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Information Experimentation in Command and Control

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Abstract

The interest in using information systems for military command and emergency response has grown dramatically during the last decade. Consequently, high-level management has become concerned with efficient utilization of computer recourses to support their work. The Nature of Complex Dynamic Processes and Operations can be characterized as high-risk activities, where human and artificial team members together perform a task, which exacts extreme mobility, efficiency, agility and endurance, and where small actions or decisions may have serious and irreversible consequences for the mission as a whole. In military operations mission performance relies increasingly on distributed systems (with many team-players, widely separated, forced to co-ordinate with one another) to attain high safety and effectiveness without risking excessive resource depletion. High-capacity Command and Control support is needed to facilitate omnidirectional, continuous information flows from the chief executive level to the team-on-site levels. Sometimes even individual operators and sensor systems must without delay be allowed to affect decisions and actions of a senior commander. This is beyond reach unless novel, cutting-edge solutions can support the humans and systems engaged.

1. Introduction

The interest in using information systems for military command and emergency management has grown dramatically during the last decade. Consequently, high-level management has become concerned with efficient utilization of computer resources to support their work. Performance within areas such as rescue services, air traffic control and military operations relies increasingly on novel organizational principles and innovative system architectures. Facilitation of dynamic, distributed command and control in order to allocate and use accessible resources in the best possible way with the purpose of avoiding excessive resource depletion. In Sweden and many other western countries, assumptions have been put forward regarding future technological development and its potential since the mid 1990's. These notions have resulted in several visions of how command and control systems (C^2 systems) could look like in the future. Furthermore, assumptions are made considering what novel abilities and means these C^2 systems can offer commanders to support detection of and adaptation to organizational and environmental changes and how to facilitate decision-making upon those changes. In all essentials, these visions have become widely accepted and currently serve as guidance for research and systems development within various domains. The Swedish Government and the Supreme Head Quarters of the Swedish Armed Forces recently expressed directions and regulations addressing Sweden's Total Defence and Armed Forces' development of its next generation of C^2 systems. A key issue in those directions and regulations is a new command structure that is considered as a necessary element of the transition to a network defence. In a statement, where development of the future Swedish Defence is regulated, the Swedish Government (Sveriges Regering, 2001) says that the network defence could be described from an overall classification of the Swedish Total Defence capability in three parts;

- Information about and perception of the surrounding environment
- Command and control with decision support
- Insertion of resources and their impact

Furthermore, it is said in the governmental regulations that information about and the perception of the surroundings should be achieved through a construction of a picture, or an image, over what is happening. This common situational picture should allow relevant command information distribution in near real-time to different levels of command, units, components of action and certain commanders that are in use for it. This implies that information acquired from different sensors and other sources of intelligence have to be made available through a network, which can be used for creating an expedient and shared view that include our own activities, as well as those of other actors, resource allocation and resource expenditure.

Organizations as e.g. the rescue services or the Military have traditionally been hierarchically structured. As such, the command and control function has been located in the uppermost hierarchical level. Today it is argued that current hierarchical organizations are too rigid to be able to act and react on situations in future and highly dynamic environments. As an option of handling the dynamics, so called "network organizations" have been proposed as a solution. The structure of network organizations is considered a possible answer to several problems of exerting command and control among military communities (e.g., see Alberts, Gartska, & Stein, 2000; Brehmer & Sundin, 2000; Cebrowski & Garstka, 1998). Implementation of such an organizational structure imply that traditional hierarchical levels of command could be flattened out, reduced or maybe completely removed. Reducing levels of command is considered advantageous and necessary to shorten the reaction time for changes in the environment, since data processing within every level of command is considered time consuming and thereby would seriously hamper any necessary action. Furthermore, it is assumed that as long as a decision-maker is provided with enough data presented in an understandable way, he or she will be able to make "optimal" decisions. Consequently, larger amounts of data have to be handled by the commanders within network organizations in comparison with traditional hierarchical organizations. Thus, greater demands will be made on mission control centers as the ROLF 2010[1] staff unit, since "…it will require that the commander and his staff will be able to handle greater amounts of information and greater complexity than before" (Brehmer & Sundin, 2000). One cause could be that organizational filters, present in hierarchical organizations are reduced or completely removed within network organizations. Although these differences never have been tested, they are generally held valid among many western countries today where major systems development projects are in progress.

