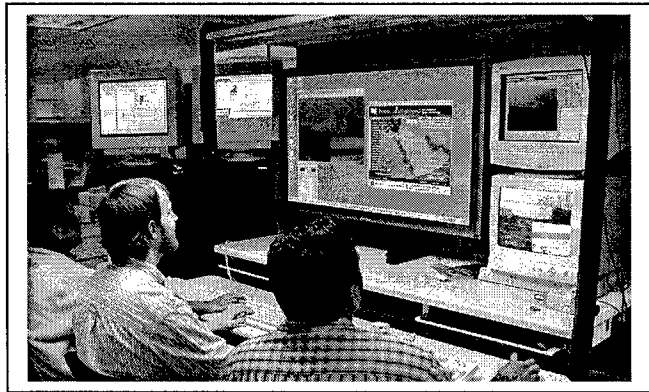
Exhibit 4. Sample Collaborative Team Using the Distributed MERMAIDS Information

5.7 The Experiment

The team members are assigned their respective workstations. The experimenter starts the scenario by selecting appropriate time controls and signal levels. This is shown in Figure 3. After the selection, the MERMAIDS system is activated with the respective signals, see, e.g., Figure 4.

Figure 3. Signal and Time Control Selection.　　　Figure 4). Sample Screen with Three Signals with Two Imminent Threats

The participants used a computer mouse to click on the respective signal, e.g., Figure 5.

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Figure 5.   Sample Screen Where the User Clicks to Indicate Which Signal is
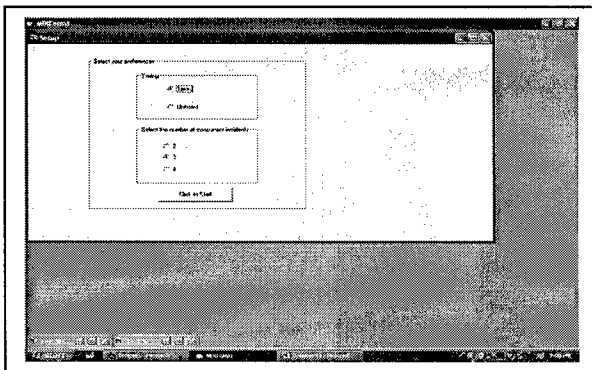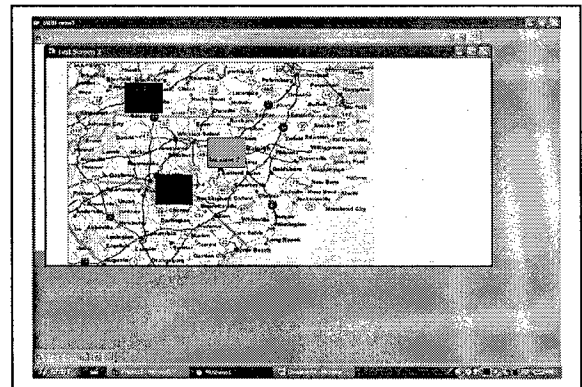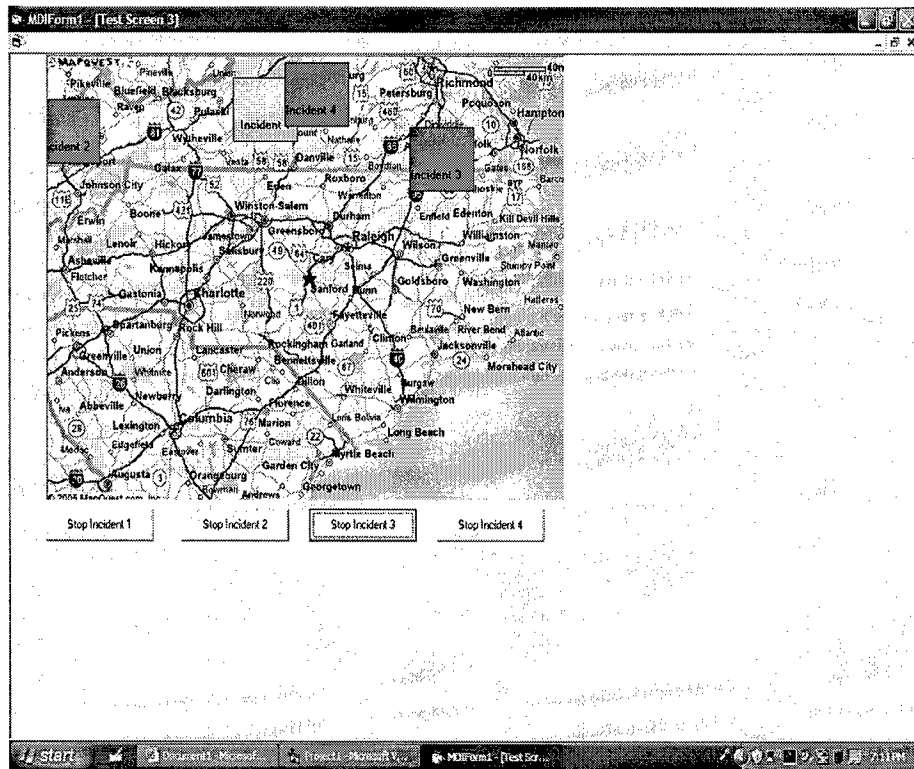Recognized in Multiple Signal Situation

CHAPTER 6
DATA COLLECTION AND ANALYSIS

6.1 Data Collection

6.1.1 Team Dimension Effect

Data was collected and summarized on team SA (TSA) and converted into average percentage equivalents. This is shown in Table 3. Similarly, Table 4 shows average team informity reflecting the frequency of information exchange. The data from team informity was obtained by reviewing a video that captures the frequency of communication between team members. Figures 6 and 7 shows the graphic plots of information on Tables 3-4.