2. Problems of developing and using different methodologies

Developing command posts that provide decision makers with efficient and required support imply capabilities to handle complexity and a large problem space. A piece of that problem space is to consider proposed technologies (currently existing or not) that are assumed essential to exert command and control efficiently in the future. Unfortunately, we find ourselves (as customers, researchers or designers) in a situation where little or no knowledge is available about what these technologies finally will look like. Furthermore, as new technologies emerge we also have little knowledge about how they will affect the users and their work practices. In addition, researchers and designers cannot reliably foresee how the new technology will be learned or used. Thus, methods and procedures have to be used and/or developed that sufficiently can guide and handle these kind of problems.

A common way to handle complex problem areas is to draw upon multiple disciplines where representatives from different scientific fields, engineers, users, etc., are put together to solve the problems. This has also been the case within the ROLF 2010 project, but not without oppositions over what different representatives from diverse field of research mean when using terms in daily work. Consequently, it is of great importance that collaborating groups come to an agreement over what different scientific methods can be used for, as well as to reduce risks for communication problems. The problem of cross-disciplinary collaboration during design work is also discussed elsewhere. Monarch et al. (1997) stress that emergence of communication problems could be dependent on differences in terminology, visualization, interests, and aims indigenous to the perspectives between participants involved. Based on their arguments, the authors emphasize the importance of carefully creating mutual linking, translation of terms, visualizations and models across groups from different disciplines to accommodate information and common knowledge among collaborating parties. Accordingly, a common ground must be established between daily collaborating researchers and engineers, as well as within the different scientific communities involved in current C^2 system development. Interesting enough, a group of decision-makers that form a team must go trough the same type of processes in order to sufficiently carry out their work. In other words, this process could be viewed as a general matter that has to be considered in many forms of cooperative work and collaboration.

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[1] ROLF 2010 is an acronym for a Swedish research project that stands for Mobile Joint Command and Control Concept 2010. The aim of the project is to develop a command and control post for the future. (For a description over the project, see Sundin & Friman, 1998; 2000).

2.1 Studies of team decision-making

Organizations as e.g. the military, the police or rescue services have traditionally been hierarchically structured together with a bureaucratic order over how things should be carried out – what different positions are needed within the staff; what different competence that is necessary for each position; who is responsible for and does what, etc. Accordingly, the composition of a traditional staff is rather regulated and static where a single individual retains final decision authority.

New technologies are said to radically alter how and where that work gets performed by e.g. communication support among interconnected parts of organizations, supplying means of monitoring of internal and external processes, as well as to facilitate decision-making by automation (see Galbraith & Lawler III, 1993). Furthermore, requirements on future command post, as envisioned in the ROLF 2010 project, should also allow situation dependent and flexible composition of collaborating decision-makers that are forming a temporarily composed group assigned to reach a common goal. This is in large contradictory with traditionally composed staffs, where individuals are more permanent assigned to a group with a fixed set of tasks. Thus, considering current work and decision-making processes compared to those needed in proposed environments for the future, they most likely have to be developed and evolved. One possible concept that could serve as a guideline for that work is what goes under the notion of team decision-making (TDM).