Table 3: Team SA (Percentage of Members Reporting Seeing the Same Thing)

	(0-5)sec		(5-10)sec		(10-15)sec		Random (0-15)sec	
Signal Complexity Level	Team=3	Team=5	Team=3	Team=5	Team=3	Team=5	Team=3	Team=5
1	70	85	96	96	200	100	77	90
2	60	80	90	83	92	98	85	85
3	55	75	67	80	80	89	70	81
4	35	55	50	62	75	80	55	68

Table 4: Team Informity (Average Percentage of Members Telling Others What They See)

	(0-5)sec		(5-10)sec		(10-15)sec		Random (0-15)sec	
Signal complexity (n)	Team=3	Team=5	Team=3	Team=5	Team=3	Team=5	Team=3	Team=5
1	10	20	30	45	35	50	28	35
2	55	60	65	60	65	65	60	68
3	68	77	70	75	78	85	70	87
4	75	80	85	90	90	90	90	95

As shown in Figure 6, the distributions of mean percentage TSA tend to show exponentially decreasing function (negative slopes) as the number of signals to be monitored increases. At signal control time of 10 to 15 sec; team G3 shows the least mean % TSA, while team G5 shows most reported TSA. It is not clear from these results whether teams with more members tend to identify more signals of interest.

In Figure 7, the distributions of mean percentage team informity tend to show an increasing exponential function (positive slope) under different signal time controls. Team G3 shows the least report on information exchange among members at signal control time of 0-5 sec, but scored high when the signal timing was random. Team G5 exhibited more information sharing among its members at signal time control of 10-15

sec. The performance of the teams at signal control time of 0-5 sec confirms the degradation performance under stress (see, e.g., TADMUS study ; Freeman & Wolf, 1996). The increase in information sharing after latency (i.e., after individual or group search for signal) may be responsible for the average increase on informity metric between 10-15 sec signal timing controls.
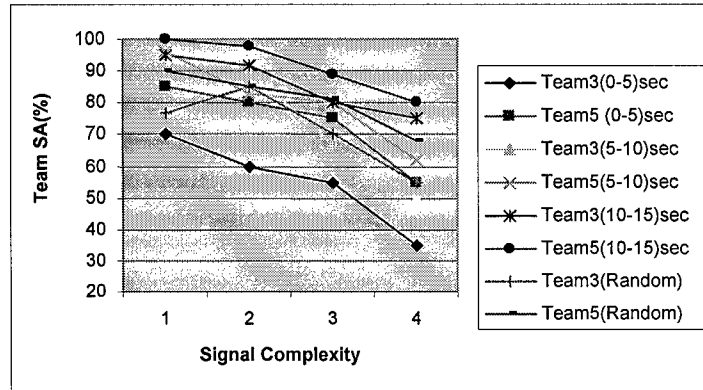

Figure 6. A Plot of Team SA Report by Teams
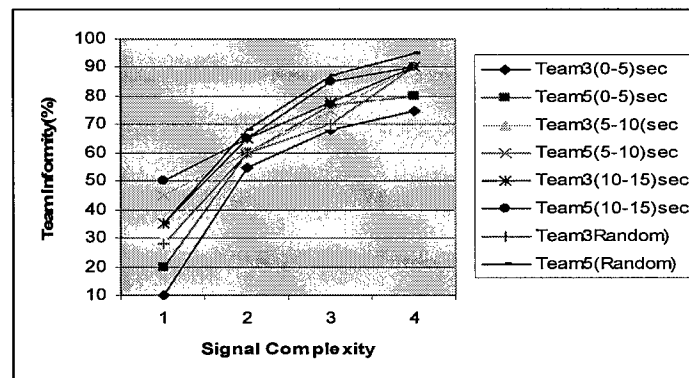
Figure 7. A Plot of Team Informity Reported by Teams

6.1.2 Detection Accuracy

Data on signal detection accuracy was collected for all conditions and the two teams. Table 5 shows the data for groups G3 and G5. The corresponding bar charts are shown in Figures 8-9, respectively.

Table 5: Average Signal Detection Accuracy (%)

Signal complexity	(0-5)sec		(5-10)sec		(10-15)sec		Random (0-15)sec	
	Team=3	Team=5	Team=3	Team=5	Team=3	Team=5	Team=3	Team=5
1	90.33	91.7	92.67	93.6	91.3	98.4	88.9	85.6
2	80.65	84.1	90.16	89.5	95.6	94.4	81.5	86.1
3	79.7	80.55	88.24	90.8	94.3	91.7	79.67	80.66
4	77.5	80.2	83.6	88.4	85.3	93.22	74.3	70.3

Figure 8: Frequency Plot of % Detection Accuracy for a Team of 3 Members (G3)

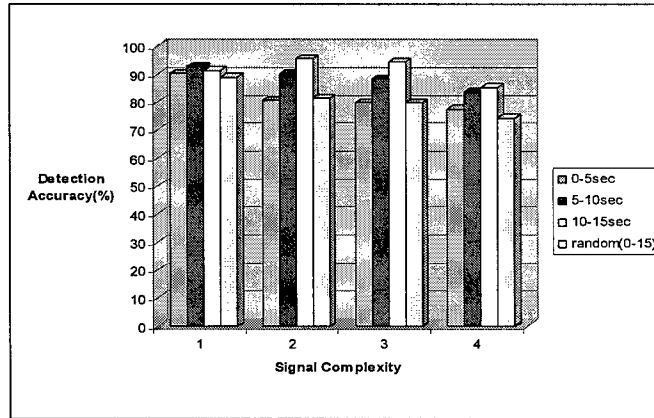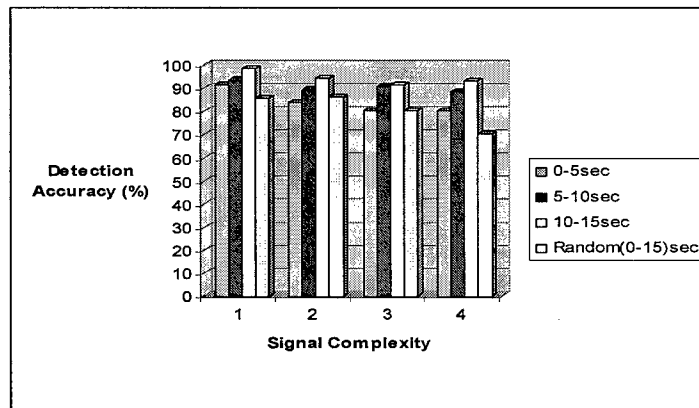Figure 9: Frequency Plot of % Detection Accuracy for a Team of 5 Members (G5)

6.1.3 Detection Response Time

Data on signal detection time (in msec) was collected for all conditions and the two teams. Table 6 shows the data for groups G3 and G5. The corresponding bar charts are shown in Figures 10-11, respectively

Table 6: Average Signal Detection Time (msec)

Signal complexity	(0-5)sec		(5-10)sec		(10-15)sec		Random (0-15)sec	
	Team=3	Team=5	Team=3	Team=5	Team=3	Team=5	Team=3	Team=5
1	110	88	95	80	70	55	100	82
2	256	230	205	150	100	98	175	170
3	717	645	610	520	430	320	540	610
4	826	730	715	680	610	450	652	580

Figure 10: Signal Detection Time by G3 Team

Figure 11: Signal Detection Time by G5 Team

6.1.4 Signal Detection Sensitivity Analysis

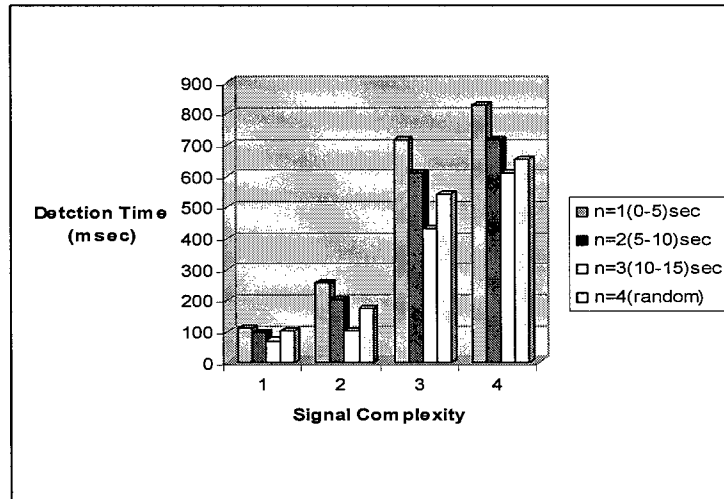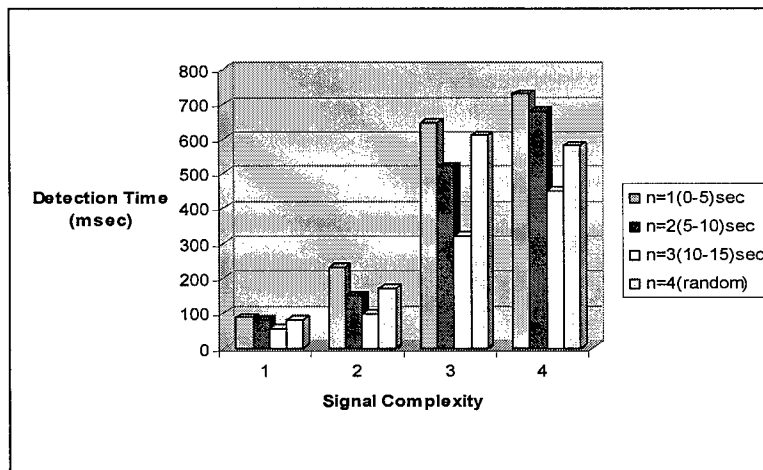Signal detection theory (SDT) provides another tool for analyzing signal detection data. The SDT allows for the quantification of human tendencies to make correct judgments, misses, and false alarms. Such quantification serves as an analytical metric to measure human performance in signal detection tasks (Wickens, 1984). Signal detection theory was used to measure the participant's ability to discriminate incidents considered to be a threat by judging whether the signal is present or absent. The SDT is a function of two processes: the observer's perceptual sensitivity and response bias. This theory enables separation of the effects of perceptual sensitivity, in this case, the observer's ability to discriminate signal occurrence from response bias. Response bias represents the observer's willingness to say "yes" or "no."

In a signal detection experiment, events can be categorized in a 2 x 2 matrix showing the event that occurred and the observer's response to that event. Figure 7 shows the four possible categories. A hit is said to occur when a signal is present and the observer reports that the signal is present. A false alarm occurs when a signal is absent and the observer reports that the signal is present. A miss occurs when a signal is present

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and the observer reports that the signal is absent. A correct rejection occurs when a signal is absent and the observer reports that the signal is absent. Table 7 illustrates this situation.

Data on signal detection frequency was collected for all conditions and the two teams. Tables 8-9 show the data for groups G3 and G5. Figures 12- 16 are used to capture the Relative Operating Characteristics (ROC) based on the Equation 1 (Swets, 1996):

$$h = p \ (1\text{-}p)f \qquad\qquad\qquad (1)$$

where h is the probability of a "hit"; f is the probability of "false alarm", and p is the "hit" probability corrected chance success, and is often defined by $p = (h\text{-}f)/(1\text{-}f)$. In Tables 8-9, true positive is denoted by "TP", and false positive by "FP". Both FN (false negative) and TN (true negative) are redundant information for signal detection analysis. The ROC plots for different experimental scenarios are shown in Figures 12-16.

Table 7. An Illustration of Signal Detection Data Classification

	Participant's response Yes	No
Signal Present	TP	FN
Signal Absent	FA	TN

In Figures 12-16, the lower parts of the ROC indicate less sensitivity of the observer to signal. As will be described in the next section, the metric, d' (pronounced D prime) is used to detect the levels of the sensitivity for specific signal strengths.