In Cannon-Bowers et al. (1993) TDM is described and considered as; "a team process that involves gathering, processing, integrating, and communicating information in support of arriving at a task-relevant decision". Furthermore, they stress that the process does not require that the team members arrive to a consensus, nor does it suggest that all of the team members are involved in all of the aspects of a decision. Instead TDM imply that; "team members process and filter "raw" data, apply individual expertise, communicate relevant information, and (often) make recommendations to other [team] members" (p. 222). Furthermore, it is pointed out that the operational environment of TDM often is embedded in a larger task, where the goal of the team is to accomplish a task rather to make a simple decision (p. 223). These views are comparable to the expressed teamwork and team-decision procedures envisioned in the ROLF 2010 project. Much is still unknown about how to adequately design artifacts that support TDM and to develop methodological tools in order to measure possible success (e.g., see Brannick, Salas, & Prince, 1997). Thus, to be able to develop efficient technological support we believe it is of great importance to accomplish understanding of; (1) what processes that are going on within decision-teams; and (2) given we have ideas of how to technically support TDM, we have to try them out in order to avoid increased workload or other unwanted effects.

2.2 Managing Multiple Data Sources and Multiple Displays

Woods & Watts (1997) addressed some important issues in one of the most important areas of research in the networked world - information navigation. They give examples of powerful principles in display design to address problems caused by large networks of data sources and by displaying massive amounts of raw data out of context. Three trends in information visualization together provide an important conceptual base of design principles in representing highly dynamic systems and their properties:

- Information animation. The computer medium allows designers to highlight change, activities and contrasts extending into the future as well in the past.
- Integrated representation. The computer medium facilitates development of coherent views of available data into an activity, process or system.
- Co-ordination of multiple views. The computer medium can create a virtual perceptual field or workspace to aid the operator in performing his/her work.

In the domain of dynamic and complex systems, it is considered very important for an operator to have access to the big picture of the process. This supports the operator to step back and assess the overall status, and decide where to look next within the system to acquire the next piece of information needed. Woods' and Watts' concepts: "status at a glance", "structure and domain semantics", and their use of Schneiderman's (1982; 1983) "direct manipulation" all resemble two of the fundamental principles of control theory: observability and action. Woods and Watts claimed that a status summary function must include the following attributes:

- The summary information must be distilled.
- Information in the summary must be abstracted.
- Information about change and sequence must be included.
- Information must be relevant to the viewer's context.
- The summary information must support "check reading".

3. Current methodologies used during C^2 system studies

For anyone that has studied people using technology, it is no news that that new technology seldom is used as envisioned by designers. Still the predominant perspectives in contemporary system development are mainly focused upon the infrastructure of technology rather than activities of use. Furthermore, a lot of technology for cooperative use is designed for groups that have a tradition of doing things, which must be considered and adapted to existing group conventions. Either the technology must be adapted to the group conventions, or else the group conventions must be changed to fit the new technology. However, to be able to measure the level of the changes, and whether the result of the design coincide with the intended or not, it is necessary to create an understanding among developers of how users traditionally have acted and how they will act in that new setting. Below we present tree methods used up to day in order to gain more knowledge about interrelationships between data, information, information flow, human-human and human-machine interaction, organization, TDM, and team situation awareness (TSA). The first two are used within the framework of the ROLF 2010 project and carried out in the SNDC C^4-laboratory. The latter is resulting from studies on a tactical level of military command.

4. Observations of staff work during exercises

In one of the our studies it is pointed out that conventions and practices seldom are explicit when confronted with something that could be experienced as their opposites (Artman & Persson, 2000). In line with our arguments above, such effects can occur when decision-teams' work practices are altered from the traditional ones. Consequently contradictions only become apparent when the intended users meet new technology (see fig. 1). To create an overall understanding and achieve experiences for our design efforts exercises are of great importance. Currently we have used our observations over such events as a "tool" that can support researchers and designers in narrowing and making their research questions more explicit.