Table 8: Hit Rate (True Positive) and False Alarm (False Positive) Counts for 3 Team

Signal Complexity	Timing→ TP	(0-5) sec FP	TP	(5-10)sec FP	TP	(10-15)sec FP	TP	Random FP
1	10	6	8	10	12	6	9	12
2	12	6	16	6	15	0	14	16
3	15	9	18	12	20	7	19	10
4	13	5	14	11	22	0	24	15

Table 9: Hit Rate (True Positive) and False Alarm (False Positive) Counts for 5 Team

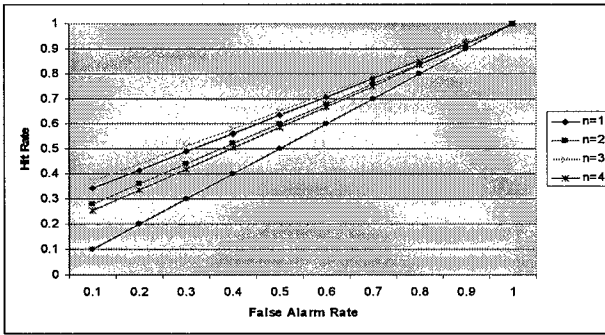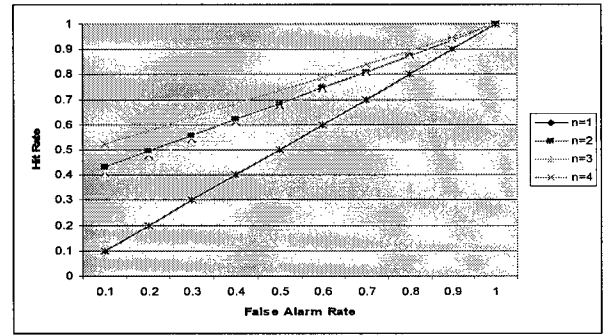| Signal Complexity		(0-5) sec		(5-10)sec		(10-15)sec		Random
	TP	FP	TP	FP	TP	FP	TP	FP
1	12	10	16	8	20	3	14	8
2	15	11	14	10	18	9	18	10
3	10	10	17	7	16	5	12	12
4	12	14	16	10	16	6	16	10

Figure 12(a): ROC for (0-5 sec);G3

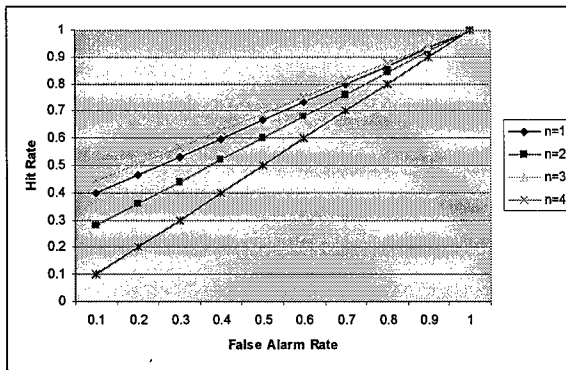Figure 12(b): ROC for (0-5 sec);G5

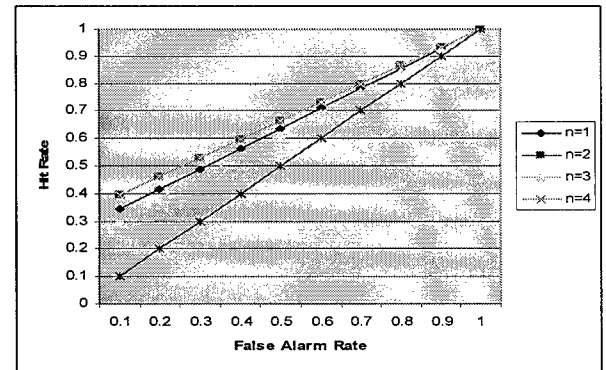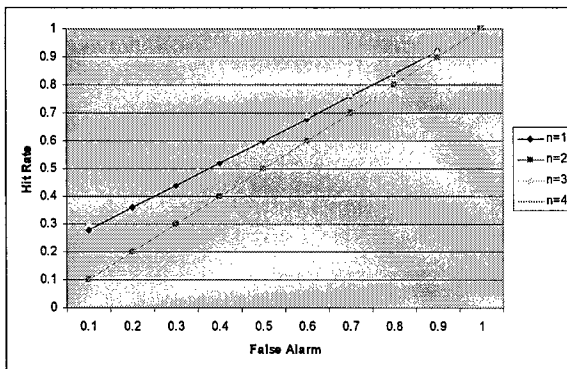
Figure 13(a): ROC for (5-10 sec);G3

Figure 13(b): ROC for (5-10 sec);G5

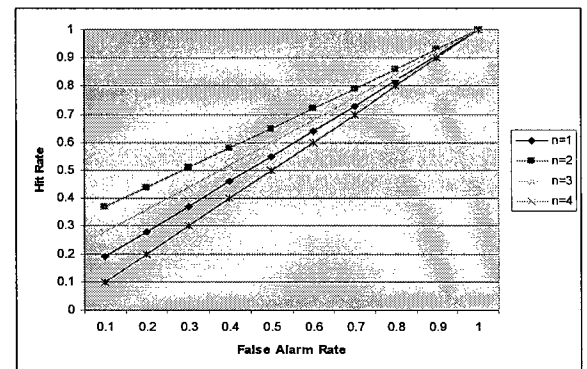Figure 14(a): ROC for (5-10 sec);G3
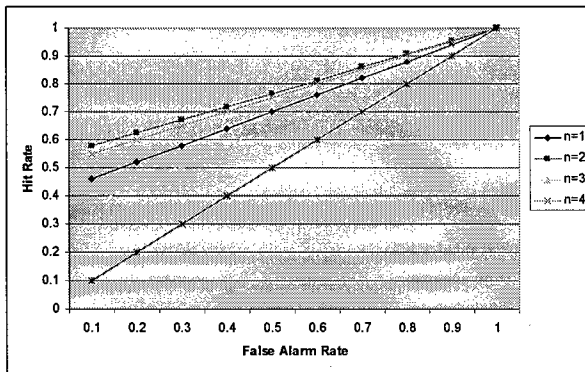

Figure 14(b): ROC for (5-10 sec);G5

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Figure 15(a): ROC for (5-10 sec);G3
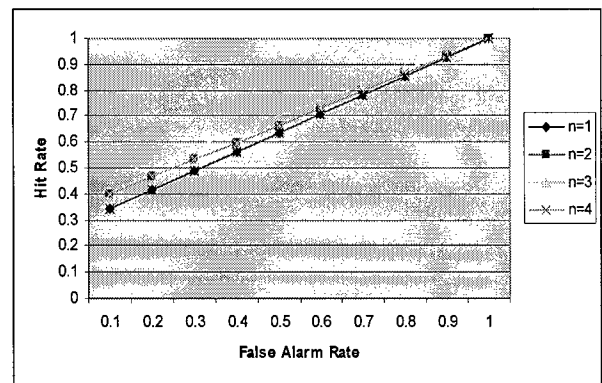
Figure 15(b): ROC for (5-10 sec);G5

6.1.5 Signal Detection Sensitivity (d')

Sensitivity is measured typically by an index called d'. The sensitivity, d' is a statistic that measures the difference between "hit" rate and "false alarm " rate. However, d' is not simply a geometric distance; rather, it is the difference between the z-transforms (assumes a normal distribution with mean zero and standard deviation, 1) of these 2 rates (Green and Swets, 1988) and is denoted by Equation 2 as:

$$d' = z(H) - z(F) \qquad\qquad (2)$$

Tables 10 and 11 shows the calculated d' for teams G3 and G5, respectively. The higher values of d' measures how good the signal is detected by the group. For example, in team G3, single or multiple signals presented randomly (random time control) tends to reduce the operator sensitivity. It is not clear why three signals with timing control levels of 5-10 sec and 10-15 sec induce poor sensitivity. The best d' for G3 team occurs with monitoring 4 signals at 10-15 sec time control (d' = 5.15) and also when 2 signals are presented at the same time control. With team G5, higher d' occurs at timing control of 5-10sec. for a single signal monitoring task (d' = 2.96); the worst d' occurs when 2 signals are monitored under random time control.

Table 10: Detection Sensitivity (d') Values for Group with 3 Team Members (G3)

Signal Complexity	(0-5)sec	Time (5-10)sec	Control (10-15)sec	Random
1	0.35	0.7	0.63	-0.04
2	0.64	1.69	4.07	0
3	0.26	0	-2.27	-1.75
4	0.78	1.84	5.15	-1.64

Table11: Detection Sensitivity (d') Values for Group with 5 Team Members (G5)

		Time	Control	
Signal Complexity	(0-5)sec	(5-10)sec	(10-15) sec	Random
1	0.36	2.96	0.48	0.97
2	0.75	-0.47	0	-2.22
3	0.23	0.91	1.11	-0.41
4	0	0.85	1.18	0.22

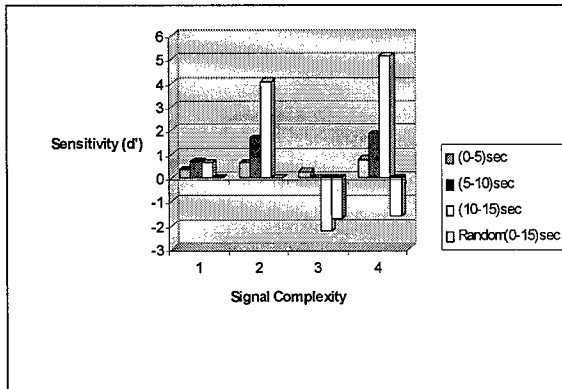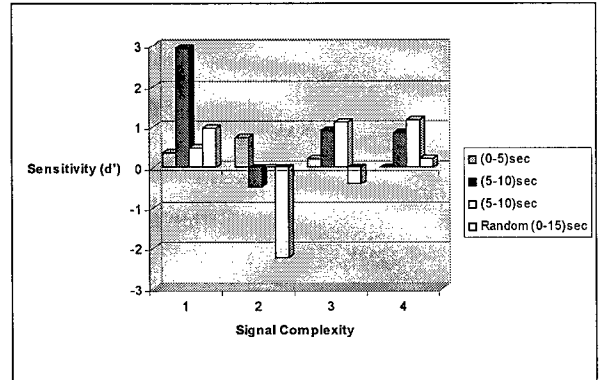Figure 16(a): d' for a Team of 3 Members (G3)

Figure 16(b): d' for a Team of 5 Members (G5)

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CHAPTER 7
PERMANCE ANALYSIS

7.1 Background

In this study, the main performance analyses are associated with two major tasks:

Task 1: An Assessment of Collaborative Team Characteristics Using Simulated Emergency Response Teams

One of the fundamental challenges confronting team performance is understanding the characteristics of the team. A team characteristic is multidimensional and requires a multidisciplinary approach. For this reason, different disciplines have different descriptions of what a team is which, at times, conflict with our understanding of homogenous group characteristics. In this task, two main hypotheses are investigated:

(1) There is a difference in mean team SA(how teams see the same thing) between a team with 3 members and teams with 5 members when performing signal monitoring tasks.
(2) There is a difference in mean team informity (how teams exchange information on what they see) between a team with 3 members and a team with 5 members when performing signal monitoring task

Task 2: Assess the Dimensions of Team Performance with Respect to Information Processing

In this task, we measure objective attributes of performance in terms of detection accuracy and detection time. Thus, two hypotheses were tested:

(1) There is a difference in mean signal detection accuracy between a team with 3 members and a team with 5 members when performing signal monitoring tasks.
(2) There is a difference in mean signal detection time between a team with 3 members and a team with 5 members when performing signal monitoring tasks

In testing the four hypotheses, possibilities of interaction effects were analyzed. All tests were conducted using a level of significant (α) of 0.05.

7.2 Analysis of Variance for Statistical Measures

An ANOVA was conducted to investigate mean differences in each of the performance measures and to validate the hypotheses of the study. There are three levels of main effects: two levels of teams, denoted by A (G3, G5), four levels of signal complexity, denoted by B (1,2,3,4), and four levels of time control, denoted by C (0-5sec,

5-10sec, 10-15sec, Random), respectively. The experiment is 2*4*4 between teams and within signal complexity and timing. All experimental blocks had 10 replications, leading to 320 observations.