Figure 1 A live picture from an exercise at the Swedish National Defence College C^4-laboratory. (Photo by Martin Nauclér)

Exercises admit opportunities to study patterns and behavior of how individuals and teams handle information, interact with each other, and how artifacts are used in "real" situations[2]. Accordingly, one main interest when studying decision-teams during exercises have been to investigate *how* different processes and different interaction are organized, in contrast to numbers of other studies that have focused on *what* interactions have occurred in a work setting (e.g., see Bernard, Kwok-kee, Choon-Ling, & Krishnamurthy, 1999; Ferratt, Agarwal, & Short, 1992; Wideström, Axelsson, Schroeder, Nilsson, Heldal, & Abelin, 2000).

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[2] A 'real situation' should not be interpreted here as a situation where the SNDC C^4-laboratory is used for handling live crisis situations. Instead, exercises give an opportunity to study decision-teams during work, where the situation during the exercise could be viewed as simulated with a non-predetermined or non-predictable outcome. The subjects of study during exercises have been students training for their coming positions in current high-level staffs, or actual members in such staffs as upholder of a position during the exercise in order to obtain own experience of the new and intended future environment. Thus, we consider observations of exercises of great importance to study how actual and forthcoming users will cope with a situation that is as near reality as possible together with new technology.

Activities during exercises in the C^4-laboratory are audio and video recorded from several angles, which make it possible to study events of interest in detail. Furthermore, e-mail traffic in and out from the environment is logged and collected, which in turn could be used during the video analysis, e.g. as verification against some video recorded event, or for analysis of messages and their content. However, exercises are most often going on for several days, which in turn could result in a tremendous amount of data that must be handled. One method we have found applicable to use conducting this kind of analysis is what goes under the notion of ethnographic microanalysis. Although, the method primarily is developed for studies of education, we found that the procedure of this type of analysis could be useful also in other settings.

Ethnographic microanalysis of audiovisual recordings is described by Erickson (1992) as a method providing; "means of specifying learning environments and processes of social influence as they occur in face to face interaction" with the purpose of identifying how routine processes of interaction is organized. Furthermore, the methodology is said to be "especially appropriate [where] …it is important to have accurate information on the speech and nonverbal behavior of particular participants in the scene" (p. 204-205), which in turn could help us to more clearly see experience in practice. Such results could also be of importance when acceptance and success should be investigated after e.g. implementing new work practices and methods.

Considering the research process of ethnographic microanalysis, two issues are of importance; (1) to identify the full variation in the organization of interaction; and (2) to establish the typically and atypically of various event types and modes of interactional organization. This identification is carried out by data collection from audio and video recordings together with e.g. field notes that are taken during the observational event. Thereafter data are analyzed in five stages (Erickson, 1992:p. 217-222);

1. by reviewing the whole event in regular speed of the recording
2. identification of major consistent parts of the event
3. identification of different aspects of organization within major parts of events
4. focus on individuals actions
5. comparative analysis of instances across the research material

The research process is rather time consuming, but we found it necessary to follow the steps as much as possible. In addition we practiced "active watching" in the beginning where notes were taken together with approximate time locations of easy identifiable events. This procedure helped us to roughly locating parts of interest, which then could be found more easily for further analysis. A bonus effect worth mentioning from our experiences using this methodology have been situations where collaborating researchers possess different levels of pre-knowledge of how e.g. military representatives carry out their work. From the results of the analysis we have been able to extract events that could be used and serve as a learning tool for such purposes.

The study referred to here started with a question how new technology is introduced and used by representatives from an old and relatively homogenous community – the military. Furthermore, another background of the study was that the military organization and practices are known to be quite formal. By providing new technology and a novel environment for command and control, this formal behavior was assumed to be lighten up and support creative, reflective discussions among decision-teams. The results from the study presented below could be reviewed in greater detail in Artman & Persson (2000).