7.2.1 The Difference in Mean Team SA. (How teams see the same thing) between a team with with 3 members and a team with 5 members when performing signal monitoring tasks.

The corollary of hypothesis in 7.2.1 is that there is an interaction effect between teams and signal complexity and /or signal time control. Table 12 gives the ANOVA results.

Table 12:   Three-Way ANOVA Using Mean Team SA Data (Seeing the Same   Thing)

Source	DF	SS	MS	F	p	Decision
Team (A)	1	27.6534	27.6534	5.69	0.037	**
Signal Complexity (B)	3	47.443	15.814	3.524	0.0001	**
Time Control (C)	3	104.495	34.832	7.167	0.0411	**
AB	3	42.982	14.327	2.948	0.168	*
AC	3	77.7114	25.904	5.333	0.992	*
BC	9	78.557	8.729	1.796	0.0026	&
ABC	9	161.4006	17.933	3.69	0.321	*
Error	288	1399.68	4.86			
Total	319	1939.922				

** Reject null hypothesis (not statistically significant based on F-statistics at 0.05).
* Test is not statistically significant. & Accept null hypothesis.

As shown in Table 12, the equality of Team SA between teams was rejected ($F_{0.05}$ = 3 < $F_{1, 288}$ (5.69); p= 0.037). Similarly, signal complexity was not significant ($F_{0.05}$= 2.26 < $F_{3, 288}$ (3.524); p = 0.0001); Time control was not significant ($F_{0.05}$ = 2.6 < $F_{3, 288}$ (7.167); p = 0.0411). An interaction effect was observed between signal complexity and time control ($F_{0.05}$ = 1.88 > $F_{9, 288}$ (1.796); p = 0.0026). Thus, we accept the hypothesis that signal complexity and signal timing control may interact to affect signal monitoring performance. Figures 17(a)- 17(b) are used to show the interaction points. In both figures, interactions are more pronounced at a signal timing control of 10-15 sec.
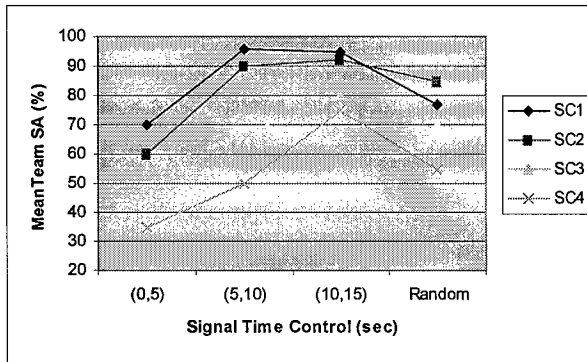
Figure 17(a). Time-Signal Complexity
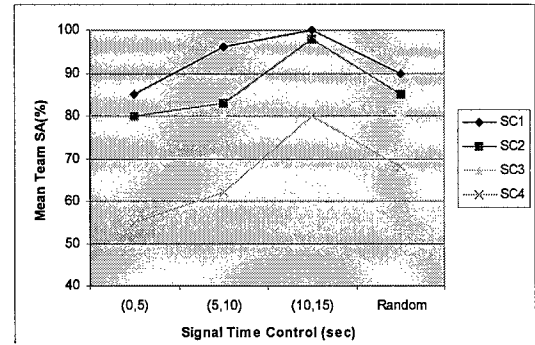Interaction for G3

Figure 17(b) Time-Signal Complexity for G5

7.2.2 Difference in Mean Team Informity (how teams share information on what they see) between a team with 3 members and a team with 5 members when performing signal monitoring tasks.

The corollary of hypothesis in 7.2.2 is that there is interaction effect between teams and signal complexity and /or signal time control. Table 13 gives the ANOVA results.

Table 13:Three-Way ANOVA Using Mean Team Informity Data (Telling What You See):

Source	DF	SS	MS	F	p	Decision
Team (A)	1	19.532	19.532	3.82	0.238	*
Signal Complexity (B)	3	21.321	7.7107	1.39	0.001	&
Time Control (C)	3	41.8755	13.9585	2.73	0.167	*
AB	3	79.456	26.485	5.18	0.0001	**
AC	3	45.097	15.03	2.94	0.316	*
BC	9	56.739	6.304	1.233	0.093	*
ABC	9	155.078	17.23	3.37	0.077	*
Error	288	1472.544	5.113			
Total	319	1891.6385				

** Reject null hypothesis (not statistically significant based on F-statistics at 0.05).
* Test is not statistically significant. & Accept null hypothesis.

As shown in Table 13, the equality of team informity between teams was rejected $(F_{0.05} = 3 < F_{1, 288} (3.82)$; p= 0.0.238). Signal control was not significant $(F_{0.05} = 2.6 < F_{3, 288} (2.73)$; p = 0.167). There were no interaction effects. Results proved the null hypothesis for signal complexity to be accepted $(F_{0.05} = 3 > F_{3, 288} (1.39)$; p = 0.001).

7.2.3 There is a difference in mean signal detection accuracy between a team with 3 members and a team with 5 members when performing signal monitoring tasks.

The corollary of hypothesis in 7.2.3 is that there is an interaction effect between teams and signal complexity and /or signal time control. Table 14 gives the ANOVA results.

Table 14:   Three-Way ANOVA Using Mean Detection Accuracy Data

Source	DF	SS	MS	F	p	Decision
Team (A)	1	9.2565	9.2565	2.493	0.631	*
Signal Complexity (B)	3	18.6467	6.2156	1.674	0.00001	&
Time Control (C)	3	10.459	3.4865	0.939	0.007	&
AB	3	29.7077	9.903	2.667	0.364	*
AC	3	20.4178	6.806	1.833	0.157	*
BC	9	25.6643	2.852	0.768	0.0003	&
ABC	9	85.581	9.509	2.561	0.081	*
Error	288	1069.344	3.713			
Total	319	1269.077				

** Reject null hypothesis (not statistically significant based on F-statistics at 0.05).
* Test is not statistically significant. & Accept null hypothesis.