4.1 Result

One of the most important wishes of the described vision in the ROLF 2010 project is that the physical organization and common representation(s) should elicit creative and reflective discussions. These discussions should break-down formal rank and let each team member take the floor as he or she feels there is an opportunity to contribute to the discussion. This was not what happened, rather the opposite where discussion between the team members is rare for updating the situation. Furthermore, we did not find any situation or indication that the chief of operations (COP), asks the team members explicitly during a meeting or implicitly before a meeting who would like to start. Each officer also addresses the commander by gaining eye contact or trying to get response from the commander during the speech rather than addressing other team members. In subsequent questioning the team members also ask the commander for permission to speak by waving their hand before they start to question the officer who had the floor. Thus, during information sharing sessions the commander and the team members confirmed the traditional view of the centrality of the commander in their way of approaching any other team member during the information sharing sessions

Considering main aim of the technological design, it is to create a shared awareness, or a shared understanding, among the members of a decision-team. Models used to accomplish that, and to guide the design, are basically top-down. As such, they also provide an ideal view over how information should be mediated and exchanged among the team-members (fig. 2). However, from our experiences and analysis of how interaction and information exchange was carried out during the exercise, the result was quite different (fig. 3). By categorizing the team processes in three phases; (1) a pre-team meeting; (2) a team meeting; and (3) a post-team meeting, it is possible to make observations and reflections of how intensively a team member engages himself in distributing, questioning and discussing different information. During the phase of pre-team meeting an intense work of exchanging information with external representatives, e.g. a subordinate (sub), could be observed (fig. 3).

The information received during this phase is processed by the individual team member and then generically presented for the commander during the team meeting. During the phase of the team meeting the other members of the team were passively listening to the presentation and accepting the information mediated. When the team-meeting phase reached its end, then the commander gave his directions for the next action. After the commander closed the meeting the post-team meeting phase started, in which officers turned to their computers and continued to communicate with their external subordinates. We believe that the team members become more coupled to external units because of this rapid, continuous and committed communication as long as its equivalent within the team as not created or supported. How this should be handled must be an urgent question for research within the field C^2 systems design in the near future.

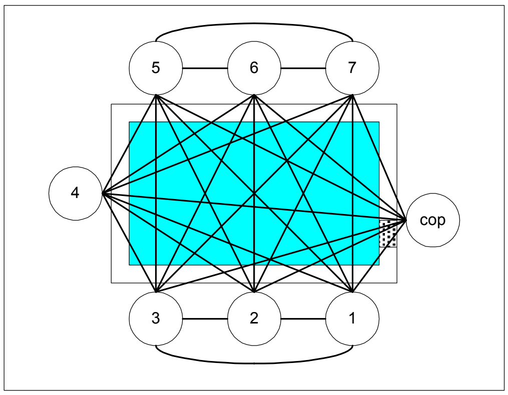

Figure 2 The ideal view on communication and mediation of information among participating members of the decision-team.

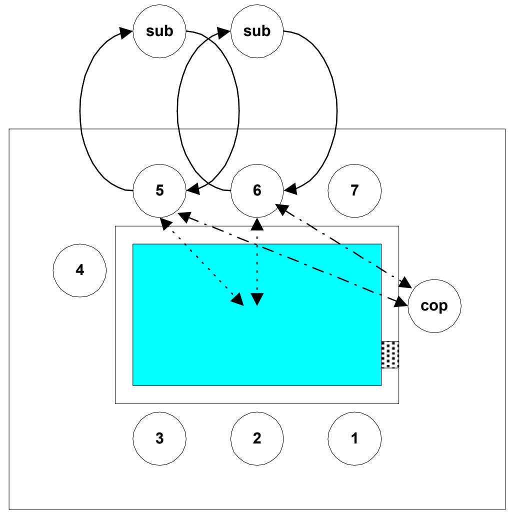

Figure 3 The strength of interaction and information exchange between external and internal representatives. The heavier a line is, the stronger is the coupling

5. Simulating assumed technological capabilities and their impact on TDM

From our experiences of observing exercises together with presupposed technological requirements and properties that are to be needed for exerting command and control in the future, we have been able to extract a number of questions for further investigation. For that purpose we have continuously developed and implemented a micro-world called C3Fire. The C3Fire micro-world has been used for several experimental settings with different aims (e.g., see Granlund, 1997; Granlund, 2002; Granlund, Johansson, & Persson, 2001; Granlund, Johansson, Persson, Artman, & Mattsson, 2001; Johansson, Granlund, & Wærn, 2000). C3Fire make it possible to configure and simulate different forms of organizations and ways of how the system allows the subjects to handle and to exchange information. Accordingly, it is possible to accomplish a command situation that have comparable similarities to current or envisioned where researchers can investigate as e.g. team performance from a predetermined and controlled situation, which in turn could have different levels of constraints in information flow.

The C3Fire micro-world can be viewed as a command, control and communication simulation environment, which can be used for investigation, experimentation and training on TDM and TSA. The C3Fire micro-world has shown to provide an excellent support for quantitative data retrieval, which in turn is supplemented with qualitative data retrieval from audio and video recordings, as well as questionnaires.

The environmental domain, which is forest fire fighting, is of subsidiary interest and has been chosen because it generates a good dynamic target system. The system generates a task environment in which a group of people cooperate to extinguish a forest fire. The simulation includes forest fire(s), different kinds of vegetation, infrastructure ("villages" and "cities" – that are represented as houses), computer-simulated agents (fire-fighting units and reconnaissance personnel). The user interface consists of three basic elements; (1) a Geographic Information System (GIS); (2) a diary; and (3) an e-mail system. The GIS can be manually or automatically updated, as well as shared with other users (fig. 4.).

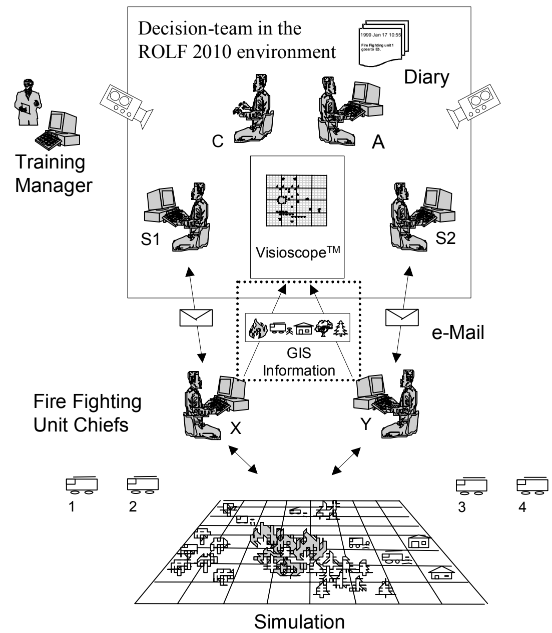

Figure 4 The C3Fire micro-world in the ROLF-2010 environment. The environment can be configured so that the decision-team shares a digital map of the environment, which can be updated in different ways depending on the configuration.

During a session, the simulator updates the GIS around the simulated units for the actors who are controlling these units. The players who run the system are part of a fire-fighting organisation and can take on the roles of decision-team members or fire-fighting unit chiefs. The task of the decision-team is to have an overview of the situation, and to co-ordinate and schedule the fire-fighting units so that they can extinguish the fire and save the infrastructure. Communication among the different organizational parts is mainly conducted through mail and GIS updates.

To be able to analyse the collaborative work in the C3Fire system, computer-based monitoring has been used. The monitoring is integrated in the simulation and all the information tools used by the subjects. During a session the C3Fire system creates a log with all events in the simulation and all computer-mediated activities. The log process receives information from the simulation about all current activities in the simulated world. It also receives information about individual work (in terms of marks in the personal GIS), and on the collaborative work (in terms of information about the e-mail communication, the use of the distributed GIS, and the diary).