As shown in Table 14, the equality of mean detection accuracy between teams was rejected ($F_{0.05} = 3 < F_{1, 288}$ (2.493); p= 0.631). Similarly, interactions between teams and signal complexity and teams with signal time control were not observed. Signal complexity was significant ($F_{0.05} = 3 > F_{3, 288}$ (1.674); p = 0.00001). Signal time control was significant ($F_{0.05} = 3 > F_{3, 288}$ (0.939); p = 0.0.007). There was interaction between signal complexity and signal time control ($F_{0.05} = 1.88 > F_{9, 288}$ (0.768); p = 0.0003). Thus, we accept the hypothesis that signal complexity and signal timing control may interact to affect signal monitoring performance. Figures 18(a)- 8(b) are used to show the interaction points. In both figures, interactions are more pronounced at signal timing control of 10-15 sec; Team G5 show two possible interactions at Random signal timing for signal complexities 1 and 2, respectively.
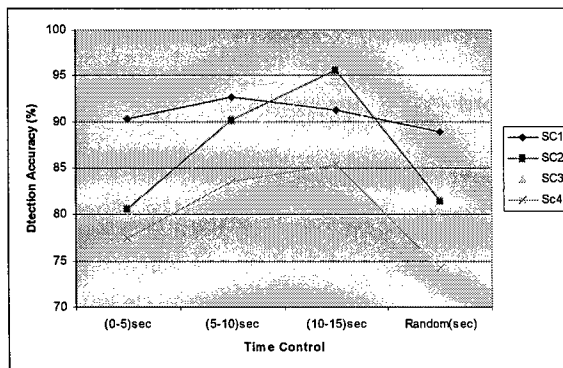

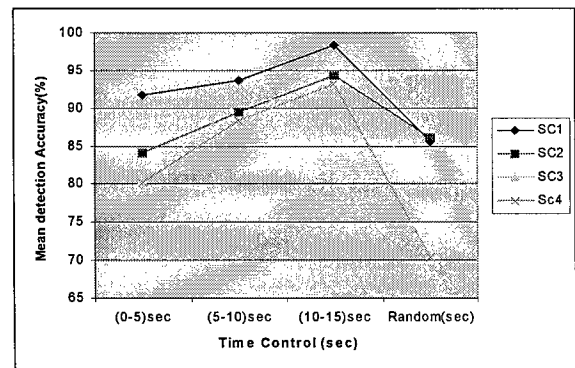Figure 18(a): Mean Detection Accuracy Interaction for G3

Figure 18(b): Mean Detection Accuracy Interaction for G5

7.2.4 There is a difference in mean signal detection time between a team with 3 members and a team with 5 members when performing signal monitoring tasks.

The corollary of hypothesis in 7.2.4 is that there is interaction effect between teams and signal complexity and /or signal time control. Table 14 gives the ANOVA results

As shown in Table 15, the equality of mean detection time between teams is accepted ($F_{0.05} = 3 < F_{1, 288}$ (1.773); p= 0.0001). Similarly, signal complexity has effect on mean detection time ($F_{0.05} = 3 > F_{1, 288}$ (0.915); p = 0.036); Signal time control was significant ($F_{0.05} = 3 > F_{3, 288}$ (2.38); p = 0.0.00001); There were interaction between teams and signal time control ($F_{0.05} = 1.88 < F_{9, 288}$ (1.291); p= 0.001); Signal complexity and signal time control ($F_{0.05} = 1.88 > F_{9, 288}$ (0.77); p = 0.00001). Thus, we accept the hypothesis that teams have effect on signal performance. The statistical tables in Chapter 6 show the mean detection times. Signal complexity and signal timing control may interact to affect signal monitoring performance. Figure19 shows the interaction between teams; Figure 20(a) and 20(b) shows the interaction between signal complexities and signal timing control.

Table 15: Three-Way ANOVA Using Mean Detection Time Data : 10 Replications per Experiment Block.

Source	DF	SS	MS	F	p	Decision
Team (A)	1	5.1116	5.1116	1.773	0.0001	&
Signal Complexity (B)	3	7.9138	2.638	0.915	0.036	&
Time Control (C)	3	20.58462	6.862	2.38	0.00001	&
AB	3	30.7558	10.252	3.556	0.064	*
AC	3	11.16586	3.7219	1.291	0.001	&
BC	9	19.97919	2.2199	0.77	0.00001	&
ABC	9	65.72375	7.3026	2.533	0.083	*
Error	288	830.304	2.883			
Total	319	991.53862				

[**] Reject null hypothesis (not statistically significant based on F-statistics at 0.05).
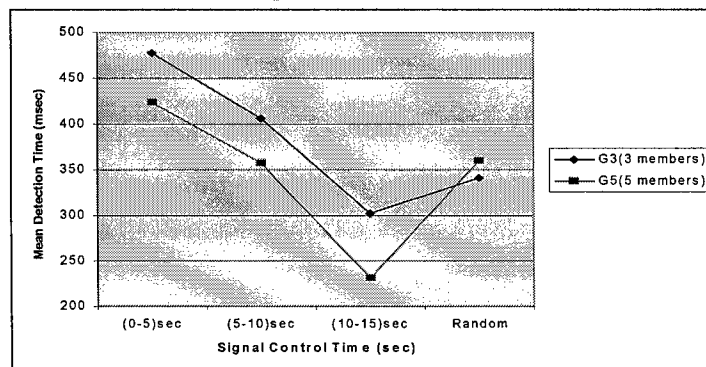[*] Test is not statistically significant. [&] Accept null hypothesis.