From our latest studies with C3Fire, hypotheses have been tested that have shown some preliminary but interesting results. Those tests have been conducted and designed from experiences drawn from exercises together with current assumptions were decision-teams will benefit largely from having access to novel technologies (Artman & Persson, 2000; Granlund & Johansson, 2002; Granlund, Johansson, & Persson, 2001; Granlund, Johansson, Persson, Artman, & Mattsson, 2001; Johansson, Granlund, & Wærn, 2000; Persson & Johansson, 2001).

The initial claims expressed within the ROLF 2010 project assumed that there were differences in performance between; (1) decision-teams supported with monitoring capabilities and provided with real-time data presented directly from the field; and (2) decision-teams working in a more "traditional" way with poor monitoring capabilities and information presented from the field that is organizationally composed and filtered. We tried to examine this in an explorative study using the C3Fire micro-world. Based on this question a study was performed where a total of 60 subjects were tested, 6 subjects in each group, performing three trials. All the subjects were professional military officers of at least the rank of captain. There were two independent variables, namely a direct updating of the shared map and a manual one. In direct updating, the fire-fighting unit chiefs could put information on the map by placing symbols on a small screen, which creates a fast and precise way of distributing information. In manual updating, all information to the staff is based on e-mail communication, which has to be inferred manually into the shared map. During both tests two sets of data were collected – audio and video recordings, as well as log-files from the micro-world.

5.1 Results

From studies conducted using the C3Fire micro-world some interesting differences between the two conditions were found. Although there were no significant difference between the two conditions in terms of performance, it was clear that the condition using text-based communication performed more similarly in contrast to the direct-update condition where the teams had a great variety in terms of performance. Furthermore, it seems like the shortened delay in information presentation has an impact on the planning that the team conducts. Generally, in both conditions the teams make plans in advance, which they probably have intended to carry out. However, in the condition that admits direct updates, the decision-teams often seem to loose focus of their original plan and start to perform actions that effect events in the near future. In the filtered condition, the teams more often follow their original plans to the end.

6. Trident

From the studies within the TRIDENT project a number of particularly interesting causes of mission failure or poor performance could be identified. The predominant error modes were:

- Timing of movement and of tactical unit engagement.
- Speed of movement or maneuver, which is especially important in the initial phase of engagement.
- Selection of wrong object. The environments of ground warfare or emergencies offer many opportunities for choosing wrong objects, in navigation, in engagements, or in visual contact.

After a retrospective cognitive reliability and error analysis (Hollnagel, 1998) it was found that mission failure or poor performance in every case could be attributed to:

- Slow or even collapsed organizational response.
- Ambiguous, missing or insufficiently disseminated, communicated and presented information.
- Equipment malfunction, e.g. power failure or projectile/missile impact.
- Personal factors: inexperience, lack of team training etc.

Empirical results obtained by Worm (2000) suggest three potentially significant mechanisms influencing how the team is able to execute mission control, which consequently also influences mission efficiency:

- Time-dependant filtering functions like defence and coping mechanisms according to the cognitive Activation Theory of Stress (Eriksen, Olff, Murison, & Ursin H, 1999; Levine & Ursin, 1991).
- Performance limiting factors due to specific mission and task situation factors and resource requirements (Hollnagel, 1998; Reason, 1997; Worm, 1998; Worm, 2000).
- Balance between feed forward and feedback in mission-critical action control (Reason, 1997; Worm, 2000)

7. Conclusion

At present, very little empirical results are available that epitomize shared situation awareness in advanced use of C^2 artifacts that are concurrently used by command teams. Furthermore, current attempts to conceptualize C^2 system design lack the models that can serve as necessary guidance when developing future C^2 systems. Experiments performed during 2000 and 2001 provided preliminary results and valuable experience that will serve as baseline for hypothesis generation and for further inquiries. We will also evaluate and further develop the conceptual models generated by this work with the aim to aid future C^2 systems analysis design.

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