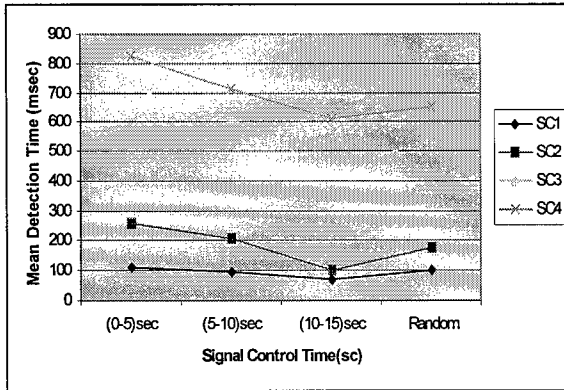Figure 19: Graphical Display of Team and Signal Control Interaction for Detection Time

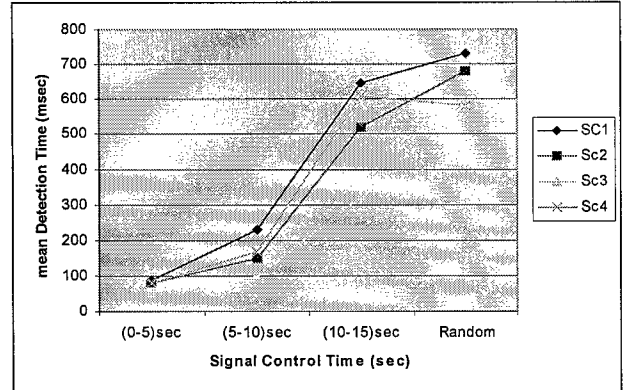Figure 20(a): Mean Detection Time Interaction for G3

Figure 20(b): Mean Detection Time Interaction for G5

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CHAPTER 8
DISCUSSIONS AND CONCLSIONS

8.1 Discussions

Most tasks today depend on information displays, and more so, by teams of people using the displayed information for key decisions. Significant uses of information displays and visualization by teams span across important task domains of national security significance: monitoring city traffic for unusual events by a team of controllers, a team of monitoring traffic and other events in a mall using cameras, a pilot and co-pilots monitoring the cockpit for flight information, or monitoring a nuclear facility by a team of operators. Team characteristics, coupled with information characteristics can lead to degradation in performance rather than improve it—especially as information becomes more dense and complex—for example, a team of two operators watching traffic in Minneapolis mall with over 500 cameras.

This research was conducted to understand this phenomenon—whether complex information processing affects teams performance—specifically, using information display and visualization. The study used both subjective and objective measures. The subjective measures were used to assess team effect in terms of team SA and team information sharing. The objective measures—signal sensitivity (d'), time and accuracy metrics were used to analyze effects of task performance, specifically, signal monitoring.

The following results were observed:

(1) There was no difference between the teams used in the study with respect to how they reported seeing the same thing (team SA) and exchanging information (team informity).

(2) For the team with 3 members, the distributions of the mean percentages of same team SA tend to follow an exponentially decreasing function (negative slopes) as the number of signal presented increases. The team with 5 members reported more team SA. It is not clear from these results whether teams with more members tend to identify more signals than teams with less number of members (G3).

(3) It is possible that signal complexity and signal timing control may interact to affect signal monitoring performance—which in turn affects the way people report what they see under stress. This was apparent by the interaction between signal complexity and signal timing control.

(4) The distributions of mean team informity show increasing positive slopes under different signal timing controls. Team G3 shows the least report on information exchange among members at signal control time of 0-5 sec, but scored high when the signal timing was random. Team G5 exhibited more information sharing among its members at signal time control of 10-15 sec. The performance of the teams at signal control time of 0-5 sec confirms the degradation performance under stress (see, e.g., TADMUS study). The increase in information sharing after latency (i.e., after individual or group search for signal) may be responsible for

the average increase on informity metric between 10-15 sec signal timing controls.

(5) Signal detection sensitivity was calculated across all experimental blocks. The results showed some results that need further investigation. For example, in team G3, single or multiple signals presented randomly (random time control) tends to reduce the operator sensitivity. It is not clear why three signals with timing control levels of 5-10 sec and 10-15 sec induce poor sensitivity. The best d' for G3 team occurs with monitoring 4 signals at 10-15 sec time control (d' = 5.15) and also when 2 signals are presented at the same time control. With G5 team, a higher d' occurs at timing control of 5-10sec. for a single signal monitoring task (d' = 2.96); the worst d' occurs when 2 signals are monitored under random time control.

(6) Team composition has no effect on detection accuracy. However, the signal timing and complexity showed some statistical significance indicating that information complexity affects performance in terms of detection accuracy. The histograms plotted in Chapter 6 show some points where such differences occur. Detection accuracy differences can be caught by analyzing the differences in mean performance at the points of interaction. In this study, interactions are more pronounced at signal timing control of 10-15 sec. G5 team shows two possible interactions at Random signal timing for signal complexities 1 and 2, respectively.

(7) In terms of detection (response) time, both teams tend to perform almost equally. This result may be different when comparing experts and novices. Note that teams were almost a balance of males and females and no classification was made as how the team was to perform the signal detection tasks.

(8) Both signal complexity and signal control timing showed effects. There were interactions between teams and signal time control—indicating the possibility of effect of constraints on timing. For example, with a short timing of 0-5 sec, performance is less due to shortness of the signal duration. However, as the signal duration increases to 10-15sec, people can take more time to scan the environment for the target signal.

8.2 Conclusions

The results obtained in this study indicate that non-classified team composition (with assumption of homogeneity in task performance) does not affect signal monitoring task performance. However, caution must be exercised in this observation since detection sensitivity (d') may produce different results by teams as shown in the study. It is also observed as an affirmation in past studies (Vogel, et al., 2001) that information complexity—a function of number of signals monitored and signal control time for signal shell life affects performance—either in detection accuracy or detection (response) time.

The study has many implications for a complex information processing environment. First, understanding team SA and how teams exchange information in either a confined environment, such as a pilot or a ship sonar operator, or in teams who may be dispersed geographically, but use the same display and visualization tools. Second, signal vigilance research (Carter, 1982) has traditionally observed the

performance of one operator. This study will allow for signal vigilance research to be extended to team situations where team performance in automation monitoring—such as multiple operators monitoring a missile control station, nuclear power plant, or a port security monitoring information for a potential terrorist, can be assessed. Third, it will be advantageous to extend this experiment to more realistic domains. For example, at present, it is not known how the installation of multiple cameras in high-risk monitoring environments affects the operator's performance--for example, monitoring a stadium during a Super Bowl game. Workload measures—both subjective and objective can be used to develop performance metrics for complex information processing environment.

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